ASPHALT-RUBBER CONCRETE (ARC) EVALUATION

Eastside Bypass
Klamath Falls Section

Interim Report

OR-RD-99-14

by

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16. Abstract

This report reviews the construction of four pavement test sections using asphalt-rubber as the binder and three hot mix asphalt concrete pavement control sections. The pavements were constructed in Klamath Falls, Oregon in 1992. The control sections were constructed with hot mix asphalt concrete. The test sections consisted of one gap graded asphalt-rubber concrete (ARC) mix and two open graded ARC mixes. The fourth test section was constructed using a powdered rubber asphalt-rubber concrete (PRARC) open graded mix. The ARC binder was made by blending shredded tire material and asphalt. The PRARC binder was made by blending natural rubber and asphalt. Powdered rubber from tire sources was supposed to have been used, but unfortunately, natural rubber was used instead. The blending for both types of binders was done at the asphalt plant by International Surfacing, Inc. There were two open graded mix control sections and one dense graded mix control section.

There were no problems in constructing the open graded and gap graded ARC test sections. There were some concerns with construction of the PRARC mix. Possibly because of the natural rubber or the slightly higher binder content, the PRARC mat was sticky. Just after compaction, several applications of sand were needed as a blotter on the surface of the mat prior to opening the section to traffic.

The ARC test sections, PRARC test section and the control sections showed no signs of rutting or cracking when inspected several days after construction. Friction values of the test and control sections were similar, indicating adequate skid resistance. Deflection data indicated the pavement overlays and inlays reduced pavement deflection.

Development of performance based specifications are needed for asphalt-rubber mixes to ensure satisfactory performance after placement. Performance of the sections will be monitored and documented through the *Crumb Rubber Modifier Study* being coordinated by ODOT's Research Group.

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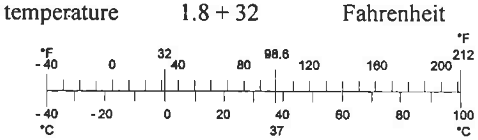
SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

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

APPROXIMATE CONVERSIONS FROM SI UNITS

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



* SI is the symbol for the International System of Measurement

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DISCLAIMER

ASPHALT-RUBBER CONCRETE (ARC) EVALUATION
EASTSIDE BYPASS - KLAMATH FALLS SECTION

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1.0 INTRODUCTION

1.1 BACKGROUND

The storage and disposal of worn rubber tires is a problem for local governments. One option to consider is using the waste tire rubber in asphalt concrete pavements. The first application of this process in Oregon pavement construction was with rubber modified asphalt concrete (RUMAC). RUMAC is produced by adding rubber to aggregate which is then mixed with the binder (dry process).

To test another alternative, the Eastside Bypass, Klamath Falls Section project was constructed with asphalt-rubber concrete (ARC) to allow for comparison to RUMAC. The ARC is created by blending the rubber with the binder before mixing with the aggregate (wet process). Prior to this project, the Oregon Department of Transportation (ODOT) had no experience with ARC pavement construction.

Another factor in choosing the Eastside Bypass project in Klamath Falls for ARC testing was the climate in the project area. The RUMAC projects constructed by ODOT were located in a geographic area of the state with mild climates and relatively small changes in temperature. Klamath Falls, however, undergoes significant seasonal temperature changes, which would allow analysis of the ARC under these conditions. On the Eastside Bypass project, test sections were constructed using asphalt-rubber concrete and standard ODOT hot mix asphalt concrete.

The purpose of the research was to compare the asphalt-rubber concrete test sections with the standard ODOT hot mix asphalt concrete mixes. The Eastside Bypass project test sections were constructed and original data collected in 1992. At that time, ODOT was investigating systems to meet requirements of the Intermodal Surface Transportation Efficiency Act (ISTEA). ISTEA encouraged the use of recycled rubber in asphalt pavements with the aim of achieving 20 percent usage by 1997. The ISTEA goal is no longer a federal mandated requirement. Although ODOT is currently not using ARC as a paving material, the findings in this report can be used to determine the appropriate use of asphalt-rubber or to address issues if future mandates or policy changes evolve.

1.2 ODOT TEST SECTIONS FOR RESEARCH

The Eastside Bypass, Klamath Falls Section project included four test sections and three conventional mix control sections.

Test Sections

ARC - The ARC test sections were constructed with asphalt-rubber blended by International Surfacing, Inc. (ISI) using a "wet process". In this process, crumb rubber produced from tire grindings is mixed with asphalt. The asphalt-rubber is then mixed with 19 mm - 0 mm, gap graded or open graded aggregate to produce asphalt-rubber concrete (ARC). Two mixes, ISI ARC open graded (Class "F") mix (2 test sections) and an ISI ARC gap graded (Modified Class "B") mix test section, were used in the test sections.

Powdered Rubber Asphalt Rubber Concrete (PRARC) - One test section was constructed with the PRARC open graded (Class "F") mix. PRARC uses a type of "wet process" similar to the ISI process. The difference is that the binder is blended with powdered rubber from tires to create powdered rubber asphalt concrete.

For the Eastside Bypass project, the ISI ARC gap and open graded mixes used recycled tire rubber. The rubber used in the powdered rubber PRARC section, unfortunately, was natural rubber and not rubber made from tire sources. As a result, conclusions about the use of powdered rubber from recycled tires cannot be determined from this project's test section.

Control Sections

ODOT Open Graded Class "F" Mix (25 mm - 0 mm) – Two sections were constructed with an open graded "F" mix.

ODOT Dense Graded Class "B" Mix (25 mm - 0mm) – One control section was constructed with a dense graded "B" mix.

1.3 OBJECTIVES

The particular combination of asphalt concrete mix designs was chosen to gather as much information as possible on one construction project. This would allow a thorough evaluation of the use of recycled tire rubber in hot mix asphalt concrete pavements. Although most of these processes had been tried in other areas of the state, none had been constructed on the same project.

The primary research objective was to evaluate and compare the constructability and performance of ISI ARC gap graded, ISI ARC open graded, and PRARC open graded mixes to conventional Class "B" and Class "F" mixes. A second objective was to determine appropriate revisions to the ODOT specifications for wearing surfaces that contain recycled tire rubber. A third objective was to recommend changes to the ODOT mix design procedure for including ground used tire rubber. A fourth objective was to develop ODOT construction sampling methods and test procedures to determine the appropriate asphalt binder content, aggregate gradation, and rubber content of the various mixes.

Annual monitoring of the test and control sections will continue until 1999. This report will document the construction details relating to the test sections including:

- The project's location and design;
- Materials;
- Mix designs;
- Construction process;

- Sampling and testing;
- In-place unit costs; and
- Pavement conditions.

The long-term performance will be documented in the reports for State Planning and Research (SP&R) Project #355, "Crumb Rubber Modifiers in Asphalt Concrete Pavements."

2.0 LOCATION, DESIGN, AND MATERIALS

2.1 LOCATION, LAYOUT, CROSS SECTION, AND DESIGN

The Eastside Bypass Section is located on Highway 50 (State Route 39) in Klamath Falls, Oregon as shown in the Vicinity Map, Figure 2.1(a). A close-up of the project site is contained in Figure 2.1(b).

Both ends of the test and control pavement sections were marked on the shoulder with paddles that display the mix type. Within each test and control pavement section, shorter evaluation sections were designated for performance monitoring until 1999. The evaluation sections were marked with "Coring Site" paddles installed near the roadway shoulders.

Table 2.1 below, gives the location of the test and control sections by station and mile post. Each section contained a 64 mm thick wearing course. Note that the X miles refer to negative miles. Figure 2.2 depicts the test section layout.

Table 2.1: Test Section Layout

Test Section	Milepoints Stationing	Lane Lift
ODOT Class "B"	M.P. X5.21 to X5.02 (STA 73+50 to 83+50)	Outer Eastbound Top Lift
ISI ARC Modified Class "B" (Curbed Section)	M.P. X5.02 to X4.49 (STA 83+50 to 111+50)	Outer Eastbound Top Lift
PRARC Class "F"	M.P. X4.42 to X4.07 (STA 115+50 to 133+75)	Outer Eastbound Top Lift
ODOT Class "F"	M.P. X4.03 to X3.78 (STA 136+00 to 149+00)	Outer Eastbound Top Lift
ODOT Class "F"	M.P. X3.78 to X3.97 (STA 149+00 to 139+00)	Outer Westbound Top Lift
ISI ARC Class "F"	M.P. X3.97 to X4.42 (STA 139+00 to 115+50)	Outer Westbound Top Lift
ISI ARC Modified Class "B"	M.P. X4.49 to X5.21 (STA 111+50 to 73+50)	Outer Westbound Top Lift

