Using RAP to Stretch Your Pavement Dollars

ASPHALT PAVEMENT ASSOCIATION OF MICHIGAN

Reduce / Reuse / Recycle

HMA – America's Most Recycled Product

SMOOTH | DURABLE | SAFE | QUIET

Using RAP to Stretch Your Pavement Dollars

- Benefits of using RAP
- Specification changes
- Performance Studies
- Recommended practices

Recyclability

ASPHALT PAVEMENT ASSOCIATION OF MICHIGAN

- Asphalt is the No. 1 recycled material in the US
- Asphalt Pavements are 100% recyclable
  - Can re-use binder
  - Return on investment

Why Recycle RAP into HMA?

- Best and Highest use
- Same or better performance as virgin mix
- Reduces demand for new materials
- Reduces carbon footprint
- Contains valuable materials
- Save $

Why Recycle RAP into HMA?

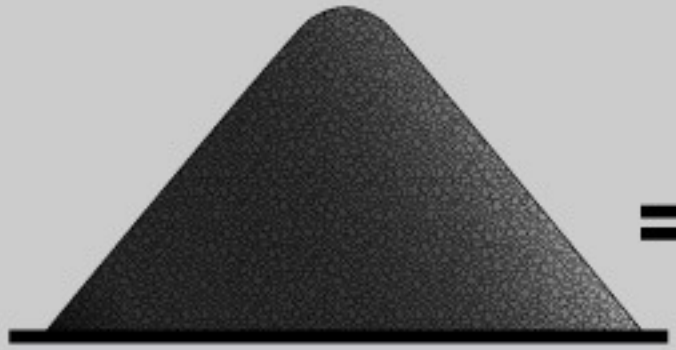
- RAP contains valuable materials :
  - Aggregate ~ 94% @ $10/ton
  - Asphalt ~ 6% @ $585/ton
  - Value = $44.50 /ton (minus processing)

Economics Savings Example

- Aggregate: $10.00/ton
- Asphalt: $585.00/ton
- RAP: $9.00
- Mix Design AC Content: 6.0%

Material	0% RAP	17% RAP	27% RAP
Aggregate	$9.40	$7.70	$6.70
Asphalt	$35.10	$29.13	$25.62
RAP		$1.53	$2.43
Total	$44.50	$38.36	$34.75
$ Savings		**$6.14**	**$9.75**
% Savings		**13.8%**	**21.9%**

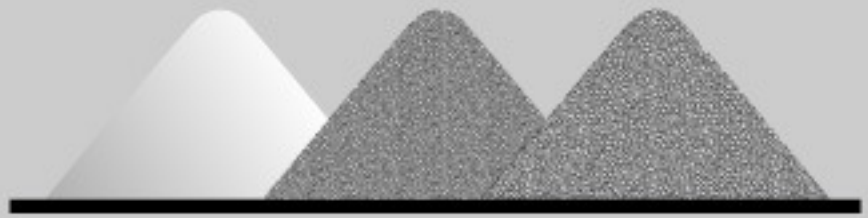
ASTEC
INDUSTRIES, INC.



30,000 Tons of RAP

=

70 - 6,000 Gallon Transport Trailers
and 28,200 Tons of Clean Aggregate



RAP is Worth the Virgin Material It Replaces

Binder Properties

- Binder in the RAP is aged and much harder than Virgin Binder
- Need to account for this at higher RAP %
  - Use a softer asphalt with higher Rap %
  - This will prevent brittle mixes and ensure good performance

Binder Replacement Calculation

$$\text{Binder Replacement, \%} = \frac{(A \times B)}{C} \times 100\%$$

Where:

A = RAP binder content (percent)

B = RAP in mixture (percent)

C = Total binder content in mixture(percent)

Binder Replacement Calculation

Example: For a mix containing 20 % RAP

A = 4.5 % (binder in the RAP)

B = 20 % (RAP in mixture)

C = 5.7 % (Total binder in mixture)

$$\text{Binder Replacement} = \frac{(A \times B)}{C} \times 100\%$$

$$= \frac{4.5 \times 0.20}{5.7} \times 100\%$$

$$= .90 / 5.7 \times 100\%$$

$$= \mathbf{15.8\ \%}$$

Superpave Asphalt Binder Specification

The grading system is based on climate

PG 58 - 28

Performance Grade

Average 7-day max pavement temperature

Min pavement temperature

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- Benefits of using RAP
- Specification changes
- Performance Studies
- Recommended practices

MDOT RAP Specifications For 2014

1. Review of Current MDOT RAP / RAS Spec

2. Nov 2013 - New Local Agency RAP spec

MDOT RAP/RAS Spec For 2014

ASPHALT PAVEMENT ASSOCIATION OF MICHIGAN

SPECIAL PROVISION
FOR
RECYCLED HOT MIX ASPHALT and RECYCLED ASPHALT SHINGLES IN SUPERPAVE MIXTURES
DATED 04-22-13 12SP 501(G)

- **Just minor editorial/clarification changes**
- **Retroactive to Dec. 2012 letting projects**

MDOT RAP/RAS Spec For 2014

ASPHALT PAVEMENT ASSOCIATION OF MICHIGAN

SPECIAL PROVISION
FOR
RECYCLED HOT MIX ASPHALT and RECYCLED ASPHALT SHINGLES IN SUPERPAVE MIXTURES
DATED 04-22-13 12SP 501(G)

- **Allows the permissive use of RAS**
- **Addresses the combined use of RAP and/or RAS**

MDOT RAP/RAS Spec 2014

DATED April 2013 12SP501(G)

ASPHALT PAVEMENT ASSOCIATION OF MICHIGAN

- Process the RAS by ambient grinding or granulating
  - 95-100 percent passing the 3/8 inch size sieve
  - 90-100 percent passing the No. 4 sieve.
- RAS must be stockpiled separately from other materials plus
  - separated into post-consumer RAS and post-manufacture RAS stockpiles.

MDOT RAP/RAS Spec 2014

DATED April 2013 12SP501(G)

ASPHALT PAVEMENT ASSOCIATION OF MICHIGAN

- RAP and RAS must be fed to the plant by separate feed systems capable of metering at the design rate.
- RAS may be blended with up to 20% fine aggregate during processing
  - Avoids clumping
  - Allows proper metering

MDOT RAP/RAS Spec 2014

DATED April 2013 12SP501(G)

ASPHALT PAVEMENT ASSOCIATION OF MICHIGAN

- RAS must not contain extraneous waste materials:
  - asbestos, metals, glass, rubber, nails
  - soil, brick, tars, paper, wood, cellulose mat, plastics
- Waste materials:
  - shall be removed by hand (before processing)
  - must not exceed 1.5 percent by weight as determined on material retained on the No. 8 sieve.

