STATE OF FLORIDA

Resurfacing of SR-471 Using the Hot-in-Place Recycling Process

Research Report
FL/DOT/SMO/04-472

Gregory A. Sholar
Gale C. Page
James A. Musselman
Howard L. Moseley

June 2004

STATE MATERIALS OFFICE

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The Florida Department of Transportation (Department) used a hot-in-place recycling process for the rehabilitation of SR-471 in Sumter County in 2002. The Contractor was H.I.P. Paving, LLC of Safety Harbor, Florida. This project is the first Department hot-in-place recycling project that required the Contractor to provide a three-year warranty against pavement distresses including: rutting, rideability, cracking, raveling, delamination, potholes, slippage and segregated areas. The warranty was instituted for this project because the Department had limited success with two hot-in-place recycling projects constructed in 2001 by two different Contractors utilizing different recycling technologies. Construction of the SR-471 project occurred in a timely manner and the as-produced mixture met all specification requirements for the project. The rideability and frictional resistance of the finished pavement surface were good. The pavement is starting to show signs of rutting on both lanes of the north half of the project. The rutting appears to be occurring in the same locations where rutting was present prior to the rehabilitation. The exact cause of the rutting is unknown at this time. One drawback to the hot-in-place recycling process is the likelihood that the resulting mixture will not meet Superpave mixture design requirements when recycling a non-Superpave mixture. Superpave is the Department's standard mix design procedure. Therefore, at this time, hot-in-place recycling may best be suited for low volume roads or maintenance applications.

INTRODUCTION

In the 1980's, the Florida Department of Transportation, herein referred to as the Department, experimented with the hot-in-place recycling process with mixed success (1, 2, 3). Based on the outcome of these experimental projects, the hot-in-place recycling process was not accepted as a standard rehabilitation technique by the Department.

Based on feedback from the hot-in-place recycling industry that there had been significant advances in hot-in-place recycling technology, the Department decided to construct several projects to evaluate this method of pavement rehabilitation. These advances include the capability to add new materials and on-board pugmills to mix the virgin and recycled materials to produce a homogenous final product. Industry worked very closely with the Department in developing the construction specification for the improved recycling process.

In 2001, the Department constructed two hot-in-place recycling projects and again experienced mixed success. One of the projects, CR-315 in Putnam County, began to crack and delaminate within two weeks of completion. After several more weeks, over 50% of the project experienced cracking and delamination. The entire project was subsequently milled and resurfaced with hot-mix asphalt. The second project, SR-19 in Lake County, has performed better than the CR-315 project, but has also experienced distress in the form of slippage and slight cracking. Details of both projects and hot-in-place recycling methods are documented in FDOT Report 02-455 (4).

In 2002, a third project was rehabilitated by H.I.P. Paving, LLC of Safety Harbor, Florida, (herein referred to as H.I.P.) using the hot-in-place recycling process. The project was a five-mile section of SR-471 in Sumter County and is the focus of this report. The hot-in-place recycling process used for this project was different than the processes used in the CR-315 and SR-19 projects. In addition, due to concerns with premature failures, a three-year warranty requirement was added by the Department for this project. The remainder of this report will focus on the hot-in-place recycling process used for the SR-471 project, project specifications, and test results.

HOT-IN-PLACE RECYCLING PROCESS

In general terms, hot-in-place recycling is a process used to rework a distressed pavement surface with the result being a rejuvenated, distress-free pavement. The process used for the SR-471 project is referred to as a "mixed in place" process, which uses heat to soften the existing pavement material, a milling process for the removal of the heated pavement material, mixing of the milled material with new paving materials where necessary, and reapplication of the rejuvenated material to the roadway. Unlike a conventional cold milling/inlay resurfacing project, the recycled pavement material is never removed from the roadway location to an offsite area.

H.I.P.'s equipment used for this project included the following:

1. Small milling machine: Used for the removal of paint striping.
2. Three propane preheaters: The preheaters are 30 feet long and have expandable widths from 10 to 18 feet. For this project, the preheaters were used in succession and the third preheater had the capability to dispense sand, which was mixed into the recycled pavement material to raise the air void content.
3. A recycling unit with multiple functions:

   a. Heating system: An additional heating system 12 feet long and 10 to 18 feet wide further heats the pavement beyond that of the preheaters.
   b. Extendable milling heads: These milling heads on each side of the recycling unit extend the available milling width from 10 to 16 feet. A milling depth of at least two inches can be achieved. These milling heads move the milled asphalt material into the center where the main milling head is located.
   c. Main milling head: The main milling head mills the center 10 feet of roadway and centers the material into a windrow. A milling depth of at least two inches can be achieved. Rejuvenating oil is added during this process and is mixed with the milled material.
   d. Pugmill: This mixing chamber receives the material windrowed from the milling heads and mixes the milled material and rejuvenating oil thoroughly to produce a uniform material. The resulting material is placed in a centered windrow.
4. Dump truck: Provides extra hot-mix asphalt for cross-slope correction.
5. Asphalt paving equipment: Consists of the following three parts:
   a. Boom arm: Attached to the front of the laydown equipment and is used to clean around utility structures.
   b. Pickup Conveyor: This device picks up the windrowed material from the pugmill and conveys it up into the paving hopper.
   c. Paver: A conventional hot-mix asphalt paver and screed with crowning ability and full vibratory compaction.
6. Compaction equipment: Two rollers were used; a steel-wheeled vibratory roller for primary compaction and a rubber-tired traffic roller for final compaction and finishing.

PROJECT DESCRIPTION

This project, Financial Project Number 413535-1-52-01, is located in FDOT District 5, Sumter County, on SR-471 south of Tarrytown. The two-lane highway had a project length of 5.115 miles (10.23 lane miles and 96,026 sy) with the northbound and southbound 12-feet wide lanes (plus four-feet wide shoulders) to be recycled in-place to a depth of 2.0 inches. The average annual daily traffic (AADT) is 2800 vehicles. The last resurfacing occurred in 1991. The crack rating of the pavement was 4.5 out of a scale of 10.0. The pavement was considered “deficient” based on the low crack rating and was scheduled for rehabilitation. The Department characterized the project as an innovative construction process and negotiated a contract with H.I.P. for a lump sum price of $615,000, or an average unit cost of $60,117 per lane mile or $6.40/sy. Included in the $615,000 lump sum price was $80,000 to provide a three-year maintenance bond, which is discussed later in this report. Excluding the $80,000 maintenance bond cost from the lump sum price results in an average unit cost of $52,297 per lane mile or $5.57/sy. Construction began on November 18, 2002 and was completed on December 9, 2002, for a total of 22 calendar days (16 work days).

COST COMPARISON WITH CONVENTIONAL HMA

In March 2003, a project directly north of the hot-in-place recycling project was resurfaced using conventional milling and resurfacing techniques for the two 12-feet wide lanes and four-feet wide shoulders. The project was milled to a depth of three inches, an asphalt rubber membrane interlayer (ARMI) was placed over the milled surface followed by a 1.5 inch Type SP structural Superpave layer and a 1.5 inch Type FC Superpave friction course layer. The total length of the project was 9.181 miles (18.362 lane miles and 172,358 sy). D.A.B.

Constructors, Inc. built the project at a cost of $1,899,162. This equates to an average unit cost of $103,429 per lane mile or $11.02/sy. For this particular comparison, the hot-in-place recycling project was 49.5% less expensive than the conventional milling/resurfacing process on a square yard basis, when excluding the maintenance bond cost from H.I.P.'s price.

However, the conventional HMA project used a dense graded friction course layer (FC-6), consisting of virgin aggregates and asphalt-rubber binder and typically costs $3.00/sy per inch of thickness. For a more accurate cost comparison with the conventional HMA project, the cost of a one inch thick FC-6 layer was added to the cost of the H.I.P. project bringing the total price to $8.57/sy ($5.57/sy + $3.00/sy). It should also be noted that the Department requires the use of a friction course on roadways with an average annual daily traffic (AADT) of 3000 or greater. The total thickness of asphalt for the H.I.P. project would then be 3 inches (2 inches of recycled mix + 1 inch of FC-6 HMA). This is the same thickness used for the conventional HMA project constructed by D.A.B. Examining construction costs only, the hot-in-place recycling project would be 22.2% less expensive than the conventional milling/resurfacing process on a square yard basis. The conventional HMA project also had additional cost associated with the use of an ARMI layer, which would not be a feasible construction practice with the H.I.P. process.

To compare the cost effectiveness between the H.I.P. and conventional HMA projects, a life cycle cost analysis is required. This requires assuming service lives for each project and converting the costs to equivalent uniform annual costs (EUAC). Four service lives were assumed for the H.I.P. project, 5, 7, 10 and 12 years. Then the number of years was calculated for the conventional HMA project to have the same EUAC as the H.I.P. project. A discount rate of five percent was used. Table 1 is an analysis comparing the

H.I.P. project versus the conventional HMA project. Table 2 is an analysis comparing the H.I.P. project with an additional one inch FC-6 friction course layer versus the conventional HMA project. The H.I.P. values shown in Tables 1 and 2 exclude the $80,000 cost of the maintenance bond.

Table 1 – Cost Analysis; H.I.P. Project versus Conventional HMA

H.I.P. Assumed Service Life (years)	H.I.P. EUAC at $5.57/sy	HMA (north project) at $11.02/sy Required Equivalent Service Life (years)
5	$1.29/sy/yr	12
7	$0.96/sy/yr	18
10	$0.72/sy/yr	30
12	$0.63/sy/yr	42

Note: EUAC = equivalent uniform annual cost

Table 2 – Cost Analysis; H.I.P. Project with FC-6 versus Conventional HMA

H.I.P. Assumed Service Life (years)	H.I.P. with 1" FC-6 EUAC at $8.57/sy	HMA (north project) at $11.02/sy Required Equivalent Service Life
5	$1.98/sy/yr	7
7	$1.48/sy/yr	10
10	$1.11/sy/yr	14
12	$0.97/sy/yr	18

Note: EUAC = equivalent uniform annual cost

MIX DESIGN

The mixture was designed per Marshall mixture design criteria (50 blows). Because the insitu properties of the northbound and southbound lanes were slightly different, two mix designs were used, one for each direction. New materials added to the milled asphalt included clean concrete sand which was used to increase the compacted air void content of the mixture and an oil-based liquid asphalt-rejuvenating agent (Sundex 540T by Sun Co., Inc.) necessary to bring the design penetration value of the recovered binder between 40 and 80 (in units of 0.1 mm). Properties of each mix design are shown in Table 3. Additional Marshall type S-III hot-mix asphalt was added after the pugmill to correct cross-slope as necessary.