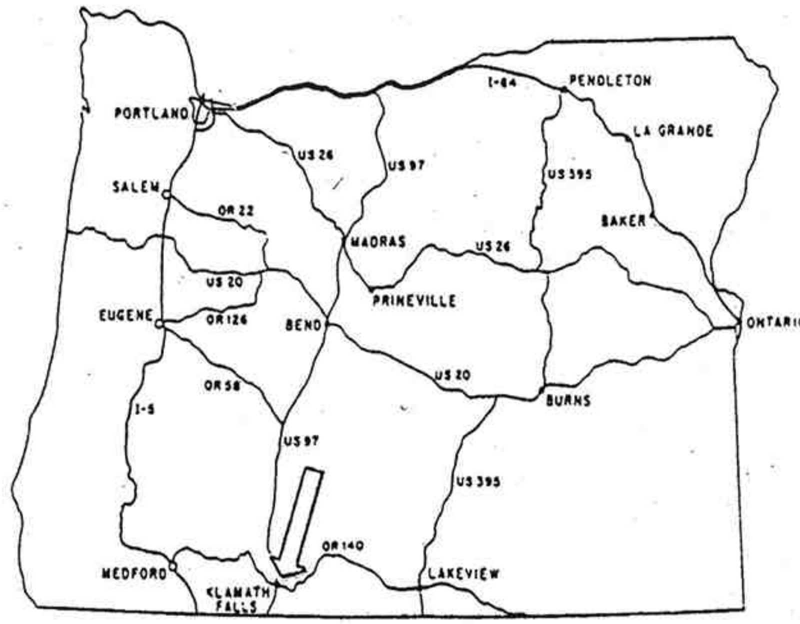


Figure 2.1(a): Project Location

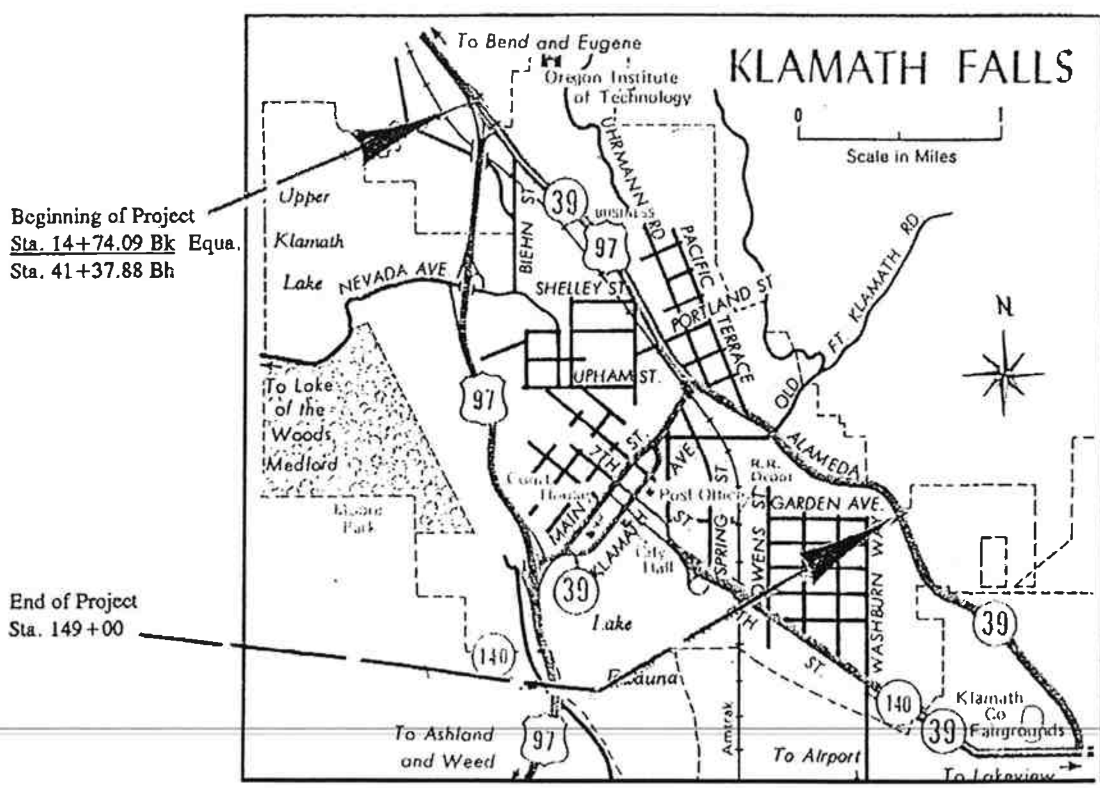


Figure 2.1(b): Close-up of Project Site

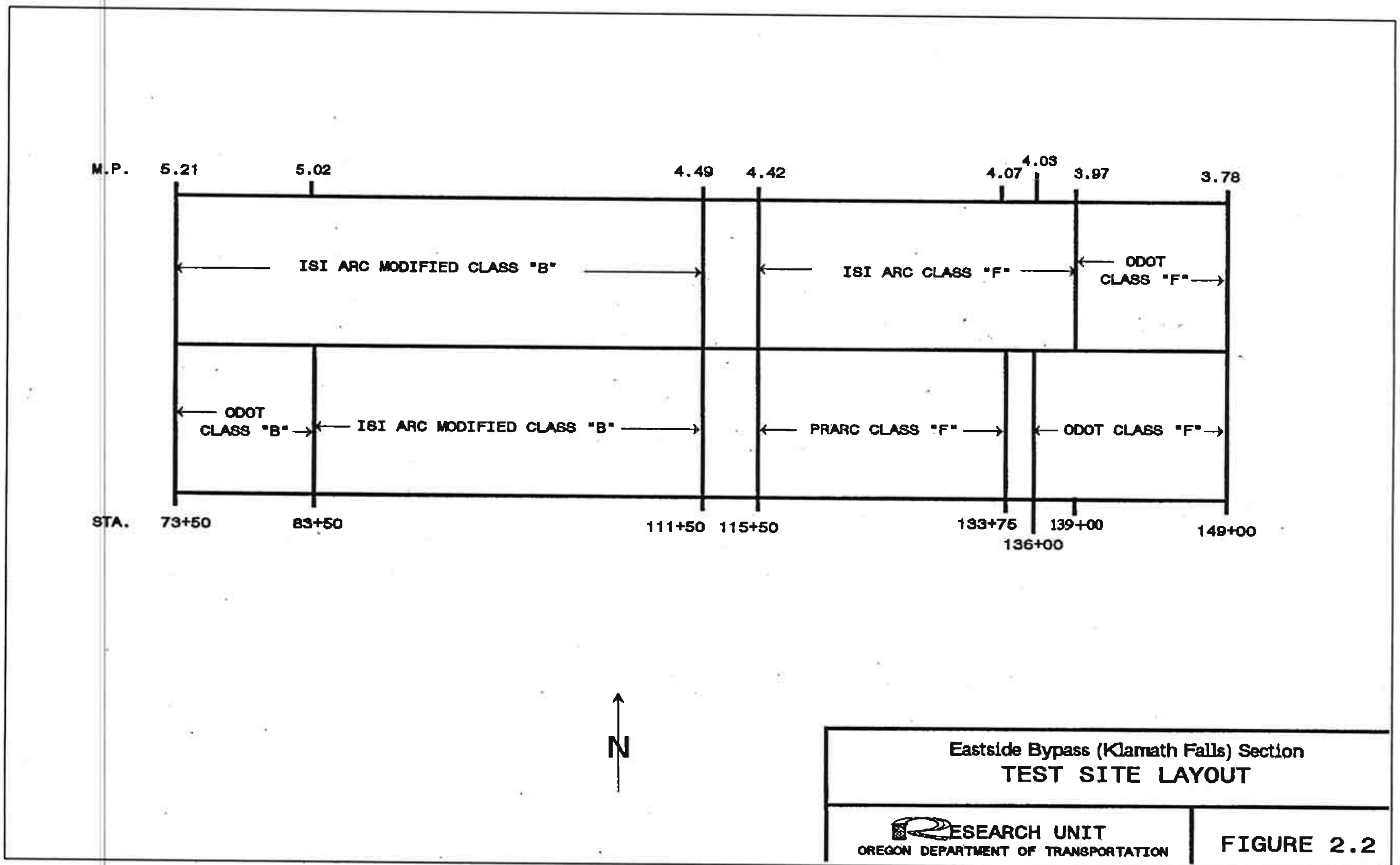


Figure 2.2: Test Site Layout

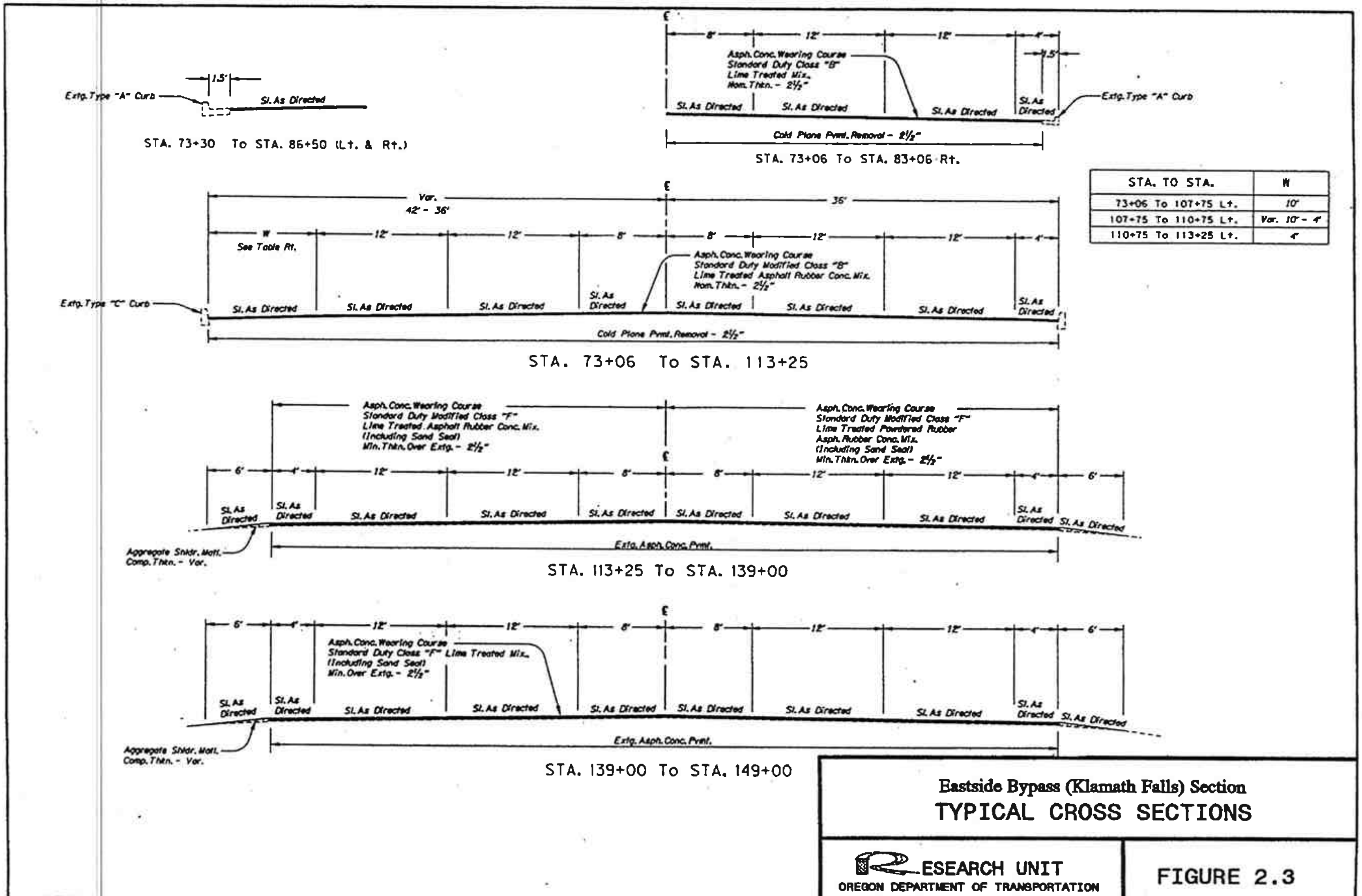
The aim of the Eastside Bypass, Klamath Falls Section project was to rehabilitate the existing pavement to provide additional structural capacity for future traffic growth. Construction of the project would also improve driving conditions and enhance safety and rideability.

As shown in the Typical Cross Section, Figure 2.3, the existing asphalt concrete pavement had four 3.7 m travel lanes with 1.2 m shoulders on each side with a fifth left turn lane at the intersections. The old pavement was a 165 to 305 mm-thick layer of asphalt concrete. The original pavement was constructed in the 1940's. The pavement had been rehabilitated during the 1960's and 1970's with 50 to 100 mm of asphalt concrete overlay. The base layer under the old pavement included crushed aggregate of varying thickness. The subgrade material was identified as clayey silt with some sand.

A pavement condition survey was performed in the summer of 1990. The survey indicated that the existing pavement condition varied along the roadway. At that time, the pavement rated fair to poor in condition.

The existing pavement was cold planed to a depth of 64 mm from STA 73+06 to STA 113+25 to eliminate the pavement distress and maintain the pavement profile at the existing curb line. The removed material was then replaced with 64 mm of new pavement. The original pavement design specified a 64 mm inlay followed by a 64 mm overlay of dense graded mix. The final pavement design included only the 64 mm inlay with the ISI ARC Modified Class "B" mix. In order to maximize the curb height and evaluate a reduced thickness ARC section, the Region suggested constructing the inlay but deleting the overlay. The reduced pavement thickness was compared to the control section, also constructed through the curb section with only a 64 mm inlay.

From STA 113+25 to STA 149+00, the existing pavement was overlaid to a minimum thickness of 64 mm.



STA. TO STA.	W
73+06 To 107+75 Lt.	10'
107+75 To 110+75 Lt.	Var. 10' - 4'
110+75 To 113+25 Lt.	4'

Figure 2.3: Typical Cross Section

2.2 ENVIRONMENT AND TRAFFIC

The project is located in the south central climatic region of Oregon. This region's weather is characterized by cold, dry, snowy winters, and warm, dry summers. The climate was a significant factor in selecting the Eastside Bypass for research.

The test and control pavements are located on a primary state highway which runs through the City of Klamath Falls.

The climate and traffic data for the highway is included in Table 2.2.

Table 2.2: Environment and Traffic Data Eastside Bypass

Elevation, meters	1,251
Average Daily Temperature of Coldest Month, January, °C	5
Average Daily Temperature of Warmest Month, July, °C	20
Average Annual Precipitation, mm	450
1992 Average Daily Traffic, (vehicles/day)	10,200
Heavy trucks, (% of Average daily traffic)[1]	1.1
1992 Annual 80 kn Equivalent Single Axle Loads, (ESALs)	27,483

[1]Single unit, 2-axle, 6-tire or larger vehicles are classified as "heavy trucks.

2.3 MATERIALS AND SUPPLIERS

