Performance of Bottom Ash Asphalt Mixes

Symposium on Prediction of Pavement Performance

June 24, 2004
Cheyenne, WY

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George Huntington, P.E.
University of Wyoming
Overview

- Bottom Ash: The Disposal Problem
- Materials and Laboratory Testing
  - Superpave Mix Design
  - Georgia Loaded Wheel Test (GLWT)
  - Thermal Stress Restrained Specimen Test (TSRST)
  - Tensile Strength Ratio (TSR)
- Field Test Site
  - Construction Methods
  - Falling Weight Deflectometer (FWD)
  - Pavement Condition Index (PCI)
- Economics
Coal Ash

- 78 million tons per year in the USA
- Bottom Ash – 20%
- Fly Ash
  - the other 80%
  - lighter material carried through the furnace and collected by precipitators
Bottom Ash

- Slag that builds up on the heat absorbing surfaces of the furnace, then falls to the bottom and is collected in a hopper.
- Most Wyoming bottom ash is wet bottom ash, sometimes referred to as boiler slag.
  - Material that falls from the furnace into water in a molten state.
Bottom Ash Gradations

Sieve (0.45 Power Curve)

Percent Passing

Ash Source
- DJ
- JB
- LR

#200 #30 #4 1/2" 1"

Sieve (0.45 Power Curve)
Coal Ash Disposal

“It’s time to recognize coal plant waste disposal facilities for what they are – huge, unregulated toxic dumps…Some of Pennsylvania’s dumps are nothing more than abandoned strip mine pits and mine shafts where the waste pollutes the groundwater Pennsylvanians depend on for drinking and agriculture.”

Joseph Minott, Executive Director, Clean Air Council
Bottom Ash Uses

- Structural fills
- Road bases and subbases
- Asphalt filler
- Roofing granules
- Sand-blasting grit
- Snow and ice control
- Filtration
- Aggregate in concrete products
Research Objective

- Evaluate the performance and feasibility of using Wyoming bottom ash in asphalt mixes
  - Laboratory study
  - Field study
    - Warlow Drive in Gillette, Wyoming
Bottom Ash Sources

- **Dave Johnston Power Plant (DJ)**
  - Glenrock, Wyoming
- **Jim Bridger Power Plant (JB)**
  - Point of Rocks, Wyoming
- **Laramie River Power Plant (LR)**
  - Wheatland, Wyoming
Aggregates

- Limestone
  - Coarse aggregate
    - Pete Lien, Sundance, Wyoming
  - Crushed fines
    - Pete Lien, Rapid City, South Dakota
  - Most test results available
  - Field test section placed in 2002

- Granite
  - Lewis and Lewis, Southwestern Wyoming
  - Testing has begun
Asphalt and Lime

**Asphalt**
- PG 64-22 from the Sinclair refinery in Casper, Wyoming

**Lime**
- 1% hydrated lime slurry
- Pete Lien, Rapid City, South Dakota
Aggregate Testing

- Aggregate and Bottom Ash
  - Gradation
  - Specific Gravity
  - Absorption
  - Magnesium sulfate soundness

- Coarse aggregate
  - LA Abrasion tests
Mix Designs

- 8 Superpave Level I mix designs
  - 75 gyrations
- Control and with 15% bottom ash
  - Control, no bottom ash
  - 15% DJ (Dave Johnston) bottom ash
  - 15% JB (Jim Bridger) bottom ash
  - 15% LR (Laramie River) bottom ash
- Blended to get similar gradations
- 4.0% Air Voids
## Aggregate Qualification Test Results

<table>
<thead>
<tr>
<th>Source</th>
<th>Specific Gravity</th>
<th>Sand Equivalent</th>
<th>Flat + Elongated</th>
<th>Aggregate Angularity</th>
<th>Fine Aggregate Faces</th>
<th>Abrasion Fractured</th>
<th>L.A. Abrasion</th>
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<tbody>
<tr>
<td></td>
<td>coarse</td>
<td>fine</td>
<td>combined</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Granite</td>
<td>2.584</td>
<td>2.594</td>
<td>2.586</td>
<td>74</td>
<td>0</td>
<td>47</td>
<td>100</td>
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<tr>
<td>Limestone</td>
<td>2.666</td>
<td>2.608</td>
<td>2.631</td>
<td>79</td>
<td>5</td>
<td>46</td>
<td>100</td>
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</table>
Limestone JMF (0.45 Curve), including 15% bottom ash

