Reclaimed Asphalt Pavement (RAP)

Recycling prevents depletion of natural resources and reduces energy use.
Reclaimed Asphalt Pavement (RAP)

Topics

- Overview
- Benefits of using RAP
- History / Specifications
- Performance Studies of RAP mixes
- Recommended practices
RAP Sources

Pavement Milling

Asphalt Pavement Removal

Plant Waste Material

HMA – America’s Most Recycled Product
Recyclability

• Asphalt is the No. 1 recycled material
• 1995 FHWA Report to congress
  ♦ 90 Million tons reclaimed
  ♦ 80% recycled
• Asphalt Pavements are 100% recyclable
  ♦ Can re-use binder
  ♦ Return on investment
Recyclability

Percent Recycled

- Glass bottles
- Paper
- Newsprint
- Aluminum cans
- Scrap Steel
- Asphalt Pvmnt

FHWA / USEPA Report to Congress, EPA/600/R-93/095.

HMA – America’s Most Recycled Product

SMOOTH | DURABLE | SAFE | QUIET
HMA – America’s Most Recycled Product

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- **Asphalt pavement**: 80.3 millions of tons
- **Scrap steel**: 70 millions of tons
- **Newsprint**: 6.2 millions of tons
- **Concrete pavement**: 3.3 millions of tons
- **Glass bottles**: 2.9 millions of tons
- **Aluminum cans**: 0.9 millions of tons
- **Lead-acid batteries**: 0.8 millions of tons
- **Magazines**: 0.5 millions of tons
- **Plastic containers**: 0.3 millions of tons

**SMOOTH | DURABLE | SAFE | QUIET**
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 $
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
Why Recycle RAP into HMA?

• RAP contains valuable materials:
  ♦ Aggregate ~95% @ $10/ton
  ♦ Asphalt ~5% @ $450/ton
  ♦ Value = $32.00/ton (minus processing)
Materials savings will depend on...

- Virgin binder cost
- Asphalt content of the mix design
- Aggregate cost
- RAP cost (trucking and processing)
- Asphalt content of the RAP
- Percentage of RAP
Example Materials Savings for RAP Utilization

Based on $15 Aggregate, $9 RAP

HMA – America’s Most Recycled Product
RAP Givens

RAP mixes need to meet the same specs as virgin mixes:
- Gradation, Asphalt content (binder)
- Aggregate properties
- Volumetric properties (AV, VMA)
- Fines to AC ratio
- And final Binder Properties (stiffness)
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
RAP Specification's

History of RAP usage and development
MDOT RAP specs.
Michigan RAP History

- Late 1970’s – MDOT pilot projects
- Common practice in the 1980’s
- Very prescriptive process
- Many Improvements over 35 years
  - Plant, Process, Asphalt Technology
Michigan RAP History

1990 MDOT Standard Spec Book:

- RAP specified based on the % RAP used in the mix (% of total weight of mixture)

- If 15 % RAP or less - no change in the AC grade

- If greater than 15 to 50 % - may require a change in AC grade
NCHRP 9-12 Mix Design Guidelines

• Binder Grade Selection
  – 15%
  – 25%

• AASHTO M323 (Superpave Mix design)
AASHTO SPECIFICATIONS

- 0 to 15%  No change in base binder grade
- 15 to 25% Reduce one grade
- >25%  Binder evaluation (recovery, blending, etc.)
MDOT RAP System

Introduced in 2002

– 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 ( % )
    – Tier 1: 0 – 17%
    – Tier 2: 18 – 27%
    – Tier 3: ≥ 28%
MDOT RAP System

Introduced in 2002

– Spec language:
  • “Contribution of RAP binder toward the total binder, by weight “
  • “RAP binder by weight of the total binder in the mixture”

– Or

  • National terminology:
  • Binder replacement
Binder Replacement Calculation

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

Where:
A = RAP percent binder content
B = RAP percent in mixture
C = Total percent binder content in mixture
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)

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

\[
\begin{align*}
&= \frac{4.5 \times 0.20}{5.7} \times 100\% \\
&= \frac{0.90}{5.7} \times 100\% \\
&= 15.8\%
\end{align*}
\]
Add the following subsection to Section 501.02.4.2 of the standard specifications.