Paving material suppliers used on the project are listed in Table 2.3. The materials used in the overlay and inlay are described below:

Asphalt Concrete - The ISI ARC Modified Class "B", ISI ARC Class "F", PRARC Class "F", and conventional asphalt concrete mixes were supplied by the contractor.

Binders and Components - ISI's Type II asphalt-rubber binder was used for both the ISI ARC open graded mix and the ISI ARC gap graded mix. This binder contained 77% (of total binder weight) Witco PBA-2, 6% Witco Cyclogen "L" extender oil, and 17% Atlos #1710 Type IIA ground automobile and truck tire rubber.

The PRARC contained 79% Witco PBA-2, 6% Witco Cyclogen "L", and 15% Rouse NR-80 powdered rubber. The binder was blended at the construction site the same way as the ISI Type II asphalt-rubber.

Albina PBA-3 and PBA-6 were used in the conventional ODOT dense graded standard duty (SD) and open graded SD control sections.

Table 2.3: Materials Suppliers

Material	Supplier
Asphalt Cement: PBA-3 and PBA-6	Albina Fuel 3246 N.E. Broadway Portland, OR 97212 Contact Person: Bob Davis
Granulated Rubber	Atlos Rubber Inc. 1522 Fishburn Avenue Los Angeles, CA 90063 Contact Person: Robert Winters
Powdered Rubber	Rouse Rubber Industries, Inc. P.O. Box 820369 1000 Rubber Way Vicksburg, MI 39182-0369 Contact Person: Mike Rouse
Extender Oil	Witco Corporation Golden Bear Products P.O. Box 456 Chandler, AZ 85244-0161
Asphalt-Rubber ISI ARC Binder	International Surfacing, Inc. 6751 W. Galveston Chandler, AZ 85226 Contact Person: Kent Hansen
Lime	Chemstar Hydrated Lime Type N
Truck Bed Release Agent	Slipeazee SB (Water Soluble) Rochester Midland Manufacturing Co. Rochester, NY

Rubber - Crumb rubber used by ISI was supplied by Atlos Rubber Inc. in Los Angeles, California. The rubber was delivered on pallets with a net weight of 1362 kg in 27 kg bags. There were two production lots of rubber used in the ISI mix with slightly different gradations. The slightly varied gradations changed the consistency of the binder a little but did not affect the ISI ARC mixes.

The powdered rubber was supplied by Rouse Rubber Industries, Inc. in Vicksburg, Mississippi. The intent of using powdered rubber was to test Rouse Rubber Industries' GR-80 or an equivalent product produced by another manufacturer. The rubber specifications for this project were based on specifications for GR-80, which is a powdered rubber made from tires. The rubber supplied by ISI for the test section was Rouse Rubber Industries' NR-80.

The NR-80 rubber was delivered in 23 kg bags. The specifications required the powdered rubber to be produced from ground tires. The rubber supplied, however, was from a non-tire source.

Extender Oil - Witco Cyclogen "L" was supplied by Golden Bear Division of Witco Chemical Company in Klamath Falls, Oregon.

Truck Bed Release Agent - Slipeazee SB (water soluble) was supplied by Rochester Midland Manufacturing Company.

Aggregates - Crushed basalt from the quarry located on Stukel Mountain, ODOT Source No. 18-036-4, was used as the aggregate for all mixes. The aggregates were produced in four separate stock piles that included 25 mm – 12.5 mm, 12.5 mm – 6.3 mm, 6.3 mm – 2.0 mm, and 2.00 mm – 0. As a precaution against potential moisture damage, the aggregates were lime treated prior to entering the paving hot mix plant at a rate by weight of 1.0% of weight of the dry aggregate.

