INTERIM REPORT

EVALUATION OF RECYCLED ASPHALTIC CONCRETE

by

C. S. Hughes
Assistant Head

and

R. V. Fielding
State Materials Engineer

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

Virginia Highway & Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Highways & Transportation and the University of Virginia

In Cooperation with the U. S. Department of Transportation
Federal Highway Administration

Charlottesville, Virginia

March 1977

VHTRC 77-R42

INTERIM REPORT

EVALUATION OF RECYCLED ASPHALTIC CONCRETE

by

C. S. Hughes
Assistant Head

and

R. V. Fielding
State Materials Engineer

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 the 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-pound 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 is to determine and evaluate the economics and the technical feasibility of recycling asphaltic concrete through a conventional asphalt batch plant. The evaluation includes plant modifications to reduce the adverse effect of the dryer burner flame on the crushed plant hot mix and to provide for adequate compliance with air pollution control regulations for stack emissions.

SCOPE OF STUDY

The asphaltic concrete pavement to be recycled is roughly a 5,000-foot 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. This road is a four-lane highway with an ADT count of about 17,200, of which 15% are trucks and buses. In its entirety, the project will involve approximately 6,200 tons of recyclable asphaltic concrete. This report covers only the first 2,400 tons of the project.

The contract construction cost of the first 2,400 tons was $17.50 per ton. Plant modifications necessary to complete the project will increase the contract cost for the remaining tonnage to $22.08 per ton. The project is being financed under a 50-50 agreement between the Virginia Department of Highways and Transportation and the Federal Highway Administration.

An economic analysis will be presented in the final report on the project.

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 1. 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".

The gradation, asphalt content, and properties of the recovered asphalt were determined from the cores. The results are shown in Tables 1 and 2. The average core density was 95.3% of the maximum theoretical.

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 asphalt layers and had created a rough riding condition (Figure 2), which was the primary reason for pavement rehabilitation.

Table 1

Average Gradation and Asphalt Content

Sieve Size	% Passing NBPL	NBTL	SBPL	SBTL	Average
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
Pentration	19	17	18	23	19.3
Softening Pt., Deg. C.	70	69	71	68	69.5
Ductility, cm	7	9	7	11	8.5
Visc. 140°F	71,565	54,275	89,455	39,939	63,809

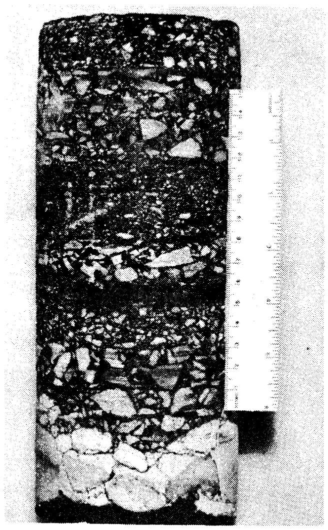

Figure 1. Core showing typical number of overlays on concrete base.

Figure 2. 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.

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" and some flights near the end of the dryer were removed to help 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 3) and a Galion Planer (Figure 4) 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.

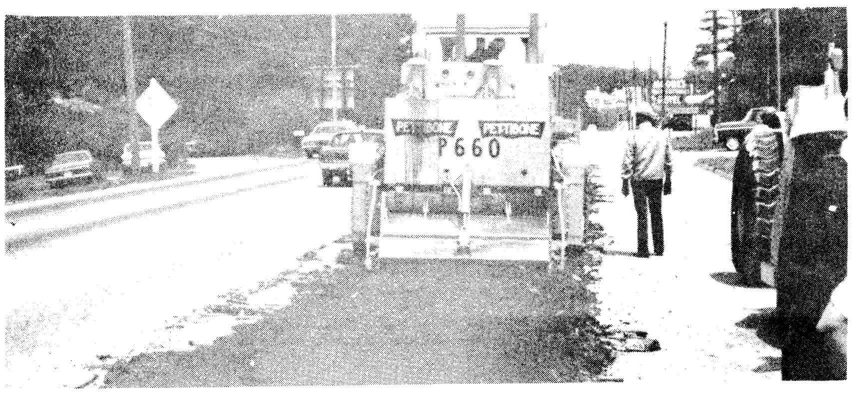

Figure 3. Pettibone pulverizer in use.