Table 3 – Mix Design Information

Direction	% AC Content	% Air Voids	G_{mm}	G_{mb}	Recovered Penetration (0.1 mm)	Rejuvenator Addition		Sand Addition (lb/sy)
						gal/ton	gal/sy	
Northbound	5.7	4.1	2.420	2.321	55	1.35	0.13	12.8
Southbound	5.4	4.3	2.423	2.319	51	1.24	0.12	11.5

WARRANTY SPECIFICATION

Due to the Department's mixed success with previous hot-in-place recycling projects, the Department instituted warranty requirements for this project. The warranty requirements were included in the contract documents as part of the hot-in-place recycling specification, Section 324. Section 324 of the specifications is included in Appendix A of this report. Highlights of the warranty requirements include:

1. The warranty period extends for three years after final acceptance of the project.

2. The warranty is backed by a Maintenance Bond in the amount of $720,000. This would provide for milling and replacing two inches of pavement with hot-mix asphalt and associated maintenance of traffic and striping operations.
3. All unresolved disputes between the Department and Contractor will be addressed by an independent Dispute Review Board, with their majority vote ruling binding on both parties with no rights to an appeal.
4. The warranty does not apply to deficiencies that are a result of factors beyond the control of the Contractor. Some of these include:
    a. A deficient pavement thickness design.
    b. The accumulated 18-kip Equivalent Single Axle Loads (ESALs) over the three-year warranty period are 25% or greater than the ESALs used in the pavement design.
    c. Deficiencies due to failures of the base, subgrade or underlying asphalt layers.
    d. Deficiencies due to work on the roadway by a third party.
5. The Department's Flexible Pavement Condition Survey Program will be used as the basis for determining the extent and magnitude of the pavement distresses.
6. The project will be divided into LOTs of 0.1 miles in length for evaluation purposes.
7. The distresses to be evaluated include: rutting, rideability, cracking, raveling, delamination, potholes, slippage and segregated areas.

Thresholds and remedial actions for each type of distress are shown in Table 4 and are applicable throughout the three year warranty period.

Table 4 - Thresholds and Remedial Actions for Distress Types

Type of Distress	Type of Survey	Threshold Level for Each LOT (0.1 Mile) per lane	Remedial Action
Rutting	Any Survey	Depth > 0.25 inch	Remove and replace the distressed LOT(s) to the full distressed depth and full lane width.
		Depth ≤ 0.25 inch	None required.
Rideability	Any Survey	RN < 3.70	Remove and replace the distressed LOT(s) to the full distressed area(s) and full lane width.
Cracking	Any Survey	Cracking >1/8 inch (Class 1B), accumulative cracking length > 30 feet	Remove and replace the distressed LOT(s) to the full distressed depth and full lane width.
Raveling, delamination and other disintegrated areas affecting the friction course	Intermediate Survey	Underlying layer exposed, individual length > 10 feet	Remove and replace the distressed area(s) to the full distressed depth and full lane width or patch the distressed area(s).
		Underlying layer exposed, individual length < 10 feet	Patch the distressed area(s) and remove and replace the distressed area(s) to the full distressed depth and full lane width prior to the final survey.
	Final Survey	Observation by Engineer	Replace the distressed areas (including all patches) and extend 50 feet at both ends at full lane width.
Potholes, slippage area(s), segregated area(s) and other disintegrated areas.	Any Survey	Observation by Engineer	Remove and replace the distressed area(s) to 150% of the area(s) or temporarily patch the distressed area(s) and remove and replace the distressed area(s) to 150% of the area(s) prior to the final survey.

Notes: 1. The Ride Number (RN) established by the laser profiler will express the ride quality of the pavement of a LOT being tested.

2. For any two deficient LOTs not separated by 3 passing LOTs, the repair work shall cover the entire stretch (including the passing LOTs). If the area of cracking, patching or raveling within a LOT exceeds 60% of the LOT area, the total LOT shall be corrected by approved methods.

3. The longitudinal construction joint at lane line is not considered as cracking during survey.
4. Removal and replacement (if necessary) will entail removal by milling (per Section 327) to a 2 inch depth, and replacement with a Type SP-12.5 (Traffic Level B) mix, meeting the requirements of Section 334. As an exception, the Contractor may elect to have an Engineering evaluation conducted on the pavement LOTs requiring removal and replacement to determine if other suitable methods of repair (including hot in-place recycling meeting these specifications) may be appropriate. The Engineering evaluation must be conducted by a licensed Professional Engineer as approved by the Department. The method of repair shall be approved by the Engineer.

TEST RESULTS

Specification Section 324 requires the contractor to furnish and maintain a "Quality Control System", in which the Contractor is completely responsible for monitoring and correcting the construction process dependent on the test results obtained. Additionally, Section 324 provides that the Department's Engineer may obtain samples at any time for informational purposes and for determining the effectiveness of the Contractor's quality control operations. Personnel from the Department's State Materials Office (SMO) obtained random samples throughout the duration of the project for these purposes.

Asphalt Content and Gradation

During construction, the asphalt content and gradation of the as-produced mix were determined in accordance with FM 5-544 and FM 5-545 for both Quality Control testing by the Contractor and testing conducted by the SMO for informational purposes. Quality Control tests were performed at a frequency of one test per LOT, where a LOT is defined as a 5,000 feet pass of the paving train, or a minimum of one test per day. Test results for gradation and asphalt binder content are presented in Tables 5A and 5B. The design asphalt binder content for the northbound lane was 5.7%. Quality Control test results averaged 5.0%

Table 5A – H.I.P. and SMO Laboratory Test Results

State Materials Office and H.I.P. Test Results

Asphalt Property		Sample Date													
		11/18/2002 HIP	11/19/2002 HIP	11/20/2002 HIP	11/20/2002 HIP	11/21/2002 HIP	11/21/2002 HIP	11/22/2002 HIP	11/22/2002 HIP	11/22/2002 SMO	11/23/2002 HIP	11/25/2002 HIP	11/25/2002 HIP	11/25/2002 SMO	11/26/2002 HIP
Direction		SB	SB	SB	SB	SB	SB	SB	SB	SB	SB	SB	SB	SB	NB
Gradation % Passing	1"	100	100	100	n/a	100	n/a	100	n/a	100	100	100	100	100	100
	3/4"	100	100	100	n/a	100	n/a	100	n/a	100	100	98	98	100	100
	1/2"	99	100	99	n/a	98	n/a	98	n/a	96	100	92	97	99	99
	3/8"	96	96	96	n/a	93	n/a	94	n/a	92	96	85	94	95	93
	#4	67	63	59	n/a	57	n/a	60	n/a	64	63	51	60	61	57
	#8	47	43	39	n/a	39	n/a	42	n/a	45	42	34	43	41	41
	#16	41	38	35	n/a	35	n/a	37	n/a	39	37	31	37	36	37
	#30	35	33	31	n/a	32	n/a	33	n/a	34	33	29	32	32	32
	#50	23	23	22	n/a	22	n/a	24	n/a	25	24	21	21	23	22
	#100	8	9	10	n/a	9	n/a	11	n/a	11	10	10	10	12	9
	#200	4.5	4.9	5.6	n/a	4.9	n/a	6.6	n/a	6.9	6.0	5.5	6.3	7.9	5.4
% AC Content (Vacuum Extraction)		4.8	4.8	5.2	4.9	4.9	5.1	4.8	5.1	5.7	5.3	4.7	5.3	6.2	4.7
Absolute Viscosity (Poises)		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	8,882	n/a	n/a	n/a	16,177	n/a
Penetration (0.1 mm)		42	52	49	55	50	49	48	48	43	54	57	66	39	54
Gmm		2.428	2.415	2.396	2.409	2.418	2.412	2.423	2.413	2.402	2.399	2.397	2.397	2.398	2.420
Gmb		2.308	2.303	2.303	2.313	2.304	2.311	2.322	2.304	n/a	2.298	2.311	2.308	2.317	2.285
% Air Voids		5.0	4.7	3.9	4.0	4.7	4.2	4.2	4.5	n/a	4.2	3.6	3.8	3.3	5.6
Stability (lbs.)		4,775	3,750	3,750	3,300	3,950	3,700	4,450	3,650	n/a	3,150	3,550	3,550	4,340	4,050
Flow (0.01")		13.8	10.8	12.8	10.7	11.5	11.5	12.5	12.5	n/a	13.8	13.5	13.5	13.0	14.0

Asphalt Property		Sample Date													
		11/26/2002 HIP	11/26/2002 SMO	11/27/2002 HIP	11/27/2002 SMO	12/2/2002 HIP	12/2/2002 HIP	12/2/2002 SMO	12/3/2002 HIP	12/3/2002 HIP	12/3/2002 SMO	12/4/2002 HIP	12/4/2002 HIP	12/4/2002 SMO	12/5/2002 HIP
Direction		NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	SB	SB	SB	NB
Gradation % Passing	1"	100	100	100	100	100	n/a	100	100	n/a	100	100	100	100	100
	3/4"	95	97	100	100	100	n/a	99	100	n/a	97	100	100	100	99
	1/2"	94	95	98	98	100	n/a	98	98	n/a	92	99	100	99	97
	3/8"	90	91	96	95	97	n/a	95	94	n/a	86	96	97	95	94
	#4	56	62	62	62	61	n/a	64	58	n/a	52	65	65	66	63
	#8	37	43	41	41	40	n/a	44	39	n/a	35	45	44	45	43
	#16	33	37	35	35	35	n/a	38	35	n/a	31	39	38	39	38
	#30	30	32	31	31	31	n/a	34	31	n/a	28	34	34	34	34
	#50	21	24	23	23	22	n/a	25	22	n/a	19	23	25	25	23
	#100	10	11	11	11	10	n/a	12	9	n/a	8	9	11	11	10
	#200	5.9	6.9	6.7	7.2	6.0	n/a	7.6	5.0	n/a	5.2	5.4	6.6	7.07	5.8
% AC Content (Vacuum Extraction)		4.9	5.9	5.1	5.6	5.1	5.3	6.2	4.8	5.0	4.2	4.8	5.2	6.0	4.8
Absolute Viscosity (Poises)		n/a	11,574	n/a	9,274	n/a	n/a	7,342	n/a	n/a	n/a	n/a	n/a	5796	n/a
Penetration (0.1 mm)		55	42	51	46	58	58	49	53	56	n/a	66	56	54	65
Gmm		2.415	2.402	2.407	2.395	2.397	2.402	2.392	2.410	2.401	2.418	2.410	2.404	2.400	2.402
Gmb		2.290	2.304	2.285	2.340	2.285	2.285	n/a	2.285	2.285	n/a	2.250	2.313	n/a	2.309
% Air Voids		5.2	4.1	5.0	2.3	4.7	4.8	n/a	5.2	4.8	n/a	6.6	3.8	n/a	3.9
Stability (lbs.)		3,650	3,707	3,950	4,070	3,750	3,650	n/a	3,700	3,325	n/a	3,125	3,875	n/a	3,065

Table 5B – H.I.P. and SMO Laboratory Test Results (continued)

