Understanding the Value of RAP:

OLDCASTLE MATERIALS
FEBRUARY 23, 2017
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Importance and Value of Increasing Binder Replacement
Every 0.1% liquid asphalt binder (i.e., AC) has impact of $0.43 per mix ton ($425 / ton AC)

- Contribution of liquid asphalt binder to total mix cost has increased dramatically
- The price of oil will eventually increase from the current low prices
- Asphalt binder is the main focus of mix engineering

Binder Replacement Represents Significant Opportunity

AC is 65 to 70% of Material Cost
Binder Replacement Represents Significant Opportunity

- Millions of Tons Available For Recycling in the United States
Binder Replacement Represents Significant Opportunity

- Value of Available Recycled Materials, $5.1 Billion

Value of Recycled Materials, Billions of Dollars

- RAP Aggregate: 1.5
- RAS Aggregate: 0.2
- RAP Binder: 2.1
- RAS Binder: 1.3
Binder Replacement Represents Significant Opportunity

  - Annual U.S. production of asphalt mix was 352 million tons for the 2014 construction season.
  - Contractors used 99.8% of the 76 million tons brought to their plants.
  - RAP conserved 20 million barrels of asphalt binder along with 68 million tons of virgin aggregate.
  - A combined savings of asphalt binder ($550/ton) and aggregate ($9.50/ton) by using RAP and RAS in asphalt mixes is more than $2.8 billion.
OMG produced 47.5M + tons in 2016

- Decreasing the liquid demand by 0.1%
  - 0.001 x $425 per ton liquid / ton x 47.5 M tons = $20,187,500 per year
Binder Replacement Represents Significant Opportunity

- Percent Energy Conserved
  - 15% RAP Conserves 5% Energy
  - 25% RAP Conserves 9% Energy
  - 40% RAP Conserves 15% Energy

- The Diversion of RAP and RAZ from landfills is estimated to save up to 34% of landfill space in the U.S.

- These savings are a result from reduced raw material production for aggregate and asphalt, as well as reduced transportation of raw material.

(Robinette & Epps, 2010)
Binder Replacement Represents Significant Opportunity

- Percent Emissions Reduction in CO$_2$eq
  - 15% RAP Reduces 5% Emissions
  - 25% RAP Reduces 9% Emissions
  - 40% RAP Reduces 15% Emissions

(Robinette & Epps, 2010)
Binder Replacement Represents Significant Opportunity

- Potential Cost Savings with RAP and RAS

<table>
<thead>
<tr>
<th>Reference</th>
<th>Material</th>
<th>Cost Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zhou et al. (2013b)</td>
<td>5% RAS</td>
<td>2–5%</td>
</tr>
<tr>
<td>Brock (2008)</td>
<td>20% RAP</td>
<td>&gt;16%</td>
</tr>
<tr>
<td></td>
<td>50% RAP</td>
<td>&gt;40%</td>
</tr>
<tr>
<td>NCAT (Willis et al., 2012)*</td>
<td>25% RAP</td>
<td>14–20%</td>
</tr>
<tr>
<td></td>
<td>50% RAP</td>
<td>29–35%</td>
</tr>
</tbody>
</table>

* Used different amounts and stiffness of virgin binders used in mixtures.
Why Focus on Binder Replacement?

- Asphalt content is the primary factor in asphalt mix cost
  - Should manage AC as a **valuable asset** in mixes
    - Use only what you need!
  - AC prices can be very high and can be volatile
Why Focus on Binder Replacement?
## Asphalt Binder Price Trend

![NJDOT Logo](https://example.com/njdot-logo.png)

**Transport Software**

### Asphalt Cement and Fuel Price Index

The Asphalt Price Index is the average of suppliers selling price in both North and South New Jersey. The Fuel Price Index is the average statewide selling price of Unleaded Regular Gasoline and Diesel Fuel.

Contractors and Estimators are to use the index price from the month before receipt of bids, regardless of posted date.

<table>
<thead>
<tr>
<th>Effective Date</th>
<th>Asphalt Cement North of Route 195</th>
<th>Asphalt Cement South of Route 195</th>
<th>Entire State Fuel</th>
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<tr>
<td></td>
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<tr>
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<tr>
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<td>$568.00</td>
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</tbody>
</table>
Asphalt Binder Price Trend

New Jersey Historical Asphalt Cement Prices

$100 Change in AC $ ~ $5 Mix Impact

http://www.state.nj.us/transportation/business/transport/PriceIndex.shtml
Oregon Monthly Asphalt Cement Material Price

![Graph showing monthly asphalt cement material prices from January 2007 to January 2017. The graph indicates fluctuations in price with a peak in January 2008 and a general downward trend towards January 2017.](image-url)
Figure 2-3. Kansas DOT Monthly Computed Asphalt Material Index, 2006–2016 (KDOT, 2016).
Aggregate Value ???

All Permit M1983065 Persigo Pit
ID = M1983065
Site Name = Persigo Pit
Permittee = Oldcastle SW Group, Inc. dba United Companies of Mesa County
Mine Type = SR
Status = Terminated

View Additional Details | Edit Feature
Aggregate Value ???

