CHAPTER 2. PERFORMANCE DATA OF RECYCLED MIXTURES

INTRODUCTION

Use of recycled asphalt pavements has increased appreciably since its inception in 1915 and revival in the mid-1970s, when Arab oil embargo caused inflation of construction costs. Experience gained over the years by different states has shown that asphalt pavement recycling is a technically viable rehabilitation technique. Properly designed recycled asphalt pavements have performed similar to and in many cases better than the conventional overlays. A literature search was conducted to collect the results of performance evaluation of recycled projects in the different states. The objective of this session is to present the laboratory and field performance data on recycled asphalt pavements.

PERFORMANCE OF HOT MIX ASPHALT RECYCLING

Hot mix asphalt recycling has been used extensively and routinely in the U.S. during the last several years. It is no longer considered an experimental operation because recycled HMA pavements have generally performed equal to or better than conventional HMA pavements. Therefore, very few experimental projects which have evaluated the relative performance of recycled and conventional HMA pavements, have been reported in the literature. A limited number of projects (mostly constructed in the 1970s) are reported here.

Florida

Florida has been using recycled HMA since 1978. Pavements constructed by milling and replacement by recycled HMA are reported to be performing better than pavements constructed of conventional overlay and leveling courses. Reflective cracks have been removed successfully by full-depth milling of cracked layers. Laboratory and in-place evaluation of recycled HMA has indicated similar or better performance compared to conventional HMA.[(1)] A comprehensive specification and sampling and testing program is used by Florida DOT for recycling HMA. The plans include monitoring all phases of mixture design including verification of the blending between the new asphalt cement and aged binder in the recycled asphalt pavement (RAP). Samples are taken during production routinely to recover asphalt cement and test its properties.

Georgia

An evaluation study consisted of performance evaluation of recycled and conventional HMA surface courses in each of five projects ranging in age between 1½ and 2¼ years. The RAP content in these mixes was mostly 25 percent with a range of 10 to 40 percent.[(2)] Both virgin and the recycled sections were reported to be performing satisfactorily after 1½ to 2¼ years of service with no significant rutting, raveling and weathering, and fatigue cracking. The recycled sections had an average rut depth of 2 mm (0.08 in), with no raveling or alligator cracking, and very few transverse and longitudinal cracks.[(2)] Statistical analysis revealed no significant difference in the properties of in-service HMA mix and recovered asphalt cement, and performance of recycled and conventional HMA test sections in these five projects.[(2)] Figures 2-1 and 2-2 show