Asphalt Property		Sample Date									Averages HIP NB	Averages SMO NB	Averages HIP SB	Averages SMO SB
		12/5/2002 SMO	12/6/2002 HIP	12/6/2002 SMO	12/7/2002 HIP	12/7/2002 HIP	12/7/2002 SMO	12/8/2002 HIP	12/8/2002 SMO	12/4/2002 Reworked Area SMO				
Direction		NB	SB	SB	NB	NB	NB	NB	NB	SB	NB	NB	SB	SB
Gradation % Passing	1"	100	100	100	100	n/a	100	100	100	n/a	100	100	100	100
	3/4"	100	100	98	100	n/a	100	100	99	n/a	99	99	100	100
	1/2"	99	99	97	99	n/a	97	98	98	n/a	98	97	98	98
	3/8"	95	95	93	93	n/a	94	94	93	n/a	94	93	94	94
	#4	62	60	64	59	n/a	62	59	64	n/a	59	61	61	64
	#8	43	41	45	40	n/a	43	39	44	n/a	40	42	42	44
	#16	38	37	39	36	n/a	37	35	38	n/a	35	36	37	38
	#30	34	33	35	32	n/a	33	31	34	n/a	31	32	32	34
	#50	24	24	26	23	n/a	25	22	26	n/a	22	24	23	25
	#100	11	10	12	11	n/a	11	10	13	n/a	10	11	10	12
	#200	6.6	5.9	7.6	6.1	n/a	6.8	5.5	7.9	n/a	5.8	6.9	5.7	7.4
% AC Content (Vacuum Extraction)		6.1	4.8	5.3	5.0	5.2	5.4	4.9	5.8	n/a	5.0	5.6	5.0	5.8
Absolute Viscosity (Poises)		4926	n/a	19,000	n/a	n/a	10,485	n/a	10,501	9,042	n/a	9,017	n/a	11,779
Penetration (0.1 mm)		54	48	39	49	47	46	48	45	51	54	47	53	45
Gmm		2.396	2.415	2.410	2.407	2.401	2.407	2.404	2.402	2.405	2.406	2.402	2.410	2.403
Gmb		2.330	2.313	n/a	2.314	2.293	n/a	2.311	2.324	n/a	2.294	2.325	2.304	2.317
% Air Voids		2.8	4.2	n/a	3.8	4.4	n/a	3.8	3.3	n/a	4.7	3.1	4.4	3.3
Stability (lbs.)		3,187	4,000	n/a	3,800	3,750	n/a	3,850	3,770	n/a	3,685	3,684	3,755	4,340
Flow (0.01")		10.4	11.5	n/a	13.3	13.5	n/a	12.8	11.5	n/a	13.0	11.9	12.5	13.0

and SMO test results averaged 5.6%. The design asphalt binder content for the southbound lane was 5.4%. Quality Control test results averaged 5.0% and SMO test results averaged 5.8%. With respect to gradation, a design gradation was not established since the Contractor only had in-place materials to work with. Quality Control and SMO test results compared very well, with the SMO gradation 1% to 2% finer on a majority of the sieves.

Viscosity and Penetration

During construction, hot-mix asphalt samples were obtained and the binder recovered and tested for resistance to penetration by Quality Control personnel. SMO personnel also obtained independent hot-mix asphalt samples and tested the recovered binder for resistance to penetration and absolute viscosity. The binder was recovered in accordance with FM 5-524 and FM 3-D5404. Penetration values of the recovered binder samples were determined at 77°F in accordance with FM 1-T 049 and the absolute viscosity of the recovered binder samples was determined at 140°F in accordance with FM 1-T 202. Quality Control tests were performed at a frequency of one test per LOT, where a LOT is defined as a 5,000 feet pass of the paving train, or a minimum of one test per day. Test results for penetration and absolute viscosity are presented in Tables 5A and 5B. The design penetration value (in units of 0.1 mm) for the northbound lane was 55, with an allowable range during production of +/-10. Quality Control test results averaged 54 and SMO test results averaged 47. The design penetration value for the southbound lane was 51. Quality Control test results averaged 53 and SMO test results averaged 45. There were no design values for absolute viscosity. For the northbound lane, SMO test results averaged 9,017 Poises and for the southbound lane, the average was 11,779 Poises. These absolute viscosity values are within the normally specified range of 4,000 – 12,000 Poises for the recovered binder from hot-mix asphalt mixtures containing recycled materials.

Maximum Specific Gravity, Bulk Specific Gravity, Air Voids, Marshall Stability and Flow

During construction, the maximum specific gravity (G_{mm}), bulk specific gravity (G_{mb}), air void content, Marshall stability and flow values were determined by Quality Control and SMO personnel. G_{mm} values were determined in accordance with FM 1-T 209. Specimens were compacted and stability and flow values were determined in accordance with FM 5-511. G_{mb} values were determined in accordance with FM 1-T 166. Quality Control tests for G_{mm} were performed once per production day. Quality Control tests for G_{mb} and % air void determinations were performed at a frequency of one test per LOT, where a LOT is defined as a 5,000 feet pass of the paving train, or a minimum of one test per day. Marshall stability and flow were not required Quality Control tests but were performed at the same frequency as G_{mb} tests and % air void determinations. Test results are presented in Tables 5A and 5B. G_{mm}, stability and flow values were nearly equal between Quality Control and SMO test results. Average G_{mm} values ranged between 2.402 and 2.410. Average stability values ranged between 3,684 and 4,340 lbs. Average flow values ranged between 11.9 and 13.0 (0.01 inch units). However, Quality Control and SMO G_{mb} test results were substantially different from each other resulting in a wide disparity in calculated % air voids. For the northbound lane, the design air void content was 4.1%. Quality Control air voids averaged 4.7% and SMO air voids averaged 3.1%. For the southbound lane, the design air void content was 4.3%. Quality Control air voids averaged 4.4% and SMO air voids averaged 3.3%. Only one individual Quality Control test result and one individual SMO test result for both lanes did not fall within the specified range of +/- 1.5% of the mix design value. No air void test results fell below 2.0%, which, according to the specifications, would require a mixture blend adjustment to raise the air void level.

Roadway Density

Roadway density requirements were specified on a LOT basis, where a LOT could contain from three to seven sublots. A sublot is defined as 1000 feet of roadway per lane. The minimum specified average density for a LOT was 92% of G_{mm}. Roadway density was determined by cutting six-inch diameter roadway cores (one per sublot) and determining the G_{mb} in accordance with FM 1-T 166. G_{mm} tests were performed in the field laboratory by Quality Control personnel on the as-produced mix per FM 1-T 209. The roadway density data, shown in terms of % G_{mm}, is shown in Table 6. The average roadway density for the

Table 6 – H.I.P. Roadway Test Results

Date	Average % Gmm Compaction	Average Thickness (in.)	# Cores	Lane	Location (mileposts)	Cross-slope (%)	Rejuvenation Rate (gal/sy)	Asphalt Mixture Temperature (F)
11/18/2002	92.3	2.0	4	SB	4.927 - 4.488	1.64	0.111	249
11/19/2002	92.8	2.4	4	SB	4.363 - 3.834	1.58	0.130	255
11/20/2002	93.8	2.3	5	SB	3.763 - 3.023	1.90	0.133	244
11/21/2002	94.0	2.0	4	SB	2.828 - 2.272	2.13	0.130	244
11/22/2002	91.7	2.1	4	SB	2.034 - 1.453	1.74	0.134	242
11/23/2002	93.2	2.2	5	SB	1.348 - 0.519	1.93	0.153	241
11/25/2002	94.0	2.1	4	SB - NB	0.420 - 0.157	1.66	0.132	248
11/26/2002	93.3	2.1	5	NB	0.287 - 1.013	1.76	0.141	246
11/27/2002	94.4	2.5	4	NB	1.194 - 1.653	1.71	0.156	239
12/2/2002	95.6	2.3	5	NB	1.984 - 2.429	2.01	0.160	234
12/3/2002	93.1	2.3	5	NB	2.498 - 3.200	1.90	0.153	233
12/4/2002	93.7	2.5	6	SB	5.023 - 4.004	2.00	0.054	248
12/5/2002	92.8	2.6	4	NB	3.408 - 3.930	2.10	0.141	221
12/6/2002	93.5	2.2	3	SB	3.940 - 3.876	2.20	0.034	240
12/7/2002	93.6	1.8	4	NB	3.983 - 4.566	2.20	0.150	226
12/8/2002	92.0	2.1	3	NB	4.916 - 5.086	2.32	0.121	230
Weighted Average	93.4	2.2				1.90	0.130	241

project was 93.4% of G_{mm}. Only one LOT had a density value less than 92% of G_{mm} (91.7 %).

Thickness

The specified thickness for the recycled pavement was 2.0 inches. Quality Control personnel measured the compacted pavement thickness from the cores that were obtained for roadway density determination at a frequency of one core per 1000 feet of roadway per lane. Average thickness measurements per LOT are shown in Table 6. The average thickness for the project was 2.2 inches, with a minimum thickness of 1.8 inches and a maximum thickness of 2.6 inches. Only one LOT had a thickness below 2.0 inches (1.8 inches).

Cross-slope

The specified cross-slope for the recycled pavement was 2.0 %. Quality Control personnel measured the cross-slope at a frequency of once per 100 feet of roadway per lane. Average cross-slope measurements per LOT are shown in Table 6. The average cross-slope for the project was 1.90%, with a minimum cross-slope of 1.58% and a maximum cross-slope of 2.32%.

Rejuvenation Rate

An oil-based liquid asphalt-rejuvenating agent (Sundex 540T by Sun Co., Inc.) was added to the recycled mixture during production to increase the penetration value (in units of 0.1 mm) of the recovered binder to closely match the mix design values, which were 55 for the northbound lane and 51 for the southbound lane. The targeted rejuvenation rate to obtain these values was 0.13 gal/sy for the northbound lane and 0.12 gal/sy for the southbound lane. Average rejuvenation rates for each LOT are shown in Table 6. The average rejuvenation for the project was 0.130 gal/sy. Two southbound LOTs had rejuvenation rates well below the targeted value (0.054 and 0.034 gal/sy). These two LOTs were processed with less rejuvenator because they were in an area which had to be recycled twice due to issues associated with cross-slope. The low rejuvenation rate on the second recycling effort was to prevent over-asphalting the mixture.

Temperature

Quality Control personnel obtained three temperature measurements transversely across the asphalt mat at a frequency of once every 100 feet. Temperature measurements were obtained using an infrared temperature-measuring device. The average temperature data for each LOT is displayed in Table 6. The specified temperature range was 240°F +/- 20°F. The average temperature for the project was 241°F, with a minimum temperature of 221°F and a maximum temperature of 255°F.