- using 21% RAP
- If future demand for aggregates do not deviate from current demands, in 100 years, approximately 20 years worth of aggregate will have been saved.
Recycled Asphalt Pavement (RAP)
RAP Sources

Pavement Milling

Asphalt Pavement Removal

Plant Waste Material
Millings

- Minimal Processing Required
- Potential Processing
  - Scalping
  - Fractionating
  - Typically no crushing is required
    - Best not to crush in order to keep minus 200 down
Millings and General RAP Piles
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.
- Treat recycled products during production the same as virgin aggregates.
  - At higher recycled percentages (~35 to 40%+), this is a MUST!
    - Cover/paved stockpiles
    - Multiple recycle bins
Minimize Contamination of RAP

- Contaminated RAP should not be tolerated.
- Monitor returned RAP to ensure no contamination (e.g., dirt, wood, plastic, other building debris, etc.) is present.
- If found, immediately remove from stockpile prior to further processing.
- **Better monitoring = better RAP = increased RAP asphalt and better binder replacement efficiency.**
This Has NO Place in any RAP Pile!
RAP Stockpile Management
Plant Waste

- Plant waste can and should be utilized
  - Process and blend material to provide desired consistency
- What type of waste?
  - Reject mix
  - Start up
  - Switch over
  - Clean out
- Asphalt coating?
  - Uncoated
  - Partially coated
  - Fully coated
RAP Inventory Analysis

- Purpose is to establish realistic goals for how much RAP can be used at a particular plant
- Analysis should include:
  - Inventory of RAP on hand and RAP generated per year
  - Summary of mix produced per year by mix types and customers
  - Determine the max amount of RAP that can be used
  - Comparison of the quantity of RAP available to the amount of RAP needed
**RAP Inventory Analysis**

- Simple spreadsheets can be developed to evaluate different use scenarios to identify the best case for individual plants.
  - Analysis should consider allowable RAP % by specifications and any plant limitations.
  - Analysis can show the maximum opportunity to use RAP.
  - Assists in managing stockpiles.
Single Source or Multiple Source RAP Stockpiles

- Initial RAP management decision is whether or not to create one or multiple RAP stockpiles based on following factors:
  - Agency specifications
    - RAP from other sources
    - Captive vs. Replenished stockpiles
  - Potential for contaminants
  - Space availability
  - Target use levels
  - RAP from a single project or multiple projects
Types of RAP Stockpiles

- Captive Stockpiles
  - Some agencies require no additional material can be added to a RAP stockpile once it is built and tested
  - Based on premise that the properties of the stockpile must be precisely known if it to be used
  - This requirement can be problematic if plant footprint is limited

- Continuously Replenished Stockpiles
  - Many agencies allow RAP stockpiles to be replenished with new material
    - Need to ensure RAP consistency through a RAP quality control plan
**Processing and Crushing RAP**

- Goals of processing RAP are to:
  - Create uniform stockpile from a collection of different RAP materials
  - Break apart large agglomerations of RAP particles to a size that can be used during production
  - Reduce the max aggregate size so RAP can be used in surface mixes
  - **Minimize** the generation of additional P200
    - Screening prior to crushing will help reduce unnecessary aggregate breakdown
Processing Millings

- Millings from single project are usually very consistent in:
  - Gradation
  - Binder content
  - Aggregate properties
  - Binder properties

- Processing may only be required to:
  - Eliminate agglomerations
  - Reduce max aggregate size
    - Reducing may be scalping and not crushing.

- Recommended Processing Options
  - Sample and test multiple locations of the millings stockpile to determine RAP quality
  - If the max aggregate size is too large either:
    - Fractionate the RAP for use in different mixes
    - Process by crushing to the desired aggregate size
Processing Millings

- It is considered a best practice *not* to further crush millings, but to use it “as is” in mix designs or to screen the milling to remove larger particles.

- Not all millings belong to contractors.
  - State may retain a portion (or all) in some cases.
OMG State of Practice – Millings Ownership

On the majority of DOT projects, who retains ownership of millings (RAP)?

- DOT retains 100% (43.4% (23))
- DOT splits 50/50 with contractor (18.9% (10))
- Contractor retains 100% (18.9% (10))
- Other (please specify)

Other Items:
- Contract / region specific (5)
- State keeps 25% (2)
- State keeps 75% (2)

OMG National Survey (April 2013)
Processing RAP From Multiple Sources

- RAP from multiple sources must be processed to create a uniform material
  - Data suggest very consistent material can be produced
- Key is careful blending as part of the processing operation
  - Bulldozer, excavator, loader can be used to blend materials from different areas of the stockpile
- In most cases, processed RAP will be moved to the plant site for convenient use
  - This is an opportunity to remix the RAP to improve its consistency
  - Use the loader to mix the RAP from different locations in the processed RAP stockpile
Fractionating RAP

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

- Typical Sizes
  - 3/4” – 3/8”
  - 3/8” – 3/16”
  - Minus 3/16”

- Fractionating increases RAP cost
  - Evaluate benefit/cost ratio

- When should fractionating be considered:
  - Plants can produce mixes with more than 20% RAP
  - Typical specifications allow more than 20% RAP
  - RAP is readily available
  - Plant site has space for multiple RAP stockpiles
  - Problems meeting mix design requirements
  - Problems meeting project QC requirements
Fractionating RAP

- Fractionating should not be mandated
  - It should be the contractor’s decision if and when to fractionate RAP based on ability to meet specification requirements (i.e., reward good contractor process control and decisions)
OMG National Survey (April 2013)

OMG State of Practice – Fractionating RAP

Do you normally fractionate your RAP? Note: Screening of the RAP over one screen (e.g., 1/2'') should not be considered fractionating for this survey.

- Yes: 18.9% (10)
- No: 81.1% (43)
OMG State of Practice – Why Fractionate RAP?