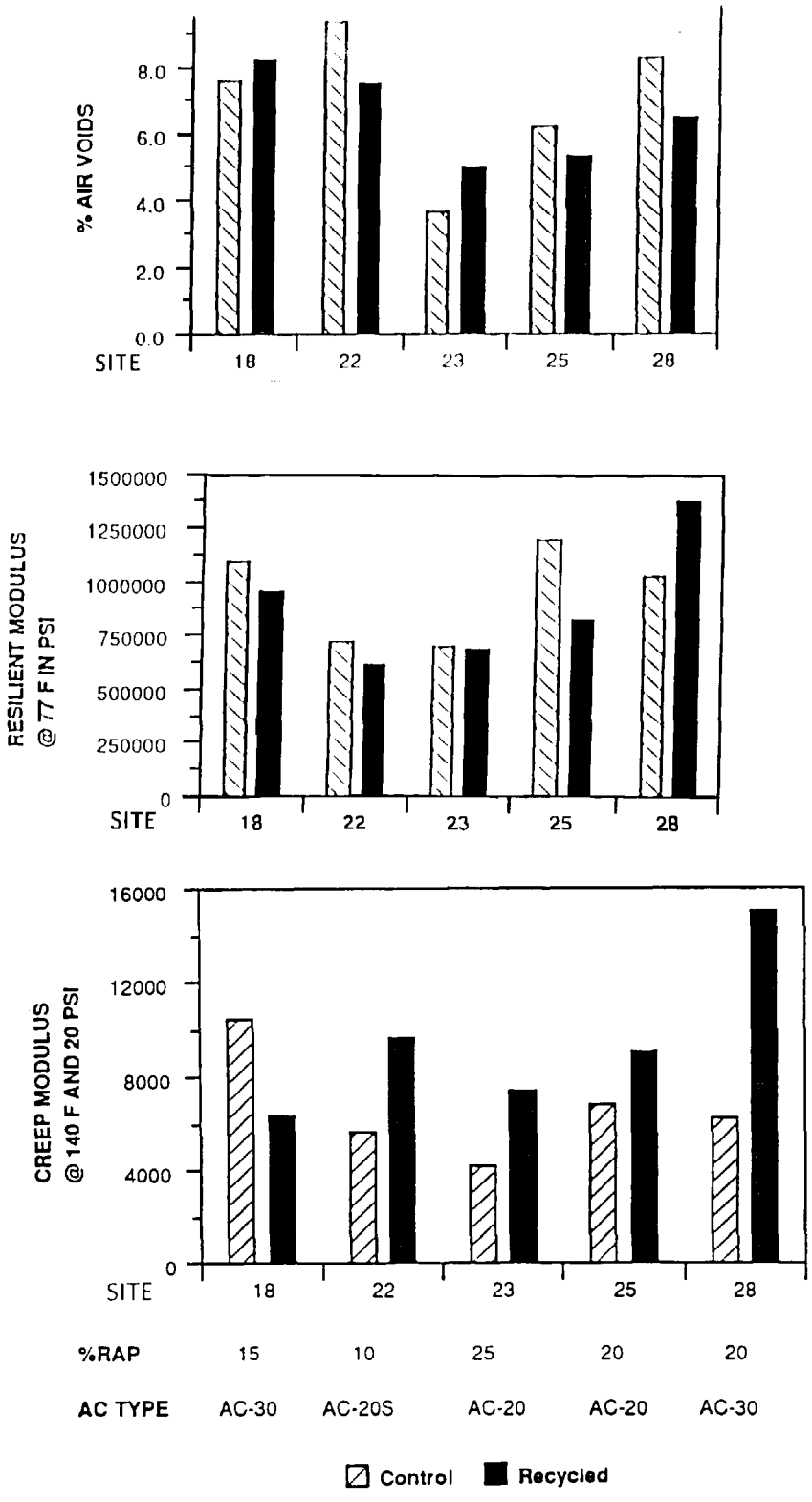

Figure 2-1. Comparison of air voids, resilient modulus, and creep modulus of in-place cores from control and recycled mixes.

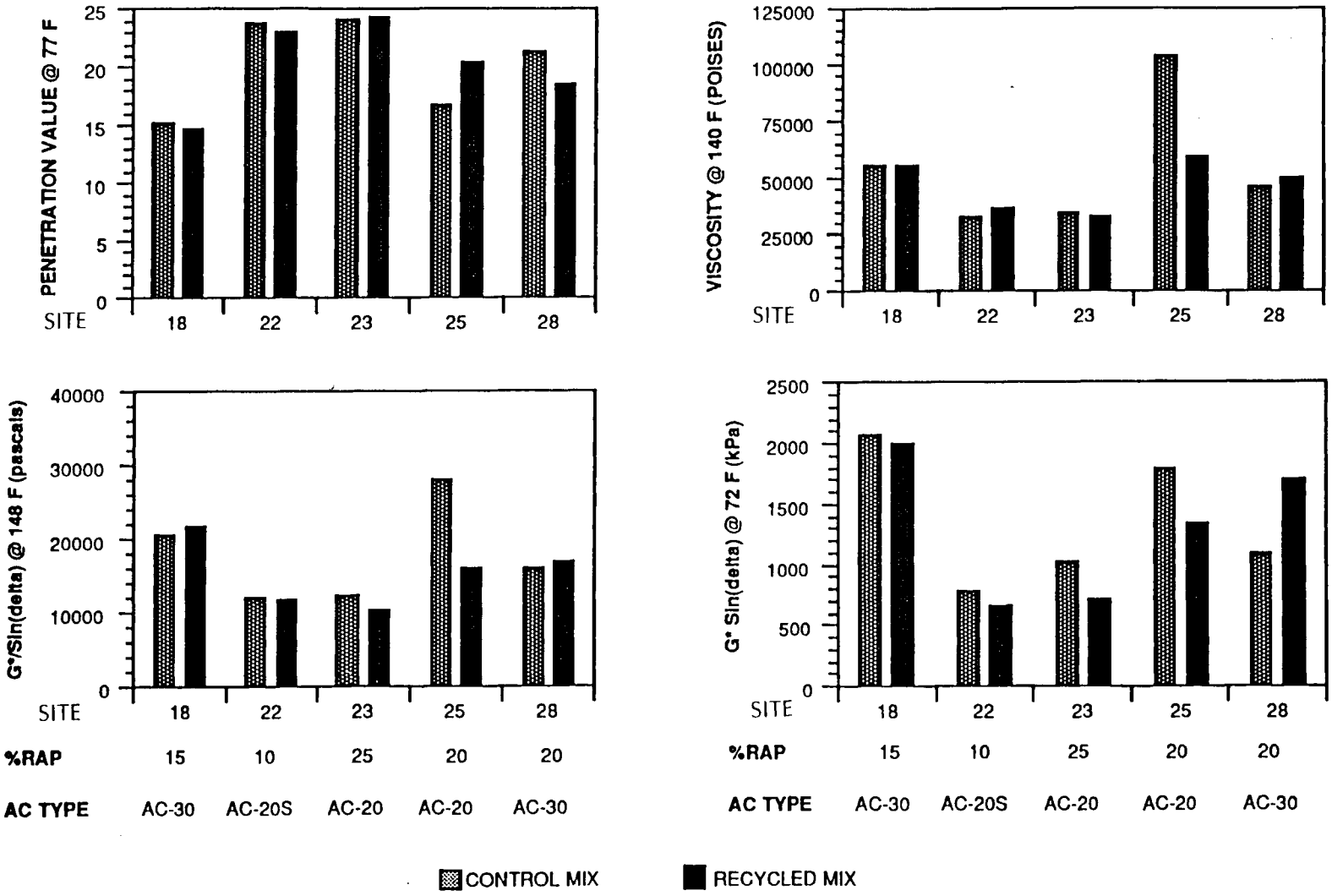

Figure 2-2. Comparison of binder properties of in-place cores from control and recycled mixes.

comparisons of air voids and resilient modulus of pavement cores, creep moduli of recompacted mixes, and properties of recovered asphalt binder from conventional (control) and recycled HMA sections. It was concluded rutting properties were similar based on creep moduli, and the extent of asphalt aging was equal for control and recycled mix based on the properties (both conventional as well as Superpave) of the recovered asphalt binder.

