WOODBURN HOT IN-PLANT ASPHALT PAVEMENT RECYCLING PROJECT

Final Report

Demonstration Project No. 39
and
Experimental Features Project No. 76-01

by

James S. Rusnak
Research Specialist

Haiping Zhou, Ph.D.
Senior Research Specialist

and

Scott E. Nodes, P.E.
Research Coordinator

Oregon Department of Transportation
Materials and Research Section
Research Unit

In cooperation with

FEDERAL HIGHWAY ADMINISTRATION
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16. Abstract

In 1977, the Oregon Department of Transportation constructed a demonstration project using approximately 47,000 tons of stockpiled asphalt concrete (AC) material to overlay a section of pavement in Oregon. The stockpiled AC material was hot in-plant recycled and paved as a conventional hot AC mix. For twelve years of service, the hot in-plant recycled pavement performed well and carried traffic well in excess of the design loadings.

The construction details of this demonstration project were documented in an interim report published in 1977. This final report provides various information regarding the project, including the design, construction, and performance of the recycled AC pavement.

Based upon the design, construction, and performance of this project, the following conclusions were drawn:

1) Asphalt concrete material can be hot in-plant recycled and reused for surface paving.

2) The properties of slightly aged asphalt cement can be adequately modified through the addition of new "soft" asphalt cements without the incorporation of recycling additives.

3) Emissions in recycling are a function of many factors, including mix temperature, grade of new asphalt being added, amount of new aggregate added, amount of water added, and plant production rate.

4) Variability in the material properties may be expected. The additions of new asphalt and aggregate may further increase the variability.

5) Cost savings and conservation of natural resources can be expected due to the use of the recycled AC materials.

6) The new hot in-plant recycled pavement surface was rougher than average new AC pavements.

7) The pavement performed well and carried traffic well in excess of the design loadings.

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Woodburn Hot In-Plant Asphalt Pavement Recycling Project

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1.0 INTRODUCTION

1.1 BACKGROUND

During the national energy crises of the 1970's, an awareness for the need to conserve energy led the Oregon Department of Transportation (ODOT) to evaluate the feasibility of recycling asphalt pavements. Utilizing a hot in-plant recycle process, ODOT decided to construct a demonstration project by recycling approximately 47,000 tons of stockpiled bituminous material that was salvaged from a previous project (1). This stockpiled material was obtained from a temporary roadway built to carry a large volume of detour traffic resulting from a 13.5-mile reconstruction project on Interstate 5 (I-5). The temporary roadway had 5 inches of asphalt concrete (AC) before removal. The removed asphalt concrete material was of good quality with very little aging. The demonstration project using the hot in-plant recycled AC was constructed in 1977. After twelve years of service, the pavement surface received a chip seal in 1989.

The construction details of this demonstration project were documented in an interim report published in 1977. This final report provides various information regarding the project, including the design, construction, and performance of the recycled AC pavement.

1.2 OBJECTIVE

The objective of this demonstration project was to determine if the hot in-plant recycled AC mix could provide a serviceable pavement, while conserving natural resources, and reducing energy consumption.

2.0 PROJECT DESCRIPTION

2.1 PROJECT LOCATION

The hot in-plant recycled AC project was located on the Hillsboro-Silverton Highway, Oregon Highway Number 140 (Oregon State Route 219), in Marion County, Oregon. The project began at St. Paul (M.P. 28.33) and ended at the West City Limits of Woodburn (M.P. 36.5). Figure 2.1 shows the project location.