c. Reclaimed Asphalt Pavement (RAP) Percentages and Binder Grade Selection. The method for determining the binder grade in hot mix asphalt (HMA) mixtures incorporating RAP is divided into three categories designated Tier 1, Tier 2 and Tier 3. Each tier has a range of percentages that represent the contribution of the RAP binder toward the total binder, by weight. The tiers identified below apply to both Superpave and Marshall mixtures with the following exception: Superpave mixture types E3, E3 High Stress and E10 used as leveling or top course shall be limited to a maximum of 17% RAP binder by weight of the total binder in the mixture. Superpave mixture types E10 High Stress, and all E30 and E50 mixtures used as leveling or top course shall be limited to a maximum of 14% RAP binder by weight of the total binder in the mixture.

Tier 1 (0% to 17% RAP binder by weight of the total binder in the mixture)

No binder grade adjustment is made to compensate for the stiffness of the asphalt binder in the RAP.

Tier 2 (18% to 27% RAP binder by weight of the total binder in the mixture)

The selected binder grade for the asphalt binder is one grade lower for the high temperature than the binder grade required for the specified project mixture type. For example, if the specified binder grade for the mixture type is PG58-28, the required grade for the binder in the recycled mixture would be PG52-28.

The asphalt binder grade can also be selected using a blending chart for high and low temperatures. The Contractor shall supply the blending chart and the RAP test data used in determining the binder selection.

Tier 3 (≥ 28% RAP binder by weight of the total binder in the mixture)

The binder grade for the asphalt binder is selected using a blending chart for high and low temperatures. The Contractor shall supply the blending chart and the RAP test data used in determining the binder selection.
For Marshall and Superpave mixes:

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

Use same grade (design binder grade)

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

Use one grade lower for the high temperature

If design binder grade is PG58-28, Use PG52-28.
For Marshall and Superpave mixes:

Tier 3 - ≥ 28% RAP (binder replacement)

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

Restrictions (on leveling and top course mixes):

E3 and E10 mixes – maximum 17 % RAP

E30 and E 50 mixes - maximum 14 % RAP
For Superpave mixes only

MDOT RAP Spec 12SP501 (G) 2011

MICHIGAN DEPARTMENT OF TRANSPORTATION

SPECIAL PROVISION FOR RECYCLED HOT MIX ASPHALT IN SUPERPAVE MIXTURES

C&T.CJB 1 of 1 C&T:APPR:SP:JWB:09-14-10
FHWA:APPR:06-01-11

Add the following subsection to subsection 591.02.A.2, on page 234 of the Standard Specifications for Construction.

c. Reclaimed Asphalt Pavement (RAP) and Binder Grade Selection. The method for determining the binder grade in HMA mixtures incorporating RAP is divided into three categories designated Tier 1, Tier 2 and Tier 3. Each tier has a range of percentages that represent the contribution of the RAP binder toward the total binder, by weight. The tiers identified below apply to Superpave mixtures with the following exception: Superpave mixture types E3, E3 High Stress, E10, E10 High Stress, E30, E30 High Stress, E50, and E50 High Stress used as leveling or top course must be limited to a maximum of 17 percent RAP binder by weight of the total binder in the mixture.

RAP will not be allowed in the following mixture types, Gap Graded Superpave or Asphalt Stabilized Crack Relief Layer.

- Tier 1 (0% to 17% RAP binder by weight of the total binder in the mixture). No binder grade adjustment is required to compensate for the stiffness of the asphalt binder in RAP.

- Tier 2 (18% to 27% RAP binder by weight of the total binder in the mixture). The required asphalt binder grade must be at least one grade lower than the design binder grade required for the specified project mixture type. Lowering the high temperature of the binder one grade is optional. For example, if the design binder grade for the mixture type is PG 56-22, the required grade for the binder in the HMA mixture containing RAP would be a PG 52-26 or a PG 50-26.

No binder grade change will be required in Tier 2 for all shoulder and temporary road mixtures.

No binder grade change will occur for Tier 2 LVSP, E03 and E1 mixtures used as leveling or top course.