MDOT RAP/RAS Spec 2014

DATED April 2013 12SP501(G)

ASPHALT PAVEMENT ASSOCIATION OF MICHIGAN

3 Tier system

Determines the grade of binder used in the mix

Based on the amount of the total binder that comes from the RAP and /or RAS (%) (Binder Replacement)

Tier 1: 0 – 17%
Tier 2: 18 – 27%
Tier 3: ≥ 28%

MDOT RAP/RAS Spec 2014

DATED April 2013 12SP501(G)

ASPHALT PAVEMENT ASSOCIATION OF MICHIGAN

The maximum amount of RAS is limited by specification:

"RAS materials must not contribute more than 17 percent by weight of the total binder content for any HMA mixture."

MDOT RAP/RAS Spec 2014

DATED April 2013 12SP501(G)

ASPHALT PAVEMENT ASSOCIATION OF MICHIGAN

Tier 1 - 0% to 17% RAP and/ or RAS (binder replacement)

Use same grade (design binder grade)

Tier 2 - 18% to 27% RAP and/ or RAS (binder replacement)

At least one grade lower for the low temperature
Optional- lowering the high temperature one grade

If design binder grade is PG58-28 :

Use PG58-34 or 52-34

MDOT RAP/RAS Spec 2014

DATED April 2013 12SP501(G)

Asphalt Pavement Association of Michigan

Tier 2 - 18% to 27% RAP and/ or RAS (binder replacement) (continued)

No binder grade change for:

All shoulder or temporary road mixes

LVSP, E03 and E1 mixtures used as leveling or top course.

MDOT RAP/RAS Spec 2014

DATED April 2013 12SP501(G)

ASPHALT PAVEMENT ASSOCIATION OF MICHIGAN

Tier 2 - 18% to 27% RAP and/ or RAS (binder replacement)

(continued)

When using RAS in Tier 2 :

The asphalt binder grade will be selected using a blending chart for high and low temperatures.

Another option :

When using only RAP in Tier 2 :

A blending chart may be used to select the high and low temperatures of the binder

MDOT RAP/RAS Spec 2014

DATED April 2013 12SP501(G)

Asphalt Pavement Association of Michigan

Tier 3 - ≥ 28% RAP and /or RAS (binder replacement)

Use a blending chart to determine the high and low temperature values

MDOT RAP/RAS Spec 2014

DATED April 2013 12SP501(G)

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How much RAS can be added ?

- Manufacturers' waste (Post-manufacture)
  4.25 to 5 %

- Tear offs (Post-consumer)
  2.5 to 3 %

based on 5 - 6 % total binder in mix, and 17 % binder replacement

MDOT RAP Specifications For 2014

ASPHALT PAVEMENT ASSOCIATION OF MICHIGAN

1. Review of Current MDOT RAP / RAS Spec

2. Nov 2013 - New Local Agency RAP spec

New MDOT Local Agency RAP Spec
12SP501 (E), dated 11-06-13

Tier 1 - 0% to 17% RAP (binder replacement)

- **No binder grade change required**

New MDOT Local Agency RAP Spec
12SP501 (E), dated 11-06-13

ASPHALT PAVEMENT ASSOCIATION OF MICHIGAN

Tier 2 - 18% to 27% RAP (binder replacement)

- **The required asphalt binder grade must be at least one grade lower for the low temperature than the design binder grade required**
- **Optional - lowering the high temperature one grade**
  - If design binder grade is PG 64-22, Use PG 64-28 or 58-28
- **Blending chart can also be used for selecting the required binder grade**

New MDOT Local Agency RAP Spec
12SP501 (E), dated 11-06-13

ASPHALT PAVEMENT ASSOCIATION OF MICHIGAN

Caution Advised - risk of flushing / rutting using the softer liquid (-34) in tier 2 without strong aggregate structure.

SuperPave mixes have a tougher Aggregate Skelton (more rut resistant)

Marshall mixes - 50 Blow designs, Lower Crush Count & Lower Fine Aggregate angularity

- Especially the 13A and 36A mixes

New MDOT Local Agency RAP Spec
12SP501 (E), dated 11-06-13

Spec is currently under review

Current discussions with FHWA, CRAM, MDOT and APAM

Tier 2 (18% to 27%)

- For Marshall Mixes, no binder grade change will be required when ADT is above 7000 or CADT is above 700.
- No binder grade change will occur for LVSP, E03 and E1 mixtures used as leveling or top course.
- Regression of all mixes to 3.5% Air Voids

Cost Implications

- Aggregate: $10.00/ton
- Asphalt: PG 64-28 $655/ton
- Asphalt: PG 58-28 $585/ton
- Asphalt: PG 58-34 $705/ton
- Asphalt: PG 52-34 $725/ton
- RAP: $9.00
- Mix Design AC Content: 6%

Cost Implications

- Old Spec.: 64-28, Tier II using 58-28 (27% Binder Replacement)
- New Spec.: 64-28, Tier II using 58-34

DG: 64-28	
Tier II	Cost/Ton
Old Spec	$34.75
New Spec	$40.01
Difference $	$5.26
Difference %	15.12%

For every 6.6 miles of paving, 1 extra mile could be paved.

Cost Implications

- Reduce RAP to Tier I
- 64-28 (with 17% RAP Binder Replacement)

DG: 64-28	
Tier I	Cost/Ton
Old Spec	$34.75
New Spec	$41.95
Difference $	$7.20
Difference %	20.71%

For every 4.8 miles of paving, 1 extra mile could be paved.

Cost Implications

- Design Grade = -34 (Superior Region)
- Old Spec – Tier II using 52-34 (27% Binder Replacement)
- New Spec.: Reduce RAP to Tier I, 58-34 (with 17% Binder Replacement)

DG: 58-34	
Tier I	Cost/Ton
Old Spec	$40.89
New Spec	$44.34
Difference $	$3.45
Difference %	8.45%

For every 11.8 miles of paving, 1 extra mile could be paved.