2.4 SPECIFICATIONS AND TEST RESULTS ON BINDERS, GRANULATED RUBBER, POWDERED RUBBER, AND ASPHALT-RUBBER

This section provides the specifications and test results of products that were incorporated in the various mixtures to construct the control and test sites. Most of the tests followed AASHTO, ASTM and ODOT methods *(AASHTO 1990, ASTM 1991,ODOT 1986)*. Special sampling and test methods are discussed in Chapter 4. The sections of the specifications that apply to the ISI ARC and PRARC are included in the project's Special Provisions, attached as Appendix A. The specification limits listed in the tables relate to the specifications at the time of construction. Current specifications can be found on the ODOT web site at http://www.dot.state.or.us/techserv/roadway/supplement/0745supl.pdf.

2.4.1 Binders

Paving Grade asphalts were tested by standard laboratory procedures for PBA graded asphalt cement. The test results for PBA-3 and PBA-6 are included in Tables 2.4 and 2.5, respectively.

ISI ARC Binder - For the ISI ARC mixes, the suppliers sent representative samples of PBA-2, ground tire rubber, and extender oil to the laboratory of Western Technologies, Inc. in Phoenix, Arizona, for the mix designs. The laboratory reacted the asphalt, rubber and extender oil to make the Type II binder. The test results and specifications are listed in Table 2.6.

Powdered Rubber ARC - For the PRARC mix, the suppliers sent representative samples of PBA-2, ground tire rubber, and extender oil to the laboratory of Western Technologies, Inc. in Phoenix, Arizona, for the mix designs. The laboratory reacted the asphalt, rubber, and extender oil to make the binder. The test results and specifications are listed in Table 2.7.

2.4.2 Rubber

ISI ARC Rubber - The specifications and test results are listed in Table 2.8(a). The ISI ARC rubber met specifications.

Rouse Rubber Industries' NR-80 Powdered Rubber - The specifications and test results are listed Table 2.8(b). The powdered rubber did not meet specifications. The gradation was too coarse and was deficient passing all of the sieves. Also, the NR-80 powdered rubber exceeded the allowable ash content. This is indicative of rubber that is not from a tire source.

Table 2.4: **Binder Test Results - PBA-3 (Dense-graded Binder)**

Test	Method	Test Results	Specifications
Pen. @ 39.2°F (4 °C), 100g, 5s, on Residue (dmm)	AASHTO T49[b]	11[a], 13[c]	None
Pen. @ 39.2°F (4 °C), 200g, 60s, on Residue (dmm)	AASHTO T49[b]	39[a], 38[c]	30 (min.)
Pen. @ 77°F (25 °C), 100g, 5s, on Residue (dmm)	AASHTO T49[b]	73[a], 70[c]	None
Abs. Vis. @ 140°F (60 °C), on Original (P)	AASHTO T202[d]	2,140[a], 2,330[c]	1,100 (min.)
Abs. Vis. @ 140°F, 30 cm, Hg Vac, on Residue (P)	AASHTO T202[b,d]	5,150[a], 5,640[c]	3,000 (min.)
Abs. Vis. Ratio (Residue/Original)	AASHTO T202	2.4[a], 2.4[c]	4.0 (max.)
Kin. Vis. @ 275°F (135 °C), on Original (cSt)	AASHTO T201	592[a], 632[c]	2,000 (max.)
Kin. Vis. @ 275°F, on Residue (cSt)	AASHTO T201[b]	865[a], 930[c]	275 (min.)
Duct. @ 45°F (27.2 °C), 1 cm/min., on Residue (cm)	AASHTO T51[b,e]	27[a], 25+[c]	None
Duct. @ 77°F, 5 cm/min., on Residue (cm)	AASHTO T51[b,e]	81[a], 100+[c]	75 (min.)
Flash Point, COC, Original (°F)	AASHTO T48	545[a] (285 °C), 570[c] (299 °C)	450 (min.) (230 °C)
Loss on Heating, of Residue (%)	AASHTO T47[b]	.14[a], .14[c]	None

Note – Test data are entered in the format (dual units) used at the time the testing was conducted in 1992.

[a] Acceptance tests on the binder used in mix design for ODOT Class "B" mix.
[b] AASHTO T240 method used to age asphalt.
[c] Check/record test on the binder used in Class "B" 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).

Table 2.5: Binder Test Results - PBA-6 (Open-graded Binder)

Test	Method	Test Results	Specifications
Pen. @ 39.2°F (4 °C), 100g, 5s, on Residue (dmm)	AASHTO T49[b]	12[a], 12[c]	None
Pen. @ 39.2°F (4 °C), 200g, 60s, on Residue (dmm)	AASHTO T49[b]	36[a], 37[c]	30 (min.)
Pen. @ 77°F (25 °C), 100g, 5s, on Residue (dmm)	AASHTO T49[b]	67[a], 73[c]	None
Abs. Vis. @ 140°F (60 °C), on Original (P)	AASHTO T202[d]	3,010[a], 3,440[c]	2,000 (min.)
Abs. Vis. @ 140°F, 30 cm, Hg Vac, on Residue (P)	AASHTO T202[b,d]	6,490[a], 10,000[c]	5,000 (min.)
Abs. Vis. Ratio (Residue/Original)	AASHTO T202	2.2[a], 2.9[c]	4.0 (max.)
Kin. Vis. @ 275°F (135 °C), on Original (cSt)	AASHTO T201	682[a], 785[c]	2,000 (max.)
Kin. Vis. @ 275°F, on Residue (cSt)	AASHTO T201[b]	1,000[a], 1,210[c]	275 (min.)
Duct. @ 45°F (27.2 °C), 1 cm/min., on Residue (cm)	AASHTO T51[b,e]	25+[a], 25+[c]	None
Duct. @ 77°F, 5 cm/min., on Residue (cm)	AASHTO T51[b,e]	98+[a], 92[c]	60 (min.)
Flash Point, COC, Original (°F)	AASHTO T48	580[a] (304 °C) 585[c] (307 °C)	450 (min.) (230 °C)
Loss on Heating, of Residue (%)	AASHTO T47[b]	.25[a], .37[c]	None

Note – Test data are entered in the format (dual units) used at the time the testing was conducted in 1992.

[a] Acceptance tests on the binder used in mix design for ODOT Class "F" mix.
[b] AASHTO T240 method used to age asphalt.
[c] 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).

Table 2.6: Binder Test Results - ISI Type II Asphalt Rubber (ISI ARC Mixes)

Test	Method	Test Results	Specifications[i]
Pen. @ 39.2°F (4 °C), 200g, 60s, on Original (dmm)	ASTM D5	33[a], 29[c], 38[d]	25 (min.)
Pen. @ 39.2°F (4 °C), 200g, 60s, on Residue (dmm)	ASTM D5	27[a], 33[c], 20[d]	None
Pen. Retention @ 39.2°F, (Residue/Original x 100) (%)	ASTM D2872	82[a], 114[c], 76[d]	75 (min.)
Pen. @ 77°F (25 °C), 100g, 5s, on Original (dmm)	ASTM D5	55[a], 56[c], 52[d]	50 (min.) 100 (max.)
Cone Pen. @ 77°F, 150 g, on Original	ASTM D217	51[c]	None
Apparent vis. @ 347°F (175 °C), Spindle 3, 10 to 20 RPM,: on Original (cP)[b]	ASTM 2669	None	1,000 (min.) 4,000 (max.)
Haake Vis. @ 350°F (177 °C), #1 Rotor, on Original (cP)[b]	(Reference 6)	2,250[c] 1,300[e] 3,500[f] 7,000[g]	1,000 (min.) 4,000 (max.)
Softening Point, on Original (°F)	ASTM D36	149[a] (65 °C), 131[c] (55 °C), 136[d] (58 °C)	120 (min.) (50 °C)
Duct. @ 39.2°F, 1 cpm, on Original (cm)	ASTM D113	17[a], 12.5[c], 31[d]	10 (min.)
Duct. @ 39.2°F, 1 cpm, on Residue (cm)	ASTM D113	14+[a], 16[c], 25[d]	None
Duct. Retention @ 39.2°F, (Residue/Original x 100) (%)	ASTM D2872	128[c], 81[d]	50 (min.)
Resilience @ 77°F, Rebound, on Original (%)	ASTM D3407	21[c]	10 (min.)

Note – Test data are entered in the format (dual units) used at the time the testing was conducted in 1992.

[a] Acceptance tests on binder including 6% cyclogen "L", 17% Atlos 1710 ground rubber, and 77% Witco PBA-2 used in mix design for ISI "F" mix and ISI modified Class "B" mix.
[b] Apparent viscosity tests are typically used for determining viscosities in the laboratory and Haake viscosity tests are used in the field. However, for this project Haake viscosity tests were used in place of apparent viscosity tests for both the mix design and construction quality control.
[c] ISI's mix design tests and specified test methods on binder after the rubber was reacted with the base asphalt for 60 minutes at 344°F (173 °C).
[d] ODOT check/record tests on binder used in ISI ARC mix.
[e] Viscosity from ISI's on-site test at 30 minutes reaction time at 341°F (172 °C).
[f] Viscosity from ISI's on-site test at 135 minutes reaction time at 352°F (178 °C).
[g] Viscosity from ISI's on-site test at 360 minutes reaction time at 362°F (183 °C).
[h] AASHTO T179 used to age binder for ISI's mix design, and AASHTO T240 was used to age ODOT's sample.
[i] Parameters apply to asphalt-rubber reacted at 350°F (175 °C)± 10°F (5 °C)± for 30 minutes.