Bond Strength

An experimental test procedure, developed at the SMO, was used to measure the strength of the bond between the recycled mixture and the underlying surface. The device shears a roadway core at the bond interface between the two layers (see Figure 1). Twenty cores were tested, ten from the outside wheelpath and ten from between the wheelpaths. The cores were obtained from evenly distributed locations throughout the length of the project approximately two months after completion of the project. Test results are presented in Table 7. The average strength for the wheelpath cores was 94 psi and the average strength for the between-the-wheelpaths cores was 114 psi. For comparison, bond strength testing was performed on the SR-19 project in Lake County, which was constructed by a different Contractor using a different hot-in-place recycling process. The average strength for the wheelpath cores for the SR-19 project was 165 psi and the average strength for the between-the-wheelpaths cores was 96 psi. Strength values for both projects are comparable to the strengths encountered between two conventionally placed fine graded HMA mixtures.

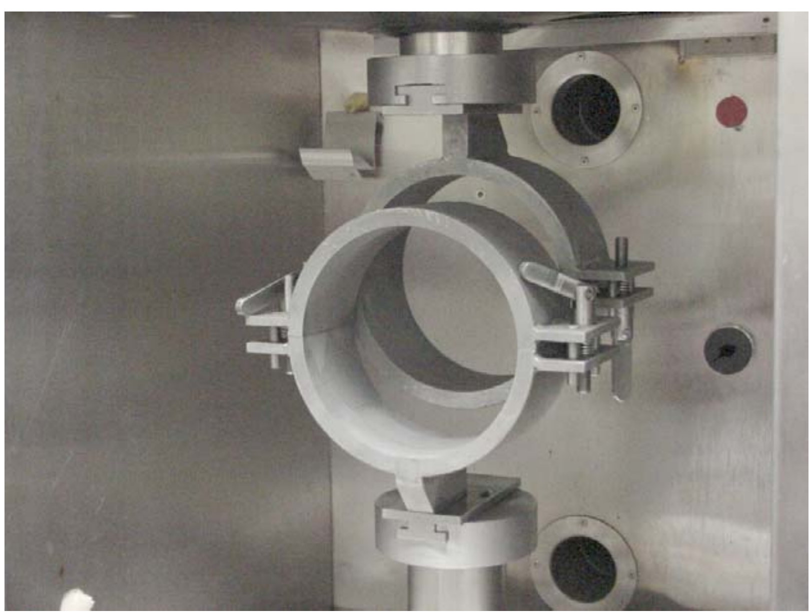

Figure 1 – Bond Strength Test Device

Table 7 – Bond Strength Test Results

Core ID	Direction	Shear Strength (psi)	
		Wheelpath	Between Wheelpath
1	Northbound	103	183
2	Northbound	108	131
3	Northbound	64	64
4	Northbound	129	114
5	Northbound	103	136
6	Southbound	82	damaged
7	Southbound	99	damaged
8	Southbound	84	damaged
9	Southbound	104	113
10	Southbound	60	54
	Average	94	114

Friction

The Pavement Evaluation Section of the SMO conducted ribbed-tire wet friction testing in accordance with ASTM E 274 at various points along the project before construction, approximately one month after construction, and again approximately 13 months after construction. This data is presented in Table 8. The average friction number for the northbound lane (only lane tested) prior to construction was 45.7. One month after construction, the average friction number for both the northbound and southbound lanes was 51.6. Thirteen months after construction, the average friction number for both the northbound and southbound lanes was 48.9.

Friction data for the conventional HMA project constructed to the north side of the hot-in-place recycling project is shown in Table 9 for comparison purposes. The average friction number for the northbound lane (only lane tested) prior to construction was 49.1. Two months after construction, the average friction number for both the northbound and southbound lanes was 56.9.

Table 8 – Friction Test Results – H.I.P. Project

Property	Before Construction (4/10/00)	One Month After Construction (1/14/03)			Thirteen Months After Construction (1/22/04)		
	Northbound	Northbound	Southbound	Combined	Northbound	Southbound	Combined
Mean	45.7	53.5	49.6	51.6	50.2	47.5	48.9
SD	1.27	3.56	4.09	3.83	2.58	2.08	2.34
Range	43.7 - 47.2	44.3 - 60.7	43.6 - 59.5	43.6 - 60.7	45.6 - 56.4	45.0 - 53.6	45.0 - 56.4
# tests	14	21	21	42	15	16	31

Table 9 – Friction Test Results - Conventional HMA Project

Property	Before Construction (1/14/03)	After Construction (5/5/03)		
	Northbound	Northbound	Southbound	Combined
Mean	49.1	59.5	54.3	56.9
SD	2.42	1.78	2.58	2.22
Range	45.9 - 54.4	56.0 - 62.5	47.7 - 57.2	47.7 - 62.5
# tests	27	19	19	38

Ride Rating

The Pavement Evaluation Section also performed a survey of the pavement for roughness, rut depth, and cracking at the following times: 35 days before construction commenced and 10 days, six months, and twelve months after construction was completed. Roughness and rut depth data were obtained using the Department's high speed laser profiler vehicle. Cracking data was determined by visual ratings. The roughness values are given in terms of the International Roughness Index (IRI) and Ride Number (RN). The data is presented in Table 10. Examination of the data shows that the ride quality as measured by IRI and RN did not change significantly after construction, nor did it change significantly after twelve months of traffic. The pre-construction and post-construction values are considered to be good or better

Table 10 – Pavement Condition Survey Test Results – H.I.P. Project

Date Tested		Average IRI		Average RN		Laser Profiler Rut Depth (inches)				Crack Rating	
		Northbound	Southbound	Northbound	Southbound	Northbound		Southbound		Northbound	Southbound
						Average	Std. Dev.	Average	Std. Dev.		
10/14/2002	Before Overlay	54	52	4.13	4.20	0.22	0.113	0.23	0.104	KF / 4.5	KF / 4.5
12/18/2002	After Overlay	59	58	4.13	4.20	0.05	0.028	0.04	0.026	AA / 10.0	AA / 10.0
7/24/2003	6 Months After Overlay	57	56	4.16	4.23	0.12	0.052	0.12	0.048	AA / 10.0	AA / 10.0
1/5/2004	12 Months After Overlay	57	57	4.16	4.23	0.13	0.056	0.13	0.048	AA / 10.0	AA / 10.0

and within the range expected for new conventional HMA construction. After construction, the rutting had been nearly eliminated and the crack rating was perfect at AA/10.0, both to be expected. AA means there was 0 to 5% cracking in the wheelpaths and outside the wheelpaths, respectively. A 10.0 means there were no point deductions for cracking. At the six and twelve month intervals after construction, the crack ratings were still at the AA/10.0 rating.

However, at the six and twelve month intervals, the pavement was showing signs of rutting in both the northbound and southbound lanes, especially in the northern half of the project. Some of the rut depth measurements on the northern half of the project were approaching 0.20 inches and at some locations exceeded 0.20 inches after twelve months of traffic. The cause of the rutting is unknown at this time. Figures 2 and 3 show the rut depth measurements obtained at 0.1 mile intervals for both the northbound and southbound directions. Also, shown on Figures 2 and 3 are the rut depths of the same section of roadway after 11.5 years of traffic prior to rehabilitation by H.I.P.