- Results from a OMG National Survey (April 2013)

Why do you fractionate RAP? (Select all that apply)

- Allows more or better RAP utilization in your mix types: 80.0% (8)
- To lower the RAP gradation variability: 40.0% (4)
- To lower the RAP asphalt content variability: 40.0% (4)
- Required by specification: 30.0% (3)
- Other (please specify): 10.0% (1)
OMG State of Practice – RAP Fractionating Cost

What is your average additional cost per ton for fractionating RAP?

- 3.50 $: 20.0% (2)
- 4.00 $: 20.0% (2)
- 0.25 $: 10.0% (1)
- 2.00 $: 10.0% (1)
- 2.50 $: 10.0% (1)
- 3.00 $: 10.0% (1)
- 3.25 $: 10.0% (1)
- 5.00 $: 10.0% (1)

Average Cost = $3.10

OMG National Survey (April 2013)
Stockpiling RAP

- Segregation Control
  - There is a potential for RAP to become segregated in stockpile
    - More common when:
      - Piles are built using fixed conveyors that allow RAP to drop long distances
      - Steep sided conical piles are built
  - Use of an indexing conveyor can be used to help eliminate pile segregation
Stockpiling RAP

- Moisture Control
  - Consider the following to reduce the moisture in RAP
    - Process RAP on an as needed basis when possible
    - Cover the processed material with a shelter or building
    - Place RAP in well built conical stockpile
    - Place on a paved sloped surface
    - Avoid depressions in piles which will accumulate water
Advantages and Disadvantages of Different RAP Processing Options

- When making your business decision on how to handle and process RAP to ensure you consider the advantages and disadvantages of each process
- Do not automatically assume one process will provide the maximum benefit and lowest cost

<table>
<thead>
<tr>
<th>Process</th>
<th>Possible Advantages</th>
<th>Possible Disadvantages</th>
</tr>
</thead>
</table>
| Use of Millings without Further Processing   | • Avoids further crushing of aggregate particles in RAP, which may allow higher RAP contents in mixes  
   • Lowest cost of RAP processing options  
   • Millings from large projects are likely to have a consistent gradation and asphalt content | • Requires multiple RAP stockpiles at the plant  
   • Millings from individual projects are different; therefore, when a particular millings stockpile is depleted, new mix designs must be developed with other RAP |
| Screening RAP Before Crushing                | • Limits crushing of aggregate particles in RAP, which reduces dust generation       | • Few RAP crushing and screening units are set up to pre-screen RAP                      |
| Crushing all RAP to a Single Size            | • Allows the processed RAP to be used in many different mix types  
   • Generally provides good uniformity from RAP materials obtained from multiple sources  
   • Large RAP stockpiles can be generated for annual production                      | • Tends to increase the dust content of RAP stockpiles, which may limit how much RAP can be used in mix designs |
| Fractionating RAP                            | • Using different sized RAP stockpiles provides greater flexibility in developing mix designs | • Requires the most space for multiple smaller stockpiles  
   • Most expensive processing option (cost of fractionation unit plus additional RAP cold feed bin)  
   • May generate an excess of a RAP size if the mix designs are not balanced to the RAP feed |
RAP Testing

- General properties:
  - Asphalt content
  - Aggregate gradation
  - Aggregate bulk specific gravity (Gsb)
  - Fine aggregate angularity
  - Fractured face count
  - Flat & elongated percentage
  - Deleterious materials
- Depending on agency specifications, aggregate source properties may also need to be tested
  - LA Abrasion
  - Sulfate Soundness
- For use of RAP in friction courses, additional aggregate properties such as acid insoluble, loss on ignition, or petrographic analysis may be needed.
RAP Asphalt Content

- Solvent extraction or ignition furnace can be used for asphalt content determination.
- Ignition method is generally the most accurate, most preferred and most commonly used. An aggregate correction factor must be assumed.
Accurate and Consistent $G_{sb}$ is Critical for VMA

Volumetric Bulk Specific Gravity Analysis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$G_{sb}$ True</td>
<td>2.650</td>
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<tr>
<td>Abs True (%)</td>
<td>0.50</td>
</tr>
<tr>
<td>AC (%)</td>
<td>5.00</td>
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<tr>
<td>Gmb</td>
<td>2.400</td>
</tr>
</tbody>
</table>

AASHTO T85 or ASTM C127 (Coarse Aggregate)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Std Dev (1σ)</th>
<th>Acceptable Range of 2 Results (d2s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Operator Precision</td>
<td>0.009</td>
<td>0.025</td>
</tr>
<tr>
<td>Multiop Precision (Gsb)</td>
<td>0.013</td>
<td>0.038</td>
</tr>
</tbody>
</table>

AASHTO T84 or ASTM C128 (Fine Aggregate)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Std Dev (1σ)</th>
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<tbody>
<tr>
<td>Single Operator Precision</td>
<td>0.011</td>
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<tr>
<td>Multiop Precision (Gsb)</td>
<td>0.023</td>
<td>0.066</td>
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</tbody>
</table>

Change in VMA with Respect to Bulk Specific Gravity

0.01 Change in $G_{sb}$ -- 0.3% Change in VMA

\[ VMA = 100 - \frac{G_{mb} P_s}{G_{sb}} \]
**RAP Grading**

- Sample and test RAP material to determine average grading and standard deviation.
- Use these data to determine potential impact on overall mix grading at various RAP addition percentages
  - Example: No. 8 standard deviation = 3.8%
    - 20% = 0.20 * 3.8% = 0.76% contribution of RAP to overall blend No. 8 deviation
    - 40% = 1.52%
This process establishes the initial baseline RAP properties for the stockpile.
RAP Stockpile Management and Production Testing Plan

Establish Initial Baseline RAP Stockpile Properties

- AC%
- Binder Grade
- Gradation

Questions Answered
1. Is a binder grade adjustment needed?
2. Is the RAP gradation variability acceptable?
3. Is the binder content variability acceptable?