Table 2.7: Binder Test Results - Powdered Rubber ARC

Test	Method	Test Results[a]	Specifications
Pen. @ 39.2°F (4 °C), 200g, 60s, on Original (dmm)	ASTM D5	19[c], 45[d]	25 (min.)
Pen. @ 39.2°F, 200g, 60s, on Residue (dmm)[f]	ASTM D5	25[d]	None
Pen. Retention @ 39.2°F (4 °C), (Residue/Original x 100) (%)	ASTM D2872	56[d]	75 (min.)
Pen. @ 77°F (25 °C), 100g, 5s, on Original (dmm)	ASTM D5	71[c], 85[d]	50 (min.) 100 (max.)
Cone Pen. @ 77°F, 150 g, on Original	ASTM D217	66[c]	None
Apparent vis. @ 347°F (175 °C), Spindle 3, 12 rpm, on Original (cP)[b]	ASTM 2669	None	1,000 (min.) 4,000 (max.)
Haake Vis. @ 350°F, #1 Rotor, on Original (cP)[b]	(Reference 6)	3,500[c] 2,250[e]	1,000 (min.) 4,000 (max.)
Softening Point, on Original (°F)	ASTM D36	130[c] (54 °C), 129[d] (54 °C)	120 (min.) (50 °C)
Duct. @ 39.2°F, 1 cpm, on Original (cm)	ASTM D113	21[c], 25+[d]	10 (min.)
Duct. @ 39.2°F, 1 cpm, on Residue (cm)[f]	ASTM D113	25[d]	None
Duct. Retention @ 39.2°F, Residue/Original x 100) (%)	ASTM D2872	81[d]	50 (min.)
Resilience @ 77°F, Rebound, on Original (%)	ASTM D3407	16[c]	10 (min.)

Note – Test data are entered in the format (dual units) used at the time the testing was conducted in 1992.

[a] Tested binder was 6% cyclogen "L", 15% Rouse NR-80 powdered rubber, and 79% Witco PBA-2.
[b] Apparent viscosity tests are typically used for determining viscosities in the laboratory and Haake viscosity tests are used in the field. However, for this project Haake viscosity tests were used in place of apparent viscosity tests for both the mix design and construction quality control.
[c] ISI's mix design tests and specified test methods on binder after the rubber was reacted with the base asphalt for 60 minutes at 310°F (154 °C).
[d] ODOT check/record tests on binder used in PRARC mix.
[e] Viscosity from ISI's on-site test at 30 minutes reaction time at 315°F (157 °C).
[f] AASHTO T240 was used to age the ODOT's binder sample.

Table 2.8(a): **Granulated Rubber - Atlos 1710 Rubber Type II Used in ISI ARC**

Gradation (% Passing)	Test Results	Specification
Sieve Size #10 (2.03 mm) #16 (1.18 mm) #30 (600 µm) #50 (300 µm) #200 (75µm)	 100 100 54.1 18.9 0.0	 100 70 – 100 25 – 60 0 – 20 0 – 5
Max Length	Okay	3/16"
Fiber Content	0.0	< 0.5%
Moisture Content	0.43%	< 0.75%
Mineral Contaminants	< 0.25%	< 0.25%
Metal Contaminants	None visible	No visible

Table 2.8(b): **Powdered Rubber - Rouse NR80 Ultrafine Powder Used in PRARC**

Sieve Size: #60 #80 (175 µm) #100 (150 µm) #200 (75 µm)	NR-80 89.6, 97.1[b] 61.7, 76.2[b] 44.5, 59.0[b] 0.0, 10.1[b]	 99 – 100 89 – 100 74 – 90 24-90
Moisture Content	0.37, 1.1[b]	< 1%
Specific Gravity (ASTM D297-16)[a]	1.17	1.15± 0.02
Acetone Extract (ASTM D297-19)[a]	18.7%	23% max.
Carbon Black Content (ASTM D297-39)[a]	29.1%	34% max.
Ash Content (ASTM D297-39)[a]	10.8%	7% max.
Rubber Hydrocarbon (ASTM D297)[a] Content (by difference)	41.4%	42% max.

Note – Test data are entered in the format (dual units) used at the time the testing was conducted in 1992.

[a] Modified test method. Methods on file in the ODOT's Research Unit.
[b] Tests performed on backup sample.

2.5 MIX DESIGNS

This section presents the mix designs and job mix formulae for the test and control pavements.

2.5.1 ODOT's Class "B", Dense Graded, Mix Design

The mix design used ODOT's modified Hveem method *(George, Boyle & Blachly 1989)*. Broadband limits, mix design criteria, and design mix properties are listed in Table 2.9.

Table 2.9: Broadband Limits, Mix Design Criteria, and Design Mix Characteristics at Design Binder Contents – Class "B", Dense-Graded, Mix

Characteristics	Class "B" Mix Design Criteria	Class "B" Design Mix
Gradation (% Passing Screen)		
1-inch (25.4 mm)	99 - 100[a]	100[b]
3/4-inch (19.1 mm)	90 - 98	95
1/2-inch (12.7 mm)	75 - 91	80
3/8-inch (9.5 mm)	-	72
1/4-inch (6.3 mm)	50 - 70	56
#10 (2.03 mm)	21 - 41	29
#40 (425 μm)	8 - 24	13
#200 (75 μm)	2 - 7	5.6
Binder Content (%)	4 - 8[a]	6.1
Binder Film Thickness	Sufficient	Sufficient
Sp. Gr. @ 1st Comp.	None	2.297[c]
Voids @ 1st Comp. (%)	5.5 - 6.5	5.4
Stab. @ 1st Comp. (Hveem)	≥37	39
Sp. Gr. @ 2nd Comp.	None	2.358[c]
Voids @ 2nd Comp. (%)	≥2.5	2.9
Stab. @ 2nd Comp. (Hveem)	≥37	46
Rice Max. Sp. Gr.	None	2.427
Voids in Mineral Aggregate (%)	≥14	14.9
Index of Ret. Strength (%)[d]	≥75	80
Index of Ret. Resilient Modulus (%)	≥70	117

Note – Test data are entered in the format (dual units) used at the time the testing was conducted in 1992.

[a] Broadband limits for gradation and binder content. Gradations are percentage of dry ingredient weight, including 1% lime. Binder contents are percentage of total mix weight.
[b] Mix design sample at design binder content test results in this column.
[c] Based on immersed unit weight of unsealed core (AASHTO T166).
[d] Based on effect of water on cohesion of compacted bituminous mixtures (AASHTO T165).

2.5.2 ISI ARC Modified Class "B", Gap Graded, Mix Design

The design criteria and procedures were based on ODOT's modified Hveem method *(George, Boyle & Blachly 1989)*. The mix design was supplied by Western Technologies, Inc. The mix design data is shown in Table 2.10.

International Surfacing, Inc. (ISI) proposed to waive the Index of Retained Resilient Modulus (IRM_r) testing as a requirement for approval of the proposed mix design. The suitability of the test was questioned for a gap graded mix since the procedure was developed for dense graded mixes. ODOT waived the requirement with the understanding that the test would still be

Table 2.10: Broadband Limits, Mix Design Criteria, and Design Mix Characteristics at Design Binder Contents – ISI ARC Modified Class "B"

Characteristics	ODOT Modified Class "B" ARC Mix Design Criteria	ISI ARC Modified Class "B" Design Mix
Gradation (% Passing Screen)		
1-inch (25.4 mm)	99 - 100[a]	100[b]
3/4-inch (19.1 mm)	90 - 98	92
1/2-inch (12.7 mm)	65 - 85	71
3/8-inch (9.5 mm)	-	56
1/4-inch (6.3 mm)	25 - 40	33
#10 (2.03 mm)	10 - 25	17
#40 (425 μm)	4 - 12	9
#200 (75 μm)	2 - 6	4.9
Rubber Content (%)	15 - 20[c]	17
Binder Content (%)	7.5 - 9.5[a]	8.0
Sp. Gr. @ 1st Comp.	None	2.253[d]
Voids @ 1st Comp. (%)	3 - 5	3.1
Stab. @ 1st Comp. (Hveem)	≥35	28
Sp. Gr. @ 2nd Comp.	None	2.295[d]
Voids @ 2nd Comp. (%)	None	1.4
Rice Max. Sp. Gr.	None	2.327
Stab. @ 2nd Comp. (Hveem)	≥35	28
Voids in Mineral Aggregate (%)	≥17	18.2
Tensile Strength Ratio (%)	None	93.6

Note – Test data are entered in the format (dual units) used at the time the testing was conducted in 1992.

[a] Broadband limits for gradation and binder content. Gradations are percentage of dry ingredient weight, including 1% lime. Asphalt-rubber binder contents are percentage of total mix weight.
[b] Mix Design values interpolated from briquette with 6.5% and 7% binder content.
[c] Rubber content is percentage of total asphalt-rubber blend.
[d] Based on immersed unit weight of unsealed core (AASHTO T166).

performed for informational purposes. During the "information testing", the specimen at a binder content of 7.5% did not survive the conditioning. The specimen at a binder content of 8% had an IRM_r of 92% and the specimen at a binder content of 8.5% had an IRM_r of 173%. The results indicate adequate resistance to moisture damage according to ODOT criteria.