Figure 4. View of Galion scarifier.

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" of plant mix and the Galion removed the top 2".

Table 3

Gradation of Material Produced by Pettibone and Galion Machines

Sieve	% 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 and S-5 blend as shown in Table 4.

Table 4

Gradation of Virgin Material

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

Average Properties of Recycled Mix — First Trial

Marshall Stability, lb.	2960
Voids Mineral Aggregate, %	18
Voids Filled W/Asphalt, %	80
Voids Total Mix, %	3
Asphalt Content, %	6.3

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

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.

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°F	125,000	19,500

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.

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

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. at a production rate of 50 tons/hr. As can be seen from Table 7 this standard was easily met.

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

Plant Problems

Soon after starting the process 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 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 trial 1.

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 per hour) because of the buildup of material on the dryer walls and flights, the smoke was not visible (Figure 5). When the plant production was increased (60 tons per hour) and the material was still building up on the dryer, the blue smoke did appear (Figure 6). Plant production was low, ranging from 77 tons/day to 353 tons/day. This relatively low rate resulted from many factors. The removal of the material from the road was slow, the clogging of the dust collector and dryer required stopping the plant frequently for cleaning, and attempts to eliminate the blue smoke and the buildup all contributed to the low production.

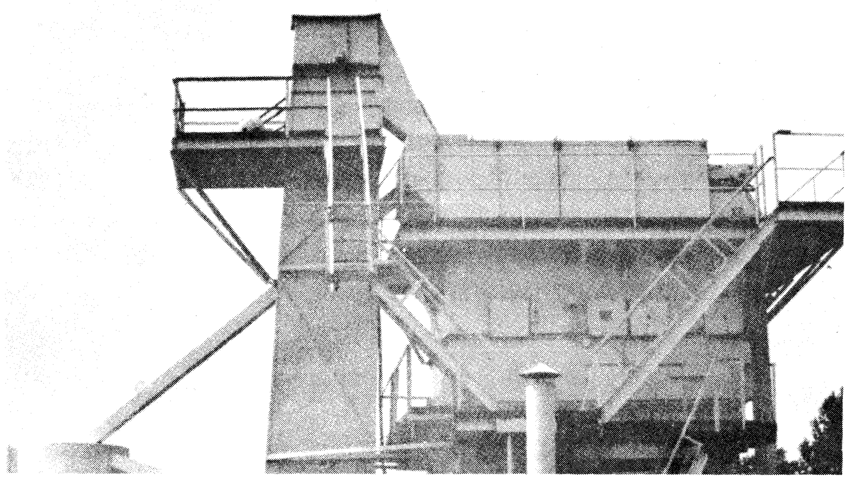

Figure 5. No stack emissions visible.