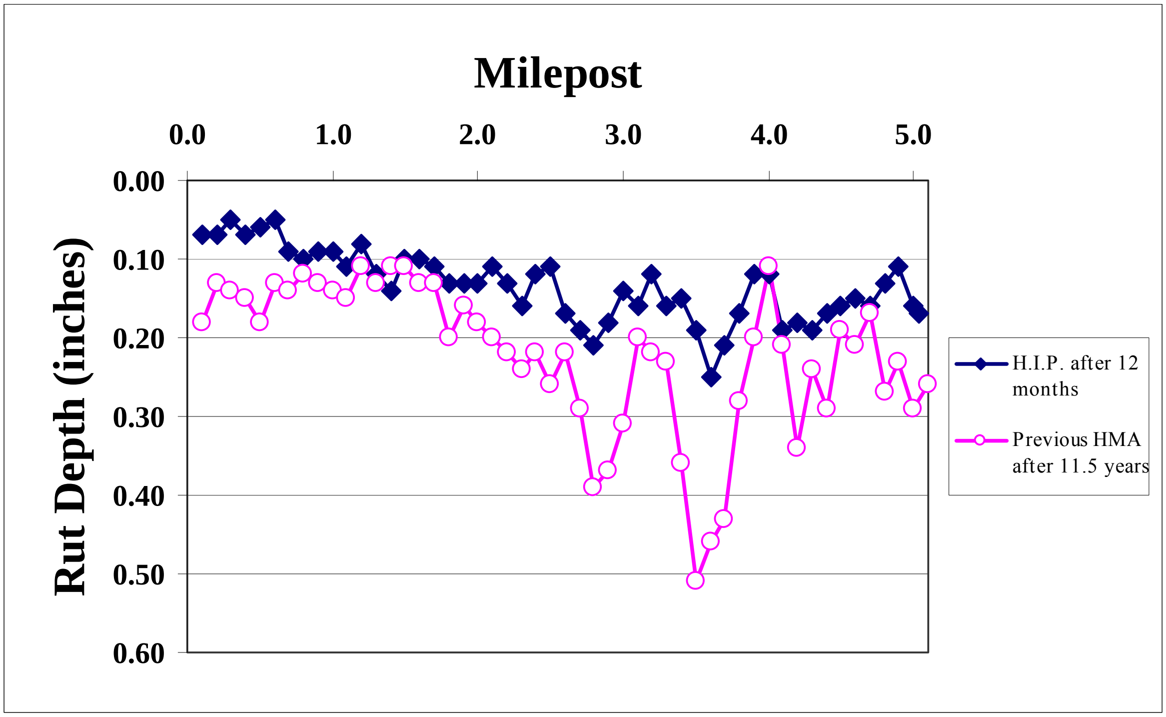

Figure 2 – Northbound Rut Data – H.I.P. Project

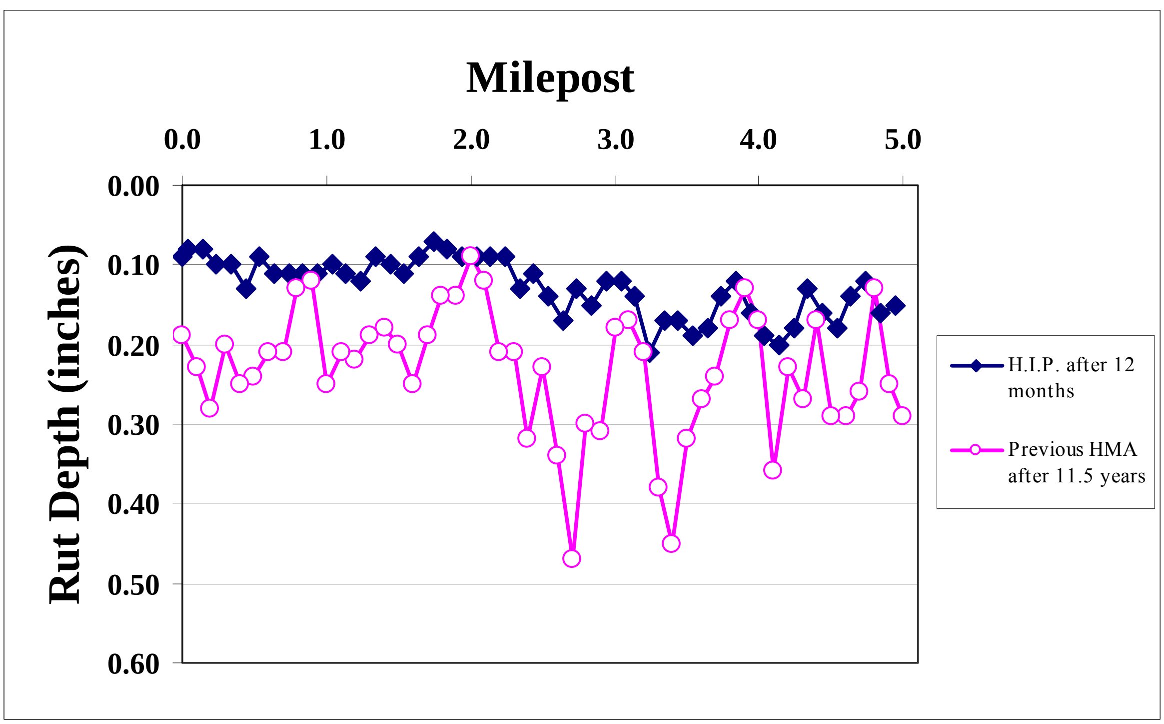

Figure 3 – Southbound Rut Data – H.I.P. Project

The pavement condition survey data for the conventional HMA project constructed to the north side of the hot-in-place recycling project is shown in Table 11 for comparison purposes. Pavement smoothness data, as expressed by the IRI and RN are nearly equivalent between the two projects. Cracking and patching ratings for both projects are perfect at AA/10.0. With respect to the average rut depth for the project, after eleven months of traffic the conventional HMA project is rutting 0.10 inches less than the hot-in-place recycling project after twelve months of traffic. Figures 4 and 5 show the rut depth measurements obtained at 0.1 mile intervals for both the northbound and southbound directions 11 months after construction. Figure 4 additionally shows rut depth measurements for the northbound direction obtained 10 months before construction when the pavement was 19 years old. Rut depth measurements prior to construction for the southbound direction are not available. Figures 4 and 5 use the same ordinate scale as Figures 2 and 3 for comparison purposes.

Table 11 – Pavement Condition Survey Test Results – Conventional HMA Project

Date Tested		Average IRI		Average RN		Laser Profiler Rut Depth (inches)				Crack Rating	
		Northbound	Southbound	Northbound	Southbound	Northbound		Southbound		Northbound	Southbound
						Average	Std. Dev.	Average	Std. Dev.		
6/10/2002	Before Overlay	70	n/a	4.12	n/a	0.04	0.057	n/a	n/a	KC / 4.5	n/a
5/27/2003	2 Months After Overlay	59	n/a	4.14	n/a	0.02	0.026	n/a	n/a	AA / 10.0	n/a
2/12/2004	11 Months After Overlay	58	59	4.11	4.09	0.03	0.028	0.03	0.028	AA / 10.0	n/a

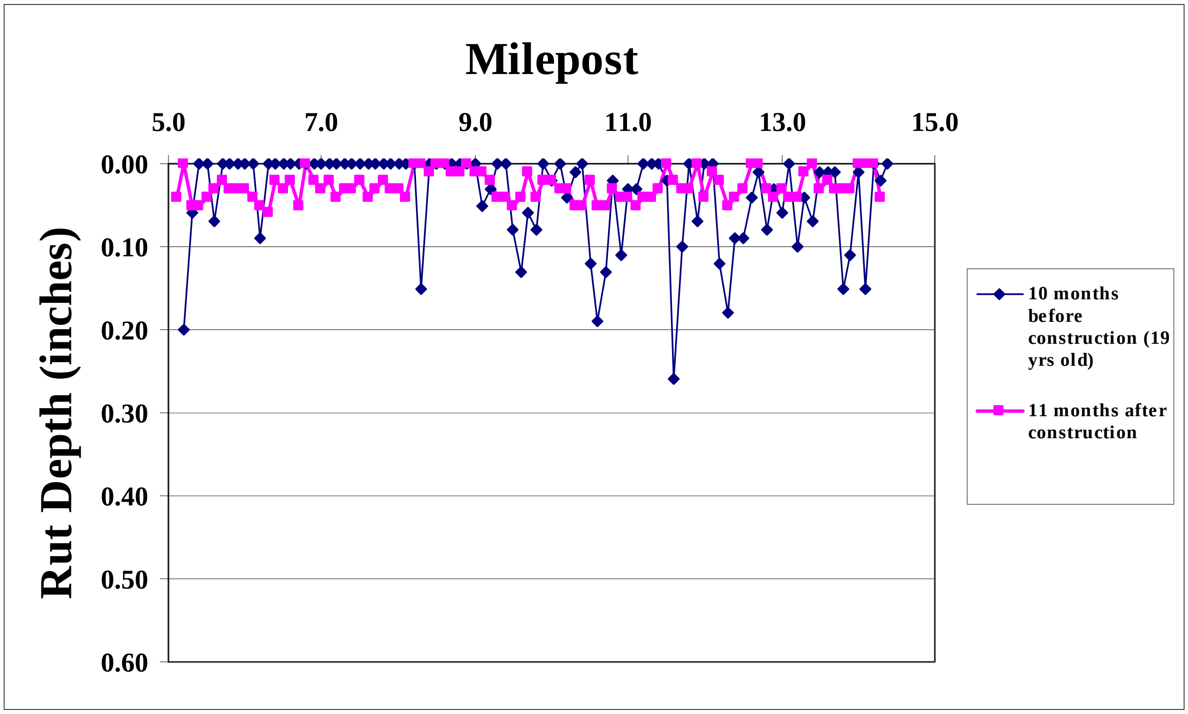

Figure 4 – Northbound Rut Data - Conventional HMA Project

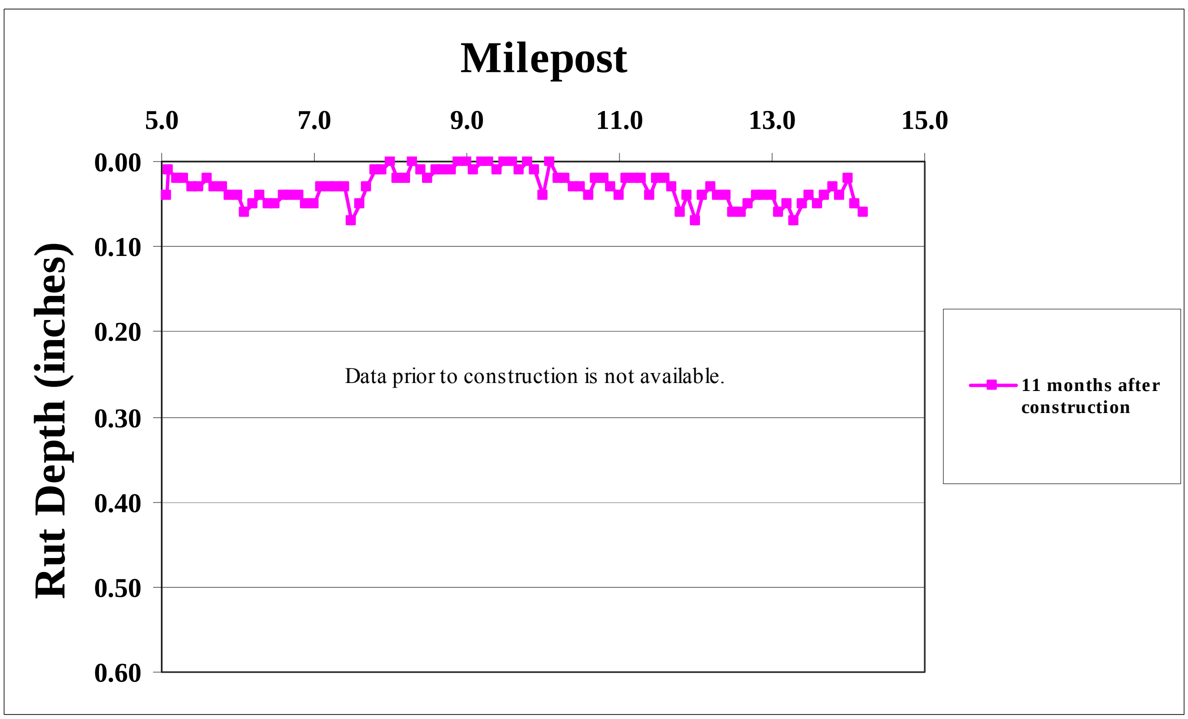

Figure 5 – Southbound Rut Data - Conventional HMA Project

CONCLUSIONS

1. The SR-471 project is the first hot-in-place recycling project under the Department's jurisdiction to incorporate a three-year performance warranty. This warranty, backed by a Maintenance Bond in the amount of $720,000, places the responsibility for premature failures (such as that with the CR-315 Putnam County project mentioned previously) on the Contractor, rather than on the Department.

2. The hot-in-place recycling process used for this project was efficient. The Contractor was able to recycle 10.23 lane miles of pavement in 22 calendar days (16 work days).

3. The ride quality of this recycled pavement is equivalent to conventional hot-mix asphalt paving.

4. After twelve months of traffic, the north half of the project is experiencing signs of rutting in both the northbound and southbound lanes. Rutting has exceeded 0.20 inches in a few locations. It should be noted that the warranty criterion for rut depth is removal and replacement of LOTs where the rut depth > 0.25 inch, if it is determined that the responsibility of the excessive rutting is the Contractor's. The rutting appears to be occurring in the same locations where rutting was present prior to the rehabilitation. At this time, the cause of the rutting is unknown.

5. Frictional properties of the recycled mixture were not compromised by the process. The average friction numbers one month and thirteen months after construction were 51.6 and

48.9 respectively, which are considered very good. It should be noted that Department policy is that roadways with an AADT less than 3,000 do not warrant a friction course mixture, since the accumulated traffic is not great enough to result in polishing of the aggregate in the pavement which would result in low friction values.

6. Laboratory mixture properties (penetration, viscosity, air voids, etc.) and roadway properties (density, thickness, temperature, etc.) met specification requirements.

7. Because existing roadway materials are used in the recycled mixture, with the addition of very little new material, it may be difficult, to meet current Superpave mix design requirements when recycling a non-Superpave mixture. The Superpave mix design system is currently specified by the Department for all conventional hot-mix asphalt construction projects. Therefore, by using the hot-in-place recycling process, the Department may receive a recycled mixture that does not meet the same requirements as required for conventional hot-mix asphalt.

8. The specifications written for this project were written knowing that the contract for the project would be negotiated with this Contractor, and that there would be a three year performance warranty.