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Performance of High RAP Content Mixes

From Presentation by

Randy West

Director, NCAT

Performance of High RAP Content Mixes

ASPHALT PAVEMENT ASSOCIATION OF MICHIGAN

FALL 2009
Volume 21, Number 2

Asphalt Technology News

In This Issue

LTPP Data Shows RAP Mixes Perform As Well As Virgin Mixes

NCAT recently completed a study comparing virgin and recycled asphalt pavements using data from the Long Term Pavement Performance (LTPP) program. The LTPP SPS-5 study was designed to compare the performance of various approaches to overlay rehabilitation over a period of approximately 20 years. Eighteen projects within the United States and Canada were constructed for the SPS-5 study. Most were built prior to the implementation of the Superpave mix design specification. Each included nine sections, 152 m in length, including one control section and eight rehabilitated sections used to compare the following:

- overlay type – virgin asphalt mix vs. recycled asphalt mix containing approximately 30 percent recycled asphalt pavement (RAP)
- overlay thickness – 50 mm vs.125 mm
- surface preparation – milled vs. not milled

The primary purpose of this study was to compare pavement performance data between RAP mixes and virgin mixes based on the differences between distresses observed in the two mix types. The study also examined the impacts of several other important factors (location, age, overlay thickness and milling of the existing pavement). Seven pavement performance measurements were analyzed: International Roughness Index (IRI), rutting, fatigue cracking, longitudinal cracking, transverse cracking, block cracking and raveling.

Methodology

An analysis of variance (ANOVA) was performed to assess the impact of the following factors on each distress measurement category:

- location (i.e. state or province)
- age of pavement
- milled vs. not milled
- overlay thickness
- overlay mix type

For this statistical evaluation, a significance level of 0.10 was used.

Statistical comparisons were also conducted between the RAP mixes and the virgin mixes using paired t-tests. In order to isolate mix type from the other factors, each virgin section was compared directly to the RAP section with the same corresponding surface preparation and overlay thickness:

- RAP vs. virgin, 50-mm overlay, non-milled surface
- RAP vs. virgin, 125-mm overlay, non-milled surface
- RAP vs. virgin, 50-mm overlay, milled surface
- RAP vs. virgin, 125-mm overlay, milled surface

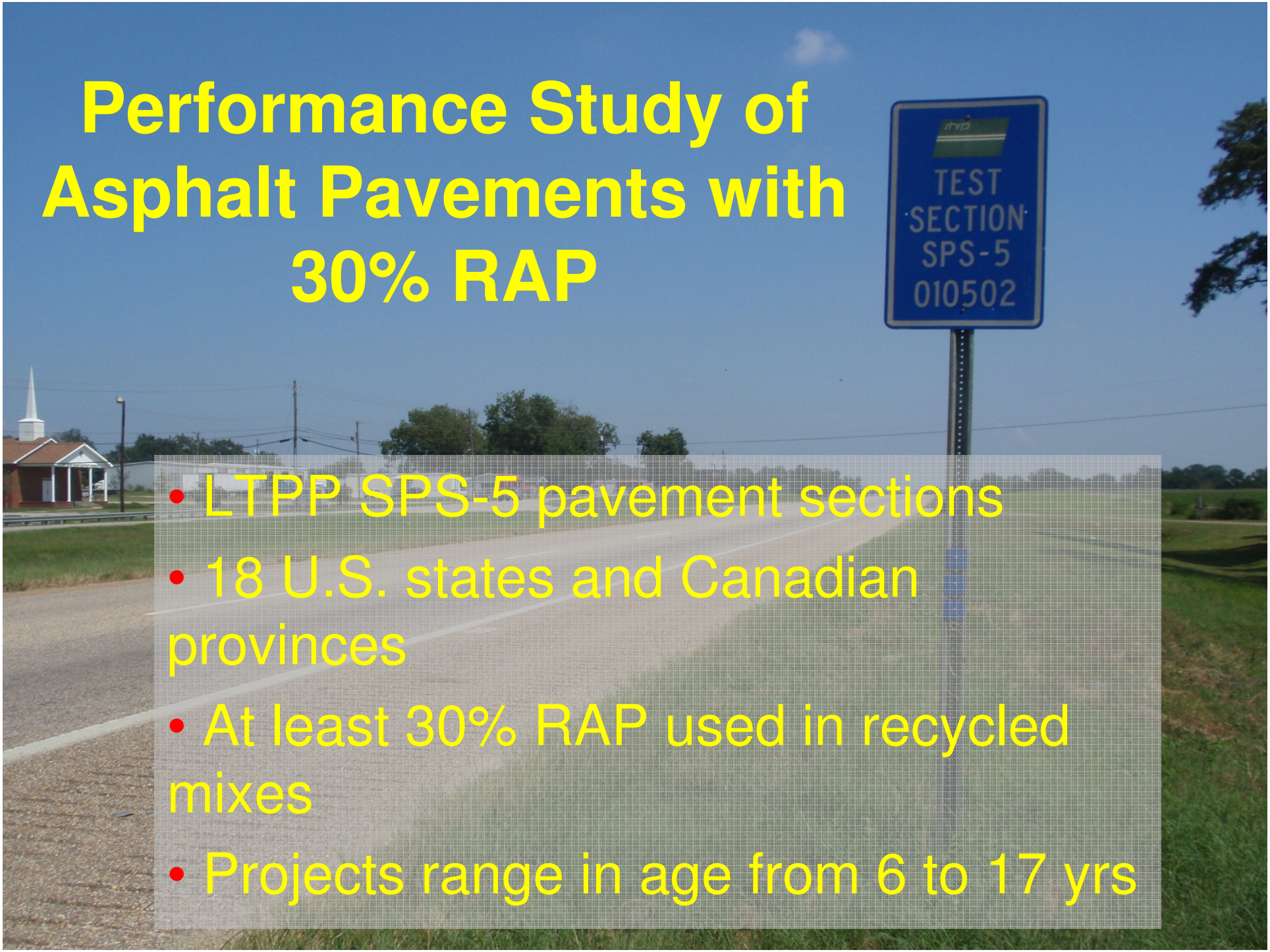
A significance level of 0.10 was used in order to include some of the practical differences. If the p-value was less than 0.10 and the t-value was a negative number, then the RAP sections performed significantly better than the corresponding virgin sections. If the p-value was less than 0.10 and the t-value was a positive number, then the virgin sections performed significantly better than the corresponding RAP sections.