Index of Retained Strength (IRS) (AASHTO T165) samples did not survive conditioning, so stripping was evaluated based on the Tensile Strength Ratio (TSR). The TSR for the ISI ARC Modified Class "B" design mix was 93.6%, indicating acceptable resistance to stripping. ODOT uses the TSR test to estimate shipping susceptibility. The minimum accepted TSR is 80%.

2.5.3 ODOT's Class "F", Open Graded, Mix Design

This design used an ODOT modified Hveem procedure to determine asphalt content based on void contents, stabilities, and binder film thickness *(George, Boyle & Blachly 1989)*. In this design, a 6% target asphalt content was used to give as thick a coating as possible to the aggregate. Based on the results of index of retained strength testing, an anti-stripping agent was required to reduce the potential for moisture damage. Broadband limits, mix design criteria, and design mix properties are listed in Table 2.11.

Table 2.11: Broadband Limits, 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
Gradation (% Passing Screen)		
1-inch (25.4 mm)	99 – 100[a]	100[b]
3/4-inch (19.1 mm)	85 - 96	91
1/2-inch (12.7 mm)	60 - 71	66
3/8-inch (9.5 mm)	-	47
1/4-inch (6.3 mm)	17 - 31	27
#10 (2.03 mm)	7 – 19	14
#40 (425 μm)	-	8
#200 (75 μm)	1 – 6	4.3
Binder Content (%)	4 – 8[a]	6.0
Binder Film Thickness	Sufficient[c]	Thick[c]
Rice Max. Sp. Gr.	None	2.375
Voids in Mineral Aggregate (%)	None	-
Index of Retained Strength (%)[d]	≥75	75
Draindown (%)	≥75	75

Note – Test data are entered in the format (dual units) used at the time the testing was conducted in 1992.

[a] Broadband limits for gradation and binder content. Gradations are percentage of dry ingredient weight, including 1% lime. Binder contents are percentage of total mix weight.
[b] Mix Design sample at design binder content test results in this column.
[c] Visual examination based on ODOT mix design procedure and guidelines (*Chehovits 1989*).
[d] Based on effect of water on cohesion of compacted bituminous mixtures (AASHTO T165).

2.5.4 ISI ARC Class "F", Open Graded, Mix Design

The original design was provided by Western Technologies, Inc. of Phoenix, Arizona for ISI. At ODOT's request, the design objective was to produce a free-draining and durable pavement. The design was based on methods included in "Design of Open-Graded Asphalt Friction Courses," Report No. FHWA-RD-74-2, modified to account for the properties of asphalt-rubber binder *(Chehovits 1989)*. The target asphalt content was 7.5%.

After the design was submitted to the State, ODOT's Bituminous Laboratory converted the design to their standard format and presented it to the contractor. Broadband limits and data from the mix design are listed in Table 2.12.

Table 2.12: Broadband Limits, Mix Design Criteria, and Design Mix Characteristics at Design Binder Contents - ISI ARC "F", Open-Graded, Mix

Characteristics	ISI ARC Mix Design Criteria	ISI ARC Design Mix
Gradation (% Passing Screen)		
1-inch (25.4 mm)	99 – 100[a]	100
3/4-inch (19.1 mm)	85 - 96	91
1/2-inch (12.7 mm)	60 - 71	66
3/8-inch (9.5 mm)	-	50
1/4-inch (6.3 mm)	12 - 38	20
#10 (2.03 mm)	4 – 14	10
#40 (425 μm)	0 - 8	6
#200 (75 μm)	0 – 5	3.6
Mineral Filler	.5 – 1.5	Not used
Binder Content (%)	8 – 11[a]	7.5
% Rubber in Binder	15 – 20[a]	17
Sp. Gr. @ 1st Comp.	None	1.88[c]
Voids @ 1st Comp. (%)	None	7.2[d], 20.2[c]
"Rice" Max. Sp. Gr.	None	2.356
Index of Retained Strength (%)[e]	≥75	Waived
Binder Runoff @ 300°F (150 °C)	≥1/4"[b] (6 mm)	0" - 1/4"

Note – Test data are entered in the format (dual units) used at the time the testing was conducted in 1992.

[a] Broadband limits for gradation, binder and rubber content. Gradations are percentage of dry ingredient weight, including 1% lime. Binder content is percentage of total mix weight.
[b] Diameter of spots based on FHWA-RD-74-2.
[c] Based on dimensional analysis.
[d] Calculated from specific gravity determined by immersed unit weight of unsealed core.
[e] Based on effect of water on cohesion of compacted bituminous mixtures (AASHTO T165).

ISI proposed to waive the IRM_r testing (ODOT Test Method 315) as a requirement for approval of the proposed mix design. ISI stated that it was their opinion that the test method was not appropriate for open graded ARC mixtures and therefore, should not be required. ODOT waived the requirement. IRM_r testing was done, however, for informational purposes.

The results of the IRM_r testing on three specimens at varying binder contents, indicated a decrease in IRM_r with increasing binder content. A binder content of 7.4% would meet the minimum IRM_r requirement of 70%. Typically, an increase in the index of retained resilient modulus would be expected with an increase in binder content. ISI provided the following possible reasons for a decrease in IRM_r with increasing binder content *(Beaty & Stonex 1992)*:

> "Open graded mixes take on water easily during vacuum saturation because of their high volume of voids, but also drain freely for the same reason. The target design air void content for the "F" mix was 20%. Experience has shown when a specimen is removed from the saturating vessel, some of the water in the voids may run out, thus lowering the degree of saturation. As binder content increased, the void volume of the "F" mix test specimens decreased. This makes the specimens increasingly less free draining, resulting in a greater degree of saturation than the lower binder content specimens. With a higher degree of saturation, the samples are more likely to incur greater damage during the freeze-thaw cycle, resulting in a lower index of retained resilient modulus."

ISI also suggested that the variance in IRM_r could be due to specimen conditioning procedure. The procedure specifies a vacuum pressure of 30.5 mm of HG and a saturation time of 30 minutes. The procedure does not control the degree of saturation so that all the specimens may not be equally saturated. A degree of saturation based on volume of air voids may be more effective for the open graded mixes *(Beaty & Stonex 1992)*.

The index of retained strength samples did not survive conditioning in the 60°C waterbath (AASHTO T165). The IRS criteria was waived. Root-Tunnicliff tests run by ISI, using a freeze/thaw conditioning, however, had acceptable results.

ODOT currently requires that a TSR test be performed on a dense graded surrogate sample for all open graded mixes.

2.5.5 PRARC Class "F", Open Graded, Mix Design

The mix design used for the PRARC was the same design developed for the ISI ARC Class "F" mix. The intent was to construct the mixes the same to evaluate the constructability and performance. The PRARC mix design data is shown in Table 2.13.

ODOT waived the requirement for IRM_r testing. In addition, index of retained strength samples did not survive conditioning in the 60°C waterbath (AASHTO T165) and the IRS criterion was waived. The current ODOT requirement uses the TSR test on a surrogate dense graded sample to determine stripping susceptibility.

Table 2.13: Broadband Limits, Mix Design Criteria, and Design Mix Characteristics at Design Binder Contents – PRARC "F", Open-Graded, Mix

Characteristics	ISI ARC Mix Design Criteria	PRARC "F" Design Mix
Gradation (% Passing Screen)		
1-inch (25.4 mm)	99 – 100[a]	100[b]
3/4-inch (19.1 mm)	85 - 96	91
1/2-inch (12.7 mm)	60 - 71	66
3/8-inch (9.5 mm)	-	50
1/4-inch (6.3 mm)	12 - 38	20
#10 (2.03 mm)	4 – 14	10
#40 (425 μm)	0 - 8	6
#200 (75 μm)	0 – 5	3.6
Mineral Filler	.5 – 1.5	1.0
Binder Content (%)	8 – 11[a]	7.5 8.0[d]
% Rubber in Binder	15 – 20[a]	15
Sp. Gr. @ 1st Comp.	None	1.88[e] 1.92[d,e]
Voids @ 1st Comp. (%)	None	7.5[f], 20.2[e] 6.5[d,f], 18.0[d,e]
"Rice" Max. Sp. Gr.	None	2.356 2.340[d]
Index of Retained Strength (%)[g]	≥75	Waived
Binder Runoff @ 300°F (150 °C)	≥1/4"[c] (6 mm)	Satisfactory

Note – Test data are entered in the format (dual units) used at the time the testing was conducted in 1992.

[a] Broadband limits for gradation, binder, and rubber content. Gradations are percentage of dry ingredient weight, including 1% lime. Binder content is percentage of total mix weight.
[b] Mix design sample at design binder content.
[c] Diameter of spots based on FHWA-RD-74-2.
[d] Results of tests at field adjusted binder content of 8%.
[e] Based on dimensional analysis.
[f] Calculated from specific gravity determined by immersed unit weight of unsealed core.
[g] Based on effect of water on cohesion of compacted bituminous mixtures (AASHTO T165).

