NCHRP 9-46

Improved Mix Design, Evaluation, and Materials Management Practices of HMA with High RAP Content

SEAUPG Meeting
Savannah, GA
Nov. 16, 2011

Presentation Outline

- Review of Objectives
- Best Practices for RAP Management
- Mix Design Sample Preparation Guidelines
- Experimental Plan
- Experimental Findings
- Preliminary Conclusions and Recommendations

Project Objectives

- Provide Guidance on Characterizing RAP
- Revise Mix Design Procedure for High RAP Contents
- Recommend Performance Tests
  - Dynamic Modulus
  - Moisture Sensitivity
  - Rutting Resistance
  - Fatigue Cracking Resistance
  - Low Temperature Cracking Resistance

Best Practices for RAP Management

Best Practices for RAP Management

- Keep large milling stockpiles separate, no additional processing to minimize $P_{0.075}$
- Multi-source stockpiles can be made into a consistent RAP through processing. Avoid over-crushing by screening material prior to crusher.
- Variability guidelines should be used rather than method specifications for processing
- Fractionation is helpful for mix designs with high RAP contents
- Sampling & testing frequency should be consistent with aggregate QC (typically 1 per 1000 tons of RAP)
- Use a loader to build mini-stockpiles for sampling

Handling RAP in the Lab

Handling RAP in the Lab

- Use fan drying rather than oven drying for RAP to avoid further hardening of the RAP binder
- Heat RAP portion of batch separately from virgin aggregate. Heat RAP for minimum amount of time to reach mixing temperature (typically 1.5 to 2 hours)

RAP Aggregate Properties

- Gradation, Specific Gravity, Consensus Properties, Source Properties, Polishing/Friction
- How to recover the aggregate?
  - Solvent extraction, AASHTO T 164
  - Ignition method, AASHTO T 308
- A joint UNR-NCAT study examined many aggregate characteristics before and after solvent extraction and the ignition method using a limited set of materials. Most characteristics are not affected significantly by either method.

RAP Aggregate Specific Gravity

- This property is important
- Three options to choose from:
  1. Determine Gse for RAP agg., assume Pba, calculate Gsb
  2. Recover RAP agg. with solvent, T84 and T85
  3. Recover RAP agg. from ignition method, T84 and T85

RAP Aggregate Bulk Specific Gravity

Option 1: Estimated G_{sb} from G_{mm} & P_{ba}

1. Determine G_{mm} (w/ dryback) of RAP sample
2. Calculate G_{se} using the formula:

$$G_{se(RAP)} = \frac{100 - P_{b(RAP)}}{\frac{100}{G_{mm(RAP)}} - \frac{P_{b(RAP)}}{G_b}}$$

RAP Aggregate Bulk Specific Gravity

Option 1: Estimated G_{sb} from G_{mm} & P_{ba}

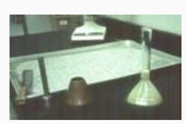
3. Estimate the absorbed asphalt, P_{ba}, based on historical values for the plant location.
4. Calculate G_{sb} using the formula:

$$G_{sb(RAP)} = \frac{G_{se(RAP)}}{\frac{P_{ba} \times G_{se(RAP)}}{100 \times G_b} + 1}$$

RAP Aggregate Bulk Specific Gravity

Option 2: Recover aggregate using a **solvent extraction**, then conduct AASHTO T84 and T85 on the fine and course fractions like any other aggregate.

Option 3: Recover aggregate using the **ignition method**, then conduct AASHTO T84 and T85 on the fine and course fractions like any other aggregate.



9-46 RAP Aggregate Gsb Results

RAP Desc.	Centrifuge	Ignition	Gmm→Gsb (C)	Gmm→Gsb (I)	Max.-Min.
FL Coarse	2.563	2.592	2.616	2.604	0.053
FL Fine	2.565	2.574	2.581	2.566	0.016
MN Coarse	2.628	2.623	2.681	2.591	0.090
MN Fine	2.618	2.606	2.656	2.585	0.071
NH Coarse	2.660		2.630		0.030
NH Fine	2.636	2.629	2.671	2.667	0.042
UT Coarse	2.567	2.599	2.693	2.622	0.126
UT Fine	2.583	2.579	2.624	2.641	0.062

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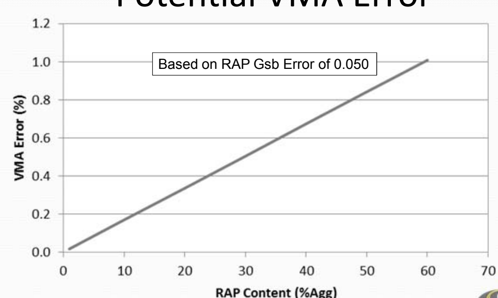
Potential VMA Error



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Comparison of VMA, VFA Using different Gsb's