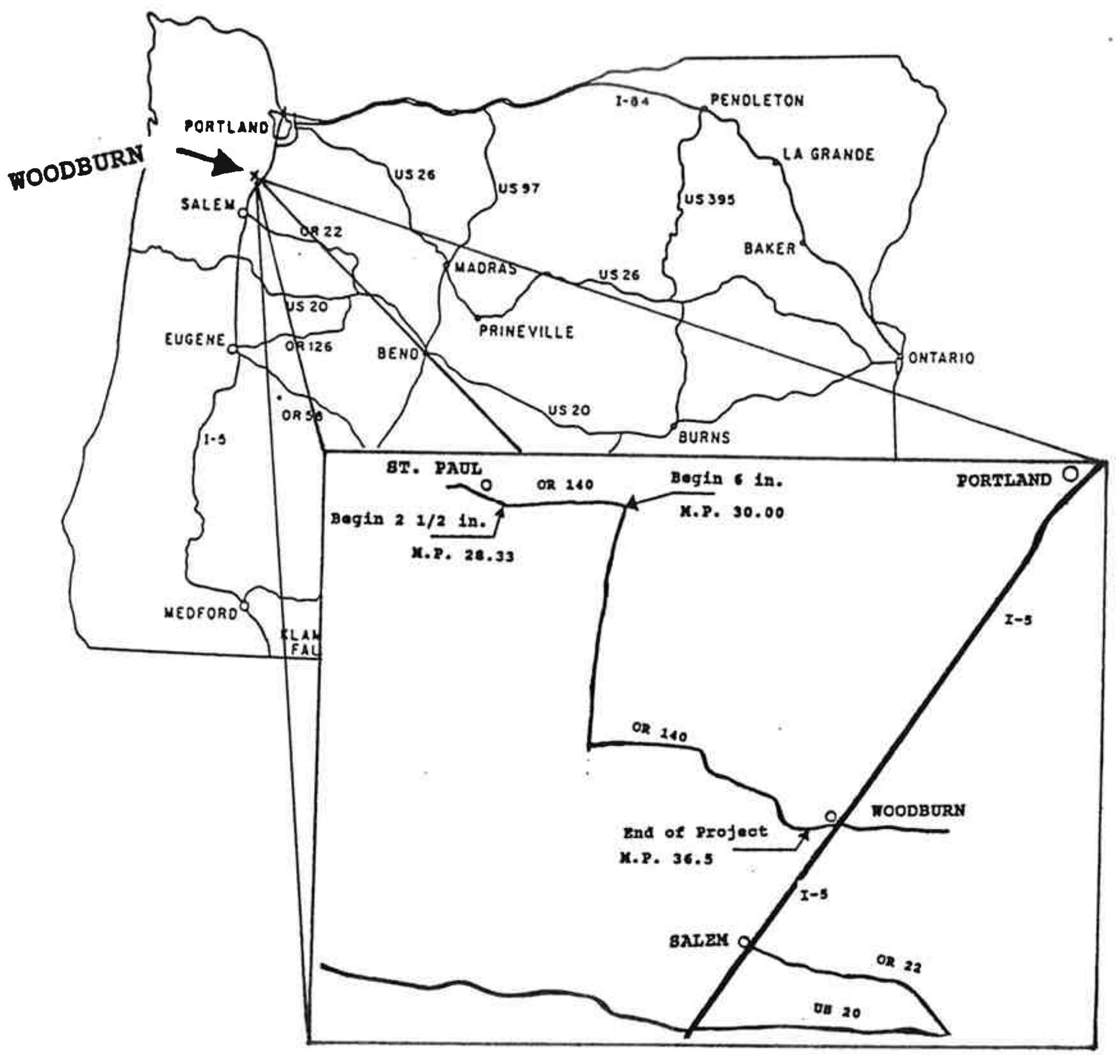


Figure 2.1: Project Location

2.2 PAVEMENT BEFORE HOT IN-PLANT RECYCLED AC PROJECT

The pavement before the recycling had a 20- to 24-foot wide AC surface with unpaved shoulders. Cores taken prior to the hot in-plant recycle project revealed an AC wearing course thickness ranging from 3 to 5 inches, and a base thickness ranging from 0 to 7 inches. The average wearing course thickness was about 4.5 inches, and the average base thickness was about 5 inches. Figure 2.2 illustrates the typical roadway cross-section and Figure 2.3 shows the pavement condition before construction.