Follow Up Testing on the RAP Stockpile
- e.g., 1 test per 1000 tons of RAP consumed
- AC% ➔ Gradation

Question Answered
Is the sampled RAP from the same population as the initial established baseline?

Evaluate Against Established Engineering Limits
Acceptable RAP Property Tolerances (i.e., Engineering Limits)?

- NCAT recommendations on RAP AC and grading.

<table>
<thead>
<tr>
<th>RAP property</th>
<th>Max. Standard Deviation (%)</th>
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</thead>
<tbody>
<tr>
<td>Asphalt Content</td>
<td>0.5</td>
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<tr>
<td>% Passing Median Sieve</td>
<td>5.0</td>
</tr>
<tr>
<td>% Passing 75 micron Sieve</td>
<td>1.0</td>
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</tbody>
</table>

- Can you make RAP with higher variability work?
  - Yes, but it becomes more difficult!
  - Increases risk of potential pay factor deductions.

- Must evaluate the use of any product (virgin or recycle) against downstream results (e.g., volumetrics, constructability, in-place density, re-work history, etc.)
Recommended RAP Sampling and Testing Guidelines

- NCAT recommendations on RAP sampling and testing. (From: NCHRP 9-46)

<table>
<thead>
<tr>
<th>Property</th>
<th>Test Method(s)</th>
<th>Frequency</th>
<th>Minimum Number of Tests per Stockpile</th>
<th>Maximum Standard Deviation</th>
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<td>AASHTO T 164 or AASHTO T 308</td>
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<td>0.5</td>
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<td>Recovered Aggregate Gradation*</td>
<td>AASHTO T 30</td>
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<td>10</td>
<td>5.0 all sieves 1.5 on 75 micron</td>
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<td>Recovered Aggregate Bulk Specific Gravity</td>
<td>AASHTO T 84 and T 85</td>
<td>1 per 3000 tons</td>
<td>3</td>
<td>0.030**</td>
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<td>Binder Recovery and PG Grading</td>
<td>AASHTO T 319 or ASTM D 5404 and AASHTO R 29</td>
<td>1 per 5000 tons</td>
<td>1</td>
<td>n.a.</td>
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* Samples for Superpave aggregate consensus properties or other aggregate testing needs may be obtained by combining the tested aggregates following sieve analyses.

**This is a preliminary value based on limited data and possible impacts to VMA for high RAP content mixes.
CDOT 401 Specification

May 2, 2013

REVISION OF SECTION 401
RECLAIMED ASPHALT PAVEMENT

Section 401 of the Standard Specifications is hereby revised for this project as follows:

Subsection (b) shall include the following:

Reclaimed Asphalt Pavement (RAP) is allowed in hot mix asphalt (HMA) up to a maximum binder replacement of 20 percent for all lifts, provided all specifications for HMA are met. Fine aggregate angularity requirements shall apply only to the virgin fraction of the fine aggregate. The RAP shall contain clay, silt, vegetable matter, or other deleterious substances, and must meet the uniformity requirements as outlined below.

HMA Project Verification Testing for asphalt content and gradation will be performed at the frequencies listed in the Field Materials Testing in accordance with CDOT 120.

The Contractor shall have an approach to design for the amount of RAP to be used. The AC content of the RAP utilized in the Contractor RAP mix design shall be the average AC content determined in accordance with CDOT 110 below, or alternatively, a minimum of five samples of the Contractor RAP stockpile may be submitted to the average AC content of the RAP be determined using AASHTO T-184, Method A or E, or in accordance with CDOT 110 below. The Contractor shall determine the total binder replaced by the binder in the RAP pursuant to the following equation:

Total Binder Replaced = (A x B x C) / 100

Where:

A = RAP % Binder Content *
B = RAP % in Mix *
C = Total Effective Binder Content

The Total Binder Replaced by the binder in the RAP shall not exceed 20 percent of the effective binder content of either the mix design or the predesign.

The use of RAP shall be coordinated in accordance with subsections 106.06 and 108.06. If the Contractor elects to use RAP, the following additional conditions shall apply:

1. The Contractor shall have an approved Quality Control (Q) Plan that details how the RAP will be processed and controlled. This Q Plan shall address the following:

   A. RAP Processing Techniques. This requires a schematic diagram and narrative that explains the processing (crushing, screening, and mixing) and storage operation for its specific projects.

   B. Control of RAP asphalt Binder Content. RAP binder content may be determined in accordance with CDOT 110. RAP asphalt Binder Content may also be determined in accordance with CDOT 120. The asphalt binder content correlation factor shall be determined through correlation testing with CDOT 120. Method A or B. The correlation factor shall be determined by performing correlation testing on the first five samples of the RAP asphalt content, then at a frequency of every five RAP stockpile samples. The correlation factor shall be determined by calculating the average difference in AC content between CDOT 120 and AASHTO T-184, Method A or E, and applying a correction to the AC content determined in accordance with CDOT 120. Frequency: 1/2000 pounds of processed RAP material (minimum five tests).