9. A theoretical life cycle cost analysis for equivalent annual cost indicates that if the H.I.P. project had an assumed 7-year service life, the conventional HMA project would need to have a service life of 18 years. Using this same analysis approach, if the H.I.P. project, with

an additional one inch thick new friction course, had an assumed 10-year service life, the conventional HMA project would need to have a service life of 14 years. The calculations for the H.I.P. process in both examples exclude the $80,000 cost of the maintenance bond.

RECOMMENDATIONS

1. Due to the recycled mixture's potential inability to meet Superpave mix design requirements for roads not previously paved with a Superpave mixture, the hot-in-place recycling process should only be used on low volume roads or maintenance applications. However, the Department should evaluate the potential for recycling an existing Superpave project using the hot in place process.

2. Should the situation arise where hot-in-place recycling may be a viable option, a life cycle cost analysis should be performed comparing hot-in-place recycling to conventional HMA construction.

3. The Department's hot-in-place recycling specification should be modified to be more generic as to prevent a sole source specification. Additionally, based on the Department's recent experience with the hot-in-place recycling process, adding a warranty period to the project appears to be a viable solution to ease concerns with premature failures and distresses.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the following individuals from the State materials Office: Susan Andrews, William Dillon for their work in obtaining, preparing and testing samples and Abdenour Nazef, Robert Schaub, William Bryant, Donald Hewett, and Charles Holzschuher for obtaining and reporting the pavement performance data.

REFERENCES

1. Murphy, K. H., G. C. Page. *Evaluation of Wirtgen Remix Process*. Research Report FL/DOT/BMR-83/260, Florida Department of Transportation, Gainesville, FL., January 1983.
2. Murphy, K. H., J. A. Musselman, G. C. Page. *Experimental Project. Surface Recycling of Asphalt Concrete Pavement. SR 20, Palatka, Florida*. Research Report 87-2, Bituminous Materials and Research. Florida Department of Transportation, Gainesville, FL., October 1987.
3. Murphy, K. H., J. A. Musselman, G. C. Page. *Experimental Project. Surface Recycling of Asphalt Concrete Pavement. SR 5, Holly Hill, Florida*. Research Report 87-3, Bituminous Materials and Research. Florida Department of Transportation, Gainesville, FL., October 1987.
4. Sholar, G. A., J. A. Musselman, G. C. Page, P. B. Upshaw, H. L. Moseley. *Evaluation of Two Hot-In-Place Recycling Projects*. Research Report FL/DOT/SMO/02-455, Florida Department of Transportation, Gainesville, FL., July 2002.

APPENDIX A

Section 324

WARRANTED HOT IN-PLACE RECYCLED ASPHALT PAVEMENT.

(REV 10-18-02)

PAGE 241. The following new Section is inserted after Section 320.

SECTION 324
WARRANTED HOT IN-PLACE RECYCLED ASPHALT PAVEMENT

324-1 Description.

Construct a warranted hot in-place recycled asphalt pavement. Furnish all labor, equipment, materials, and perform all operations in connection with heating, in-place recycling, applying recycling agent, adding new virgin materials (or hot mix asphalt), mixing, redistributing and compacting the recycled asphalt material.

After completion of the project, warranty the project for a period of three years after final acceptance of the Contract in accordance with 5-11. Warranty requirements will not apply to underlying layers, asphalt base or miscellaneous asphalt, if applicable.

Assume responsibility for the quality control, mix design, construction, compaction, testing and inspection of all asphalt mixtures. Furnish a copy of all required mix designs to the Engineer prior to any paving work.

The applicable requirements of Sections 300, 320, 327, 330 and 334 do not apply to Warranted Hot In-Place Recycled Asphalt Pavement, unless stipulated as part of remedial warranty actions stated below.

324-2 Equipment.

324-2.1 General Requirements: Use equipment to recycle the existing asphalt surface that is designed and built for this specific purpose. Use equipment that is capable of a continuous single pass, multi-step operation that includes multi-step heating, one-step milling, introducing recycling agent, virgin materials and/or hot mix asphalt (if determined necessary), mixing the reclaimed material in a separate on-board mixing chamber, redistributing the recycled material, picking up the mix, leveling it with a conventional asphalt paver, and compacting the mixture.

Assure that the equipment is on site and in good operating condition sufficiently in advance of the reworking operation to allow full evaluation. As required by the Engineer, demonstrate that the machine proposed for this purpose meets all the requirements specified herein.

324-2.2 Pavement Preheaters: Utilize pavement preheaters capable of uniformly heating the existing pavement to a temperature high enough to remove excess moisture and allow dislodging of the material to the desired depth, while minimizing the fracturing of aggregate particles. Accomplish this without charring the existing asphalt, and without producing undesirable pollutants. Uniformly heat the pavement surface across its full lane width such that cold milling of the pavement surface does not occur. Utilize heaters that are adjustable in width (while in motion) to accommodate changing roadway widths, and equipped such that the heat is under an enclosed or shielded hood to prevent damage to adjacent property or vegetation. Assume responsibility for the repair of any such damage that may occur. Assure that the heaters overlap the completed adjacent lane by a minimum of 6 inches (150 mm) to insure a hot bond at the longitudinal joint.

324-2.3 Pavement Milling Heads: Utilize milling heads for pavement recycling capable of uniformly loosening the entire pavement lane width to the depth specified in the plans. Accomplish the recycling by using down-cut rotation milling heads that have at least two grade controllers per milling head. Assure that the tooth spacing of the milling heads is sufficient to allow material to pass without excessive retention. Utilize equipment that is capable of raising and lowering sections of the milling heads in order to recycle the material around manholes and other obstacles. Assure that the entire system is continuously operating and in contact with the preheated asphalt surface at all times. The system shall be flexible in order to process the entire area with minimum monitoring of the system.

Utilize the milling heads to remove a minimum of 3 inches (75 mm) laterally of the completed adjacent pass and make a square vertical cut in the heated material such that a hot bonded longitudinal joint is achieved. Assure that all material across the full lane-width is processed between consecutive lane passes to assure that any wedges (slivers) of unprocessed materials are not left untouched by the milling heads and covered by the recycled material. Exceptions to this shall be approved by the Engineer. Cold mill and sweep clean any areas that cannot be heated and milled by the recycling equipment. Tack and pave these areas of cold milling. Remove during the recycling process materials around manholes and utility structures to allow for the plan depth of the recycled material around the structures.

Assure that the temperature of the milled surface one foot [300 mm] behind the milling heads is greater than 160ºF [70ºC] so that cold milling does not occur. All loosened asphalt material must be cleaned away by the milling heads and a milling tooth pattern must be clearly visible after milling. Equip the milling heads such that they are capable of gathering the heated and loosened asphalt concrete pavement. Operate the milling heads in such a manner as to minimize aggregate degradation. Utilize milling heads that are capable of creating a windrow of the milled material ahead of the mixing chamber. Provide a portable milling or scraping unit to completely remove heated material from around utility structures to the full Plan depth prior to placement of the recycled material. Do not attempt to remove heated material from utility structures with hand tools only and do not damage the structures. Repair any structures that are damaged, at no cost to the Department.

324-2.4 Rejuvenator Application System: Utilize a microprocessor control system for adding and uniformly applying a rejuvenator with the hot, loosened material. Equip the control system with a built-in verification software program that can be accessed to verify that it is achieving an accuracy that is within 5% of the target application rate. The application of the rejuvenator shall be synchronized with the electronic machine speed sensor and combined with a system that electronically measures the volume of milled material created from the road surface and electronically meters the rejuvenator into the recycled mix. The control system shall accurately provide a proportional application at the predetermined application rate. The rejuvenator shall be applied in gallons/ton [liters/metric ton] and the application read-out shall be formatted in this manner. Theoretical applications such as 1/10 gallon per square yard shall not be allowed as a rejuvenator application method. Equip the rejuvenator system with positive on/off capabilities to prevent any dripping that will cause bleeding in the recycled mix. Should bleeding occur, repair these areas at no cost to the Department. Add the rejuvenator during or after milling has taken place and prior to the mixing chamber to provide uniform application of the recycling agent and uniform coating of the recycled material during the mixing cycle.

324-2.5 Mixing Chamber: Use equipment with an on-board mixing chamber that is capable of thoroughly mixing the heated, reworked material with new materials. Completely enclose and configure the mixing chamber such that no milled material escapes or bypasses the mixer chamber. The rotation of the mixer apparatus shall not exceed 50 rpm such that no segregation occurs during the mixing process.

324-2.6 Asphalt Paver: Equip the asphalt paver with a heated, vibratory screed system that is capable of distributing the blended mixture, without segregation, evenly over the area being processed. The paver shall be equipped with a longitudinal non-contact grade control system with a minimum length of 25 feet [7.5 m].

324-3 Materials.

324-3.1 General Specifications: The materials used shall conform with the requirements specified in Division III of the Standard Specifications. Specific references are as follows:

Coarse Aggregate..901
Fine Aggregate..902

Note: The use of emulsified recycling agents will not be allowed.

324-3.2 Mix Design: Design the mixture using a blend of the in-situ materials and rejuvenating agent, along with the appropriate amount of the following as determined necessary: virgin aggregate, asphalt binder, and plant produced hot mix asphalt. Design the mixture to have an air void content within the range of 4-7% using the 50-Blow Marshall Design Method, when compacted in accordance with FM 1-T 245. Utilize FM 1-T 209 to establish the maximum specific gravity of the mixture.

Prior to the commencement of any recycling operations, submit a proposed mix design and corresponding materials to the State Materials Office for informational purposes. Include on the proposed mix design the proposed blend of materials, and a target value for the mixing and compacting temperatures, design air voids, asphalt binder content, and recovered penetration of the asphalt binder. Assure that the recovered penetration target value is within the range of 40 – 80 dmm when tested in accordance with AASHTO T-49.

324-3.2.1 Pavement Composition Report: The Composition of Existing Pavement Report is available on the Department's web site. The URL for obtaining this information is:
http://www.dot.state.fl.us/statematerialsoffice/Bituminous/CentralBitLab/AsphaltCompositions/Compositions.htm .

324-3.2.2 Pre-Construction Sampling and Testing: Prior to designing the mix, assume responsibility for any pre-construction sampling, testing, and analysis necessary to determine the actual characteristics of the in-place materials to be recycled. Include as a minimum the following characteristics in the analysis: asphalt binder content, gradation, air voids and asphalt binder viscosity and/or penetration.

324-4 Environmental Regulations.

Special attention is directed to the fact that local environmental and other regulations governing the operation of this type of equipment may vary considerably from place to place. Become familiar with and comply with all such local regulations, as well as State and Federal rules, and obtain all necessary permits.

324-5 Construction.

324-5.1 General Requirements: Prior to commencing construction operations repair all major defective portions of the existing pavement as indicated in the plans or as directed by the Engineer. The minimum ambient temperature required to begin recycling is 50°F [10°C] and rising. Clean the pavement such that it is reasonably free from sand, dirt, and other deleterious substances that would affect the quality of the reworked mix. Specialized equipment, such as vacuum or street sweepers, may be necessary in urban areas with curb and gutters in order to prevent excessive amounts of material from entering storm drains. Cleaning shall also include removing existing raised reflective pavement markers (RPM) and thermoplastic paint markings prior to recycling.