Kansas

In a project undertaken to evaluate performance of hot recycled mix, a 30-mm (1.2-in) HMA conventional surface course was constructed over a 125-mm (5-in) recycled HMA binder course, after cold milling 90 mm (3.5 in) of the existing pavement. A control section of 100 mm (4 in) conventional HMA overlay was also constructed. The Kansas DOT performed crack surveys each spring and fall after construction. Transverse crack and total crack evaluations were carried out for seven years after construction. Both with respect to transverse cracks and total cracks, the recycled HMA section had much better performance than the control section.[3]

Louisiana

A study[4] carried out to evaluate ten recycled pavements (about six to nine year old) constructed in the late seventies reported that both recycled binder and wearing courses performed similar to conventional pavements. The pavements, containing 20-50 percent RAP material, were compared to conventional HMA pavements in terms of pavement condition, serviceability, structural analysis, and mixture and binder properties. In general, no significant difference was observed between the pavement condition and serviceability ratings (from Mays Ridemeter and distress survey) of the recycled and conventional HMA pavements. Structural parameters (from deflection, subgrade modulus, surface curvature, and structural number) were found to be similar for the recycled and conventional HMA pavements. Penetration, viscosity, and ductility tests conducted on recovered binders showed no significant difference between the recycled and conventional HMA pavements.

Massachusetts

A rehabilitation project on a randomly cracked 8.6 km (5.3 mile) stretch of I-290 comprised of removing 50 mm (2 in) of existing pavement for the easterly two thirds of the project and replacing it with 120-mm (4¾-in) recycled HMA binder course and a 20-mm (¾-in) open-graded friction course (OGFC). The top 75 mm (3 in) in the western part of the pavement was removed and was replaced with a 95-mm (3¾-in) recycled HMA binder and a 20-mm (¾-in) OGFC. The recycled HMA had 35 percent RAP and was produced in a batch plant. During production, the original mix design of 60 percent AC-5 and 40 percent AC-20 was modified to 80 percent AC-5 and 20 percent AC-20 to conform to the asphalt cement ductility and penetration specifications.[5] Evaluations after 11 years of construction showed no signs of cracking or rutting in the pavement sections. The Massachusetts Department of Public Works concluded that it is quite possible to use RAP to produce HMA which conforms to specifications.[1]

Minnesota

The first recycled HMA project was constructed in 1976 on a 4-lane urban highway, in which the original pavement was recycled and replaced with a 175-mm (6.9-in) recycled HMA base, a 40-mm (1.6-in) recycled HMA binder and a 20-mm (¾-in) surface wearing course. The recycled HMA contained 50 percent RAP material. The recycled HMA base on the eastbound roadway was placed in three lifts, and the recycled HMA base in the westbound roadway was placed in one lift. A control section of full-depth conventional HMA section was also placed.[6] Benkelman beam deflections taken after one year of service showed similar measurements in the test sections with recycled and conventional HMA.[7] This indicates that the structural strengths of recycled and conventional HMA are comparable. The pavement with recycled HMA base placed on one lift had a higher average deflection than the pavement with the recycled HMA base placed in three lifts. Visual examination of testing of cores taken in 1991 showed that the recycled mix had a service life comparable to the life of conventional HMA.[7]

Washington

In a 1977 rehabilitation project, 45 mm (1¾ in) of an existing pavement was removed and replaced with recycled HMA. A 20-mm (¾-in) open-graded friction course was placed over the recycled HMA. A test section using the recycled HMA as the surface course was also constructed.[8] The mix consisted of about 72 percent RAP material, 0.75 percent recycling agent and no new asphalt cement. The recycling agent application rate was selected to provide a recycled binder comparable to an AR-4000W asphalt cement. Asphalt cement was extracted from field cores obtained after each of eight years after construction. It was reported that the binder in the recycled HMA did not age very much over time, and that the average properties of the recycled binder would have met specification requirements for absolute viscosity and penetration for an AR-4000W graded asphalt cement up to the fifth year. The Washington DOT also sampled the recycled HMA over time and tested those samples for mix strength in terms of resilient modulus. It was concluded that resilient modulus values for recycled HMA were comparable initially and over time to those of conventional HMA.[9] The recycled pavement had a 16 year actual service life as compared to 10 years of service life for the original HMA.

The second recycled HMA pavement constructed in 1978 consisted of milling 45 mm (1.8 in) of the existing pavement and replacing it with a recycled HMA. It was overlaid by an 18-mm (0.7-in) open graded friction course.[9] The RAP content was approximately 70 percent. The recycled HMA contained 25 to 30 percent of recycling agent, designed to meet the AR-4000W grade asphalt cement specification. A test section on the eastbound roadway was placed using only the recycled HMA as the wearing course. Performance evaluations were made for a period of six years. Data from recovered asphalt cement showed that the asphalt cement would have met specification requirements for AR-4000W grade initially and over time. Resilient modulus data indicated that the recycled HMA did not age significantly over the evaluation period.[9] The improved HMA after recycling provided actual 15 years of service as compared to 6 years for the original HMA.[1]

Wyoming

The first two recycled HMA projects were constructed on two sections of I-80 in the late seventies. In the first project the existing mix on the pavement was removed and replaced with recycled HMA containing 85 percent of RAP.[10] The mix contained 0.5 percent new asphalt binder and 1.0 percent lime. The pavement performed for 12 years before rehabilitation. The second recycled mix used on I-80 had 70 percent RAP material[11] and 1.0 percent new asphalt binder. The project was performing satisfactorily as reported in June, 1992.[1]

PERFORMANCE OF HOT IN-PLACE RECYCLING (HIR)

Performance of HIR pavements is generally satisfactory based on the reports by most of the states where it has been used. It should be noted, however, that the HIR technology and associated equipment have significantly improved during the last several years resulting in further improvement in pavement performance. Both good and poor performing pavements have been constructed in some states. The projects rated poor in performance have generally been considered as bad candidates for HIR. The performance of some HIR pavements in Canada and in New York is discussed below followed by the general performance based on a nationwide survey.