   C. (Alternate) The Contractor may propose a RAP asphalt content correction factor to be used in conjunction with CDOT 120. The proposed CDOT 120 RAP asphalt content correction factor shall be used with all RAP asphalt content tests to determine the mixture design and quality control sampling and testing.

The maximum aggregate size of the proposed RAP stockpile asphalt content correlation factor shall be outlined in detail in the proposed RAP QC Plan. At a minimum, the proposed CDOT 120 operation factors that identify the principal sources of variation in the RAP aggregates, gradation of the RAP materials, and specific ignitions of the asphalt binder used in all the RAP asphalt content testing. The RAP source.
CDOT 401 Specification

2

REVISION OF SECTION 401
RECLAIMED ASPHALT PAVEMENT

locations, material gradation, and specific equipment used shall substantiate the CRL 5120 asphalt content correction factor used for the testing. The substantiation must be from data gathered from historical information or specific asphalt content correction data obtained from tests performed on similar virgin aggregate sources, virgin material gradations, and the specific equipment used.

D. Control of RAP Gradation (CRL 5120-3A): Frequency: 1/1000 tons of processed RAP material (minimum three tests).

E. Process Control Charts shall be maintained for binder content and each screen sized in subsection 401.02(b). During addition of any RAP material to the stockpiles. The Contractor shall maintain separate control charts for each RAP stockpile. The control charts shall be displayed and shall be made available, along with RAP AC extraction testing laboratory reports to the Engineer upon request.

2. The processed RAP must be 100 percent passing the 31.5 mm (1¼ inch) sieve. The aggregate obtained from the processed RAP shall be 100 percent passing the 25.0 mm (1 inch) sieve. The aggregate and binder obtained from the processed RAP shall be uniform in all the measured parameters in accordance with the following:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binder Content</td>
<td>0.5</td>
</tr>
<tr>
<td>Percent Passing 19 mm (%)</td>
<td>4.0</td>
</tr>
<tr>
<td>Percent Passing 12.5 mm (%)</td>
<td>4.0</td>
</tr>
<tr>
<td>Percent Passing 6.3 mm (%)</td>
<td>4.0</td>
</tr>
<tr>
<td>Percent Passing 4.75 mm (%)</td>
<td>4.0</td>
</tr>
<tr>
<td>Percent Passing 2.36 mm (%)</td>
<td>4.0</td>
</tr>
<tr>
<td>Percent Passing 600 μm (#30)</td>
<td>3.0</td>
</tr>
<tr>
<td>Percent Passing 75 μm (#200)</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Uniformity is the maximum allowable standard deviation of test results of processed RAP.

3. If RAP millings generated are incorporated in the same project, in accordance with CRL 5146 the Contractor shall pave with a virgin mix design until sufficient amount of processed RAP has been stockpiled and tested to allow full production of a RAP HMA mix.
OMG State of Practice – DOT Method for Specifying Recycle

How does your state DOT limit the recycle (RAP and/or RAS) content in asphalt mixes? States use a variety of methods to specify recycle content. Two options are presented here: 1) percent total recycle and 2) percent virgin binder replacement. If your state DOT specification differs from these, please select the closest method to answer the questions. For example, your state may specify recycle based on the amount of binder contributed by recycle (e.g., 20% RAP w/ 5% AC = 1% binder contribution). In this case just select a method and the corresponding recycle contents that would be closest to your specification.
National Guidelines

- Currently AASHTO M323 provides guidance on the amount of RAP allowed.
- This guidance is a result of NCHRP 9-12 (Report 452, published in 2001).

<table>
<thead>
<tr>
<th>Recommended Virgin Asphalt Binder Grade</th>
<th>RAP Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>No change in binder selection</td>
<td>&lt; 15</td>
</tr>
<tr>
<td>Select virgin binder one grade softer than normal (e.g., select PG 58-28 if PG 64-22 would normally be used)</td>
<td>15–25</td>
</tr>
<tr>
<td>Follow recommendations from blending charts</td>
<td>&gt; 25</td>
</tr>
</tbody>
</table>

- As a result of more experience and research, many different RAP specifications are currently used by agencies and municipalities.
Recycling

FHWA Recycling Policy

FHWA recognize the need to increase our highway industry’s overall use of recycled materials. There are several reasons to be pro-recycle:

- Cost savings potential
- Life cycle cost and engineering performance
- Reduction in landfill
- Stewardship of our environment

FHWA’s Recycling Policy has several key points:

- Recycling can offer engineering, economic and environmental benefits.
- Recycled materials should get first consideration in overall materials selection.
- Engineering and environmental properties are important.
- Life Cycle Cost benefits assessment is warranted.
- Restrictions prohibiting recycled material that are without technical basis should be removed.
Considerations for Recycle Materials Mix Design

- Specification limits
- Gradation
- Aggregate consensus properties
- Binder properties
- Heating, drying, and exhaust capacity of the plant
- Moisture content of the RAP and virgin aggregates
- Temperature to which the virgin aggregate must be superheated
- Ambient temperature of the RAP and virgin aggregate
- Other factors
RAP and Virgin Aggregate: Consistency

- NCAT study evaluated 74 RAP stockpiles in 14 states, and 60 virgin aggregate stockpiles in 6 states
  - RAP was found to have lower grading variability
    - Is this surprising? Probably not, RAP has been sized and processed more than virgin aggregate
    - Is it always the case? No, but likely
  - What is your case?
Oldcastle - Northeast Division

- RAP #4 Variation (weighted by number of tests per location) = 5.1%
  - n = 744
- Stone #4 Variation (weighted by number of tests per location) = 6.9%
  - n = 2983
OMG State of Practice – RAP and Virgin Aggregate Variability

How does your RAP gradation variability compare to virgin aggregate variability in your area?