The asphalt binder grade can also be selected using a blending chart for high and low temperatures. The Contractor must supply the blending chart and the RAP test data used in determining the binder selection according to AASHTO M 323.

- Tier 3 (≥ 28% RAP binder by weight of the total binder in the mixture). The binder grade for the asphalt binder is selected using a blending chart for high and low temperatures. The Contractor must supply the blending chart and the RAP test data used in determining the binder selection according to AASHTO M 323.
MDOT RAP Spec 12SP501 (G) 2011 to Present

For Superpave mixes only:

Tier 1 - 0% to 17% RAP (binder replacement)
Use same grade (design binder grade)

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

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

If design binder grade is PG58-22, Use PG58-28, or 52-28

No binder grade change for: shoulder or temporary road mixes, LVSP, E03 and E1 mixtures used as leveling or top course.
MDOT RAP Spec 12SP501 (G) 2011
2011 to Present

For Superpave mixes only:

Tier 3 - ≥ 28% RAP (binder replacement)

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

Restrictions (on leveling and top course mixes):

E3 and E10 mixes – maximum 17 % RAP
E30 and E 50 mixes - maximum 17 % RAP
Add the following subsection to subsection 501.02.A.2, on page 334 of the Standard Specifications for Construction.

c. Reclaimed Asphalt Pavement (RAP) and Binder Grade Selection. The method for determining the binder grade in HMA mixtures incorporating RAP is divided into three categories designated Tier 1, Tier 2 and Tier 3. Each tier has a range of percentages that represent the contribution of the RAP binder toward the total binder, by weight. The tiers identified below apply to Marshall mixtures.

Recycled materials may be used as a substitute for a portion of the new materials required to produce HMA mixtures in accordance with contract documents.

- Tier 1 (0% to 17% RAP binder by weight of the total binder in the mixture). No binder grade adjustment is made to compensate for the stiffness of the asphalt binder in RAP.
- Tier 2 (18% to 27% RAP binder by weight of the total binder in the mixture). For all mixtures no binder grade change will occur in Tier 2 for all shoulder and temporary road mixtures.

For Marshall mixtures lowering the high temperature of the binder one grade is optional except in the Metro Region in which the selected binder grade for the asphalt binder is one grade lower for the high temperature than the binder grade required for the specified project mixture type. For example, if the specified binder grade for the mixture type is PG64-22, the required grade for the binder in the recycled mixture would be a PG64-22.

The asphalt binder grade can also be selected using a blending chart for high and low temperatures. The Contractor must supply the blending chart and the RAP test data used in determining the binder selection according to AASHTO M 323.

- Tier 3 (≥ 28% RAP binder by weight of the total binder in the mixture). The binder grade for the asphalt binder is selected using a blending chart for high and low temperatures per AASHTO M 323. The Contractor must supply the blending chart and the RAP test data used in determining the binder selection.
MDOT RAP Spec 12SP501 (E) 2011
2011 to Present

For Marshall mixes only:

Tier 1 - 0% to 17% RAP (binder replacement)
Use same grade (design binder grade)

Tier 2 - 18% to 27% RAP (binder replacement)
Optional - lowering the high temperature one grade

Except in the Metro Region: Must lower the high temperature one grade

If design binder grade is PG 64-22, Use PG 58-22.

No binder grade change for: shoulder or temporary road mixes
For Marshall mixes only:

Tier 3 - ≥ 28% RAP (binder replacement)

Use a blending chart to determine the high and low temperature values
Reclaimed Asphalt Pavement in Asphalt Mixtures: State of the Practice

- State-of-the-practice information on including higher amounts of RAP in asphalt mixtures.
- “The performance and life of pavement containing up to 30 percent RAP is similar to virgin pavements with no RAP.”