Results and Conclusions

Project location (i.e. state or province) and the age of the pavement had a great impact on all distresses evaluated. Overlay thickness also had a significant effect on pavement distress, with the exception of longitudinal cracking and raveling. The

Alabama's SPS-5 test section is located on Highway 84 in Houston County.

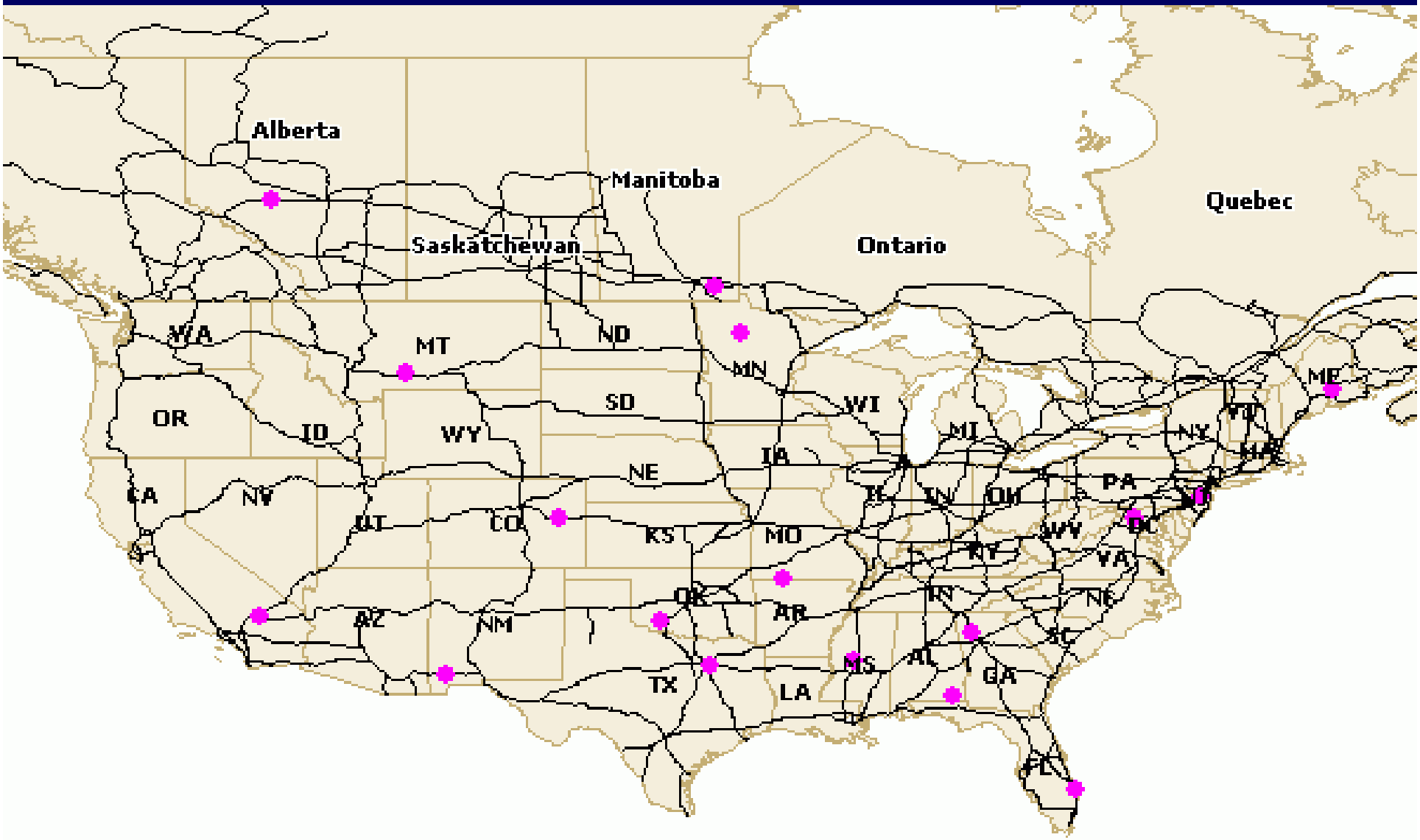
National Center for Asphalt Technology
NCAT
at AUBURN UNIVERSITY



Performance Study of Asphalt Pavements with 30% RAP

- LTPP SPS-5 pavement sections
- 18 U.S. states and Canadian provinces
- At least 30% RAP used in recycled mixes
- Projects range in age from 6 to 17 yrs

SPS-5 Project Locations



Annual Performance Data

- International Roughness Index (IRI)
- Rutting
- Fatigue Cracking
- Transverse Cracking
- Longitudinal Cracking
- Block Cracking
- Raveling