Canada

A recent reference[12] described the results of a study carried out in 1996 to evaluate the performance of ten HIR test sections constructed in Alberta since 1990. All of these sections were constructed using the two stage hot in-place recycling (HIR) processes in which the top 50 mm (2 in) was removed by heating and milling in two stages—the top 25 mm (1 in) in the first step and the bottom 25 mm (1 in) in the next step. The recycled mix was laid down as a single course with one pass of a recycling train. The field work for performance evaluation consisted of obtaining randomly located in-place cores and visual condition survey. The material properties determined in the laboratory included density, asphalt content, gradation of aggregate, penetration and absolute viscosity of recovered asphalt cement, binder film thickness and asphalt absorption. In general, the observations for all of the sections were as follows:

1. The intensity of full lane width transverse cracks in all but one section was slight. Severe cracking was observed in one section only, and the authors observed that the cracks were related to the full depth HMA pavement and were not related to the HIR process. The slight transverse cracks were considered as reflected cracks and not related to the HIR process.
2. Crack deterioration or spalling along cracks were not evident at any of the sites.
3. The average 1996 rut depths were reported to be between 3 mm (0.1 in) and 7 mm (0.3 in). Pavements with greater traffic loadings were found to have higher rut depth. The authors indicate the causes of relatively greater amounts of rutting in one section to be high asphalt content and increased thickness.
4. No significant in-place aging of binder was observed for the test sections in the six-year performance period. In most of the cases, the recovered binder penetration values were found to have remained unchanged (or increased) over the six-year performance period.
5. The air voids were found to have stabilized after four years of service.

Figures 2-3 and 2-4 show before and after recycling photographs of a pavement in Canada.

New York

Eight hot in-place recycled projects were completed in New York from 1987 to 1992. All of these projects were reported to be performing satisfactorily in 1992.[13] Of the eight projects, six were on Interstates with average daily traffic volumes of 9,000 to 62,000 vehicles.

A nationwide survey[14] has indicated excellent to good performance of hot in-place recycled pavements in 22 states as listed in table 2-1. Most states which reported fair to poor performance could identify an assignable cause such as poor project selection. Some specific HIR projects which have been reported to give satisfactory pavement performance are listed in table 2-2.[14]

PERFORMANCE OF COLD MIX AND COLD IN-PLACE ASPHALT RECYCLING

A comprehensive nationwide information on performance of cold mix asphalt recycling is not available. Some reports which contain performance evaluation of cold recycled asphalt pavements, are available in the literature. However, these reports do not use a common method of defining performance. The general performance data reported by states that have constructed a number of projects indicate that performance has been mostly good or very good, particularly with respect to cracking.[15]

California

In an evaluation study of thirteen cold recycled asphalt pavements constructed between 1979 and 1983, about 70 percent of the projects were found to have good performance.[16] The poor performance of the rest of the projects was attributed to incomplete mix design and nonuniform distribution of the binder.

Indiana

Roughness, deflection, and visual evaluation made after one year of construction (1986) indicated better performance for a cold in-place recycled mix section compared to a conventional resurfaced pavement.[17] Transverse reflection cracks and longitudinal cracks were found in the conventional HMA pavement but not in the cold recycled mix section.

Maine

A three-year performance evaluation indicated that reflective cracking and frost problems had been minimized by the use of full depth reclamation procedure.[18]

Nevada

Examination of cores and visual condition surveys done after seven years of service revealed areas of bleeding and minor cracking in one cold recycled project.[15] A large portion of the project was found to have no distress. The authors mention that the bleeding was probably

Figure 2-3. Pavement before recycling.

Figure 2-4. Pavement after HIR.

Table 2-1. Results of U.S. survey on hot in-place recycling (HIPR).[modified from 14]

State	Methods Used			Milling Depth Range, mm (in.)	Class of Highways for HIPR			Surface Seal or Overlay Commonly Placed Over HIPR Pavement	Performance of HIPR Pavements			
	Heater Scarifi-cation	Repave	Remi x		Major	Secondary	Low Volume		Excellent	Good	Fair	Poor
Alabama		x	x	50 (2)	x		x		x (remix)			
Alaska	x				x					x		
Arizona	x			25 (1)	x	x		x				x
Arkansas			x	25-32 (1-1¼)		x				x		x
California	x		x	(19-38) ¾-1½	x	x	x			x		x
Colorado	x	x		38-50 (1½-2)	x	x	x			x		
Connecticut		x		38-50 (1½-2)	x							
Delaware												
Florida	x	x	x	38 (1½)	x	x		x		x		
Georgia			x									
Hawaii												
Idaho	x		x	50 (2)	x							
Illinois		x		25-38 (1-1½)			x	x		x	x	x
Indiana												
Iowa	x			<25 (< 1)			x	x				x
Kansas	x			25 (1)	x	x	x	x		x		

Table 2-1. Results of U.S. survey on hot in-place recycling (HIPR) (continued).[modified from 14]