Publication No. FHWA-HRT-11-021   April 2011
Performance of High RAP Content Mixes

From Presentation by
Randy West
Director, NCAT
LTPP Data Shows RAP Mixes Perform As Well As Virgin Mixes

In this issue
- LTPP Data Shows That RAP Mixes Perform As Well As Virgin Mixes — page 5
- Peasing the Way to a More Sustainable Future — page 6
- Fourth Cycle Begins at NACo Test Track — page 8
- Primer on Dynamic Modulus — page 9
- Asphalt Forum — page 10
- asphaltForum Features — page 11
- Specification Corner — page 12
- Research Roundup — page 13
- Laboratory Instrumentation and Field Validation of 275 mm Symmetrical Designed Asphalt Mixtures
- Evaluation of the Effect of Recycled Asphalt Pavement Aggregate But Loss of Grain on Void in Mineral Aggregate
- Training Opportunities — page 15

Alaska's SHR-4 test sections are located on Highway 441 in Fairbanks, Alaska.

Performance of High RAP Content Mixes

ICP recently completed a study comparing virgin and recycled asphalt pavements using data from the Long-Term Pavement Performance (LTPP) program. The LTPP SPF-5 study was designed to compare the performance of various approaches to overlay rehabilitation over a period of approximately 20 years. Eight projects with the United States and Canada were selected for the SPF-5 test sections built prior to the implementation of the Superpave guidelines. Each included two sections, 100 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

In addition to the impact of the above factors, the study also examined the effects of other important factors, such as age, overlay thickness, and width of the existing pavement. Several pavement performance measurements were analyzed, including longitudinal cracking, transverse cracking, block cracking, and rutting.

Methodology

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

- Location: 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 selected.

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

- 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 k-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 k-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 the distress evaluation. Overlay thickness also had a significant effect on pavement distress, with the exception of longitudinal cracking and rutting.
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
Annual Performance Data

- International Roughness Index (IRI)
- Rutting
- Fatigue Cracking
- Transverse Cracking
- Longitudinal Cracking
- Block Cracking
- Raveling
LTPP SPS-5: RAP vs. Virgin

- 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
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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<tr>
<th>Distress Parameter</th>
<th>Virgin Performed Better than RAP</th>
<th>RAP Performed Better than Virgin</th>
<th>Insignificant Difference Between RAP and Virgin</th>
<th>RAP Performed Equal or Better Than Virgin</th>
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NCAT Study 2009

HMA – America’s Most Recycled Product
Other Performance Studies on RAP Mixes

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


Other Performance Studies on RAP Mixes

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

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

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, HRD-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 recycled 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 13 state transportation departments indicates that in 1996 53 percent of pavement removed was used as RAP in hot mix asphalt (HMA) production. 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 advancements in pavement recycling technology.

Several studies have evaluated properties and performance of mixes with RAP in the laboratory that have been documented in literature. When designed properly, RAP mixes have demonstrated a quality comparable to virgin HMA. 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 Tech Brief 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
From Publication No. FHWA-HRT-11-021  April 2011


“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)

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.”

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


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.”
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
Variability: RAP vs. Aggregate

Based on 74 RAP stockpiles in 14 states, and 60 Aggregate stockpiles in 6 states
Fractionation

- RAP can be separated into different sizes similar to virgin stone
- Finer portion contains more asphalt
- A viable option
Fractionating RAP

• Primary advantage of fractionating RAP is having stockpiles of different RAP sizes to provide flexibility in meeting mix design requirements.

• Typical Sizes
  – 3/4” – 3/8”
  – 3/8” – 3/16”
  – Minus 3/16”
  – or Coarse and fine splits
Fractionated vs. Unfractionated

Standard Deviations

- Non
- Fine
- Coarse

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<th>Pb</th>
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<td>0.47</td>
<td>0.98</td>
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Fractionating RAP

- Fractionating should not be mandated
  - It should be the contractor’s business decision if and when to fractionate RAP
Recommended Practices for Use of RAP

Follow best practices for the processing and management of RAP

RAP usage specification

Approved mix design including RAP

Test the produced Mix
Recommended Practices for Use of RAP

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

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

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<th>Plant</th>
<th>% AC</th>
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<td>GRBox</td>
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% Binder of RAP: 3.60

% New AC Added: 5.16
Ability to Meet Volumetrics

- 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

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
Why Recycle RAP into HMA?

• Best and Highest use

• Same or better performance as virgin mix

• Save $
Economics Savings Example

- Aggregate: $15.00/ton
- Asphalt: $550.00/ton
- RAP: $9.00
- Mix Design AC Content: 5.0%

<table>
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Questions ????