2.5.6 Open Graded Mix Design Comparison

The open graded ISI ARC, PRARC, and Class "F" mixes had different binder contents and gradation.

Binder Content - For the ISI ARC and PRARC mixtures, the binder content broadband limits of 8% to 11% were higher than the limits of 4% to 8% for the Class "F" mix. According to ISI, the relatively low viscosity of conventional asphalt at high temperatures limits the amount of asphalt that can be added to an open-graded mix, and any asphalt in excess of this limited amount drains to the bottom of the mix. However, they claim the blending of rubber with the asphalt increases the viscosity of the binder at mixing and placement temperatures. As a consequence of this higher viscosity, additional binder can be used in the mix to give the aggregate a thicker coating without causing excessive draindown.

Gradation - In comparison to the Class "F" mix, the ISI ARC and PRARC broadband limits allowed approximately 4% less aggregate passing the 2.03 mm screen and about 1% less fines passing the 75 μm screen. According to ISI, the amount of fine aggregate was reduced to make room for the asphalt-rubber binder and retain a porous open graded pavement.

2.6 SUMMARY

The ODOT Class "B" mix control section consisted of a 64 mm pavement inlay. The ISI ARC Modified Class "B" mix (gap-graded) was also a 64 mm pavement inlay. The original design called for an additional 64 mm dense graded mix overlay, however, a reduced section was finally specified through the curbed section. The Class "F" mix control section, ISI ARC Class "F" and PRARC Class "F mix test sections" were each 64 mm overlays placed on existing distressed asphalt concrete pavement.

The Class "B" mix design used for the control section was the standard method used by ODOT. The method is based on Hveem compacted void content, stability, asphalt binder film thickness, IRS and IRM_r. This design called for 6.1% PBA-3. Lime treated aggregates were required.

The design criteria and procedures for the ISI ARC Modified Class "B" mix were based on ODOT's modified Hveem method. The mix design was supplied by Western Technologies, Inc. The design called for 8.0% binder that included 17% tire grindings, 6% extender oil, and 77% PBA-2. Lime treated aggregates were required.

The Class "F" mix design used for the control section was based on asphalt binder film thickness, IRS, and asphalt draindown. This design called for 6.0% PBA-6. Lime treated aggregates were required.

The ISI ARC open-graded mix design was performed by Western Technologies Lab based on a modified version of a FHWA technique on binder draindown. This design called for 7.5% binder that included 17% tire grindings, 6% extender oil and 77% PBA-2. Lime treated aggregates were required.

The PRARC Class "F" mix design used the same mix design procedure as the ISI ARC Class "F" Mix. The recommended binder content for PRARC was 7.5%. The binder content was later field adjusted to 8%. The binder included 15% powdered rubber, 6% extender oil, and 79% PBA-2.

Extender oil was added to soften the asphalt-rubber binders to meet the specifications for penetration tests. The cold penetration retention test (4 $^{\circ}$C) results for the ISI asphalt-rubber were 76%, and 56% for the powdered rubber asphalt-rubber (PRAR). The lower value, especially for the PRAR, may be an indication that the binder is susceptible to thermal cracking.

Standard tests to evaluate moisture susceptibility of the mixes included IRM_r and IRS. The IRM_r tests were waived for evaluation of the asphalt-rubber modified mixes since it was felt the test was inappropriate for gap graded or open graded mixes. In addition, the samples did not survive the conditioning for the IRS testing so that test was also waived. Although the mixes did not survive the conditioning, it is presumed that this is not an indication of the moisture susceptibility of the mix, but is attributed to the gradation of the aggregate.

ODOT currently uses the TSR test on surrogate dense graded samples to evaluate moisture susceptibility.

3.0 CONSTRUCTION

This chapter describes the test and control section wearing courses constructed in September 1992. The test results, test methods, and random measurements of air temperature, road weather data are listed in Tables 3.1(a) through 3.1(e). AASHTO and ODOT sampling and testing methods were used in most cases *(AASHTO 1990, ODOT 1986, ODOT 1992)*. The Special Provisions of the contract specifications that apply to the ISI ARC and the PRARC construction are included in Appendix A.

Table 3.1(a): Job Mix Specifications and Properties - Class "B"

Test	Method	Test Results	Job Mix Specifications
Gradation (% Passing Screen):	AASHTO T11 and T27 AASHTO T2		
1-inch (25.4 mm)		100[a,b]	99-100[b,d]
¾-inch (19.1 mm)		96	90-98
½-inch (12.7 mm)		82	75-91
¼-inch (6.3 mm)		55	50-62
#10 (2.0 mm)		28	24-34
#40 (425 μm)		12	8-18
#200 (75 μm)		5.2	3.6-7.0
Binder Content (%)	ODOT TM321 ODOT TM322	6.2[c]	5.6-6.6[c]
Moisture Content (%)	ODOT TM311M	.33[c]	.8 (max)[c,f]

Note – Test data are entered in the format (dual units) used at the time the testing was conducted in 1992.

[a]Average of acceptance tests in this column unless noted otherwise.
[b]Percentages of dry ingredient weight including aggregate and 1% hydrated lime.
[c]Percentages of total mix weight.
[d]Narrowband limits in this column unless noted otherwise.
[e]Random measurements.
[f]Specifications in Special Provisions.

Table 3.1(b): Job Mix Specifications and Properties - ISI ARC Modified Class "B"

Test	Method	Test Results	Job Mix Specifications
Gradation (% Passing Screen):	AASHTO T11 and T27 AASHTO T2		
1-inch (25.4 mm)		100[a,b]	99-100[b,e]
¾-inch (19.1 mm)		94	90-98
½-inch (12.7 mm)		69	65-85
¼-inch (6.3 mm)		34	27-39
#10 (2.0 mm)		19	12-22
#40 (425 µm)		9	4-12
#200 (75 µm)		3.8	2.9-6.9
Binder Content (%)	ODOT TM321 ODOT TM322	7.9[c]	7.5-8.5[c]
Moisture Content (%)	ODOT TM311M	.25[c]	.8 (max)[c,g]
Mix Temp. at Discharge, °F, (°C)		300[h] (149)	290-310[i] (143-154)
Mix Temp. behind Paver, °F, (°C)		280-290[f,h] (138-143)	275-310[i] (135-154)
Placement Air Temp., °F, (°C)		75-82[e,h] (24-28)	60 min[h] (16)
Placement Surface Temp °F, (°C)		104-140[e,h] (40-60)	None
Wind Speed, mph, (m/s)		0-5[e,h] (0,2.2)	None
Weather		Cloudy	None

Note – Test data are entered in the format (dual units) used at the time the testing was conducted in 1992.

[a] Average of acceptance tests in this column unless noted otherwise.
[b] Percentages of dry ingredient weight including aggregate and 1% hydrated lime.
[c] Percentages of total mix weight.
[d] Narrowband limits in this column unless noted otherwise.
[e] Range of test results.
[f] Estimated.
[g] Specifications in Special Provisions.
[h] Random measurements.
[i] Limits in job mix formula.

Table 3.1(c): Job Mix Specifications and Properties - ODOT Class "F

Test	Method	Test Results	Job Mix Specifications
Gradation (% Passing Screen):	AASHTO T11 and T27 AASHTO T2		
1-inch (25.4 mm)		100[a,b]	99-100[b,d]
3/4-inch (19.1 mm)		94	85-96
1/2-inch (12.7 mm)		68	60-71
1/4-inch (6.3 mm)		28	21-33
#10 (2.0 mm)		14	9-19
#40 (425 μm)		7	3-13
#200 (75 μm)		3.1	2.3-6.0
Binder Content (%)	ODOT TM321 ODOT TM322	6.1[c]	5.5-6.5[c]
Moisture Content (%)	ODOT TM311M	.29[c]	.8 (max)[c,f]
Mix Temp. at Discharge °F, °C		250[h] (121)	247-257[e] (119-125)

Note – Test data are entered in the format (dual units) used at the time the testing was conducted in 1992.

[a] Average of acceptance tests in this column unless noted otherwise.
[b] Percentages of dry ingredient weight including aggregate and 1% hydrated lime.
[c] Percentages of total mix weight.
[d] Narrowband limits in this column unless noted otherwise.
[e] Range of test results.
[f] Specifications in Special Provisions.
[g] Limits in job mix formula.
[h] Estimated.

Table 3.1(d): Job Mix Specifications and Properties - ISI ARC Class "F"

Test	Method	Test Results	Job Mix Specifications
Gradation (% Passing Screen):	AASHTO T11 and T27 AASHTO T2		
1-inch (25.4 mm)		100[a,b]	99-100[b,d]
3/4-inch (19.1 mm)		94	85-96
1/2-inch (12.7 mm)		71	60-71
1/4-inch (6.3 mm)		20	14-26
#10 (2.0 mm)		10	5-14
#40 (425 μm)		6	1-8
#200 (75 μm)		2.5	1.6-5.0
Binder Content (%)	ODOT TM321 ODOT TM322	7.5[c]	7.3-7.7[c]
Moisture Content (%)	ODOT TM311M	.18[c]	.8 (max)[c,e]
Mix Temp. at Discharge °F, (°C)		300[g] (149)	275-310[f] (135-154)

Note – Test data are entered in the format (dual units) used at the time the testing was conducted in 1992.