State	Methods Used			Milling Depth Range, mm (in.)	Class of Highways for HIPR			Surface Seal or Overlay Commonly Placed Over HIPR Pavement	Performance of HIPR Pavements			
	Heater Scarifi-cation	Repave	Remix		Major	Secondary	Low Volume		Excellent	Good	Fair	Poor
Kentucky												
Louisiana	x	x	x	19-38 (¾-1½)	x	x		x (for heater scar)		x		x
Maine												
Massachusetts												
Maryland			x	38-50 (1½-2)	x	x				x		
Michigan		x				x				x		
Minnesota		x			x			x		x		x
Mississippi		x	x	38 (1½)	x			x		x		
Missouri												
Montana		x		25-44 (1-1¾)	x	x	x	x (interstate)			x	
Nebraska												
Nevada		x		32 (1¼)				x		x		
New Hampshire		x			x			x		x		
New Jersey												
New Mexico												

Table 2-1. Results of U.S. survey on hot in-place recycling (HIPR) (continued).[modified from 14]

State	Methods Used			Milling Depth Range, mm (in.)	Class of Highways for HIPR			Surface Seal or Overlay Commonly Placed Over HIPR Pavement	Performance of HIPR Pavements			
	Heater Scarifi-cation	Repave	Remi x		Major	Secondary	Low Volume		Excellent	Good	Fair	Poor
New York			x	25-38 (1-1½)	x					x		
N. Carolina												
N. Dakota												
Ohio	x		x	38 (1½)	x (remix)	x (heater scar.)		x (with heat scar)		x (heater scar)		
Oklahoma		x		25 (1)	x			x				
Oregon												
Pennsylvania			x		x	x					x	
Rhode Island												
S. Carolina			x	25 (1)	x				x			
S. Dakota												
Tennessee		x	x		x	x		x		x		
Texas	x	x	x	25-38 (1-1½)	x	x				x		
Utah		x		25 (1)	x	x		x		x		
Vermont			x		x			x				x
Virginia	x			38 (1½)			x	x			x	
Washington	x					x				x		
Wyoming												

Table 2-2. Summary of selected case histories of hot in-place recycled pavement.[modified from 14]

Agency/ Date Recycled	Description of Job	Condition of Old Pavement	HIPR Process Used	Milling Depth/ Overlay Depth	Rejuvenating Agent / Mix Temperature	Performance/ Remarks
Repaving Process						
FAA Carrabelle, FL 1990	Thompson Field Airport. 30 m x 212m (98.4 ft x 695.6 ft) runway	Unknown	Repaver	25 mm/25 mm (1 in/1 in)	Unknown / Unknown	Officials pleased that job met specs and appeared cost effective and had short down time.
Florida DOT 1979	US41, Ft. Myers, FL 3.9 km (2.4 mi), 6-lane ADT-39,000	Rutting, cracking, low friction; pavement structure was OK.	Cutler Repaver	25 mm/19 mm (1 in/0.75 in)	EA-SS-1 0.27 1/m^2(0.06 gal/yd) / 79.4ºC to 121ºC (175º F to 250ºF)	PSI** increased from 3.43 to 3.89. After 14 years pavement has 12 mm ruts, hairline cracking, and fair ride quality. Overall performance good.
Louisiana DOT 1980	Metairie RD from US 61-IH-10 5.8 Km (3.6 mi) curb and gutter section	Cracking, rutting	Cutler Repaver	25 mm/20 mm (1 in/0.8 in)	CSS-1, 0.45 1/m^2 (0.09 gal/yd^2) / Unknown	Eliminated cracks, and restored cross slope, and minor improvement of longitudinal undulations. Began raveling in 6 mo. Generally, satisfactory after 5 years.
Louisiana DOT 1986	11.4 km (7.1 mi) of US 71	Overlay on PCCP*** had reflection cracks with severe spalling which gave poor ride quality.	Cutler Repaver	25 mm/38 mm (1 in/1½ in)	ARA-1, 0.63 1/m^2 (0.13 gal/yd^2) / Mat 65ºC to 129ºC (150-265ºF) with 102ºC (215ºF) avg. behind paver	Difficult to achieve density. Low mat temp. Recycled section performing about equivalent to control section.
City of Phoenix 1990	City collector street. 8000 m² (10,000 yd^2)	Severe alligator cracking with longitudinal cracking distortions, bleeding and raveling	Cutler Repaver	19 mm/25 mm (0.75 in/1 in)	Yes, Type and quantity Unknown / Unknown	Early performance good. Low pollution favorable to city officials.
Lee County, Iowa 1990	Rural roads. X-38 and X-48	Oxidized surface, cracking, 13 mm (0.5 in) ruts	Cutler Repaver	19 mm/25 mm (0.75 in/1 in)	Elf ETR-1 at 0.36 1/m^2 (0.08 gal/yd^2)	Early performance good. Officials pleased with relatively little traffic disruption.