LTPP SPS-5: RAP vs. Virgin

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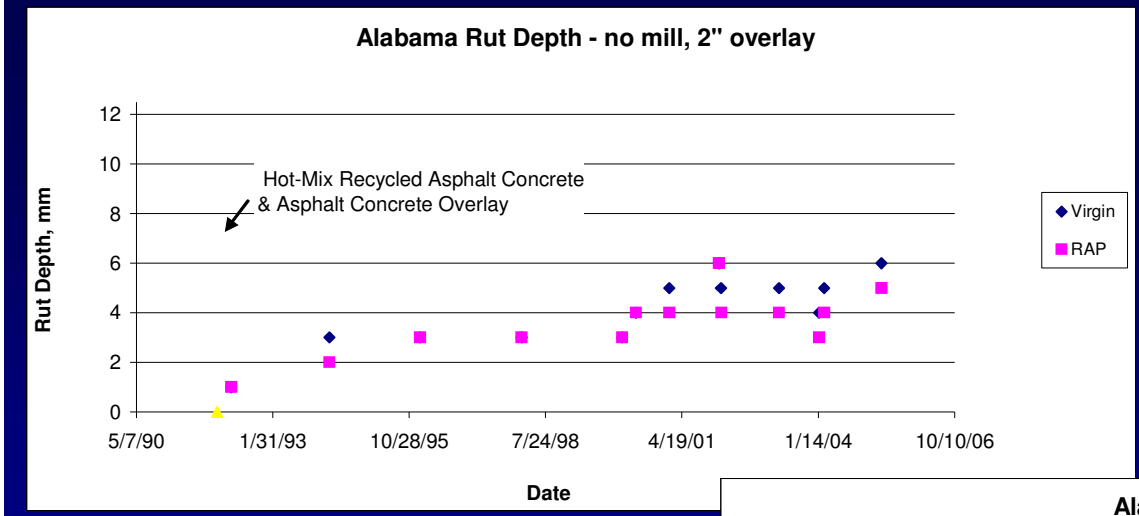
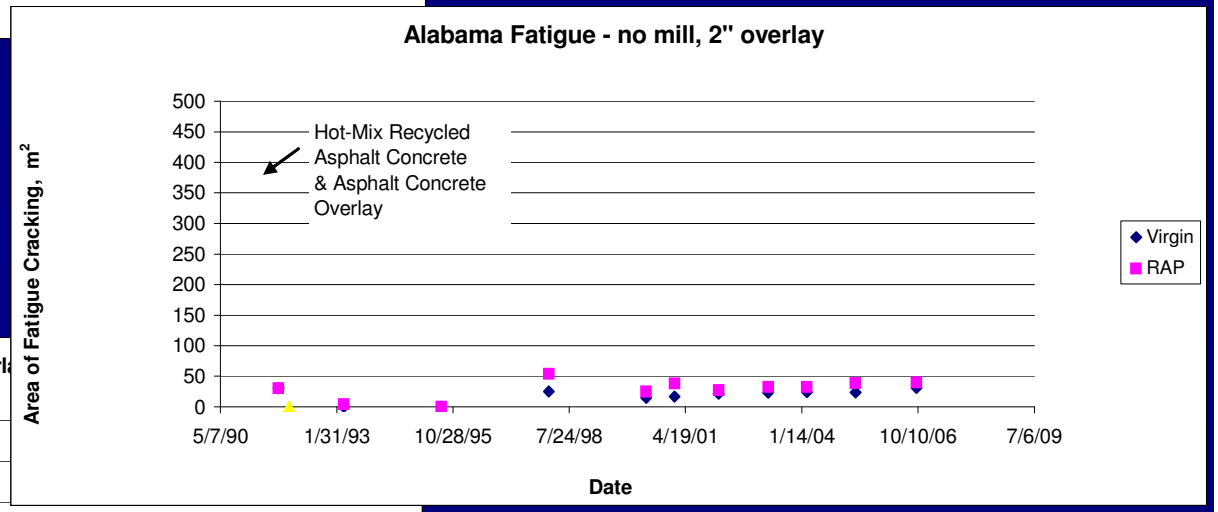
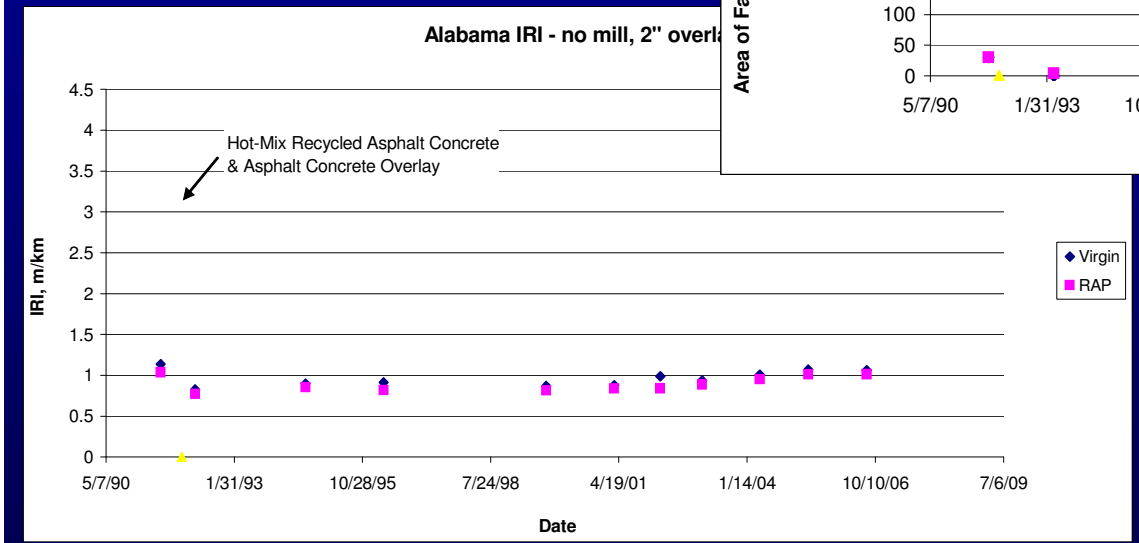
- Four comparison pairs per project (location)
  - 2” overlay, no mill
  - 2” overlay with mill
  - 5” overlay, no mill
  - 5” overlay with mill
- 504 comparisons: graphed, tabulated differences, statistical analyses







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Statistical Analyses

- Paired t-tests
  - Compared section pairs (30% RAP to virgin mix) for each location, thickness, and surface preparation
  - Since each location is subject to same traffic and environment, these effects are muted
  - Alpha = 0.10 (90% confidence interval)

Summary of Statistical Analyses

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Distress Parameter	Virgin Performed Better than RAP	RAP Performed Better than Virgin	Insignificant Difference Between RAP and Virgin	RAP Performed Equal or Better Than Virgin
IRI	42	39	19	58
Rutting	33	29	38	67
Fatigue Cracking	29	10	61	71
Long. Cracking	15	10	75	85
Transverse Cracking	32	15	53	68
Block Cracking	3	1	96	97
Raveling	7	15	78	93

