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RECYCLING ASPHALT PAVEMENTS

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FINAL REPORT

EVALUATION OF RECYCLED ASPHALTIC CONCRETE

by

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Assistant Head

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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16. Abstract

This report describes a project in which approximately 6,200 tons (5,630 Mg) of asphaltic concrete were recycled through a conventional asphalt batch plant. During the construction of the project, a buildup of asphalt-coated fines occurred in the dryer and the dust collector. The buildup is thought to have been associated with the fineness and/or the high asphalt content of the recycled mix. To solve the problem, a change was made in the recycling process. The project was completed using a heat transfer method with mix proportions as high as 50% recycled material added to 50% virgin aggregate.

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SUMMARY

This report describes a project in which approximately 6,200 tons (5,630 Mg) of asphaltic concrete were recycled through a conventional asphalt batch plant. During the construction of the project, a buildup of asphalt-coated fines occurred in the dryer and the dust collector. The buildup is thought to have been associated with the fineness and/or the high asphalt content of the recycled mix. To solve the problem, a change was made in the recycling process. The project was completed using a heat transfer method with mix proportions as high as 50% recycled material added to 50% virgin aggregate.

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INTRODUCTION

The energy crisis and the increasing cost of construction materials have heightened the need for efforts in conservation and intensified the search for new methods and processes within the highway construction industry. One of the results has been the development of several methods for recycling asphaltic concrete pavements through asphalt plants. The successful use of these methods may permit —

1. the use of less asphalt binder;
2. the use of less aggregate;
3. a reduction in fuel consumption;
4. a retention of original curb elevations; and
5. corrective measures to be taken on exposed base or subbase courses.

Robert L. Mendenhall, president of the Las Vegas Paving Corporation, Las Vegas, Nevada, has developed a prototype mixing plant (RMI Thermomatic) through which old asphaltic concrete may be recycled. A unique feature of this plant is that the dryer is designed so as to prevent the cold feed material (crushed plant mix) from coming in direct contact with the flame. The Nevada Highway Department and the Federal Highway Administration conducted an experimental recycling project using the RMI Thermomatic plant.(1) The general results of the project were promising and the performance of the pavements made from the recycled material has been excellent.(2)

However, for hot mix recycling to become practical a method is needed that permits the use of conventional asphalt plants. The Richmond District of Warren Brothers Company, Richmond, Virginia, experimented with recycled plant hot mix in their conventional 4,000-lb. (1,800 kg) batch asphalt plant near Chester, Virginia, during August 1975.(3) Their experiment consisted of introducing crushed hot mix material and virgin aggregate into the plant by the dryer cold feed system. The recycled mix thus produced was satisfactory with regard to composition and workability, but presented problems with low penetration of the asphalt and overheating of the old crushed plant mix that caused excessive smoke emissions. In an attempt to eliminate these problems, the dryer was modified by inserting "mixing plates" to produce a better distribution of heat and, hopefully, less smoke emissions. In October 1975, another recycling project was conducted at the Thompson-Arthur plant (a subsidiary of Warren Brothers Company) in Greensboro, North Carolina, using the "mixing plates" and also an atmospheric air intake arrangement at the burner end of the dryer.

In both the Virginia and North Carolina recycling projects, the old hot mix was crushed to required sizes, plant screens were removed, and aggregate gradation was controlled by the dryer feed controls. Standard paving equipment was used during both projects. The main problem encountered was smoke emissions from the dryer stack, with the emissions being lighter in North Carolina.

It is not anticipated that recycled asphaltic concrete will replace conventional asphaltic concrete production. However, it may prove to be a cost effective measure in some cases.

PURPOSE

The purpose of this study was to determine and evaluate the economics and the technical feasibility of recycling asphaltic concrete through a conventional asphalt batch plant. Two evaluations were made. The first considered the process in which the recycle mix is introduced into the cold feed and proceeds through the dryer, hot elevator, etc. It included modifications of the plant to reduce the adverse effect of the dryer flame being in direct contact with the crushed hot mix and the resultant stack emissions. The second considered the process whereby the recycle mix is introduced into the hot bins, which is often called the Minnesota method.

SCOPE OF STUDY

The asphaltic concrete pavement recycled was roughly a 5,000' (1,525 m) section of U. S. Route 1 in Chesterfield County (from the intersection with Route 10 to the intersection with Route 616) with a portland cement concrete base overlaid with several layers of asphaltic hot mix. Figure 1 is a schematic of the project limits and variables. This road is a 4-lane highway with an ADT of about 17,200, of which 15% are trucks and buses. In its entirety, the project involves approximately 6,200 tons (5,630 Mg) of recycable asphaltic concrete.