Table 2-2. Summary of selected case histories of hot in-place recycled pavement (continued).[modified from 14]

Agency/ Date Recycled	Description of Job	Condition of Old Pavement	HIPR Process Used	Milling Depth/ Overlay Depth	Rejuvenating Agent / Mix Temperature	Performance/ Remarks
Repaving Process						
FAA Texarkana, TX 1986	Airport. 2011 m (6598 ft²) and 25 yr old	Aged, brittle mix. Low friction.	Cutler Repaver	25 mm/25 mm (1 in/1 in)	Type unknown. 0.54 1/m² (0.11 gal/yd²) / 110ºC (230ºF)	After 6 yrs a few surface cracks have appeared in isolated places. Otherwise, performance is excellent.
Connecticut DOT 1981	Rt. 15 at Westport, CT. 4.7 km (2.9 mi), 4-lane divided	Rutting. Otherwise fairly good condition	Cutler Repaver	25 mm/25 mm (1 in/1 in)	AE-300R 0.36 1/m² (0.07 gal/yd²) / 121ºC ± 22ºC (250ºF ± 30ºF) by spec.	Some reflection cracking. HIPR same as control. Recycling cost about 16% more than conventional.
Transport Canada 1988	Prince George Airport, British Columbia	Extensive longitudinal, transverse, and random cracking w/ raveling. Annual crack sealing no longer cost effective.	Taisei Rotec Remixer	50 mm/50 mm -- (2 in/2 in). No new aggregate added to RAP.	Cyclogen-L at 0.36 1/m² (0.08 gal/yd²) Varied based on observing flushing during heating / 110ºC-150ºC (230ºF - 302ºF) was specified. Maintained at low end.	Extraction tests verified excellent control of rejuvenator application rate. Asphaltenes decreased by 24%; polar compounds increased 143%, which indicates improved durability.
Defence Construction Canada 1989	Airfield pavements at Canadian Forces Base, Edmonton, Alberta, 330,000 m² (412,500 yd²)	Severe raveling and thermal cracking. Badly weathered, oxidized appearance	Artec Remixer Only a small area was remixed	40 mm/50 mm (1.6 in/2 in) overlaid later; or 40 mm/19 mm (1.6 in/0.75 in) repave	RJO #3 at 0.4 1/m² (0.08 gal/yd²) / 120ºC (248ºF) behind paver was targeted value	Equipment was capable of heater-scarification, repaving, and remixing. Early performance of pavement has been good. Author states that pavement flushing is a concern, and that more inspection and testing will be required for all HIPR.
Texas DOT 1991	IH-10 and SH-87 near Beaumont	Severe rutting, age-hardened mix. Raising elevation by overlaying was impractical	Wirtgen Remixer	25 mm to 31mm (1 in/1.2 in)	ARA-1 / About 116ºC (240ºF)	No drop off during construction enhances safety. Early performance satisfactory.

Table 2-2. Summary of selected case histories of hot in-place recycled pavement (continued).(modified from 14)

Agency/ Date Recycled	Description of Job	Condition of Old Pavement	HIPR Process Used	Milling Depth/ Overlay Depth	Rejuvenating Agent / Mix Temperature	Performance/ Remarks
Repaving Process						
Tennessee DOT 1990	Northern-most 9.7 km (6 miles) of IH-75 in Tennessee	Severe rutting and other forms of distress	Wirtgen Remixer	75 mm + 24 kg/m^2 of new mix	AES-300RP (polymer) at 0.63 1/m^2 (0.13 gal/yd^2) / 107ºC (225ºF)	Officials pleased with density, stability, asphalt content, and gradation. Overall early performance very good.
Alabama DOT 1989	6.4 km (4 mile) stretch of US 78 near Fruithurst	Cracking and rutting. Unsightly.	Wirtgen Remixer	38 mm + 14 Kg/m^2 (1.5 in + 24.6 lb/yd^2) of new mix	Unknown / Near 148ºC (300ºF)	Minimal traffic disruption was important. Early performance OK.
Mississippi SHD 1990	55 lane-km (34 lane-mi) of IH-59 in Lauderdale County	Highly polished with some rutting.	Wirtgen Remixer	38 mm + 15 kg/m^2 (1.5 in + 26.4 lb/yd^2) of new mix	Yes, unknown / 110ºC (230ºF)	Early performance OK. DOT pleased with project.
Texas DOT 1990	IH-35 in La Salle County near Cotulla	Surface was severely age-hardened with cracking and rutting.	Wirtgen Remixer	50 mm + 8 kg/m^2 (1.5 in + 26.4 lb/yd^2) of new mix	None used. Asphalt was in new mix. / Unknown	Officials believe process is promising. Early performance is OK.
Canadian Dept. Of National Defense* 1989	Lancaster Park Airfield near Edmonton 4250m (13944 ft)	Unknown	Artec Repaver and Remixer	38 mm + 19 - 50 mm (1.5 in + 0.75 - 2 in) overlay; 38 mm + 41 kg/m^2 (1.5 in + 72.2 lb/yd^2) new mix	Shell RJO-3 at 0.19 1/m^2 (0.04 gal/yd^2) / Unknown	Specs on density, temperature, penetration, scar, depth and smoothness of surface were met. An acceptable economic alternative.
British Columbia Ministry of Highways* 1989	Trans-Canada Highway (Rt 1) near Vancouver, 126 lane-km (78 lane-mi)	Rutting, surface cracking and other age-related distress	Artec and Taisei Remixers	38 mm to 63 mm (1.5 in + 52.8 lb/yd^2) (no new material added)	Unknown / 105ºC (221ºF) minimum	All specs were met. Ministry was satisfied with final results. Appears to be an acceptable economic alternative. Reduced traffic disruption.