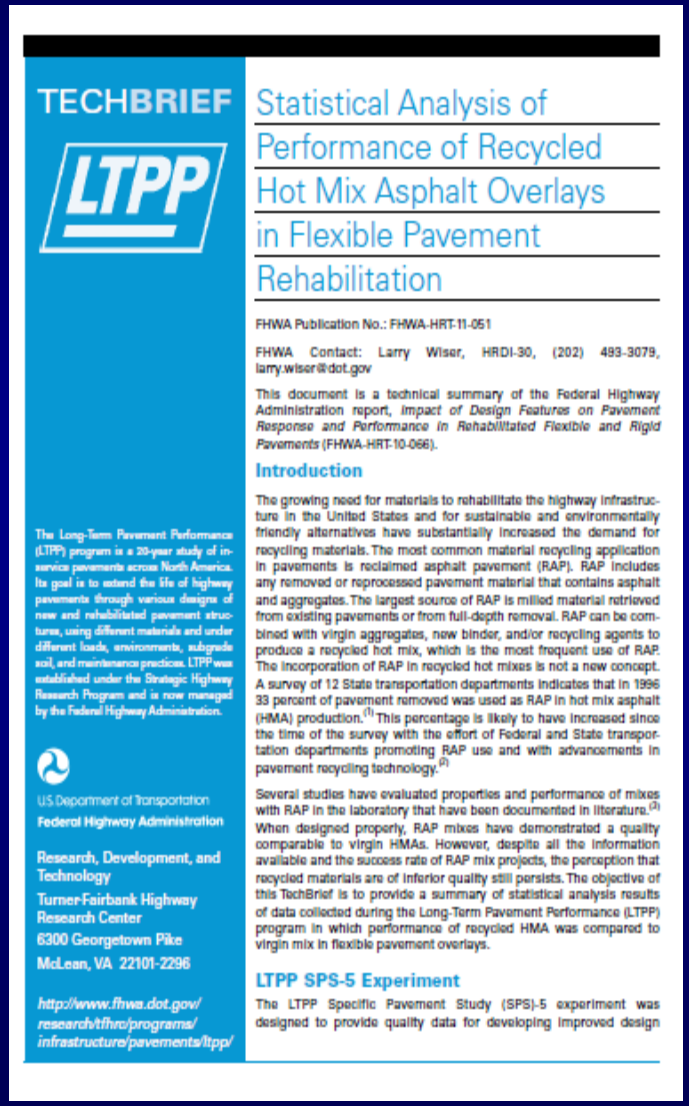
NCAT Study
2009

Other Performance Studies on RAP Mixes

ASPHALT PAVEMENT ASSOCIATION OF MICHIGAN

Statistical Analysis of Performance of Recycled Hot Mix Asphalt Overlays in Flexible Pavement Rehabilitation

FHWA Publication No.: FHWA-HRT-11-051



TECHBRIEF

LTPP

The Long-Term Pavement Performance (LTPP) program is a 20-year study of in-service pavements across North America. Its goal is to extend the life of highway pavements through various designs of new and rehabilitated pavement structures, using different materials and under different loads, environments, subgrade soil, and maintenance practices. LTPP was established under the Strategic Highway Research Program and is now managed by the Federal Highway Administration.

U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

http://www.fhwa.dot.gov/research/tfhrc/programs/infrastructure/pavements/ltpp/

Statistical Analysis of Performance of Recycled Hot Mix Asphalt Overlays in Flexible Pavement Rehabilitation

FHWA Publication No.: FHWA-HRT-11-051

FHWA Contact: Larry Wiser, HRDI-30, (202) 493-3079, larry.wiser@dot.gov

This document is a technical summary of the Federal Highway Administration report, *Impact of Design Features on Pavement Response and Performance in Rehabilitated Flexible and Rigid Pavements* (FHWA-HRT-10-066).

Introduction

The growing need for materials to rehabilitate the highway infrastructure in the United States and for sustainable and environmentally friendly alternatives have substantially increased the demand for recycling materials. The most common material recycling application in pavements is reclaimed asphalt pavement (RAP). RAP includes any removed or reprocessed pavement material that contains asphalt and aggregates. The largest source of RAP is milled material retrieved from existing pavements or from full-depth removal. RAP can be combined with virgin aggregates, new binder, and/or recycling agents to produce a recycled hot mix, which is the most frequent use of RAP. The incorporation of RAP in recycled hot mixes is not a new concept. A survey of 12 State transportation departments indicates that in 1996 33 percent of pavement removed was used as RAP in hot mix asphalt (HMA) production.[1] This percentage is likely to have increased since the time of the survey with the effort of Federal and State transportation departments promoting RAP use and with advancements in pavement recycling technology.[2]

Several studies have evaluated properties and performance of mixes with RAP in the laboratory that have been documented in literature.[3] When designed properly, RAP mixes have demonstrated a quality comparable to virgin HMAs. However, despite all the information available and the success rate of RAP mix projects, the perception that recycled materials are of inferior quality still persists. The objective of this TechBrief is to provide a summary of statistical analysis results of data collected during the Long-Term Pavement Performance (LTPP) program in which performance of recycled HMA was compared to virgin mix in flexible pavement overlays.

LTPP SPS-5 Experiment

The LTPP Specific Pavement Study (SPS)-5 experiment was designed to provide quality data for developing improved design

Other Performance Studies on RAP Mixes

Asphalt Pavement Association of Michigan

Discussed in :

Reclaimed Asphalt Pavement in Asphalt Mixtures: State of the Practice

Publication No. FHWA-HRT-11-021 April 2011

Other Performance Studies on RAP Mixes

From Publication No. FHWA-HRT-11-021 April 2011

50. Ayers, M., et al. (2009). *Impact of Design Features on Pavement Response and Performance in Rehabilitated Flexible and Rigid Pavements*, Report No. FHWA-HRT-10-066, Federal Highway Administration, Washington, DC.

51. Hong, F., et al. (2010). "Long-Term Performance Evaluation of Recycled Asphalt Pavement Results from Texas: Pavement Studies Category 5 Sections from the Long-Term Pavement Performance Program," *Transportation Research Record 2180*, Transportation Research Board, Washington, DC.

52. Zaghloul, S. and Holland, T.J. (2008). "Comparative Analysis of Long-Term Field Performance of Recycled Asphalt in California Environmental Zones," *Transportation Research Record 2084*, Transportation Research Board, Washington, DC.

53. Musselman, J. (2009). *High RAP Performance in Florida*, HMA Recycling Expert Task Group, Department of Transportation, Washington, DC. Obtained from: http://www.morerap.us/12-09/Musselman.High_RAP_Performance_Florida.pdf. Site last accessed January 4, 2011.

Other Performance Studies on RAP Mixes

From Publication No. FHWA-HRT-11-021 April 2011

50. Ayers, M., et al. (2009). Impact of Design Features on Pavement Response and Performance in Rehabilitated Flexible and Rigid Pavements, Report No. FHWA-HRT-10-066, Federal Highway Administration, Washington, DC.

"the majority of the 18 sites did not show significant differences in performance between sections overlaid with virgin and recycled mixes"

(Also summarized in Tech Brief FHWA Publication No.: FHWA-HRT-11-051)

Other Performance Studies on RAP Mixes

From Publication No. FHWA-HRT-11-021 April 2011

51. Hong, F., et al. (2010). "Long-Term Performance Evaluation of Recycled Asphalt Pavement Results from Texas: Pavement Studies Category 5 Sections from the Long-Term Pavement Performance Program," *Transportation Research Record 2180*, Transportation Research Board, Washington, DC.