- 47.2% (25)
- 26.4% (14)
- 26.4% (14)

- RAP variability is higher than virgin aggregate
- RAP variability is the same as virgin aggregate
- RAP variability is lower than virgin aggregate

OMG National Survey (April 2013)
Fractionated RAP is Not Always More Consistent

- NCAT RAP Study Data (fractionated vs unfractionated RAP)
Estimated RAP Use in the U.S.

- Percentages based on reported total HMA and RAP tons.

**Figure 6: Estimated Average Percent of RAP by State**

From: NAPA Information series 138
Estimated RAP Use in the U.S.

- Percentages based on reported total HMA and RAP tons.

Figure 3: RAP Use by Sector (Million Tons)

Figure 4: Average Percent RAP Used by Sector

From: NAPA Information series 138
What is the optimal combination of RAP?

- Depends on many factors including virgin asphalt binder cost, asphalt binder contribution from RAP, virgin aggregate cost, plant type/setup, specification allowances, total cost of RAP, etc.
- Do not blindly assume that one certain combination is the best.
- Take time to analysis the economics to optimize the cost savings per mix ton.
- Recycle optimizer is available for use.
Example Blended Binder PG Grading

- Example blended binder grades for various combinations of RAP and RAS.
- From: Oregon State University, Report OR-RD-10-12, February 2010.

Table 3.8: Effect of Reclaimed Materials on the PG Grade of the Blended Binder

<table>
<thead>
<tr>
<th>Percentage of Reclaimed Material in Batched Mixture</th>
<th>Superpave PG Grade (AASHTO M 320) of Recovered Binder</th>
<th>Change in High Temp. Grade</th>
<th>Change in Low Temp. Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAP</td>
<td>RAS</td>
<td>PG64-28</td>
<td>-1</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>PG88(^3)-22</td>
<td>+3</td>
</tr>
<tr>
<td>0</td>
<td>5</td>
<td>PG70-28</td>
<td>+0</td>
</tr>
<tr>
<td>10</td>
<td>5</td>
<td>PG82-22</td>
<td>+2</td>
</tr>
<tr>
<td>20</td>
<td>5</td>
<td>PG88(^3)-16</td>
<td>+3</td>
</tr>
<tr>
<td>30</td>
<td>5</td>
<td>PG88(^3)-16</td>
<td>+3</td>
</tr>
<tr>
<td>40</td>
<td>5</td>
<td>PG82-16</td>
<td>+2</td>
</tr>
<tr>
<td>50</td>
<td>5</td>
<td>PG82-16</td>
<td>+2</td>
</tr>
</tbody>
</table>

1 As-Received Virgin Binder Grade = PG70-28
2 Extrapolated 1 PG grade above the highest temperature grade in AASHTO M 320
### United’s RAP PG Grading

#### United Companies

**Project:** United Companies

**Sample ID:** 1096 Gymanum T14 RAP

---

**Superpave Asphalt Binder Grading Summary**

**AASHTO M320**

<table>
<thead>
<tr>
<th>Test Method</th>
<th>Test Results</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Limit</td>
<td>81.5</td>
<td>81.5</td>
</tr>
<tr>
<td>Upper Limit</td>
<td>13.0</td>
<td>13.0</td>
</tr>
</tbody>
</table>

#### Dynamic Mix Design Results

<table>
<thead>
<tr>
<th>Test Method</th>
<th>Test Results</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Limit</td>
<td>81.5</td>
<td>81.5</td>
</tr>
<tr>
<td>Upper Limit</td>
<td>13.0</td>
<td>13.0</td>
</tr>
</tbody>
</table>

### Oldcastle Materials
United’s RAP PG Grading

**Superpave Asphalt Binder Grading Summary**

<table>
<thead>
<tr>
<th>Test Method</th>
<th>Test Results</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic Shear Rheometer T 312</td>
<td>Phase Angle</td>
<td>68.3</td>
</tr>
<tr>
<td>Test Temperature, °C</td>
<td>53</td>
<td>1.92</td>
</tr>
<tr>
<td>Phase Angle, °</td>
<td></td>
<td>1.92</td>
</tr>
<tr>
<td>Direct Shear Rheometer T 263</td>
<td>Phase Angle</td>
<td>59.1</td>
</tr>
<tr>
<td>Test Temperature, °C</td>
<td>75</td>
<td>1.92</td>
</tr>
<tr>
<td>Phase Angle, °</td>
<td></td>
<td>1.92</td>
</tr>
<tr>
<td>Rolling Thin Film (RTF0) TPS Aged Binder, AASHTO T 240</td>
<td>Phase Angle</td>
<td>62.5</td>
</tr>
<tr>
<td>Test Temperature, °C</td>
<td>75</td>
<td>1.92</td>
</tr>
<tr>
<td>Phase Angle, °</td>
<td></td>
<td>1.92</td>
</tr>
<tr>
<td>Masu Change, %</td>
<td>26</td>
<td>1.92</td>
</tr>
<tr>
<td>Dynamic Shear Rheometer AASHTO T 311</td>
<td>Phase Angle</td>
<td>59.1</td>
</tr>
<tr>
<td>Test Temperature, °C</td>
<td>75</td>
<td>1.92</td>
</tr>
<tr>
<td>Phase Angle, °</td>
<td></td>
<td>1.92</td>
</tr>
<tr>
<td>Direct Shear Rheometer T 263</td>
<td>Phase Angle</td>
<td>59.1</td>
</tr>
<tr>
<td>Test Temperature, °C</td>
<td>75</td>
<td>1.92</td>
</tr>
<tr>
<td>Phase Angle, °</td>
<td></td>
<td>1.92</td>
</tr>
<tr>
<td>Rolling Thin Film (RTF0) TPS Aged Binder, AASHTO T 240</td>
<td>Phase Angle</td>
<td>62.5</td>
</tr>
<tr>
<td>Test Temperature, °C</td>
<td>75</td>
<td>1.92</td>
</tr>
<tr>
<td>Phase Angle, °</td>
<td></td>
<td>1.92</td>
</tr>
<tr>
<td>Masu Change, %</td>
<td>26</td>
<td>1.92</td>
</tr>
</tbody>
</table>