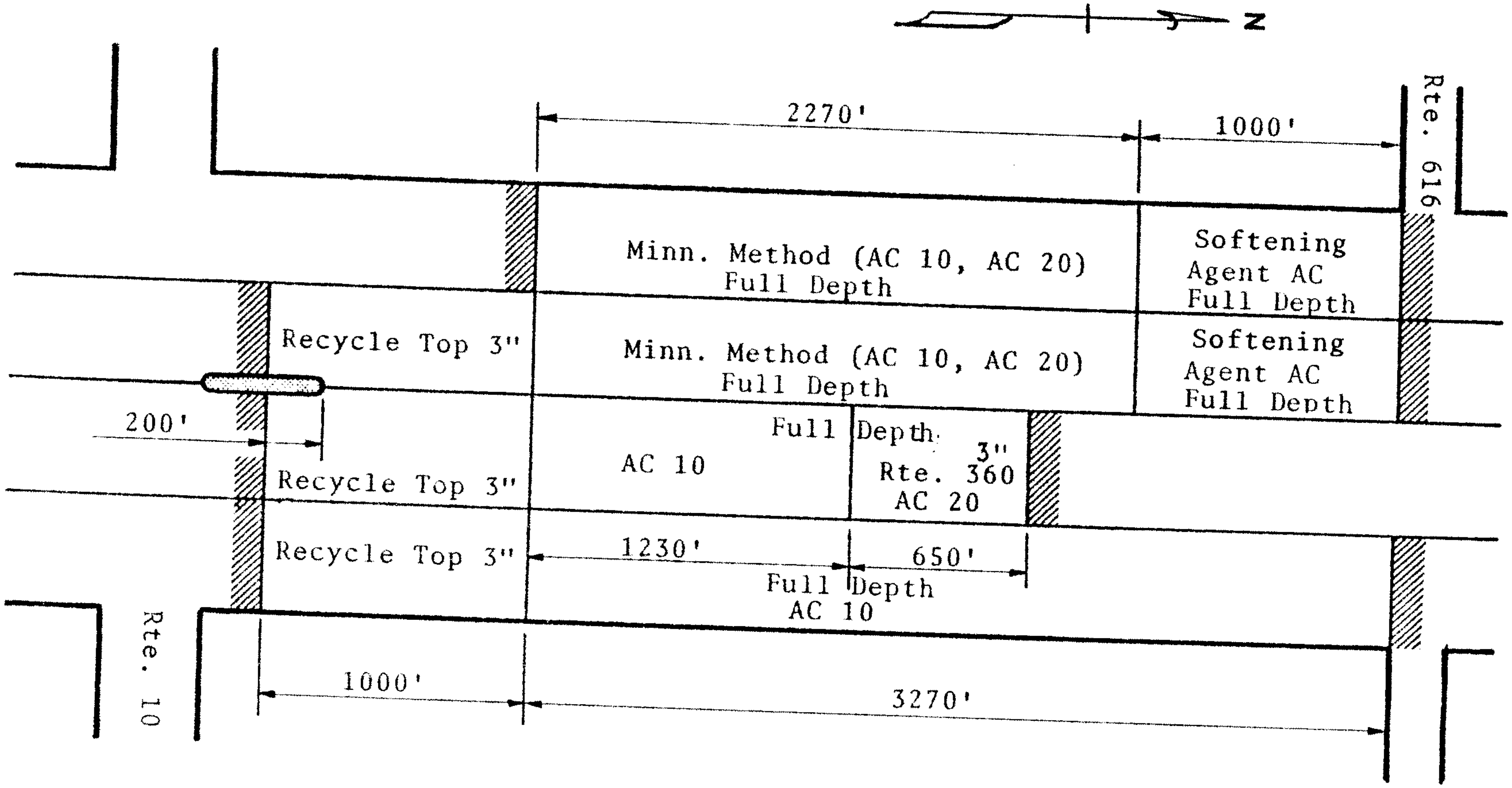

Figure 1. Schematic of project limits and variables. Basic Conversion Units: 1-in. = 25.4 mm and 1-ft. = .3048 m.

EXISTING PAVEMENT

Cores were taken from each lane of the existing roadway to gain an indication of the types of asphaltic concrete used in the overlays. A typical core is shown in Figure 2. Since some of the overlays were placed in the 1930's and others have been added in various stages since that time, a conglomeration of layers was found. Some sections had four layers of asphalt, others had as many as six making up a total overlay thickness of 5.5" (140 mm).

Figure 2. Core showing typical number of overlays on concrete base.

The gradation, asphalt content, and properties of the recovered asphalt were determined from the cores and the results are given in Tables 1 and 2. The average core density was 95.3% of the maximum theoretical (ASTM D-2726 and D-2041).

Table 1

Average Gradation and Asphalt Content

Sieve	% Passing				Average
Size	NBPL	NBTL	SBPL	SBTL	
3/4"	100	100	100	100	100
1/2"	100	94	98	96	97
#4	84	70	81	81	79
#30	37	31	37	37	36
#200	5	4	6	5	5
%AC	7.2	5.7	6.7	6.5	6.5

Table 2

Average Abson Recovery

Property	NBPL	NBTL	SBPL	SBTL	Average
Penetration	19	17	18	23	19.3
Softening Pt., Deg. C.	70	69	71	68	69.6
Ductility, cm	7	9	7	11	8.5
Visc. 140°F (60°C)	71,565	54,275	89,455	39,939	63,809

As Table 1 shows, the gradation of the overlays was fine, with approximately 80% passing the #4 sieve. The fineness of this material may indicate a potential limitation to recycling through a dryer as will be discussed later. And, as expected, Table 2 shows the recovered asphalt from the road to be very hard, with an average penetration of 19. It is worth mentioning that nothing in the extracted asphalt gave an indication of potential problems, with the possible exception that the hardness of the asphalt in the recycled material might result in the final asphaltic concrete being too brittle to provide very good performance. Although stripping was apparent in some layers, it did not appear extensive.