Source (Desc.)	Centrifuge		Ignition		Gmm→Gsb (C)		Gmm→Gsb (I)	
	VMA	VFA	VMA	VFA	VMA	VFA	VMA	VFA
FL (40% RAP, 9.5mm)	14.9	72.0	15.3	72.7	15.6	73.2	15.8	73.6
FL (40% RAP, 19.0mm)	11.6	65.2	11.9	66.0	12.1	66.6	12.1	66.8
MN (40% RAP, 9.5mm)	15.5	74.2	15.4	74.1	15.1	73.4	16.1	75.2
MN (40%RAP, 19.0mm)	13.3	72.7	13.3	72.5	12.8	71.6	14.0	74.0
NH (25% RAP)	16.2	75.2	16.1	75.1	16.4	75.7	16.4	75.6
NH (55% RAP)	14.1	71.7	14.1	71.7	13.6	70.7	13.6	70.7
UT (25% RAP)	13.8	73.3	13.9	73.4	14.7	75.0	14.4	74.4
UT (55% RAP)	14.9	74.8	14.9	74.9	16.5	77.3	15.9	76.5

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Experimental Plan

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Experimental Plan

- Mix Designs with 4 sets of materials: NH,UT, MN, FL
- RAP Contents: 0, 25, & 55% or 0 & 40%
- Two binder grades and two binder sources
- Volumetrics, E*, FN, TSR, FE, SCB and BBR

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Volumetric Results

- Fractionated RAP was necessary to get 55% RAP in the mixes. The coarse RAP fraction was used exclusively in some cases.
- Percent binder replacement ranges:
  - 25% RAP (by weight of agg.): 25 to 27% binder repl.
  - 55% RAP (by weight of agg.): 33 to 49% binder repl.
- Changing the virgin binder source or PG does not appear to affect volumetric properties.
  - "Bumping" the binder grade should not effect Opt. Pb.
  - Incompatibility of binders may not be evident in volumetric mix design.

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Dynamic Modulus

AASHTO TP 62-07

Dynamic Modulus (E*) Testing

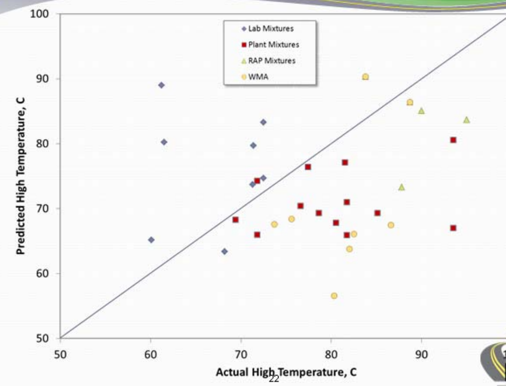
- Two purposes:
  1. To try to estimate the "effective" (combined RAP and virgin) binder properties.
  2. To assess how RAP content influences mix stiffness through the range of temperatures expected in service.

Back-calculation of Binder Properties

- Methodology
  - Use Hirsch model to backcalculate G*

$$E^*_{max} = P_C\left[4{,}200{,}000\left(1-\frac{VMA}{100}\right)+3G^*\left(\frac{VFA*VMA}{10{,}000}\right)\right]+(1-P_C)\left[\frac{1-(VMA/100)}{4{,}200{,}000}+\frac{VMA}{3(VFA)G^*}\right]^{-1}$$

  - E* = limiting maximum HMA dynamic modulus, psi
  - VMA = voids in mineral aggregate, %
  - VFA = voids filled with asphalt, %
  - G*= shear dynamic modulus of binder, psi



Statistically Significant Factors for E*

Region	Variables	4.4C	21.1C	37.8C	54.4C
FL	% RAP	% RAP	% RAP	% RAP	% RAP
MN	% RAP	% RAP		%RAP	% RAP
NH	Binder Grade Binder Source % RAP	Source % RAP	Grade % RAP	Grade % RAP	Grade Source % RAP
UT	Binder Grade Binder Source % RAP	Source % RAP	Grade % RAP	Grade % RAP	Grade Source % RAP

Statistic: General Linear Model (α = 0.05)

Summary of E* Statistical Analyses

- Virgin binder **grade** did not have a significant effect on E* at low temperatures. The influence of the virgin binder grade on E* increased with higher test temperatures.
- Virgin binder **source** was significant on E* only at the lowest and highest temperatures.
- RAP content had a significant effect on E* at all temperatures. E* of high RAP content mixes were significantly higher than for virgin mixes.