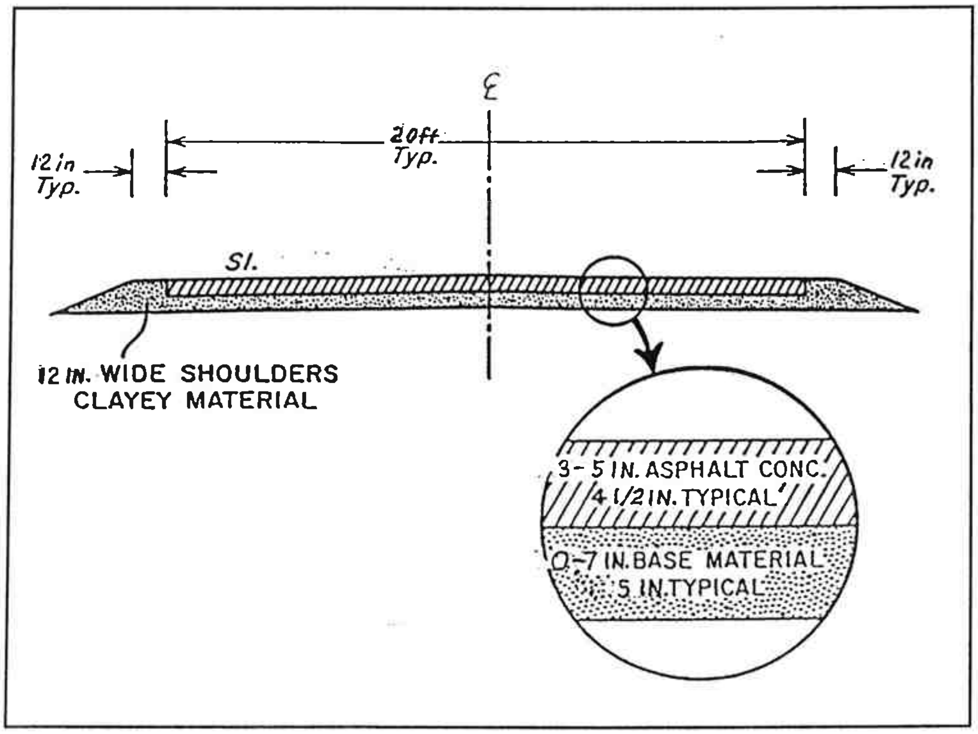
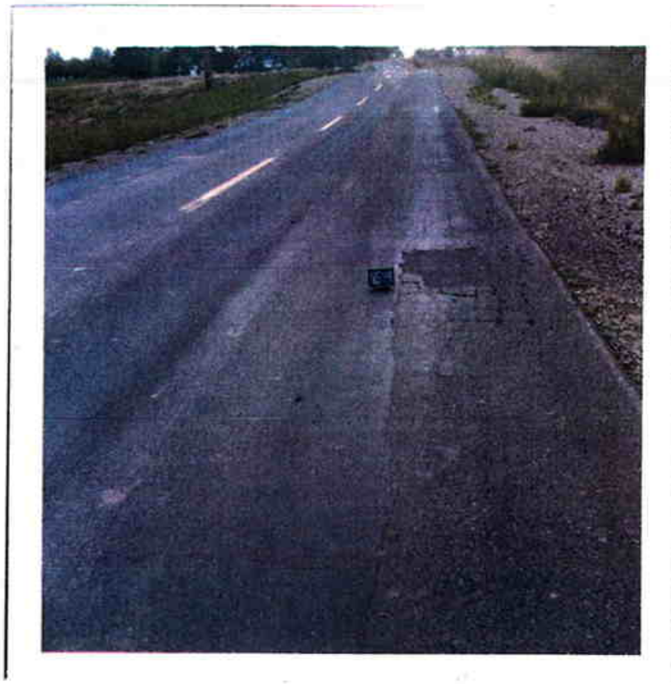


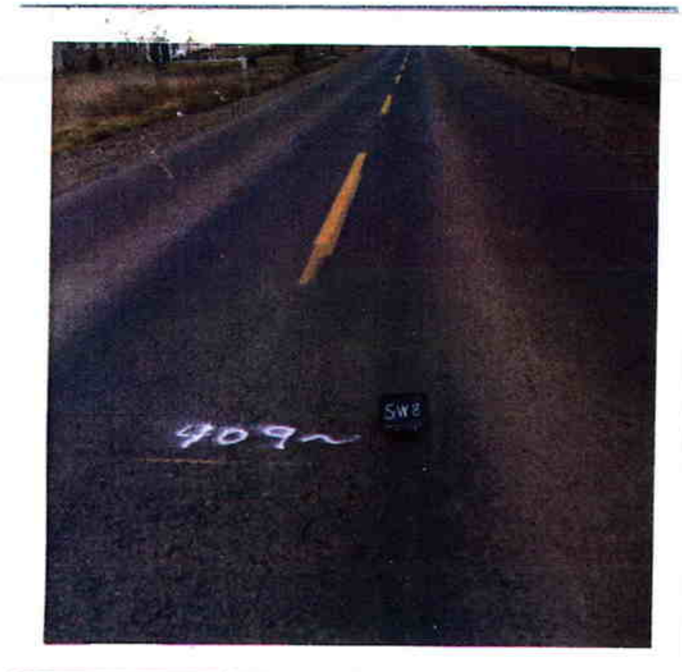
Figure 2.2: Typical Roadway Cross-Sections Before Construction

2.3 TRAFFIC DATA

Traffic data on this project was obtained from ODOT's 1977 Traffic Volume Tables (2). The average daily traffic (ADT) count at milepost 31.8 was 1,100, and at milepost 36.0 was 3,300. The project was designed to carry an estimated total of 136,000 18-kip equivalent axle loads (EALs) during a 10-year period.



a) At MP 27.00 EB



b) At MP 35.00 EB

c) At MP 35.50 WB

Figure 2.3: Pavement Condition Before Construction

2.4 PAVEMENT DESIGN

The recommended pavement design included widening the existing pavement to a 26- to 28-foot paved surface with a 2-foot paved shoulder. Between M.P. 30.00 and M.P. 36.50, two 3-inch lifts of recycled AC material were placed over the existing pavement as shown in Figure 2.4. Between M.P. 28.33 and M.P. 30.00, a single 2.5-inch recycled AC overlay was placed.