Reflection cracks from the concrete had come through the asphaltic layers and had created a rough riding condition (Figure 3), which was the primary reason for rehabilitating the pavement.

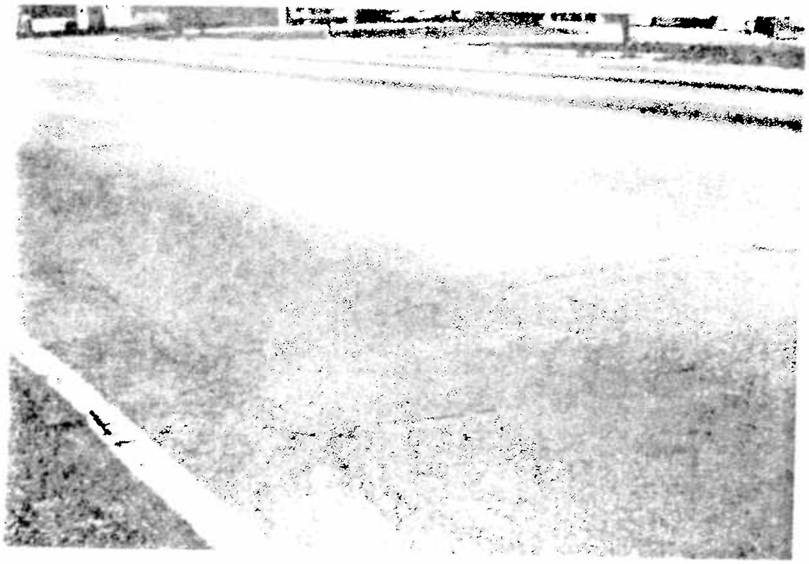

Figure 3. Pavement condition that made recycling feasible.

RECYCLING OPERATION

The project is described here chronologically because the order in which many of the problems were encountered and solutions sought is important.

Initial Plant Changes

Before starting recycling some changes were made in the dryer to reduce the excessive heating of the asphalt in the recycled material and thereby reduce the resultant blue smoke. A fan was added near the front of the dryer to introduce cooling air from the atmosphere, the burner was pulled away from the dryer 12" (300 mm), and some flights near the end of the dryer were removed to improve the combustion efficiency and lower the combustion gas temperature. Also the screens were removed from the hot bin gradation unit.

First Recycling Trial

The project began May 24, 1976. Warren Brothers had decided to try both a Pettibone Pulverizer (Figure 4) and a Galion Planer (Figure 5) to remove the asphaltic concrete layers. This operation was experimental in that the Department was interested in seeing what type of product could be obtained by these machines. Warren Brothers also felt that the equipment might produce a gradation that would not have to be crushed and would therefore reduce hauling and crushing costs.

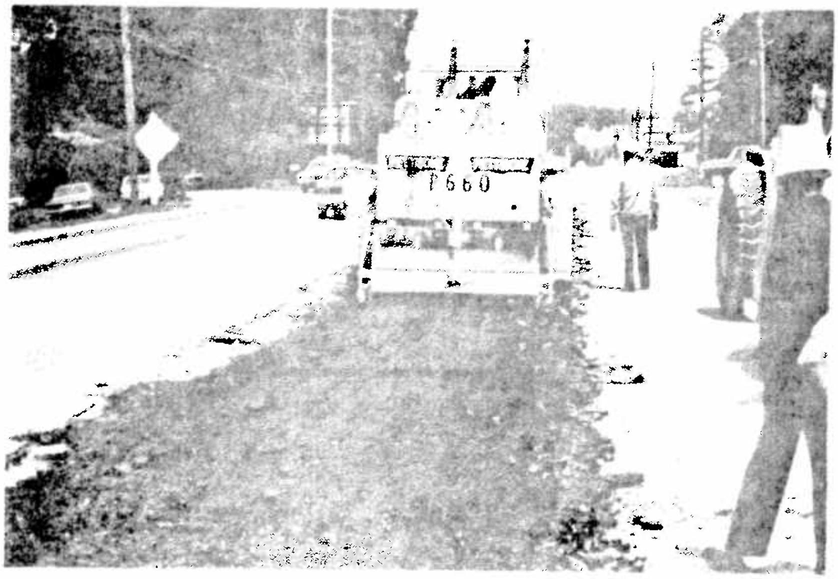

Figure 4. Pettibone pulverizer in use.