Table 2-2. Summary of selected case histories of hot in-place recycled pavement (continued).[modified from 14]

Agency/ Date Recycled	Description of Job	Condition of Old Pavement	HIPR Process Used	Milling Depth/ Overlay Depth	Rejuvenating Agent / Mix Temperature	Performance/ Remarks
Repaving Process						
Texas DOT 1989	IH-20 from Louisiana, border to FM450, 51 km (32 mi), ADT-18,000 20% trucks	Poor ride quality and some raveling. An other portion was overasphalted.	Wirtgen Remixer	38 mm + 30 kg/m^2 (1.5 in + 52.8 lb/yd^2) new mix	ARA-1 at 0 to 0.71 1/m^2 (0 to 0.15 gal/yd^2) / 110ºC (230ºF)	Officials pleases with early performance. Pleased with safety aspects of process. Good ride quality.
Texas DOT 1987	US 259 in Lone Star. Major arterial carrying heavy trucks	Oxidized, Block cracking. 25 mm (1-inch) ruts at inter-sections	Cutler Remixer	38 mm + 17 kg/m^2 (1.5 in + 29.9 lb/yd^2) new mix	AC-5 used with new mix / 93ºC (200ºF) behind screed	Early performance OK. Pleased with economics.
Oregon DOT 1987	82nd Ave from N.E. Wasco to S.E. Division a 5-lane major arterial	Rutting, Cracking, very poor drainage	Taisei Remixer	Up to 50 mm (2 in) + various mew mix	Non-emulsified product / Unknown	Officials very happy with project outcome. Ride quality and early performance good.
South Carolina DOT 1983	SC 291 from US 29 to N. St. in Greenville, 1.2 km (0.74 mi), 6-lane, ADT-37,300	Unknown	Wirtgen Remixer	41 kg/m^2 (72.2 lb/yd^2) surface mixed with 18 kg/m^2 (31.7 lb/yd^2) virgin mat	Exxon AC-2.5 used in virgin mix / Mat behind screed 110ºC (230ºF)	Stability, density and workability compare well with virgin mix. Durability of mix is a concern.
Louisiana DOT 1990	US 90 from LA 99 to Jennings	Poor ride quality due to cracks reflected form underlying PCCP***	Wirtgen Remixer	38 mm + 30 kg/m² (1.5 in + 52.8 lb/yd²) new mix	ARA-1 at 0.9 1/m$^{2.}$ (0.19 gal/yd^2) AES-300RP used in a short section / 107ºC - 148ºC (225ºF - 300ºF)	Initial economic benefit realized. Early performance OK.

caused by improper seal coat quality control or design. Examination of another three year old project showed no distress other than joint raveling.[15]

New Mexico

A total of 120 cold in-place asphalt recycling projects have been constructed in New Mexico since 1984. A recent performance evaluation of 45 projects located throughout New Mexico[19] shows that all of the pavements are providing acceptable performance levels. The projects evaluated were from 4 to 12 years old jobs. The traffic levels ranged from about 3,000 to 10,000 AADT and average daily load in terms of 80 KN ESALS ranged from about 8 to 4,000. Both condition rating by visual inspection and evaluation of cores were made for the projects. Pavement condition surveys have indicated that these pavements will far exceed their assumed service life of 10 years. More than 90 percent of the projects were found to be in excellent condition, and the rest were in fair to good condition. Comparison of density of cores obtained at the time of construction and at the time of evaluation indicated no significant change in air voids.

New York

A total of four cold in-place asphalt recycling projects were constructed in New York from 1990 to 1992. The four rural road projects total 57 lane miles, with an average traffic volume range of 500 to 4300 vehicles per day. All the projects were reported to be performing extremely well in 1992.[13] Figures 2-5 through 2-8 show before and after recycling photographs of two pavements in rural New York.

Oregon

Results from evaluation of 52 cold in-place recycled pavements indicated that 47 of the projects had good or very good performance, and only five had poor performance.[20,21,22,23] The traffic volume in these pavements varied from low to high. Three different types of treatments have been used in the Oregon projects: 1) Recycling performed on a uniform pavement built to specifications, 2) Recycling performed on pavement with significant maintenance patches over a uniform pavement, 3) Recycling performed on low-volume highways where considerable variation in pavement structure exists.

The performance data obtained from these projects have been used by Oregon DOT to revise its mixture design and construction operations as well as selection of binder for cold in-place recycling operation. By 1990, more than 450 miles of recycled mix have been placed in Oregon.[15] The following causes were responsible for the poor performance of the five pavements:

1. Too high a recycle agent content in the early years. Contents more than 2 percent with 7 to 10 percent diluent were shown to create excessive softening.
2. Placing a tight seal or dense wearing course too soon, resulting in trapping of water and diluent, followed by stripping and rutting.
3. Depth of recycle stopped at a delaminated layer of old pavement, resulting in loss of bond.
4. Failure to provide some type of seal before freeze/thaw conditions.

Figure 2-5. Pavement before recycling.

Figure 2-6. Pavement after CIR.

Figure 2-7. Pavement before recycling.

Figure 2-8. Pavement after CIR.

A comparison of ride quality data obtained from pavement prior to recycling, and recycled pavement showed that major improvement can be achieved with cold in-place recycling. This ride quality comparison is shown in figure 2-9.