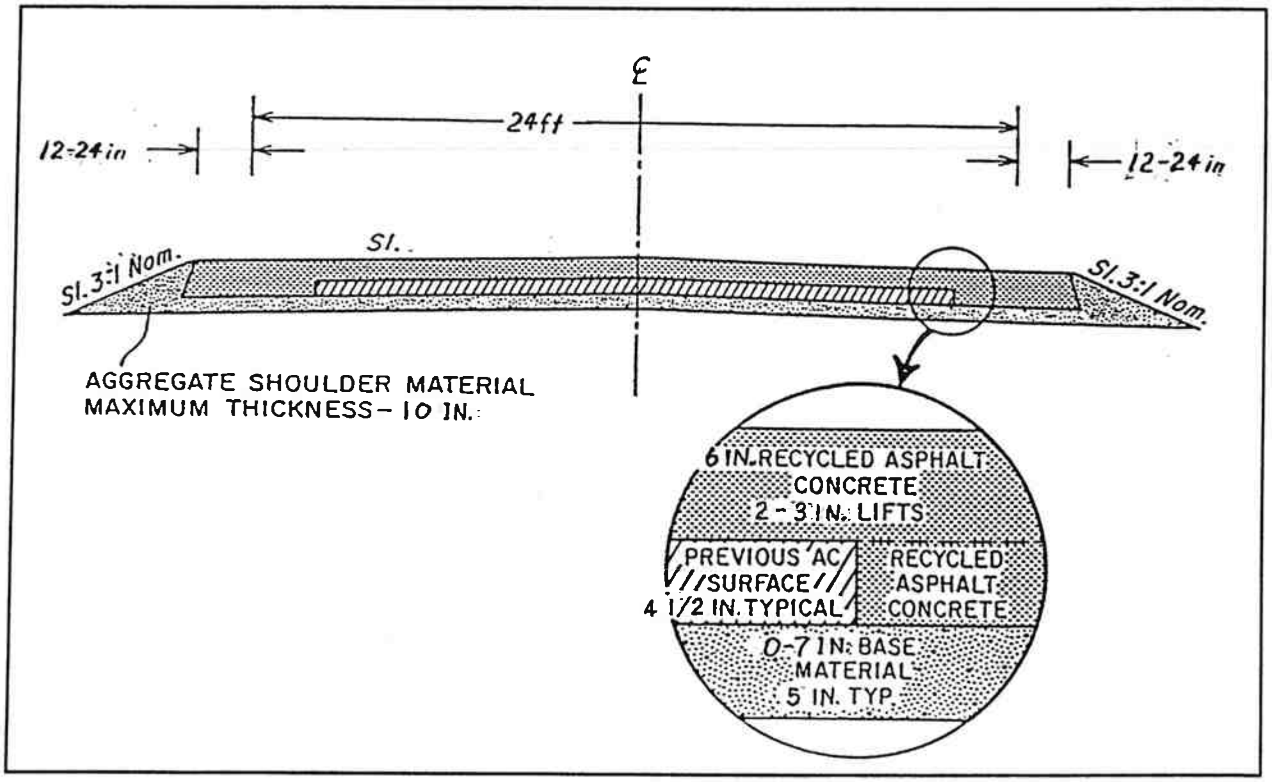


Figure 2.4: Recommended Typical Roadway Cross-Section Designs

2.5 RECYCLED ASPHALT CONCRETE MIX DESIGN

The stockpiled materials were primarily the Oregon Class "B" asphalt concrete, a dense-graded, 3/4-inch or smaller aggregate made from crushed river gravels. The original material was made of the following sizes of aggregate with a 5.6% AR4000 asphalt.

	Percent by Total Weight of Mix
3/4" - 1/4" Aggregate	34.8%
1/4" - #10 Aggregate	28.7%
#10 minus Aggregate	30.9%
AR4000 Asphalt	5.6%
	100.0%

Samples of this material were taken from the stockpile and sent to the ODOT's Materials Unit for mix designs. Three mix designs were developed. The first had 100% crushed recycled pavement without additional asphalt. The second had 90% recycled asphalt pavement (RAP) and approximately 10% 3/4" - #10 new aggregate with the addition of 0.3% asphalt (by weight). The third had 80% RAP and approximately 20% 3/4" - #10 new aggregate with the addition of 0.6% asphalt (by weight). A summary of mix properties at recommended new asphalt additions is presented in Table 2.1. The gradation change due to the addition of new aggregates is illustrated in Figure 2.5.

The final recommended mix design for the hot in-plant recycling is shown below.

Component	Percent by Total Weight of Mix	Tolerance
Crushed Recycled Asphalt Concrete (2" minus)	78 - 100	± 4%
Additional 3/4" - #10 aggregate	0 - 20	± 4%
Additional Asphalt Cement (AR-2000)	0 - 2	± 0.5%

During actual construction, however, 70% RAP and approximately 30% crushed 3/4" - #10 aggregate with the addition of 1.5% AR-2000 asphalt were used. The introduction of more virgin aggregate caused a reduction in the drum temperature resulting in reduced mix-plant stack emissions.