324-5.2 Heating and Recycling: Uniformly heat and recycle the pavement to the widths and depths as shown in the plans. Control the heating to assure uniform heat penetration without causing differential softening of the pavement. Make all efforts to protect all adjacent landscape from heat damage, and will be assume responsibility for such damage.

324-5.3 Rejuvenating, Mixing, and Placing: Blend the reclaimed materials with the recycling agent and new raw materials, then automatically feed them into the mixing chamber. The type and quantity of new material and reclaimed material will be as specified on the mix design. Thoroughly mix all materials while maintaining the minimum temperature as shown on the mix design. Add all virgin materials prior to the milling and mixing operation in order to allow for complete coating and blending. Following the remixing process, distribute and level the recycled material in such a manner as to produce a uniform cross-section in conformance with the plan thickness and cross-slope unless directed otherwise by the Engineer (i.e.; cross slope correction that may require uneven distribution of the recycled pavement). Maintain a minimum temperature of the recycled asphalt pavement of 240 +/-20ºF [120 +/-10ºC] measured directly behind the screed.

324-5.4 Application of Tack Coat: If the milled surface temperature, as measured directly behind the milling heads, is not greater than 160ºF [70ºC], apply a tack coat uniformly over the entire milled area prior to the placement of the recycled materials at no additional cost to the Department. The application rate shall be within 0.04 – 0.06 gal/yd^2 [0.18 – 0.27 L/m^2].

324-5.5 Compaction: Select the compaction equipment and rolling sequences necessary to meet the density specifications as set forth below. Complete all compaction operations before the pavement surface temperature drops to 150ºF [65ºC].

324-6 Contractor's Quality Control.

324-6.1 General: Furnish and maintain a Quality Control System that will provide reasonable assurance that all materials and products submitted to the Department for acceptance conform to the contract requirements, whether manufactured or processed by the Contractor or procured from suppliers or subcontractors. Document all Quality Control procedures, inspections, and tests and make that information available for review by the

Department throughout the life of the contract. Transfer ownership of these documents to the Department at the end of the project.

Furnish a fully equipped asphalt laboratory (permanent or portable) within 25 miles [40 km] of the project site.

Submit a proposed Quality Control (QC) Plan outlining all necessary Quality Control activities, prior to the commencement of construction. As a minimum the proposed QC Plan should contain the following:

Determination of asphalt binder content, air void content, gradation, and asphalt binder penetration – minimum frequency of one per day

Determination of gradation of incoming virgin aggregate – one per 500 tons [450 metric tons]

Determination of asphalt content and gradation of incoming hot mix asphalt – one per 500 tons [450 metric tons]

Determination of pavement temperature at three locations transversely across the pavement lane – once per 100 feet [30 m]

Determination of maximum specific gravity – minimum frequency of one per day

Depth determination (uncompacted mix) - one per 100 feet [30 m]

Determination of pavement thickness (roadway cores) - per 324-6.5

Density determination (roadway core) - one per 1,000 feet [300 m].

Determination of cross-slope - per 324-6.8.

Visual inspection - continual

Document on an electronic spreadsheet all site information and station measurements.

324-6.2 Corrective Actions: Take prompt action to correct any errors, equipment malfunctions, process changes, or other assignable causes which have resulted or could result in the submission of materials, products, and completed construction which do not conform to the requirements of the specifications.

324-6.3 Quality Control of Binder Penetration: Monitor the penetration of the asphalt binder during production. Obtain samples on a random basis at a minimum frequency of one per day. Maintain the penetration of the asphalt material in the bituminous mixture (determined in accordance with AASHTO T-49), within ± 10 dmm of the target penetration value as indicated on the mix design. When two or more consecutive tests exceed this tolerance, take corrective measures at no cost to the department. In addition, maintain the penetration of the asphalt material within the range of 40 – 80 dmm. If two or more consecutive tests exceed this tolerance, stop all recycling operations until the problem is adequately corrected. Penetration test samples shall be heated to the mix design temperature for no longer than two hours in an oven prior to testing.

324-6.4 Quality Control of Air Voids: Maintain an air void content of the recycled mixture within the range ± 1.5% of the target air void content as indicated on the mix design. (Air voids shall be based on specimens compacted in accordance with FM 5-511, and a maximum specific gravity as determined in accordance with FM 1-T 209.) When the air void content of the recycled mixture falls below 2.0%, make all necessary adjustments to the blend of materials to increase the air void content to an acceptable level above 2.0%. Submit all proposed adjustments to the mix design to the Engineer for informational purposes.

324-6.5 Quality Control of Thickness: The thickness specified in the Plans shall be the compacted in-place thickness of the rejuvenated and recycled mixture. The thickness shall be determined by the average measurement of roadway cores. Obtain cores at locations determined by the Engineer at a frequency of either one core per 1,000 feet per two lanes of roadway or five cores per day, whichever is less. Thickness can be determined based on cores cut for the evaluation of density as specified in 324-6.7. Maintain the average thickness of the rejuvenated surface (based on roadway cores) within 1/4 inch [6 mm] of that specified in the Plans. If the average thickness is deficient by more than 1/4 inch [6 mm] but no more than 1/2 inch [13 mm], take appropriate corrective actions. If the average thickness is deficient by more than 1/2 inch [13 mm], take additional cores to determine the area of deficient thickness. Correct any area deficient in thickness by more than 1/2 inch [13 mm] at no expense to the Department by repeating the Hot In-Place recycling process. If the average thickness is deficient for two consecutive days by more than 1/4 inch [6 mm] of that specified in the Plans, stop construction activities until adjustments are made to the operation that will allow placement at the specified depth. Continued operations when the thickness is deficient by more than 1/4 inch [6 mm] of the thickness specified in the Plans will not be allowed.

324-6.6 Quality Control of Asphalt Binder Content and Mix Gradation: Obtain samples randomly from the paver auger in front of the screed. Test the samples in accordance with FM 5-563 and FM 1-T 030 (Mix gradation samples are for informational purposes only). Maintain an asphalt content within ± 0.55% of the target asphalt content as indicated on the mix design. In the event the asphalt content deviates by more than 0.55% from the target, make all necessary corrections. If the test results for two consecutive samples deviate by more than 0.55% from the target, stop all operations and make adjustments to assure that the asphalt content is within 0.55% of the mix design target.

324-6.7 Quality Control of Density: The in-place density of each course of asphalt mix construction will be evaluated by the use of 6 inch [150 mm] diameter roadway cores. The required average density of a completed course will be based on the maximum specific gravity (G_{mm}) of the as-produced mix based on the daily value as determined by the Contractor's Quality Control testing described in 324-6.4. If a maximum specific gravity value is not determined for a day’s production, the previous day’s value will be used. Obtain the roadway cores at the random locations at the end of each day’s production prior to opening the roadway to traffic, at a minimum frequency of one core per 1,000 feet [300 m], with a minimum of at least three cores per day. Assume responsibility for maintenance of traffic, coring, patching the core holes, and trimming the cores to the proper thickness prior to density testing.

Determine the density of the cores in accordance with FM 1-T 166, and calculate an average for each LOT. The average density of a LOT shall be a minimum of 92% of G_{mm}. Take corrective actions for those LOTs that have an average density less than 92% of G_{mm}. If two consecutive LOTs are less than 92% of G_{mm} or if one LOT has an average density less than 90% of G_{mm}, stop construction until appropriate adjustments are made to assure the minimum density requirement is met. Continued operations at a density level less than 92% of G_{mm} will not be permitted.

Once the average density of a LOT has been determined, do not provide additional compaction to raise the average.

324-6.8 Quality Control of Cross Slope: Equip the paving machine with electronic transverse screed controls to obtain an accurate transverse slope of the pavement surface. Measure the cross slope of the pavement surface by placing an approved measuring device perpendicular to the roadway centerline. Calculate the cross slope in percentage to the nearest 0.01% and round it to the nearest 0.1%.

Measure the cross slope with a minimum frequency of one check every 100 feet [30 m] during paving operations to ensure that the slope is uniform and in compliance with the plans. When the difference between the measured cross slope and the designed cross slope exceeds ±0.2% for travel lanes including turn lanes and ±0.5% for shoulders, make all corrections immediately to bring the cross slope into an acceptable range. Record all the measurements performed on an approved form and submit to the Engineer for documentation.

When the variance of cross slope measurements are consistently within the acceptable range, the frequency of cross slope checking can be reduced to one measurement every 250 feet [70 m] during paving operations.

Calculate an average of ten randomly selected (encompassing that day's production) cross slope measurements per day. If the average of the ten random measurements per day varies more than the required tolerance (0.2% for travel lanes including turn lanes and 0.5 % for shoulders), stop all paving operations until appropriate corrective actions are made to bring the cross slope into an acceptable range. Approval of the Engineer will be required prior to resuming paving operations. Recheck ten random measurements after corrections are made. If the recheck indicates that the cross slope is still out of control, the deficient section shall be corrected at no expense to the Department by repeating the Hot In-Place recycling process.

The Engineer may waive the corrections specified above if an engineering determination indicates that the deficiencies are sufficiently separated so as not to significantly affect the ride quality and the surface drainage of pavement and corrective action would unnecessarily mar the appearance of the finished pavement.

For intersections, tapers, crossovers, transitions at beginning and end of project and similar areas, the cross slope shall be adjusted as directed by the Engineer to match the actual site conditions.

324-7 Testing for Pavement Smoothness by Laser Profiler.

324-7.1 General: The Department will perform testing on the completed pavement surface with regard to smoothness by a Laser Profiler. Testing will be performed on mainline traffic lanes only. Test all ramps, acceleration and deceleration lanes, bridge approaches, and other areas not suitable for testing with the Laser Profiler with a 15 foot [4.572 m] rolling straightedge.

The pavement smoothness as determined by the Laser Profiler will be expressed as a Ride Number (RN), which is derived from a mathematical processing of the longitudinal profile measurements to produce a ride quality or smoothness on a scale from 0 to 5. The RN will be determined in accordance with ASTM E 1489.

324-7.2 Criteria for Final Surface: Upon completion of the surface course, the pavement smoothness of each lane will be determined by a single pass of the Laser Profiler furnished and operated by the Department in accordance with FM 5-549 and ASTM E 1489. In no case will the pavement be retested once the smoothness is determined. For evaluation purposes, the pavement will be divided into 0.1 mile [0.1 km] LOTs. Upon completion of the testing, the Engineer will furnish a test report documenting the Ride Number of each individual LOT. The Ride Number will be calculated to two decimal places. The criterion for pavement smoothness is shown in Table 324-1.