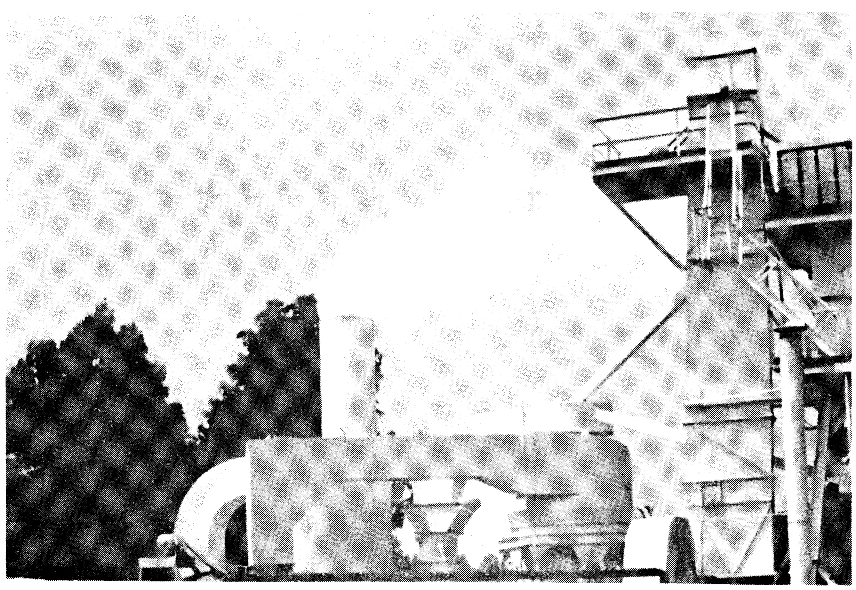

Figure 6. Blue smoke coming from stack.

A prototype smoke collector designed by MIT for Warren Brothers was used and did appear effective in eliminating the smoke. This apparatus is an electro-fluidized 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 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 was apparently a road mix material using both naptha and pulverized Trinidad asphalt. The contractor thought that this material was causing the trouble. However, this layer was not found in the northbound traffic lane which produced the sam type of problems encountered with material from the northbound passing lane.

Road Roughness

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 trial 1.

An additional problem resulted from removing and replacing one lane at a time. This required paving next to a lane that would be removed and replaced, and resulted in a very irregular joint. It would appear reasonable to expect a better job if at least two adjacent lanes could be removed before starting repaving. Ultimately, the removal of all four lanes would appear to be the best approach if traffic and geometry allowed. It is likely that a more efficient method of removing the pavement would have been attempted if this had not been an experimental project.

Although the repaving was accomplished in three lifts to provide good ridability, some of the pavement was still quite rough. The roughness was due, at least partly, to experimentation with mix temperatures 240°F and below,to reflection in the surface of irregularities left by the Galion planer, and probably to the thinness of the third and final lift.

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

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 was hauled to the asphalt plant and blended with virgin aggregate when 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 produced by the Pettibone and Galion equipment and shown in Table 8.

Table 8

Gradation of Crushed Recycled Material

Sieve Size	% 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 old crushed material to buildup during heating. The use of the concrete sand greatly reduced the tendency of the material to buildup and in general eliminated this problem, except for a continuing buildup in the plant dryer. Even there, however, 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	% 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 this material was not as fine as any 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	% 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	% Passing
3/4"	98
1/2"	92
#4	53
#30	23
#200	1
AC %	6.7

This 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, a finding 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. At this time it is still unknown whether the problem is one of gradation, asphalt type, or both. A comparison is being made between one particular suspect asphalt in the Route 1 material and another asphalt to see if any difference exists.

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

FUTURE TRIALS

The most practical alternative for use with the Route 1 material appears to be the Minnesota method. This process introduces the crushed pavement material directly into the asphalt plant hot bins or weigh box and thus avoids the problems encountered in the dryer and dust collector. The crushed material is heated through a heat exchange with the virgin aggregate in the plant weigh box or mixer. This virgin aggregate can be heated higher than normal when it is passed through the plant dryer.

Although this process is promising, problems may be encountered and it is anticipated that lower percentages of the old crushed pavement will be used, especially when producing surface mix.

The process changes will be noted as the material is placed in the field to allow any differences in performance to be correlated with the process and materials.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the several individuals who contributed greatly to the information contained in this report.

A. D. Newman, district materials engineer, is recognized and thanked for running the project for the Department; his diligence is very much appreciated. Morris Hecht, materials engineer, ran asphalt and mix tests in the Materials Division Pre Mix Laboratory. George W. Boykin, materials technician, was instrumental in coordinating the plant and field work. Thanks go to J. K. Wright, C. V. Thompson, and D. W. Terry, construction inspectors, for running tests at the plant laboratory.

James Denton, W. N. Lancaster, and B. C. Lambeth of Warren Brothers are acknowledged for their interest, cooperation, and ingenuity in attempting to make this project a success.

The cooperation of Steve Beckett, FHWA project manager, is also appreciated.

REFERENCES

1. Gregory, G., J. Hodge, 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. (SHK): 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.