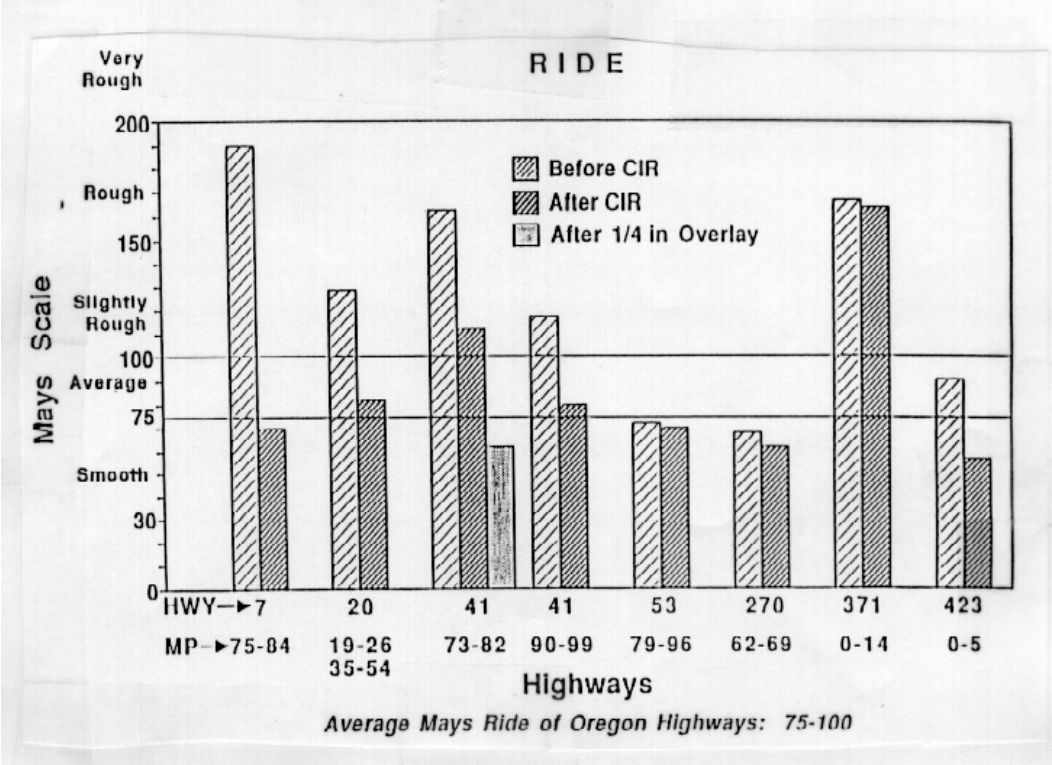

Figure 2-9. Pre- and post-construction ride data from 1986 Oregon project.[21]

Pennsylvania

Details of construction and performance data for some cold in-place recycled pavements have been presented in literature.[24] The first recycling job was on a pavement with a poor base showing considerable amount of patches and alligator cracking. The existing road was milled to a depth of 75 mm (3 in), and the resulting RAP was transferred to a mobile mixer-paver (Motopaver) by a truck. The RAP was mixed with 2 percent MS-2 emulsion (approximately 0.02 liter per kg (5 gallon per ton) of the RAP by weight) in the pugmill and laid through a screed. The recycled mix was laid to give a compacted base course of 125 mm (5 in) thickness. This base course was overlaid with a 40-mm (1.5-in) thick HMA surface course after remaining open to the traffic for a couple of weeks. The road, which carried a lot of truck traffic, was reported to be performing well.[24,25] Photographs of the pavement before and after recycling are shown in figures 2-10 and 2-11. Another cold in-place recycling project was completed on a narrow, badly cracked, heavily patched road in 1983. The existing roadway (figure 2-12) was milled and recycled to a depth of 75 mm (3 in). A CSS -1h emulsion was used in this project. The recycled pavement was provided with a single seal coat only, and was reported to be in very good condition after the 1983-84 winter (figure 2-13). However, inspection in 1986 revealed a loss of seal coat and developing potholes[25] (figure 2-14). The section in which 100 percent RAP was used was found to have more potholes than the section in which a 50/50 blend of RAP and virgin

Figure 2-10. Pavement before recycling.

Figure 2-11. Pavement after CIR.

Figure 2-12. Pavement before recycling.

Figure 2-13. Pavement in good condition after CIR.

Figure 2-14. Pavement in poor condition after CIR.

aggregate was used. The authors have also reported five other cold in-place recycling projects in northeast Pennsylvania. About two-three percent CMS-2 emulsion by weight of the RAP was used. The compacted recycled base course appeared quite dense and was covered with a single seal coat. The authors mention that since a cold recycled mix is not adequately water and abrasion resistant, a single coat may not be adequate to protect it. Potholes developed on these projects after the loss of the first seal coat. The authors have recommended the use of at least a double seal coat in cold recycled jobs. After two years of service, three projects were patched and a double surface treatment was applied. The condition of the pavements were reported to be good in 1986.[25]

PERFORMANCE OF FULL DEPTH RECLAMATION

Since in most of the cases full depth reclaimed bases are covered with HMA courses, it is very difficult to obtain long term performance data for these layers. However, the experience of several state and local agencies regarding full depth reclamation have been favorable. Depending on the type of additive used in full depth reclamation, strong and durable bases have been obtained and in many cases occurrence of pot holes and related deterioration have been avoided. With the help of falling weight deflector meter tests, full depth reclamation has been shown to increase the material strength (resilient modules), and capability to distribute loads.[26,27] Figures 15 and 16 show two photographs of before and after recycling pavements in New Hampshire.

SUMMARY

The experience of the different states indicates that in most cases the performance of the recycled

Figure 2-15. View before recycling.

Figure 2-16. View after FDR.

asphalt pavements has been superior to or comparable to conventional asphalt pavements. However, it was also observed that recycled pavements performed well only when good project selection criteria were followed, and they were designed properly and constructed under good quality control and acceptance conditions. Hence, the conclusion from this literature review is that, as in the case of conventional asphalt pavements, recycled asphalt mixtures must be designed to meet proper specifications, produced with good quality control, and placed properly with no defects or irregularities.

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