The Engineer may waive corrections if an engineering determination indicates that the deficiencies are sufficiently separated so as not to significantly affect the ride quality of the pavement and corrective action would unnecessarily mar the appearance of the finished pavement.

Table 324-1
Criteria for Pavement Smoothness

Ride Number (RN)	Action Required
4.00 and over	None
3.70 thru 3.99	See Note 1
Less than 3.70	See Note 2

Notes:

1: For all LOTs with a Ride Number ranging from 3.70 to 3.99, correct all defective areas within the LOT as identified by the Ride Number printout in 0.1 mile [0.1 kilometer] intervals. Upon completion of the corrections, straightedge the pavement with a 15 foot rolling straightedge as observed by the Engineer. Assure that there are no deficiencies greater than 3/16 inch [5 mm] in the LOT.

2: For LOTs with a Ride Number less than 3.70, correct the defective LOT by repeating the hot in-place recycling process at no cost to the Department.

324-8 Finished Pavement.

Assure that the finished pavement is free of all types of disintegration, including, but not limited to, mix delamination, slippage, potholes, raveling and flushing. At all locations the rutting shall be less then 1/8 inch [3 mm]. Areas failing to meet these criteria shall be corrected as approved by the Engineer.

324-9 Sampling and Testing by the Engineer.

The Engineer will sample the recycled mix in front of the paver auger prior to the screed and test the mix for asphalt content, gradation, recovered viscosity/penetration, and air voids. Make all Quality Control sampling and testing data for thickness and density accessible for review by the Engineer. Obtain additional roadway cores as directed by the Engineer. The Department reserves the right to run any test at any time for informational purposes.

324-10 Warranty.

324-10.1 General: Upon opening of the Warranted Hot In-Place Recycled Asphalt Pavement to traffic, provide a Maintenance Bond for the Warranted Hot In-Place Recycled Asphalt Pavement to be in effect for a three year warranty period. Provide proof of a three year Maintenance Bond commitment before execution of the Contract. Use a bonding company that, in addition to satisfying the provisions of Section 287.0935, Florida Statutes, has an A.M. Best rating of “A” or better. If the bonding company drops below the “A” rating during the three year Maintenance Bond period, provide a new Maintenance Bond for the balance of the three year period from a bonding company with an "A" or better rating, at no cost to the Department.

Furnish a Maintenance Bond written and issued in the amount of $720,000, warranting the asphalt pavement to be free from distresses exceeding the threshold values shown in Table 324-2 for the established warranty period.

At the end of the warranty period, the Engineer will release the Contractor from further warranty work and responsibility, provided all previous warranty work and remedial work, if any, has been completed.

324-10.2 Disputes Resolution: The Disputes Review Board for this project will be utilized to resolve any and all disputes that may arise involving administration and enforcement of this Specification. The Contractor and the Department acknowledge, by entering into this Contract, that the determinations of the Disputes Review Board for disputes arising out of this Warranted Hot In-Place Recycled Asphalt Pavement Specification will be binding on both the Contractor and the Department and with no right of appeal by either party.

Any and all Disputes Review Board meetings after final acceptance of the Contract in accordance with 5-11 must be requested and paid for by the Contractor. The Department will reimburse the Contractor for all fees associated with meetings only if the Disputes Review Board rules in favor of the Contractor, otherwise the Contractor shall be solely responsible for all such costs.

324-10.3 Warranty Work: During the warranty period, perform all necessary remedial work described in 324-10.4 at no cost to the Department. Should an impasse develop in regard to the remedial work required, the Disputes Review Board will render a final decision by majority vote.

The warranty will not apply to deficiencies if any one of the following factors, or any other factor, is found to be beyond the control of the Contractor:

a. Determination that the pavement thickness design is deficient. The Department will attach a copy of the original pavement thickness design package and design traffic report to the Contractor's Bidding Documents.

b. Determination that the Accumulated ESALs (Number of 18 Kip Equivalent Single Axle Loads in the design lane) have increased by 25% or more over the Accumulated ESALs used by the Department for the warranty period when the pavement was designed (See Design Traffic Handbook). In calculating ESALs, the AADT (Average Annual Daily Traffic) will be obtained from the Department's traffic count data and the T24 (Percent Heavy Trucks during a 24 hour period) will be obtained from the Department's traffic classification survey data.

c. Determination that the deficiency was due to the failure of the base, subgrade, or underlying asphalt layers for which the Contractor was not responsible. Document all existing pavement distresses consistent with these types of deficiencies prior to beginning construction.

d. Determination that the deficiency was due to work on the roadway by a third party.

In the event remedial action is necessary and if forensic information is required to determine the source of the distress, the Department may core or trench the pavement. The Contractor will not be responsible for damages to the pavement as a result of any forensic activities conducted by the Department.

The Contractor has the first option to perform all remedial work. If, in the opinion of the Engineer, the problem poses an immediate danger to the traveling public and the Contractor cannot begin remedial work within 72 hours, the Engineer has the authority to have the remedial work performed by other forces. The Contractor is responsible for all incurred costs of the work performed by other forces. Remedial work performed by other forces does not alter any of the requirements, responsibilities or obligations of this warranty.

Complete all remedial work to the satisfaction of the Engineer. Any disputes regarding the adequacy of the remedial work will be resolved by the Disputes Review Board. Approval of remedial work does not relieve the Contractor from the provisions of this warranty.

324-10.4 Pavement Evaluation and Remedial Work: The Department's Flexible Pavement Condition Survey Program will be used as a basis for determining the extent and the magnitude of the pavement distresses occurring on the project. The Department will conduct a LOT-by-LOT pavement condition survey (PCS) of the pavement following the final acceptance of the project, and then intermediate surveys will be conducted at the discretion of the Department. The final survey will be conducted not later than the 45 days prior to the end of the warranty period. All such surveys will be conducted at no cost to the Contractor. The Contractor will be advised of the survey schedule prior to the survey taking place. The results of the survey shall be available to the Engineer, Contractor and Disputes Review Board within 15 days after completion of the survey.

If the survey findings are disputed, provide written notification to the Engineer within 30 days of the date of the survey. The Disputes Review Board will resolve the dispute within 60 days of the date of the survey.

For evaluation purposes, the project will be subdivided into LOTs of one tenth (0.1) mile [0.2 km] per lane.

During the warranty period, the Contractor may monitor the project using only non-destructive procedures. Do not conduct any coring, milling or other destructive procedures without prior approval by the Engineer.

324-10.4.1 Distress Indicators: The Department will use the following pavement distress indicators and methods of measurement of distress to evaluate the warranted pavement:

a. Rut Depth - As determined by the Department's High Speed Profiler in accordance with the Flexible Pavement Condition Survey Handbook.

b. Rideability - As determined by the Department's High Speed Profiler in accordance with the Flexible Pavement Condition Survey Handbook. The Department will test the quality of the pavement smoothness by laser profiler as specified in 324-7.

c. Raveling, Delamination, Potholes, Slippage Areas, and other disintegrated areas - As determined in accordance with the Flexible Pavement Condition Survey Handbook.

d. Cracking - As determined manually in accordance with the Flexible Pavement Condition Survey Handbook.

324-10.4.2 Threshold Values and Remedial Actions: Threshold values and remedial actions for the Warranted Hot In-Place Recycled Asphalt Pavement are specified in Table 324-2.

TABLE 324-2
Condition Survey

Type of Distress	Type of Survey	Threshold Level for Each LOT (0.1 Mile) per lane	Remedial Action
Rutting	Any Survey	Depth > 0.25 inch	Remove and replace the distressed LOT(s) to the full distressed depth and full lane width.
		Depth ≤ 0.25 inch	None required
Rideability	Any Survey	RN < 3.70	Remove and replace the distressed LOT(s) to the full distressed area(s) and full lane width
Cracking	Any Survey	Cracking >1/8 inch (Class 1B), accumulative cracking length > 30 feet	Remove and replace the distressed LOT(s) to the full distressed depth and full lane width.
Raveling, delamination and other disintegrated areas affecting the friction course	Intermediate Survey	Underlying layer exposed, individual length > 10 feet	Remove and replace the distressed area(s) to the full distressed depth and full lane width or patch the distressed area(s).
		Underlying layer exposed, individual length < 10 feet	Patch the distressed area(s) and remove and replace the distressed area(s) to the full distressed depth and full lane width prior to the final survey.
	Final Survey	Observation by Engineer	Replace the distressed areas (including all patches) and extend 50 feet at both ends at full lane width.

TABLE 324-2
Condition Survey

Type of Distress	Type of Survey	Threshold Level for Each LOT (0.1 Mile) per lane	Remedial Action
Pot holes, slippage area(s), segregated area(s) and other disintegrated areas.	Any Survey	Observation by Engineer	Remove and replace the distressed area(s) to 150% of the area(s) or temporarily patch the distressed area(s) and remove and replace the distressed area(s) to 150% of the area(s) prior to the final survey.

Notes:

1. The Ride Number (RN) established by the laser profiler will express the ride quality of the pavement of a LOT being tested.

2. For any two deficient LOTs not separated by 3 passing LOTs, the repair work shall cover the entire stretch (including the passing LOTs). If the area of cracking, patching or raveling within a LOT exceeds 60% of the LOT area, the total LOT shall be corrected by approved methods.

3. The longitudinal construction joint at lane line is not considered as cracking during survey.

4. Removal and replacement (if necessary) will entail removal by milling (per Section 327) to a 2 inch depth, and replacement with a Type SP-12.5 (Traffic Level B) mix, meeting the requirements of Section 334. As an exception, the Contractor may elect to have an Engineering evaluation conducted on the pavement LOTs requiring removal and replacement to determine if other suitable methods of repair (including hot in-place recycling meeting these specifications) may be appropriate. The Engineering evaluation must be conducted by a licensed Professional Engineer as approved by the Department. The method of repair shall be approved by the Engineer.

If a measured distress value is within a threshold level for which Table 324-2 indicates remedial action is required, begin remedial action within 45 days of the survey date or a ruling of the Disputes Review Board. Distresses characterized by the Engineer as an immediate danger to the traveling public shall be corrected as stated in 324-10.3. The Disputes Review Board will determine the allowable duration for the completion of the remedial action.

Notify the Engineer in writing prior to taking any remedial action. Meet the requirements of the Department’s Specifications when performing any remedial work, including the applicable requirements of specifications otherwise excluded in 324-1.

Perform all remedial work at no cost to the Department. If remedial action necessitates a corrective action to the pavement markings, adjacent lane(s), or roadway shoulders, perform these corrective actions at no cost to the Department.

324-10.5 Traffic Control: During warranty work operations, perform all signing and traffic control in accordance with the current edition of the Department’s Roadway and

Traffic Design Standards for Design, Construction, Maintenance and Utility Operations on the State Highway System. Provide Maintenance of Traffic during remedial work at no cost to the Department. Lane closure restrictions listed in the original contract will apply to remedial work. Notification of lane closure for remedial work must be made to the Engineer 48 hours in advance.