Table 2.1: Summary of Mix Properties at Recommended New Asphalt Additions (1)

ASPHALT CONTENT AND ADDITION	100% Recycled Asphalt Concrete		90% Recycled Asphalt Concrete 10% 3/4" - #10 Virgin Aggregate		80% Recycled Asphalt Concrete 20% 3/4" - #10 Virgin Aggregate	
	SURFACE	BASE	SURFACE	BASE	SURFACE	BASE
Asphalt Content in Crushed Recycled Pavement (%)[a]	5.6	5.6	5.0[b]	5.0[b]	4.5[b]	4.5[b]
Recommended Asphalt Addition (%)	0.0	0.3	0.3	0.5	0.6	0.8
Final Asphalt Content (%)	5.6	5.9	5.3	5.5	5.1	5.3

MIX PROPERTIES	100% Recycled Asphalt Concrete		90% Recycled Asphalt Concrete 10% 3/4" - #10 Virgin Aggregate		80% Recycled Asphalt Concrete 20% 3/4" - #10 Virgin Aggregate	
	SURFACE	BASE	SURFACE	BASE	SURFACE	BASE
Stabilimeter Value - "S"						
1st Compaction	30.0	27.0	33.2	32.0	32.6	31.8
2nd Compaction	36.0	19.8	36.2	27.0	35.6	34.8
Air Voids (%)						
1st Compaction	5.7	4.7	4.3	3.7	4.9	4.3
2nd Compaction	2.8	1.8	2.6	2.0	2.8	2.0
Bulk Specific Gravity						
1st Compaction	2.32	2.33	2.35	2.36	2.35	2.36
2nd Compaction	2.39	2.40	2.39	2.40	2.41	2.42
Cohesimeter Value - "C"						
1st Compaction	572	648	863	878	485	471

[a] Percent by total weight of mix
[b] These values are obtained as follows: (Asphalt Content in 100% Recycled Asphalt Concrete) x (Percentage of Recycled Asphalt Concrete in Mix)