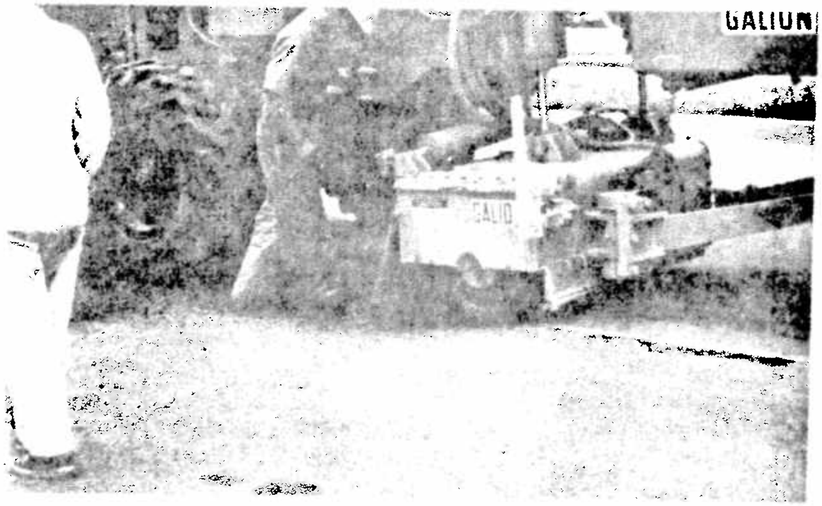

Figure 5. View of Galion scarfier.

The equipment did, in fact, produce a material that did not require additional crushing. Table 3 shows the gradation produced by the Pettibone and Galion machines. The Pettibone removed the entire 5.5" (140 mm) of plant mix and the Galion removed the top 2" (50 mm).

Table 3

Gradation of Material Produced by Pettibone and Galion Machines

Sieve	Percent Passing	
	Pettibone	Galion
1/2"	95	100
#4	78	89
#30	32	44
#200	4	7
AC %	5.3	5.8

The gradation produced was finer than that encountered in the original Warren Brothers recycling efforts and may have contributed to a buildup in the dryer and clogging of the dust collector, which will be discussed in detail later.

Initially, about 25% virgin aggregate and 75% old pavement were used. The 25% virgin material was made up of #78 aggregate stone and an S-5 blend as shown in Table 4.

Table 4

Gradation of Virgin Material

Sieve	Percent Passing	
	#78(15%)	S-5 Blend (10%)
1/2"	98	100
#4	16	63
#30	0	28
#200	0	4

Because the amounts of material produced by the machines varied, the percentage of material from each machine also varied but was maintained at a total of 75%; in many cases material from one machine only was used at one time. The combinations of materials from the two machines did not seem to affect the final product appreciably as evidenced by the analysis of the mix properties after recycling.

Mix Properties After Recycling

The average properties of the recycled materials are shown in Table 5. Table 6 shows the average asphalt properties prior to and after the addition of from 1.4% to 2.4% AC-10. The amount of asphalt added did not appear to influence the properties of the mix. As can be seen from Table 6, the addition of an average of only 1.9% AC-10 improved the characteristics of the recovered asphalt appreciably.

Table 5

Average Properties of Recycled Mix — First Trial

Marshall Stability, lb.	2,960
Voids Mineral Aggregate, %	18
Voids Filled W/Asphalt, %	80
Voids Total Mix, %	3
Asphalt Content, %	6.3

Gradation	Percent Passing	Middle Design Range
3/4"	100	100
1/2"	98	100
#4	66	60
#30	29	22
#200	7	6

Table 6

Average Properties of Recovered Asphalt

Property	Before Recycling (Residual Asphalt in Old Pavement)	After Recycling (Old Plus New Asphalt)
Penetration	17	29
Softening Point, Deg. C	73	64
Ductility, cm	7	83
Visc. 140^{o}F (60^{o}C)	125,000	19,500

Emission Tests

The Commonwealth Laboratory, Inc. was contracted to run emission tests on the plant to determine what, if any, problems would be encountered with meeting emission standards. The results for the dry and total (front and back halves of the sampling train) batch are shown in Table 7. The equipment used was that specified in EPA Method #5.

Table 7

Average Emissions
Basic Conversion Unit: kg/hr. = .454 lb./hr.

Measure	Particulates	
	Dry	Total
gr/dscf	0.7	0.9
lb/hr.	10.6	13.6
	SO_2 Gas	
ppm	398	
lb/hr.	6.5	

The state allows 33 lb/hr. (15 kg/hr.) at a production rate of 50 tons/hr.(45 Mg/hr.). As can be seen from Table 7 this standard was easily met. Visible emissions varied from 17% to 78% opacity.

In addition to the normal emission tests, the FHWA was interested in the more sophisticated polycyclic organic matter (POM) test. The results of this test indicated a concentration of 496 x 10^{-7} gr/dscf and a comparable emission rate of 78.8 x 10^{-4} lb/hr. (35.7 x 10^{-4} kg/hr.) The detailed results of this test are available from the FHWA and the Virginia Highway and Transportation Research Council.