5 test sections - 35 % RAP

16 year performance monitoring period (1991 -2007)

"Pavement constructed with 35 percent RAP, if designed properly, can perform well and as satisfactorily as a virgin pavement during a normal pavement life span."

Other Performance Studies on RAP Mixes

From Publication No. FHWA-HRT-11-021 April 2011

52. Zaghloul, S. and Holland, T.J. (2008). "Comparative Analysis of Long-Term Field Performance of Recycled Asphalt in California Environmental Zones," *Transportation Research Record 2084*, Transportation Research Board, Washington, DC.

47 RAP sections (up to 15 % RAP)

"The long-term performance of RAP was found and expected to be comparable to the other treatments based on deterioration models".

Other Performance Studies on RAP Mixes

From Publication No. FHWA-HRT-11-021 April 2011

53. Musselman, J. (2009). *High RAP Performance in Florida*, HMA Recycling Expert Task Group, Department of Transportation, Washington, DC.

Random sampling of mix designs with > 30 % RAP (30 – 50 %)

Constructed 1991- 1999

Monitored and recorded cracking

"The primary conclusion of the study is that there does not appear to be a significant difference in pavement life and performance between zero and 30 percent RAP."

New Study on RAP Mixes

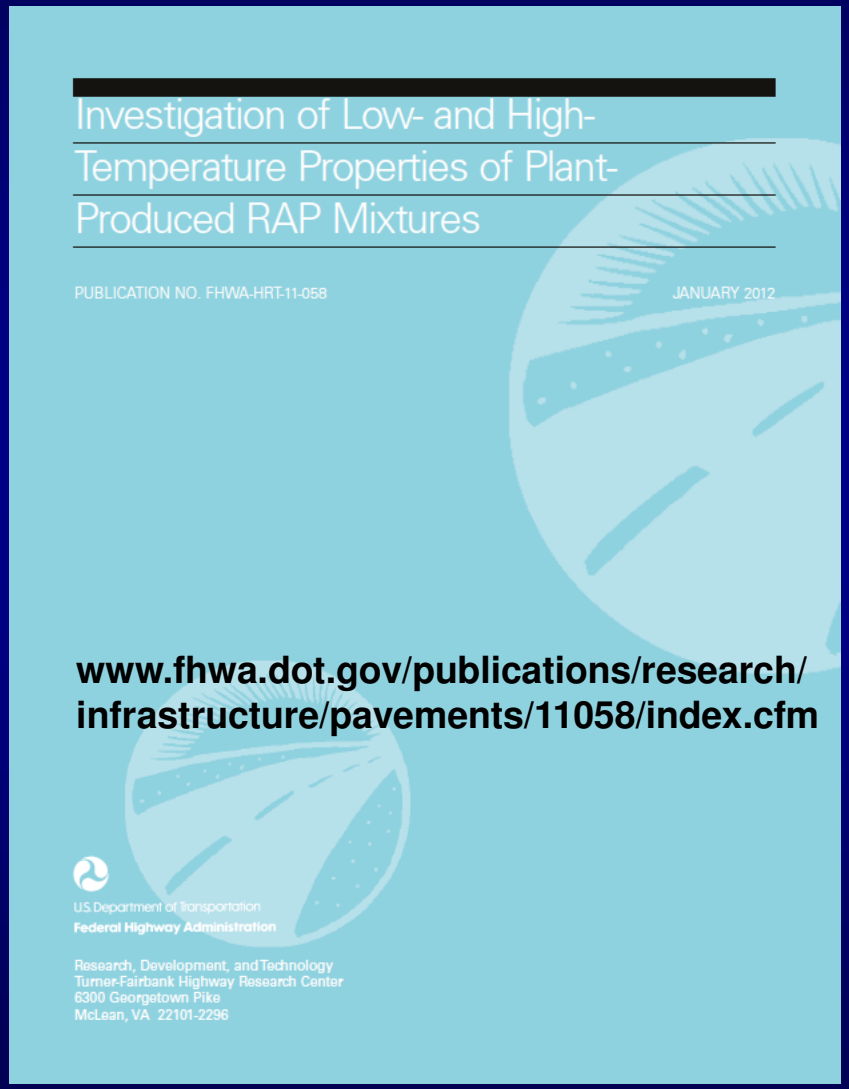
ASPHALT PAVEMENT ASSOCIATION OF MICHIGAN

Investigation of Low- and High-Temperature Properties of Plant-Produced RAP Mixtures

Rebecca S. McDaniel, Ayesha Shah, and Gerald Huber

North Central Superpave Center

2012



HMA – America's Most Recycled Product

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New Study on RAP Mixes

The goal of this project was to improve the understanding of the performance characteristics of HMA mixtures with RAP at high, intermediate, and low temperatures and to provide knowledge regarding plant-produced HMA mixtures with RAP.

- Assess the current guidelines for RAP usage by determining the low- and high temperature properties of plant-produced HMA with varying RAP contents and virgin binder grades.

- Further investigate the amount of blending that occurs between the RAP binder and virgin binder during plant production.

New Study on RAP Mixes

- Five Plants (4 in Indiana, 1 in Michigan)
- 2 Binder Grades (PG 64-22 and PG 58-28)
- 4 RAP contents (0, 15, 25, and 40%)

New Study on RAP Mixes

Asphalt Pavement Association of Michigan

Based on this Research:

- And testing RAP sources from across the state (average PG 90.1–11.1)
- INDOT increased RAP contents to:
  - 25% with no change in grade
  - 40% with a grade change
  - Based on binder replacement
- Spec change has been adopted
- Reports are coming in that other states are verifying these findings

Indiana RAP Spec Change

- January 2010
- Previously % RAP in mix
  - 15%, reduce low temp one grade
  - 25% maximum allowed
- Currently % binder replacement
  - Up to 25% no change in grade
  - 25 to 40% reduce low temp one grade
  - 40% maximum allowed

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- Benefits of using RAP
- Specification changes
- Performance Studies
- Recommended practices

Principles of RAP Management

- Good materials management practices should always be part of the quality control program for any asphalt mix production operation

- As RAP contents increase, it becomes more important to accurately determine properties of RAP and control its consistency

Recommended Practices for Use of RAP (and RAS)

Follow best practices for the processing and management of RAP

- Contractor to sample and test RAP during processing

RAP usage specification

- RAP mixes should meet same specs as virgin mixes
- Adjust binder grade appropriately