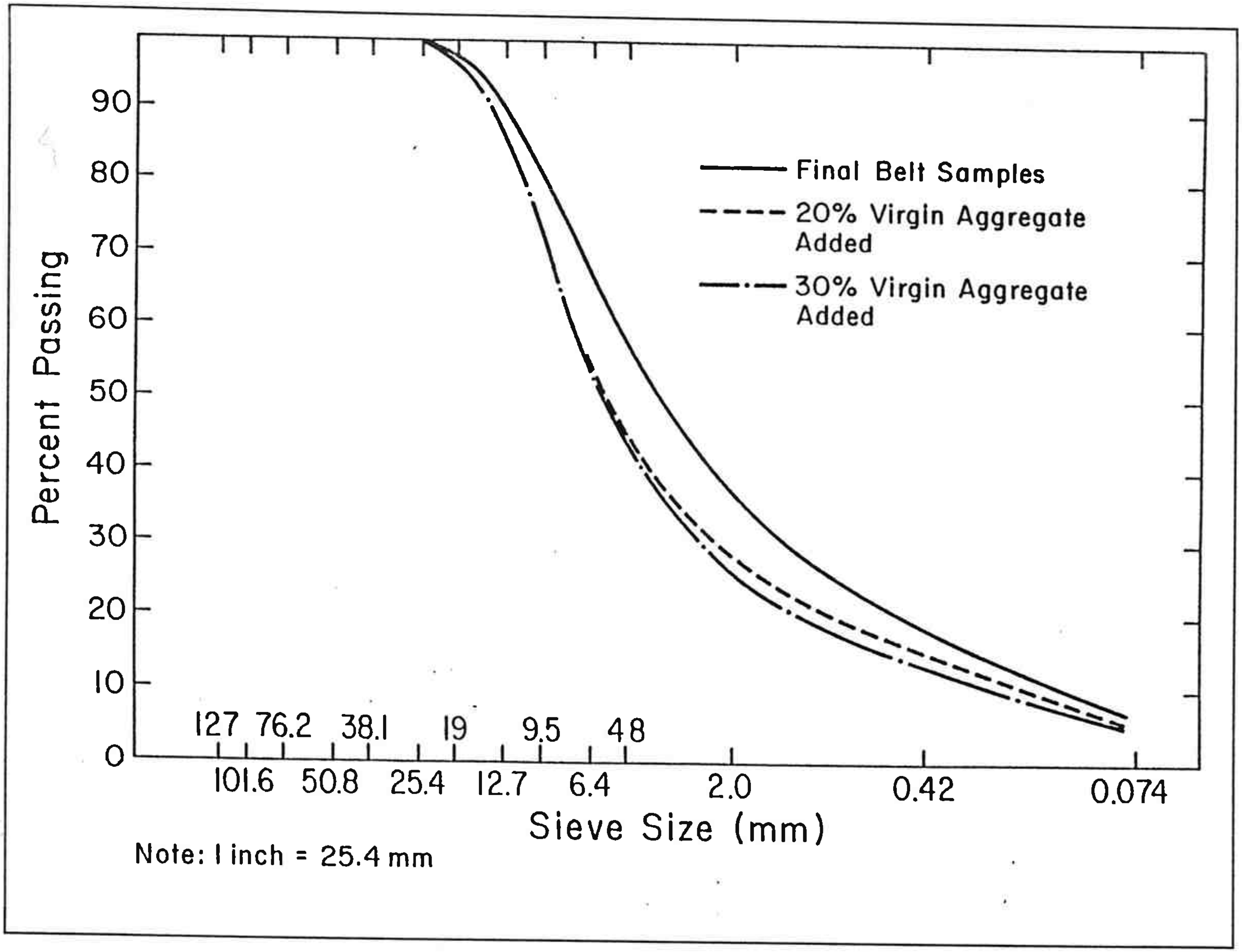


Figure 2.5: Average Gradation of Aggregate Material at the Final Belt Following Crushing with the Addition of 20% and 30% Virgin 3/4" - #10 Aggregate (3)

3.0 CONSTRUCTION

3.1 CRUSHING OPERATION

Approximately 46,616 tons of asphalt concrete was crushed using an impact crusher, a jaw crusher, and a cone crusher. The salvaged pavement was in chunks averaging about 1-foot wide by 1-1/2 to 3-feet long and 5-inches thick. As part of the crushing operation, the material was screened to recrush or reject all particles larger than 2 inches. The crushing was geared to continuously feed the paving plant. Thus, no in-between stockpiling was needed.

3.2 PLANT OPERATION

A Boeing Model 400 drum mix plant was used along with a heat shield placed between the burner and mix. The heat shield made it possible to re-mix the salvaged asphalt concrete without burning the asphalt. Plant output capacity was rated at 400 tons per hour. In this project, the actual plant production rate was 200 to 250 tons per hour. The mix temperature ranged from 200° to 250°F.

3.3 ENVIRONMENTAL CONCERNS

Since this was a research project, the Oregon Department of Environmental Quality allowed operation with 40% opacity, which is a measurement of air pollution, of plant exhaust. This was double the standard restriction of 20% opacity.

During the seven weeks of operation, the plant demonstrated its ability to run below 40% average opacity readings without control devices. Daily opacity readings followed a downward trend as modifications and better plant control were initiated. In a six-day operation, a daily average of less than 15% opacity was observed. This demonstrated that environmental pollution due to hot in-plant recycling could be controlled to a level lower than the standards.

The following practices were found helpful in reducing plant emissions:

1. The mix temperature should be kept below 250°F.

2. Light oil, such as the Shell AR-1000 used initially, created smoke. Changing to Shell AR-2000 reduced the smoke.

3. Addition of 25 - 30% new aggregate reduced emissions.

4. Production should be kept to no more than 260 tons per hour to prevent excessive plant emissions.

5. Adding the correct amount of water to the cold feed helped reduce the opacity levels.

3.4 PLACEMENT

Belly dump trucks with a twenty cubic yard capacity were used as the hauling vehicles and a Blaw Knox 220 rubber-tired paver was used as the laydown machine. The windrow of recycled asphaltic concrete placed in front of the paving machine was kept short to prevent heat loss. Lumps of recycled material were removed by shovel and replaced with fresh hot mix.

3.5 COMPACTION

Breakdown rolling was done with a 12-ton Bomag 220-A vibrator roller. A Buffalo steel wheeler, weighing 13 tons with ballast, was used as the intermediate roller. A Ray Go vibrator roller weighing 10 tons was used in static mode for finishing compaction.

A total of 99 locations were checked for compaction. An average of 92.6% compaction level was achieved. A minimum of 92% was specified by the ODOT. Some areas had a lower compaction, which may have been caused by low mixing temperatures.

3.6 MIX PROPERTIES

Samples were taken at the stockpile, at the final belt, and in the street. The street samples were taken at various locations. The samples were tested in the laboratory to determine recovered asphalt properties and mixture properties. Table 3.1 presents a summary of the test results.

The results show that an average of 1.5% asphalt and 22% of virgin aggregate were added to the recycled AC material. The final average asphalt content in the AC mix was 5.2%. The bulk specific gravity from the street samples was higher than those of the stockpile and final belt, indicating a denser mix was achieved during construction. The results also show an average index of retained strength of 82. This value is higher than ODOT's minimum requirement of 75.