Plant Problems

Soon after the process was started, it became obvious that the residual asphalt and minus 200 mesh material in the crushed pavement were sticking to the dryer and being drawn into the primary dust collector. This impregnated dust, which built up on metal surfaces heated to 180°F (82°C) and higher, was extracted and found to contain as much as 20% asphalt. Although reducing the dryer burner temperature alleviated this problem, it did not eliminate it during the first trial.

The originally anticipated blue smoke appeared to be a function of plant production and dryer buildup. When the plant production was low (40 to 45 tons/hr. [36 to 41 Mg/hr.]) because of the buildup of material on the dryer walls and flights, the smoke was not visible (Figure 6). When the plant production was increased (60 tons/hr. [54 Mg/hr.]) and the material was still building up on the dryer, the blue smoke did appear (Figure 7). This variability in blue smoke is obvious from the opacity results previously mentioned. Plant production was low, ranging from 77 tons/day (70 Mg/day) to 353 tons/day (320 Mg/day). This relatively low rate resulted from many factors. The slow removal of the material from the road, the clogging of the dust collector and dryer that required stopping the plant frequently for cleaning, and attempts to eliminate the blue smoke and the buildup all contributed to the low production.

A scaled-down model of the prototype smoke collector designed by the Massachusetts Institute of Technology for Warren Brothers was used and did appear effective in eliminating the smoke. This apparatus is an electrofluidized sand bed collector. The smoke-laden air is passed through the fluidized sand bed. Both the sand particles in the bed and the particulates in the smoke are electrically charged at high voltage to cause the smoke to be collected by the sand particles. The hydrocarbon smoke particles form an oily residue on the sand particles which can be returned to the plant process during normal operation to become part of the hot mix.

During 35 hours of production spread over seven days 1,396 tons (1,267 Mg) of material were recycled. At that time, the project was temporarily terminated and the source of the material buildup was sought. At that time it was thought that the source of the problem was in the material being recycled rather than in the operation of the asphalt plant. It was thought that the problem might lie in either the fineness of the material being recycled or an unusually soft asphalt in one or more of the layers of the material. The bottom layer of the inside (passing) lane consisted of what was apparently a road mix material that had been applied prior to the construction of the outside (traffic) lane. Thus the concrete in the outside lane came to the top of the road mix material (Figure 8). The contractor thought that this apparently soft material was causing the buildup in the dryer. However, since the different material in the outside lane also caused a buildup, the problem was probably caused by something other than the asphalt in the road mix material. However, tests were performed on the extracted asphalt from the

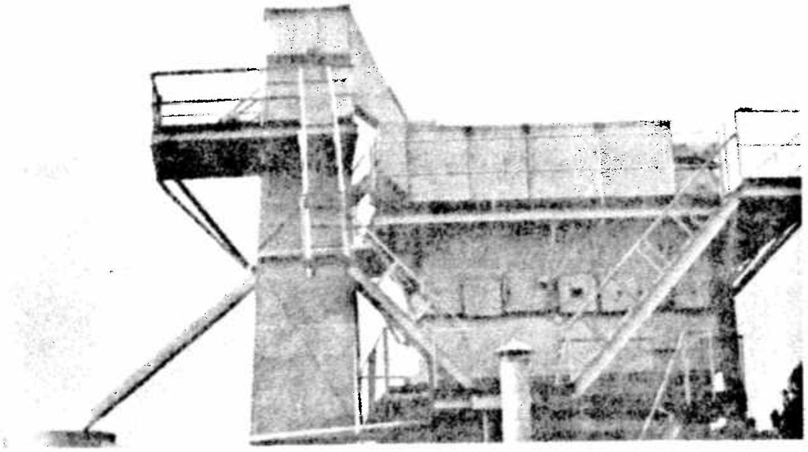

Figure 6. No stack emission visible.

Figure 7. Blue smoke coming from stack.

material in the passing lane with the following results:

penetration, 19,
softening point, Deg. C 68,
ductility, cm 33, and
viscosity, 140°F (60°C) 27,300

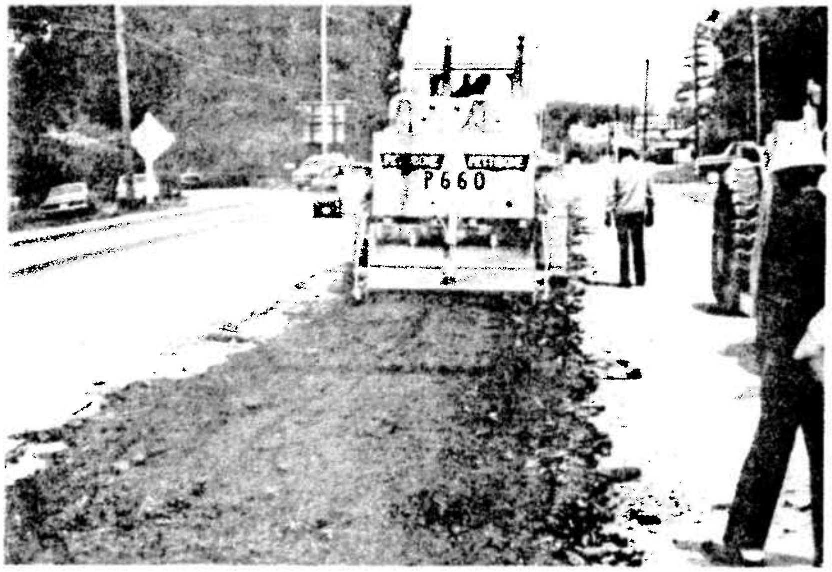

Figure 8. Road mix material in passing lane at same elevation as traffic lane.