[a] Average of acceptance tests in this column unless noted otherwise.
[b] Percentages of dry ingredient weight including aggregate and 1% hydrated lime.
[c] Percentages of total mix weight.
[d] Narrowband limits in this column unless noted otherwise.
[e] Specifications in Special Provisions.
[f] Limits in job mix formula.
[g] Thermometer inserted into mix.

Table 3.1(e): Job Mix Specifications and Properties - PRARC Class "F

Test	Method	Test Results	Job Mix Specifications
Gradation (% Passing Screen):	AASHTO T11 and T27 AASHTO T2		
1-inch (25.4 mm)		100[a,b]	99-100[b,d]
3/4-inch (19.1 mm)		93	85-96
1/2-inch (12.7 mm)		68	60-71
1/4-inch (6.3 mm)		20	14-26
#10 (2.0 mm)		11	5-14
#40 (425 μm)		6	1-8
#200 (75 μm)		2.7	1.6-5.0
Binder Content (%)	ODOT TM321 ODOT TM322	7.5[c,i]	7.3-7.7[c]
Moisture Content (%)	ODOT TM311M	.28[c]	.8 (max)[c,f]
Mix Temp. at Discharge, °F, (°C)		280-285[e, j] (138-141)	290-310[g] (143-154)
Mix Temp. behind Paver, °F, (°C)		280-285[e,h, j]	275-310[g] (135-154)
Placement Air Temp., °F, (°C)		56-80[e,h] (13-27)	60 min[f] (16)
Placement Surface Temp, °F, (°C)		60-116[e,h] (16-47)	None
Weather		Clear	None
Wind Speed, mph, (m/s)		0-10 (4.5)	None

Note – Test data are entered in the format (dual units) used at the time the testing was conducted in 1992.

[a] Average of acceptance tests in this column unless noted otherwise.
[b] Percentages of dry ingredient weight including aggregate and 1% hydrated lime.
[c] Percentages of total mix weight.
[d] Narrowband limits in this column unless noted otherwise.
[e] Range of test results.
[f] Specifications in Special Provisions.
[g] Limits in job mix formula.
[h] Random measurements.
[i] Binder content was increased to 8% by field adjustment.
[j] Thermometer inserted into mix.

3.1 BINDER MANUFACTURE AND HANDLING

ISI ARC Binder - The delivery of the base asphalt and rubber, the blending of the asphalt-rubber, and the pumping of the binder into the plant were the responsibility of ISI. The blending was done near the mix plant. Considerable open space was needed for ISI's blending operation.

The rubber (Atlos #1710 Type IIA), was delivered on pallets in 27 kg bags. The pallets had a 1,360 kg net load. The base asphalt was blended with extender oil at the refinery. The base asphalt temperature at delivery was 180 °C.

A pump mounted on the tanker trailer pulled asphalt from the tanker and pumped it into a "helper" tank. Normally the "helper" tank truck would have a pump to pull off the tanker trucks, however, the pump was broken on the "helper" unit and the tanker had to pump. Asphalt was heated to 200 °C in the helper tank before it was pumped into the storage tank on the blending unit. The "helper" tank was insulated with a capacity of 7,250 kg to 7,700 kg. The temperature of the base asphalt was maintained at 202 °C.

The temperature of the asphalt was raised to 215 °C in the blending unit prior to the addition of rubber. A large storage tank was used as an intermediate step in the heating of the asphalt. After a reaction time of one hour, the asphalt-rubber was pumped into shuttle trucks. Three shuttle trucks and one nurse truck were used at the mix plant.

Powdered Rubber ARC Binder - The powdered rubber was supplied and blended by ISI. Originally, Rouse Rubber, Inc. was going to do the blending. However, the contractor would have had to store the PRAR in his tanks and pump the PRAR with his pumps. Also, the contractor was concerned that the Rouse blender could not keep up with the mix plant production. Because of these considerations, the contractor used ISI to do the PRAR blending.

The Rouse NR-80 rubber was delivered on pallets in 27 kg bags. The base asphalt was blended with the 6% extender oil at the refinery. The base asphalt temperature at delivery was estimated at 177 °C. The reaction temperature for the PRARC was 154 °C with a reaction time of 60 minutes. ODOT instructed ISI to use its customary asphalt-rubber batch blending method for the PRARC.

Class "F" and Class "B" Binders - Conventional equipment and procedures were used to add these asphalts to the mix plant.

3.2 MIXING PLANT

All mixes were produced in a Stansteel 7,200 kg batch plant with a rated capacity of over 540 Mg per hour. The plant, however, usually operates with 5,400 kg batches at a maximum capacity of around 440 Mg per hour. The aggregate was fed to the plant from three separated stockpiles. Lime was added to the aggregate on the belt from an auger feed.

The aggregates were proportioned on to the cold feed belt, heated through the drier, elevated to the gradation screening unit and re-proportioned into four separated sizes in the 19 mm - 12.5 mm, 12.5 mm - 6.3 mm, 6.3 mm - 2 mm, and 2 mm - 0 mm hot aggregate bins. The separated sizes were then proportioned into batch weights, mixed with the binder, dumped into the hauling trucks and hauled to the area to be paved.

ODOT Class "B" Mix - No special equipment or procedures were needed for this conventional mix.

ISI ARC Modified Class "B" Mix (Gap Graded) - Mixing was the same as ISI ARC Class "F" mix except for the aggregate gradation. The gradation differed from the conventional "B" mix constructed in one of the control sections as noted in the following table, Table 3.2:

Table 3.2: Class "B" Mix Gradation Comparison to ISI ARC Modified Class "B" Mix

Sieve Size	ODOT Class "B" Design	ISI ARC Modified Class "B" Mix	% Less than ODOT Class "B" Mix
1" (25.4 mm)	100	100	---
3/4" (19.1 mm)	95	92	3
1/2" (12.7 mm)	80	71	9
1/4" (6.3 mm)	56	33	23
#10 (2.0 mm)	29	17	12
#40 (425 μm)	13	9	4
#200 (75 μm)	5.6	4.9	0.7

ODOT Class "F" Mix - Normal construction procedures were followed for open graded hot mix.

ISI ARC Class "F" Mix - Mixing the ISI ARC Class "F" Mix was routine, with the exception of some gradation changes. First, the ISI ARC "F" mix design required 7% less passing the 6.3 mm sieve, 4% less passing the 2.0 mm sieve and 7% less passing the 75 μm sieve than the conventional "F" mix. Also, the ISI ARC "F" mix was discharged from the plant at 150 °C rather than at 120 °C for the ODOT Class "F" mix.

PRARC Class "F" Mix - The same procedures and exceptions listed with the ISI ARC "F" mix were also true for this mix.

The inner lane of this section was paved with a binder content of 7.5%. After a field adjustment to add more binder, the outer lane of the pavement was constructed using a binder content of 8%. The only exception occurred from Station 116+50 to 117+50, where a 7.5% binder content was placed in the outer lane.

3.3 HAULING

The mixtures were hauled to the paving site in end dump trucks and end dump trailers with hauling time of about 30 minutes. A water soluble truck bed release agent, "Slipeaze SB", was used. Drivers said the release agent worked inconsistently. Some loads would be released cleanly and others would stick to the dump bed.

3.4 PLACEMENT AND COMPACTION

The paving operation was slow since some of the dump trucks were used to haul pavement grindings from the cold milling operation and were not available to haul hot mix. The specifications stated that all cold planed lanes must be repaved the same day the pavement was removed.

The mixes were placed using conventional equipment. A Caterpillar AP1050 paver laid the mix. Three rollers were used that included:

- Caterpillar CB-514 double-drum vibratory roller;
- Caterpillar CB-414, 7 Mg double-drum vibratory roller; and
- Hamm D85 double-drum vibratory roller.

In addition, some high traffic volume intersections were sanded after rolling and rolled again with a small Dynapac CC10, 2.3 Mg roller.

ISI ARC Modified Class "B" Mix - No major problems were noted with placement of this mix. Breakdown rolling was done with five vibratory coverages using the CB514. Slight checking was noted in the mat after the vibratory breakdown passes. The mat sizzled behind the first pass of the breakdown roller since the mat temperature was over 135 °C. Initially, no intermediate rolling was done. Finish rolling was done with a minimum of two passes. The pavement was rolled four additional times to remove any roller marks. All the finished rolling was done in the static mode. The mat internal temperature was 102 °C after breakdown rolling.

The paver operator commented that the mix did not appear to smoke more than a normal mix. He said the only difference was the smell attributed to the added rubber.

ISI ARC Class "F" Mix - No problems were noted with the laydown of this mix. The mix was produced at 150 °C. No binder runoff was noted at the plant. Since this was an open graded mix, there were no compaction requirements other than a rolling pattern. Therefore, no density readings were taken.

Powdered Rubber ARC - The mix temperature behind the paver was 138 °C to 141 °C. No density readings were taken. Problems with mix stickiness were noted with this material. The contractor had trouble providing a mat that would handle traffic without sticking. The mat was tested with a pick-up truck to check for tackiness. To reduce the stickiness, a light application of sand was applied to the mat and the mat retested for tackiness. Several applications of sand were required before traffic was allowed on the pavement.