Table 3.1: Summary of Average Values for Recovered Asphalt Properties and Asphalt Mix Data at the Stockpile, Final Belt and Street (3)

MODIFICATIONS TO CRUSHED RECYCLED ASPHALT	STOCKPILE SAMPLES	FINAL BELT SAMPLES	STREET SAMPLES										
Additional AR-2000 Asphalt Cement (%)	---	---	1.2	1.2	1.3	1.4	1.4	1.5	1.5	1.6	1.7	1.8	2.1
Additional 3/4" - #10 Virgin Aggregate (%)	---	---	10	20	20	20	30	15	20	30	20	30	30

RECOVERED ASPHALT PROPERTIES	STOCKPILE SAMPLES	FINAL BELT SAMPLES	STREET SAMPLES										
Penetration at 25°C (dmm)	46	50	47	48	47	50	53	54	48	55	54	52	57
Viscosity at 60°C (poises)	7712	7048	5921	4538	5854	4667	6075	4530	5060	4125	3954	4021	3680
Viscosity at 135°C (centistoke)	828	819	666	536	676	582	613	554	565	549	533	525	499
Asphalt Cement (%)	4.6	4.6	5.6	5.1	4.8	5.1	4.3	5.4	5.4	5.1	6.0	5.1	5.4

ASPHALT MIX DATA	STOCKPILE SAMPLES	FINAL BELT SAMPLES	STREET SAMPLES										
Bulk Specific Gravity													
1st Compaction	2.31	2.29	2.40	2.38	2.35	2.37	2.33	2.40	2.40	2.35	2.40	2.38	2.42
2nd Compaction	2.38	2.35	2.42	2.46	2.43	2.44	2.40	2.44	2.45	2.42	2.44	2.45	2.46
Stabilimeter Value - "S"													
1st Compaction	38	42	15	33	37	37	38	20	28	38	26	36	26
2nd Compaction	42	52	5	26	41	32	50	11	15	45	11	37	18
Cohesiometer Value - "C"	651	640	626	447	458	521	398	634	612	466	578	554	347
Air Voids (%)													
1st Compaction	4.9	6.2	0.6	4.8	4.1	3.5	6.3	1.4	2.1	4.5	1.2	3.7	1.6
2nd Compaction	2.0	3.3	0.0	0.2	0.8	0.6	3.4	0.0	0.3	1.9	0.1	0.7	0.0
Moisture (%)	1.66	2.15	0.78	0.74	0.92	0.92	0.92	0.72	0.72	0.84	0.70	0.69	0.61
Index of Retained Wet Strength (%)	---	---	85	92	84	94	73	90	86	83	91	90	87

3.7 PROJECT COSTS

A total of 60,739 tons of asphalt concrete mix, including both recycled AC and new materials was produced at a cost of $540,780 ($8.90/ton) in place. Approximately 46,616 tons of asphalt concrete was crushed for recycling. Part of this crushed material went to construct a road at the plant while at least 44,890 tons was used in the paving mix which was comprised of 44,890 tons (74%) recycled asphalt concrete, 14,960.2 tons (24.6%) virgin aggregate, and 888.4 tons (1.4%) new asphalt cement.

The construction process includes, feeding and crushing the reclaimed asphalt concrete, processing and loading the recycled product, hauling the mix to the paving site, and placing the mix. These construction processes are listed in Table 3.2 with the corresponding cost and energy consumption.

Major savings in terms of both cost and conservation of natural resources were realized through the use of the recycled asphalt concrete, resulting in a savings of 2,756 tons asphalt cement or $220,472. This assumes a 6.0% average asphalt content in the conventional mix.

While no cost or energy information is available regarding removing and stockpiling the old asphalt concrete, it seems reasonable that cost savings were realized over using entirely new aggregate. The unit cost in providing the virgin 3/4" - #10 aggregate, at $5.03 per ton, was substantially higher than the crushing costs for the recycled asphalt concrete, at $1.45 per ton.

Table 3.2: Summary of Costs and Energy Usage

PROCESS	COST	ENERGY CONSUMPTION
Crushing the Recycled Asphalt Concrete	$67,776.80 ($1.45/ton)[a]	Diesel Fuel: 7,941 gal. (0.17 gal/ton)[a]
Process and Load the Recycled Product	$314,497.49 ($5.18/ton)[b]	Diesel Fuel: 22,440 gal. (0.48 gal/ton)[b] Burner Fuel: 78,878 gal. (1.30 gal/ton)[b]
Hauling the Mix to the Paving Site	$86,282.89 ($1.42/ton)[b]	Diesel Fuel: 15,382 gal. (0.25 gal/ton)[b]
Placing the Mix	$72,222.36 ($1.19/ton)[b]	Diesel Fuel: 2,554 gal. (0.04 gal/ton)[b]

[a] 46,616 tons of crushed recycled asphalt concrete
[b] 60,739 tons of the asphalt concrete mixture (crushed AC, virgin aggregate, new asphalt)

4.0 POST-CONSTRUCTION EVALUATIONS

4.1 PAVEMENT FRICTION TESTS

Tests for determining the friction of the pavement were conducted on a section of the project at the beginning and at the end of the post-construction evaluation period. These friction tests were conducted using a two-wheeled skid trailer in conformance with ASTM E274.

The initial friction tests were performed seven weeks after the recycled AC was placed. The friction was measured when the testing vehicle was travelling at 40 mph. The test results indicated that the recycled pavement had good friction characteristics. In September, 1986 (nine years after construction), additional friction tests were conducted and the results were typical of those for AC pavements with similar conditions in Oregon.