These results are not much different from those obtained from the road cores (Table 2), particularly the penetration and softening point, and it was thought the problem apparently was caused by the fine gradation and/or high asphalt content.

Since both the removal of the overlays and the repaving were accomplished under traffic, a smooth paving job was hard to obtain. Although the Pettibone and Galion units produced a material that did not require additional crushing, both were slow, and the Pettibone used several sets of hammers in pulverizing the pavement.

Primarily because of the slow speeds, but also due to the uncertainty of the effect of the gradation produced, the use of both the Pettibone and Galion machines was terminated at the end of the first trial.

Second Recycling Trial

On August 9, a single-tooth ripper attached to a motor grader and a front end loader were used to remove the asphaltic concrete. The material was hauled to the company's quarry and crushed. The crushed material then was hauled to the asphalt plant and blended with virgin aggregate as it was fed to the dryer.

The gradation of the crushed material is shown in Table 8, where it can be seen that it was coarser than the gradation, shown in Table 3, of the material produced by the Pettibone and Galion equipment.

Table 8

Gradation of Crushed Recycled Material

Sieve Size	Percent Passing
3/4"	100
1/2"	91
#4	70
#30	34
#200	4
AC %	5.8

The crushed material (60%) was blended with 20% #78 aggregate and 20% concrete sand to produce the required gradation. The concrete sand was used because it did not contain any minus #200 mesh material and therefore would be helpful in reducing the tendency of the old crushed material to build up during heating. The use of the concrete sand did reduce the tendency of the material to build up and in general eliminated this problem, particularly in the dust collector. Even in the plant dryer, the buildup was noticeably less. The additional asphalt was increased to 3% to accommodate the increase in virgin aggregates. Table 9 shows the average gradation and asphalt content of the mix using the above blend of materials.

Table 9

Average Gradation and Asphalt Content of Crushed Recycled Old Hot Mix, #78 Stone, and Concrete Sand

Sieve	Percent Passing
3/4"	100
1/2"	91
#4	58
#30	27
#200	4
AC %	6.2

To verify that the material from Route 1 was the source of the buildup problem, material from another road (Route 360) was also used in the recycle process in a separate operation. The gradation of this material is shown in Table 10. It is obvious that it was not as fine as any of the material from Route 1 and that the asphalt content was not as high. It was also found that the penetration of the Route 360 material was not as low as that of the Route 1 material. When 80% of this material was blended with 15% #78 aggregate and 5% concrete sand, the average gradation shown in Table 11 was produced.

Table 10

Average Gradation and Asphalt Content Route 360 Recycle Material

Sieve	Percent Passing
3/4"	91
1/2"	87
#4	53
#30	24
#200	3
AC %	5.5

Table 11

Average Gradation and Asphalt Content of Route 360 Recycle Material Blend

Sieve	Percent Passing
3/4"	98
1/2"	92
#4	53
#30	23
#200	1
AC %	6.7

The Route 360 blend caused no sticking or clogging in the dryer or dust collector and was also more coarse than any produced with the Route 1 material, findings in keeping with the experiences in North Carolina. Since this material was recycled successfully it was tentatively concluded that the problem lay with the Route 1 material.

After running an additional 986 tons (894 Mg) of the Route 1 material, for a total of 2,382 tons (2,162 Mg), it was obvious that some other procedure had to be found, and the project was shut down for a second time.

An additional problem resulted from removing and replacing one lane at a time. This procedure required paving next to a lane that would be removed and replaced, and resulted in a very irregular joint.

Additional Plant Modifications

During the winter of 1976-77 an additional conveyor was brought to the plant and attached so that the crushed pavement material it carried would be introduced directly into the #3 hot bin. This operation was patterned after one used successfully in Minnesota in which heat transferred from the virgin aggregate is used to heat the crushed pavement in the pug mill. The addition of the conveyor led to the increased contract cost mentioned later.

Minnesota Method

Plant

On March 29, 1977, use of the Minnesota, or heat transfer, method was begun. The percentage of recycle pavement material was started at 35% and gradually increased until a 50% recycle-50% virgin aggregate blend was obtained.

The virgin aggregate was heated to 450°F (230°C) in the dryer and a dry mixing time of 15 seconds and a wet mixing time of 45 seconds produced a mix with a temperature around 280°F (140°C) in the truck.

Table 12 shows the properties of the recovered asphalt both before and after mixing and the percentage and type of asphalt added.