Performance Tests

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Moisture Damage Susceptibility

AASHTO T 283

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Summary of Moisture Damage Testing

- Increasing RAP contents generally increased conditioned and unconditioned tensile strengths
- Low TSRs can generally be improved with the addition of an antistripping agent.
- TSR can be misleading. Although using RAP may increase both conditioned and unconditioned tensile strengths, TSR values can decrease, sometimes below 0.80. A lower TSR criterion (e.g. 0.75) with a minimum conditioned tensile strength (e.g. 100 psi) can help

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Flow Number

Rutting Resistance Test

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Flow Number Procedure

- Protocol originally recommended by FHWA.
- Loose mix aged for 4 hrs. at 135°C (AASHTO R 30)
- Specimens compacted to 150 x 170 mm, then cut and cored to 100 mm dia. x 150 mm ht. with a target V_a of 7±0.5%.
- Specimens were preheated to the 50% reliability high-temperature from LTPP Bind for the location of the respective materials.
- The deviator stress = 70 psi; <u>confining stress = 10 psi</u>. Test to 20,000 cycles.

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Summary of Flow Number Testing

- Tertiary flow was not evident for any mixture; no Fn
- High RAP content mixes had statistically equal deformation compared to virgin counterparts in 8 of 9 cases.
- Although not statistically significant, using a lower virgin PG binder grade generally resulted in greater deformation.
- Recommend using <u>unconfined</u> flow number test and criteria from NCHRP Report 673

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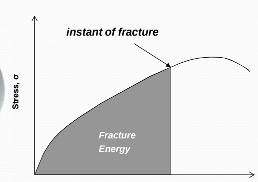
Fatigue Cracking

Tests Considered for Fatigue Cracking

Test	Method	Disadvantages
Bending Beam Fatigue	AASHTO T 321	Challenging spec. prep, time consuming test
Simplified Viscoelastic Continuum Damage	NCSU	Method still in development, Complex analysis
Texas Overlay Tester	TEX-248-F	Current method uses unrealistically high strains
Semi-Circular Bend	LTRC	Method still in development
IDT Fracture Energy	UF	National standard needed

Fracture Energy



IDT Fracture Energy at 10°C

IDT Fracture Energy (10°C)Summary

- Fairly simple test except for strain measurements
  - Simple sample preparation
  - Monotonic loading, 4 strain measurements
  - 10°C test temperature
  - Quick test
  - Analysis is straight forward
- Specimens were long-term aged prior to testing

Fracture Energy Results

- In most cases, Fracture Energy decreased with increasing RAP content
- "Good" Fracture Energy results can be obtained with high RAP mixes.
- Fracture Energy was higher for smaller NMAS mixes
- The effect of the virgin PG on Fracture Energy was inconsistent among the mix designs

Low Temperature Cracking

Testing and Analysis by Dr. Mihai Marasteanu

University of Minnesota

Low Temperature Cracking Analysis

- Semi-Circular Bend (SCB) test @ 3 temperatures
  - Fracture Toughness (K_{IC})
  - Fracture Energy (G_f)
- Bending Beam Rheometer on Mix Beams @ 2 temperatures
  - Creep Stiffness
  - m-value
- Mix Designs from MN, NH, and UT

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Low Temperature Cracking Results

- Fracture Toughness generally increases with higher RAP content and lower temperatures
- Fracture Energy generally decreases with higher RAP contents and lower temperatures
- Critical thermal cracking temperature is dominated by the virgin binder low PG
- Adequate thermal cracking resistance can be obtained with high RAP content mixes

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Preliminary Findings and Recommendations

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Preliminary Recommendations
RAP Management

- The goal for RAP Management is to achieve good consistency of the material characteristics. To measure "consistency", a QC plan must be used with a sampling and testing frequency commensurate with the proportion of the RAP in the mix design.

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Preliminary Recommendations
Handling RAP in the Lab

- RAP should be fan dried, not oven dried, before testing.
- Heating RAP samples for preparation of mix design specimens for less than 3 hours. One and a half hours was sufficient to bring RAP batch up to mixing temperature.

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Preliminary Recommendations
RAP Aggregate Gsb

- One method of determining RAP aggregate Gsb will not work for all material types. Agencies will need to evaluate options to find the best method for their materials.
- Do not use Gse. This will result in an error in VMA and the consequence will be "dry mixes".

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Preliminary Recommendations

Selecting the Virgin Binder Grade

- Use a lower PG grade when the recycled binder content is 25 percent or more of the total binder for surface layers and mixes at the bottom of the pavement structure. Although blending charts or equations may not be completely accurate, they provide a reasonable method to the selection of virgin binders.
- Using the normal binder grade with high RAP content mixes for intermediate pavement layers provides a structural benefit (high modulus mix).

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Mix Design for High RAP Contents

- Design mix to meet M 323
  - Moisture Susceptibility (always)
    - TSR or Hamburg
  - Permanent Deformation (mixes within top 100 mm)
    - AMPT Flow Number or APA
  - Fatigue (surface or base mixes) *for information purposes only*
    - Fracture Energy
  - Low Temperature (for cold climates)
    - SCB or BBR with mix beams

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Questions?

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