4.2 RIDE MEASUREMENTS

Tests for measuring the ride quality were conducted using a PCA-type ride meter in October, 1977 and a PCR or Mays Meter in May, 1985. Because of the differences in these two measurement systems, the roughness values cannot be directly compared. The following comments may be helpful in evaluating the ride quality of the hot in-plant recycled pavement.

On this project, an average roughness of about 14 inches per mile was found on each lane. The measurement was taken in 1977, using the PCA meter. As a comparison, the average roughness of new pavements in Oregon is about 4 to 6 inches per mile, as measured with the PCA meter. Exceptionally smooth new pavements would have a roughness less than 2 inches per mile. Rough new pavements would have a roughness value greater than 18 inches per mile. The ride quality for this recycled pavement appears to be rougher than average.

In 1985, an average ride roughness of 105 inches per mile was measured for the recycled AC pavement using the Mays Meter. This average value indicated a slightly rough pavement overall. As a reference, the Mays readings vary from a smooth pavement with a Mays value less than 68 inches per mile to a rough surface with a Mays value greater than 140 inches per mile. In Oregon, pavement rehabilitation is needed when the ride roughness is in the range of 150 to 200 inches per mile. For this project, the roughness value indicated that the pavement, after eight years of service, still had an acceptable ride quality.

4.3 DEFLECTION MEASUREMENTS

Deflection measurements were performed to determine the strength of the pavement structure. The deflections were measured using a Benkleman Beam on the original pavement in February, 1977 and on the new hot in-plant recycled pavement in November, 1977. Measurements were taken again in the early 1980's using a Dynaflect deflection testing device.

Benkleman Beam deflection measurements were made at twenty locations on the project. Of these, sixteen locations were on sections which received 6" of recycled AC. The other four measurements were made on sections which received 2.5" of recycled AC. At each location, sixteen individual measurements were taken at 50' intervals over a 750' length of roadway.

On the original roadway, individual deflection readings within some of the sections showed a wide variation. Within one section, measured deflections ranged form 4 mils to 113 mils. However, the mean values for all locations remained relatively consistent.

Deflection measurements were repeated at each location approximately one to two months after the overlay was completed. For the section having a 6-inch overlay, the mean deflection was reduced from 39.8 mils to 16.9 mils. This is a 58% reduction compared to the mean deflection value on the original pavement (1). For the section with a 2.5-inch overlay, the mean deflection was 42.3 mils before recycling and 28.1 mils after recycling, a reduction of 33%.

4.4 PAVEMENT CONDITION INSPECTIONS

The pavement was inspected immediately after the construction in 1977, two years after the construction in 1979, and eight years later in 1985. Typical pavement conditions are shown in Figures 4.1 to 4.3.

As can be seen in Figures 4.1 and 4.2, the pavement surface immediately and two years after the construction was in very good condition. By 1981, the pavement had carried its design EAL's and the pavement was still in good condition. In 1985, after eight years of service, another inspection was performed and the typical pavement condition is shown in Figure 4.3. The inspection results showed that the pavement surface started light ravelling and cracking. There were localized areas where pavement showed a substantial amount of moderate to high severity alligator cracking. Most of these areas were within the section where pavement received 2.5-inch recycled AC overlay.

It should be noted that by 1985, the pavement had carried approximately 270,000 EAL's, which is almost twice the design EAL's. By 1987, the pavement had received about 340,000 EAL's and was still in fair and serviceable condition. In 1989, after twelve years of service, a chip seal was applied to the pavement surface.

Figure 4.1: Typical Pavement Condition Immediately after the Construction in 1977 (At MP 27.00 EB)

a) At MP 35.00 EB

b) At MP 35.50 WB

Figure 4.2: Typical Pavement Condition Two Years after the Construction in 1979

a) At MP 29.63 EB

b) At MP 29.63 WB

Figure 4.3: Typical Pavement Condition After Eight Years of Service in 1985

5.0 SUMMARY AND CONCLUSIONS

Oregon's first hot in-plant recycling AC pavement performed well during its design life (1977-1987). By 1987, the pavement had carried approximately 340,000 EAL's, which is 2.5 times its design life (136,000 EAL's).

Based upon the design, construction, and performance of this project, the following conclusions were drawn:

1) Asphalt concrete material can be hot in-plant recycled and reused for surface paving.

2) The properties of slightly aged asphalt cement can be adequately modified through the addition of new "soft" asphalt cements without the incorporation of recycling additives.

3) Emissions in recycling are a function of many factors, including mix temperature, grade of new asphalt being added, amount of new aggregate added, amount of water added, and plant production rate.

4) Variability in the material properties may be expected. The additions of new asphalt and aggregate may further increase the variability.

5) Cost savings and conservation of natural resources can be expected as a result of the use of recycled AC materials.

6) The new hot in-plant recycled pavement surface was rougher than average new AC pavements.

7) The pavement performed well and carried traffic well in excess of the design loadings.

6.0 REFERENCES

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