**Test Method**

- **DST Original Tcomp**: Temperature at which $G' = 11.1$ kPa
- **DST RTF0 Tcomp**: Temperature at which $G' = 0.04$ kPa
- **DST PAV Tcomp**: Temperature at which $G' = 3.3$ kPa

**Results**

- DST Original Tcomp: 78.2°C
- DST RTF0 Tcomp: 77.9°C
- DST PAV Tcomp: 46.8°C

**PG Grade**: 76 - 28

*All included and low temperature tests performed using RTF0 aged RAP binder*
United’s RAS PG Grading

**Table: Superpave Asphalt Binder Grading Summary**

<table>
<thead>
<tr>
<th>Test Method</th>
<th>Test Results</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic Shear Rheometer AASHTO T 215*</td>
<td>(Test Temperature, °C)</td>
<td>G' (kPa)</td>
</tr>
<tr>
<td></td>
<td>162</td>
<td>19.9</td>
</tr>
<tr>
<td></td>
<td>140</td>
<td>8.27</td>
</tr>
<tr>
<td>Dynamic Shear Rheometer AASHTO T 313*</td>
<td>(Test Temperature, °C)</td>
<td>G' (kPa)</td>
</tr>
<tr>
<td></td>
<td>22</td>
<td>11590</td>
</tr>
<tr>
<td></td>
<td>29</td>
<td>11990</td>
</tr>
<tr>
<td>Bending Beam Rheometer (BBR) AASHTO T313*</td>
<td>(Test Temperature, °C)</td>
<td>Rf (mm)</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>92</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>135</td>
</tr>
<tr>
<td>rut Grade</td>
<td>136.0</td>
<td>17.0</td>
</tr>
<tr>
<td>PG Grade</td>
<td>154 + 20</td>
<td></td>
</tr>
</tbody>
</table>

*All tests performed using unaged RAS binder

2. DSR RTFO: \(T_{50}\)
   Temperature at which \(G'/G" = 2.00 \text{ kPa}\)
   \(139.0\)

3. DSR FAD: \(T_{90}\)
   Temperature at which \(G'/G" = 5.00 \text{ kPa}\)
   \(11.0\)

4. BBR FAD: \(T_{90}\)
   Temperature at which \(E = 200 \text{ Mpa}\)
   \(22.5\)
   Temperature at which \(n = 0.100\)
   \(27.4\)
### United’s RAP PG Grading

<table>
<thead>
<tr>
<th>River Road</th>
<th>Upper</th>
<th>Lower</th>
<th>Percent Rap</th>
<th>Percent Oil in RAP</th>
<th>Target total Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAP</td>
<td>88</td>
<td>-10</td>
<td>20.0%</td>
<td>4.54%</td>
<td>5.4%</td>
</tr>
<tr>
<td>Virgin Oil</td>
<td>64</td>
<td>-22</td>
<td>Oil From RAP</td>
<td>Virgin Oil</td>
<td></td>
</tr>
<tr>
<td>Actual</td>
<td>68</td>
<td>-20</td>
<td>0.91%</td>
<td>4.49%</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Percent oil from RAP</th>
<th>Percent oil from Virgin</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.81%</td>
<td>83.19%</td>
</tr>
</tbody>
</table>
Many DOTs require PG binder grade bumping at higher levels of recycle

- Typically, this is a one grade bump down for the high and low temperature grades.
  - Example: PG 64-22 bumped to a PG 58-28
    - PG 58-28 is the most common bumped grade reported by OMG companies

- The decision to use more recycle must be evaluated against the cost of the bumped PG binder grade.

- Cost increase will vary
  - Can be the same price or greater than $200 per ton
  - $110 is the average increased cost for bumped grade reported by OMG companies
Pay Attention to the Economics of PG Grade Bumping

- Recycle use must be compared with the potential increase in the new binder cost.
- Example: RAP increased from 15 to 25% with required PG binder bump from 64-22 to 58-28. Economics remain more favorable with **15% RAP**.