Approved mix design including RAP

Recommended Practices for Use of RAP (and RAS)

Approved mix design including RAP

Know the properties of the RAP

- **Gradation , binder content ,**
  theoretical maximum specific gravity

Mix design must be done incorporating RAP and taking into account the RAP characteristics

Mix Design Example

ASPHALT PAVEMENT ASSOCIATION OF MICHIGAN

Michigan Department of Transportation form 1931

Report of Test
SUPERPAVE ™ HMA Design Mix Formula

File 300 _____

ACCEPTED

Distribution: Project Engineer (1) -- TMI (1) -- Mix Design (1) -- Contractor (1) -- Bit File (1)

Control Section	Job Number	Project Engineer	Engineering Firm	Date
B/06 54038	54321A	R. Steel P.E.	MDOT	8/9/0X

Contractor	Plant Location	Plant No.
General Pavement	BIG RAPIDS	701-01

Mix Type	Mix Design Number	Project Location	Specification
5E3	06MD540		03SP501(F)

% Air Voids	VMA	VFA	$P200/P_{be}$	AWI	AI
4.0	15.9	74.8	1.1	288	40.9

Gmm	Gmb	Gb	Gsb	Gse	Film Thickness
2.457	2.359	1.029	2.644	2.682	7.21

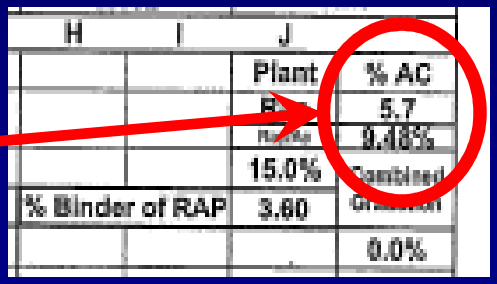
	A	B	C	D	E	F	G	H	I	J	
Pit Number	54-101	54-101	95-76	95-76						Plant	% AC
Aggregate Type	Sand PSU	Slag Sand	5/16 PSU	Sand	DNF					Rap	5.7
Blend %	10.0%	15.0%	26.0%	33.0%	1.0%					15.0%	9.48% Combined
Sieve Size	GRADATION							% Binder of RAP		3.60	Gradation
1 1/2" - (37.5mm)											0.0%
1" - (25.0mm)											0.0%
3/4" - (19mm)											0.0%
1/2" - (12.5mm)	100.0%	100.0%	100.0%	100.0%	100.0%					100.0%	100.0%
3/8" - (9.5mm)	100.0%	100.0%	100.0%	100.0%	100.0%					87.5%	98.1%
#4 - (4.75mm)	91.3%	91.7%	65.0%	99.9%	100.0%					67.9%	83.9%
#8 - (2.36mm)	69.9%	59.6%	39.7%	79.9%	100.0%					50.2%	61.1%
#16 - (1.18mm)	52.4%	38.7%	29.2%	66.2%	100.0%					40.8%	47.6%
#30 - (0.80mm)	36.8%	26.3%	23.8%	54.9%	100.0%					33.6%	38.0%
#50 - (0.30mm)	11.8%	18.0%	17.2%	24.9%	100.0%					20.8%	20.7%
#100 - (0.1mm)	3.6%	11.7%	11.7%	2.6%	100.0%					10.6%	8.6%
#200 - (0.075mm)	2.5%	7.7%	9.0%	0.4%	85.0%					7.4%	5.8%
1 FACE CRUSH %	30.0%	100.0%	100.0%	30.0%						75.0%	88.6%
2 FACE CRUSH %											-
L.A. ABRASION & YEAR	22-03	25-02	22-03								
Angularity Index	37.8	48.8	43	38							40.90
AWI FACTOR	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	
AWI VALUE #16	225	401	300	240						240	288
COMBINED Calc. Gsb	2.601	2.720	2.610	2.648						2.675	2.648
#4+ COARSE BULK S.G.			2.621								
#8 COARSE BULK S.G.		2.702	2.582								
FINE BULK S.G.	2.601	2.73	2.619	2.648						2.678	
FLAT & ELONGATED %											
SOFT PARTICLES %	0.1		0.5	0.5						0.5	

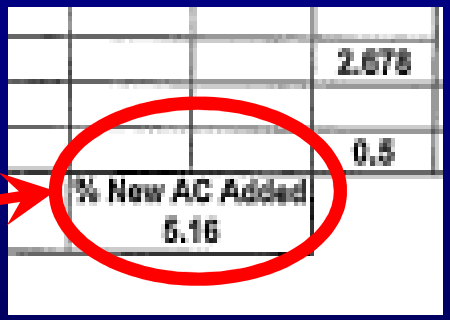
Asphalt Binder	Grade	A.C. Supplier I.D. #	% New AC Added
	PG 64-28	ABS 1005	5.16

REMARKS:

The bituminous content and aggregate characteristics are based on the submitted materials with the quantities and blend ratios indicated. Variation in materials or field conditions may require adjustments of this mix design (see TM for form 1041 for field application). This laboratory design is validated two construction seasons from date reported and should not be applied or adjusted without written approval of the Bituminous Services Unit. A signed copy is on file with the Bituminous Services Unit. Contact for information.

Bituminous Engineer





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Ability to Meet Volumetrics

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- Treat RAP as mix component
- Challenges: VMA and dust/asphalt ratio
  - Good processing practices and quality control can be used to overcome this issue

Recommended Practices for Use of RAP (and RAS)

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Test the produced Mix:

- (Binder, Gradation)
- Contractor Quality Control Tests
- Owner Quality Assurance / Acceptance tests

If you have performance concerns:

- Consider testing/monitoring other properties
- Mix volumetrics (Air Voids, VMA)
- Fines to Effective Binder Ratio

Why Recycle RAP into HMA?

- Best and Highest use
- Same or better performance as virgin mix
- Save $

Economics Savings Example

- Aggregate: $10.00/ton
- Asphalt: $585.00/ton
- RAP: $9.00
- Mix Design AC Content: 6.0%

Material	0% RAP	17% RAP	27% RAP
Aggregate	$9.40	$7.70	$6.70
Asphalt	$35.10	$29.13	$25.62
RAP		$1.53	$2.43
Total	$44.50	$38.36	$34.75
$ Savings		**$6.14**	**$9.75**
% Savings		**13.8%**	**21.9%**

Using RAP to Stretch Your Pavement Dollars

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Questions ????

Reduce / Reuse / Recycle

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