The results indicate that the characteristics of the recovered asphalt improved appreciably with the addition of both types of asphalt, with the AC 10 increasing the penetration more than the AC 20. The addition of the AC 20 with a softening agent produced about the same results as the AC 10.

Table 12

Average Properties of Recovered Asphalt — Minnesota Method

Percent Recycle Material	Before Recycling				Asphalt Added		After Recycling			
	Pen.	S. P.	Duct.	Visc.	Percent	Type	Pen.	S. P.	Duct.	Visc.
35	12	75	6	217,800	4.8	AC20	33	60	105^+	4,850
35	13	74	6	106,145	4.8	AC10	45	57	105^+	4,660
40	12	74	6	120,180	4.6	AC10	39	59	105^+	7,430
45	13	75	5	179,300	4.9	AC20	31	62	105^+	14,570
50	11	74	6	99,100	3.9	AC20*	38	57	105^+	5,950

*.2% plasticizer (APO softening agent) added.

The gradation of the final mix did not change significantly with the various percentages of recycle pavement, as shown in Table 13.

Table 13

Average Gradation and Asphalt Content of Recycle Material — Minnesota Method

	Percent Recycle			
Sieve Size	35	40	45	50
3/4	100	100	100	100
1/2	99	99	99	99
#4	69	68	70	70
#30	29	30	33	32
#200	4	5	5	5
AC %	6.3	6.3	6.6	6.4

This mix had essentially the same gradation as that obtained during the first trial (Table 5), but because the recycle pavement did not go through the dryer no plant problems were encountered.

There was no correlation between the percentage of recycled material and the mix properties which are included in Table 14.

Table 14

Average Properties of Recycled Mix — Minnesota Method

Marshall Stability, lb.	2,040
Voids Mineral Aggregate, %	20
Voids Filled W/Asphalt, %	73
Voids Total Mix, %	5

As can be seen by comparing the mix properties obtained using the Minnesota method with those obtained from the first trial (Table 14 vs. Table 5) there is a difference, particularly in stability, which should not be unexpected. The Minnesota method requires the addition of approximately 4.5% asphalt because of the greater percentage of virgin aggregate being used as compared to an average of 1.9% asphalt used with the first trial. The added asphalt was of a lower viscosity than that in the recycle mix and was probably the main reason for the difference in Marshall stability. Plant capacities were very near optimum with the heat transfer process, and provided an additional indication that for the material being recycled the Minnesota method was the better approach.

Road

At the beginning of the 1977 work, the contractor decided to remove two lanes (southbound) at a time to facilitate not only the removal but also the subsequent lay down. This operation was much smoother, as was the resultant pavement, than was the one-lane paving operation used in 1976.

However, in order to improve the riding surface obtained in 1976, an additional 125 psy of mix was applied to the entire project (shown in Figure 1) as recycle overlay only. This last mix used was a 40% blend of recycled pavement because it seemed to handle better than the 50% blend.

Road Roughness

The Materials Division, using its PCA road meter, obtained the following roughness values:

NB Passing Lane	55 in./mi.	(140 cm/mi.)
NB Traffic Lane	51 in./mi.	(130 cm/mi.)
SB Passing Lane	49 in./mi.	(125 cm/mi.)
SB Traffic Lane	47 in./mi.	(120 cm/mi.)

These results tend to confirm that the two-lane removal and repaving operation produced a smoother pavement, even though the final pavement course was intended to equalize the roughness on the entire project.

COSTS

The contract construction cost of the first 2,400 tons (2,180 Mg) was $17.50 per ton. Plant modifications necessary to complete the project increased the contract cost for the remaining tonnage to $22.08 per ton. The project was financed on a 50-50 basis by the Virginia Department of Highways & Transportation and the Federal Highway Administration, Region 15 Demonstration Projects Program.

Because the plant operation during the first two trials was so erratic no cost figures were obtained. However, the costs per ton for the Minnesota and conventional methods as furnished by the contractor were:

Description	Actual Recycle	Estimated Conventional
Labor	$ 2.60	$ 0.75
Materials	4.48	10.01
Equipment	4.10	0.93
Haul	3.18	1.00
Fuel @ $0.36/gal.	0.39	0.75
Conveyor	4.71	–
	$19.46	$13.44

Comments

Because the cost of the conveyor listed in the actual recycle cost would normally be written off for a greater period of time, the per ton cost would not be as high. Furthermore, the haul would be considerably less if the crusher and plant were located at the same site.

ENERGY REQUIREMENTS

An analysis of the energy requirements was made to compare the recycle mix with a conventional mix using the Asphalt Institute's procedure.(5) For the recycle process only the Minnesota method was analyzed.

The assumptions compare the cost of the material from each process in the trucks at the plant and thus do not include lay down, which should be the same for both processes.