<table>
<thead>
<tr>
<th></th>
<th>Base Case</th>
<th>Bumped Binder Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Binder %</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>PG 64-22 cost / ton</td>
<td>550</td>
<td>PG 58-28 cost / ton</td>
</tr>
<tr>
<td>Cost Virgin Aggregate / ton</td>
<td>12.00</td>
<td>Cost Virgin Aggregate / ton</td>
</tr>
<tr>
<td>Cost of RAP / ton</td>
<td>5.00</td>
<td>Cost of RAP / ton</td>
</tr>
<tr>
<td>RAP AC, %</td>
<td>5.0</td>
<td>RAP AC, %</td>
</tr>
<tr>
<td>Percent RAP Used</td>
<td>15.0</td>
<td>Percent RAP Used</td>
</tr>
<tr>
<td>RAP Binder, %</td>
<td>0.75</td>
<td>RAP Binder, %</td>
</tr>
<tr>
<td>Virgin Binder, %</td>
<td>4.25</td>
<td>Virgin Binder, %</td>
</tr>
<tr>
<td>Virgin Liquid cost / mix ton</td>
<td>23.38</td>
<td>Virgin Liquid cost / mix ton</td>
</tr>
<tr>
<td>Virgin Aggregate cost / mix ton</td>
<td>10.29</td>
<td>Virgin Aggregate cost / mix ton</td>
</tr>
<tr>
<td>RAP cost / mix ton</td>
<td>0.75</td>
<td>RAP cost / mix ton</td>
</tr>
<tr>
<td>Materials Cost / mix ton</td>
<td>34.42</td>
<td>Materials Cost / mix ton</td>
</tr>
<tr>
<td></td>
<td>Cost Differential</td>
<td>0.73</td>
</tr>
</tbody>
</table>
Pay Attention to the Economics of PG Grade Bumping

- Recycle use must be compared with the potential increase in the new binder cost
- Example: RAP increased from 15 to 30% with required PG binder bump from 64-22 to 58-28. Economics now more favorable with **30% RAP**.

<table>
<thead>
<tr>
<th></th>
<th>Base Case</th>
<th>Bumped Binder Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Binder %</td>
<td>5.0</td>
<td>Design Binder %</td>
</tr>
<tr>
<td>PG 64-22 cost / ton</td>
<td>550</td>
<td>PG 58-28 cost / ton</td>
</tr>
<tr>
<td>Cost Virgin Aggregate / ton</td>
<td>12.00</td>
<td>Cost Virgin Aggregate / ton</td>
</tr>
<tr>
<td>Cost of RAP / ton</td>
<td>5.00</td>
<td>Cost of RAP / ton</td>
</tr>
<tr>
<td>RAP AC, %</td>
<td>5.0</td>
<td>RAP AC, %</td>
</tr>
<tr>
<td>Percent RAP Used</td>
<td>15.0</td>
<td>Percent RAP Used</td>
</tr>
<tr>
<td>RAP Binder, %</td>
<td>0.75</td>
<td>RAP Binder, %</td>
</tr>
<tr>
<td>Virgin Binder, %</td>
<td>4.25</td>
<td>Virgin Binder, %</td>
</tr>
<tr>
<td>Virgin Liquid cost / mix ton</td>
<td>23.38</td>
<td>Virgin Liquid cost / mix ton</td>
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<tr>
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<td>10.29</td>
<td>Virgin Aggregate cost / mix ton</td>
</tr>
<tr>
<td>RAP cost / mix ton</td>
<td>0.75</td>
<td>RAP cost / mix ton</td>
</tr>
<tr>
<td>Materials Cost / mix ton</td>
<td>34.42</td>
<td>Materials Cost / mix ton</td>
</tr>
</tbody>
</table>

**Cost Differential**

-1.24
Challenges and Obstacles to Increasing Binder Replacement Through Recycle

- External Challenges
  - Restrictive (many times - archaic) specifications
  - Partial credit given for AC in RAP
  - Escalator not applied to AC in RAP
  - Bad RAP experience by agencies
    - Some agencies still remember bad RAP projects from 30 years ago.
    - Agency fear of high RAP variability (e.g., large stockpiles)
  - SHOW the agency that your variability is acceptable
  - DO NOT just say it’s OK
  - Strongly encourage partnering with DOT
Challenges and Obstacles to Maximize Recycle Use and Increase Binder Replacement

Please rank the following factors in terms of their limiting impact on your ability to maximize recycle use and increase binder replacement. (1 = most limiting impact, 10 = least limiting impact)

- Agency specifications: 3.74
- RAS availability: 4.66
- Mix design volumetrics/issus: 4.34
- RAP availability: 5.23
- Plant issues (i.e., limited recycle bins, fighting...): 5.49
- Customer pushback: 5.58
- Asphalt binder “bumped grade” cost: 5.82
- Asphalt binder “bumped grade” availability: 6.08
- Plant footprint area: 6.4
- Air permit restrictions: 7.25

(Bar chart showing the rankings)
Challenges and Obstacles to Increasing Binder Replacement Through Recycle

- Internal Obstacles
  - **COMPLACENCY**
    - Norman Vincent Peale said “Opportunities are usually disguised as hard work, so most people don't recognize them.”
  - **COMMUNICATION**
    - Various LOBs need to work together instead of being independent
    - “Who makes the final call on producing a high RAP mix?”
    - Designer can set the table with a mix design, but then what?
    - Remember, we are all on the same team!
More Questions/Thoughts Regarding Recycle Use

- Is there an adequate supply of recycle?
  - If not, what can be done to increase supply?
  - Do not pass up opportunities to obtain good quality recycle

- Maximize opportunity with regards to specifications/production/laydown
  - **Do not** fall victim to historical thoughts on recycle use

“A Pessimist is one who makes difficulties of his opportunities, and an optimist is one who makes opportunities of his difficulties.”

Harry S Truman
Information From NAPA

Use of RAP & RAS in High Binder Replacement Asphalt Mixtures: A Synthesis

Best Practices for RAP and RAS Management

High RAP Asphalt Pavements: Japan Practice — Lessons Learned

Oldcastle Materials
Thank You!