Regular Mix

6.0% asphalt; source to plant distance, 30 mi.(48 km) — 4-axle truck
85% aggregate; source to plant distance, 12 mi.(19 km) — 3-axle truck
15% sand; source to plant distance, 12 mi.(19 km) — 3-axle truck
Moisture content of aggregate, 5%
Aggregate heated (dryer), 70°F (20°C) to 300°F (150°C)

Recycle Mix 50%-50%

4.0% asphalt; source to plant distance, 30 mi.(48 km) — 4-axle truck
Aggregate —
40% virgin; source to plant distance, 12 mi.(19 km) — 3-axle truck
10% sand; source to plant distance, 12 mi.(19 km) — 3-axle truck
50% recycle; source to crusher distance, 24 mi.(39 km) — 3-axle truck
crusher to plant distance, 12 mi.(19 km) — 3 axle truck
Moisture content of virgin aggregate (50%), 5%
Aggregate heated (dryer) (50%), 70°F (20°C) to 450°F (230°C)

Energy Consumed/Ton Regular Mix

Materials

Manufacture asphalt cement =	587,500 Btu/t
Haul 30 mi. x 2 @ 5,040 Btu/ton =	302,400
	889,900

Crushed stone @ 70,000 Btu/t, 85% =	59,500
Sand @ 15,000 Btu/t, 15% =	2,250
Haul 12 mi. x 2 @ 4,270 Btu/t, 1.05	107,600
	169,350

Mix Composition

Asphalt 6% @ 889,900 Btu/t = 53,400
Aggregate 94% @ 169,350 Btu/t = 159,200
Total for mix 212,600 Btu/t

Plant Operation

Dry aggregate 5% @ 28,000 Btu/% .94t = 131,600
Heat 230°F @ 470 Btu/°F/t .94t = 101,600
Other plant operations 19,800
Total for 1 ton (.9 Mg) regular asphaltic concrete at plant 465,600 Btu/t (549,600 j/kg)

Energy Consumed/Ton Recycle Mix (50/50)

Materials

Manufacture asphalt cement (see above)= 889,900

Virgin aggregate
Crushed stone @ 70,000 Btu/t, 80% = 56,000
Sand @ 15,000 Btu/t, 20% = 3,000
Haul 12 mi. x 2 @ 4270 Btu/t, 1.05 = 107,600
166,600

Recycle aggregate
Removal & crushing = 40,000
Haul (24 + 12 mi.) x 2 @ 4270 Btu/t = 307,400
347,400

If the crusher were located at the plant not only would the contractor price be lower, but considerable energy savings could be realized.

Mix Composition

Asphalt 4% @ 889,900 Btu/t = 35,600
Aggregate virgin 48% @ 166,600 Btu/t = 79,950
Aggregate recycle 48% @ 347,400 Btu/t = 166,750
282,300

Plant Operation

Dry aggregate 5% @ 28,000 Btu/t .48 t = 67,200
Heat 380°F @ 470 Btu/°F/t .48 t = 85,750
Other plant operations = 19,800
172,750 Btu/t

Total for 1 ton (.9 Mg) recycle asphalt concrete at plant = 455,050 Btu/t (528,800 j/kg)

The difference between energy requirements of the two methods is so small as to be negligible when viewed in light of the assumptions made.

COMMENTS

There are apparent advantages and disadvantages to the two primary methods of recycling through a conventional hot plant tried in this study.

The first method, i.e. introducing the recycled pavement into the dryer, has the advantage of using a great percentage of recycle mix, possibly even 100%. The disadvantage is that the type of material being recycled must be carefully considered, as this project dramatically demonstrated.

On the other hand, the Minnesota method has the advantage of likely being able to recycle any material that can be crushed. The disadvantage may be the limitation as to the percentage of recycle pavement that can be heated by the heat transfer method. It is not believed that this project determined the maximum percentage of recycled material that can be used.

The removal of the old pavement also indicated that some methods may be more advantageous than others, depending upon the results desired. For instance, if a smooth surface is desired with the removal of a portion of the asphalt layer, then the Galion scarifier or some similar equipment may be considered. Whether the material removed in this manner can be recycled by introducing it through the dryer is still questionable. It appears from this study that the most efficient method of removing the material is by ripping it and hauling it away. Ultimately, the removal of all lanes at once would appear to be the best approach if traffic and geometry allow.

After the asphaltic concrete was removed to expose the underlying portland cement concrete, several deteriorated joints were found. This project thus demonstrated the practicality of recycling material to correct underlying maintenance problems. In this case the deteriorated portland cement concrete was removed and replaced with asphaltic concrete.

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REFERENCES

1. Gregory, G.,J. Hodge, and H. Proudy, "Recycled Asphalt Concrete," Federal Highway Administration, Implementation Package 75-5, July 1975.

2. ________, "Recycled Asphalt Concrete Pavement," Federal Highway Administration Task Order No. 3, Inspection Report No. 1, 1975.

3. Newman, A. D.: Letter to B. C. Lambeth, Warren Brothers, Inc., Richmond, Virginia, September 8, 1975.

4. Tunnicliff, D. G., Interoffice Memorandum to J. W. Thompson, Thompson-Arthur Paving Company, Greensboro, North Carolina, Warren Brothers, Inc., Cambridge, Massachusetts, November 1975.

5. ________, "Energy Requirements for Roadway Pavements," The Asphalt Institute, Misc—75—3, April 2975.

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