<table>
<thead>
<tr>
<th>Sieve</th>
<th>Percent Passing</th>
</tr>
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<tbody>
<tr>
<td>#200</td>
<td>3/4&quot;</td>
</tr>
<tr>
<td>#100</td>
<td>1/2&quot;</td>
</tr>
<tr>
<td>#50</td>
<td>#16</td>
</tr>
<tr>
<td>#30</td>
<td>#8</td>
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<tr>
<td>#16</td>
<td>#4</td>
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<tr>
<td>#50</td>
<td>3/8&quot;</td>
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<tr>
<td></td>
<td>Control</td>
</tr>
<tr>
<td></td>
<td>DJ</td>
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<tr>
<td></td>
<td>JB</td>
</tr>
<tr>
<td></td>
<td>LR</td>
</tr>
</tbody>
</table>

Sieve size and percent passing correlation.
Granite JMF (0.45 Curve), including 15% bottom ash

<table>
<thead>
<tr>
<th>Sieve</th>
<th>#200</th>
<th>#30</th>
<th>#16</th>
<th>#8</th>
<th>#4</th>
<th>3/8&quot;</th>
<th>1/2&quot;</th>
<th>3/4&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent Passing</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Control</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>DJ</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JB</td>
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<td></td>
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<tr>
<td>LR</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Sieve sizes:
- #200: 1/2" (0.5"
- #30: 3/8" (0.375"
- #16: 1/4" (0.25"
- #8: 5/32" (0.156"
- #4: 3/64" (0.047"
- #100: 3/4" (0.75"
- #50: 1/16" (0.062"
- #16: 1/32" (0.031"
- #1" (0.333"
- #3/8" (0.375"
- #1/2" (0.5"
- #3/4" (0.75"

Legend:
- Green diamond: Control
- Yellow square: DJ
- Red triangle: JB
- Green circle: LR
## Mix Design Summary (4.0% Air Voids)

<table>
<thead>
<tr>
<th>MIX</th>
<th>Asphalt Content, %</th>
<th>Bulk Density, pcf</th>
<th>Maximum Density, pcf</th>
<th>VMA, %</th>
<th>VFA, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limestone Control</td>
<td>4.6</td>
<td>150.5</td>
<td>156.8</td>
<td>12.6</td>
<td>68.8</td>
</tr>
<tr>
<td>LS &amp; 15% DJ BA</td>
<td>6.1</td>
<td>146.4</td>
<td>152.4</td>
<td>15.6</td>
<td>73.9</td>
</tr>
<tr>
<td>LS &amp; 15% JB BA</td>
<td>5.2</td>
<td>144.8</td>
<td>150.8</td>
<td>15.3</td>
<td>83.3</td>
</tr>
<tr>
<td>LS &amp; 15% LR BA</td>
<td>5.7</td>
<td>147.8</td>
<td>154.0</td>
<td>14.6</td>
<td>72.9</td>
</tr>
<tr>
<td>Granite Control</td>
<td>5.5</td>
<td>144.6</td>
<td>150.6</td>
<td>15.3</td>
<td>74.0</td>
</tr>
<tr>
<td>GR &amp; 15% DJ BA</td>
<td>6.2</td>
<td>142.8</td>
<td>148.9</td>
<td>15.3</td>
<td>73.0</td>
</tr>
<tr>
<td>GR &amp; 15% JB BA</td>
<td>6.2</td>
<td>139.5</td>
<td>145.8</td>
<td>16.1</td>
<td>75.0</td>
</tr>
<tr>
<td>GR &amp; 15% LR BA</td>
<td>6.0</td>
<td>142.9</td>
<td>149.4</td>
<td>15.2</td>
<td>72.0</td>
</tr>
</tbody>
</table>
Laboratory Evaluation: Mix Types

- Lab mixed and Superpave gyratory compacted specimens
- Plant mixed and lab compacted specimens
- Plant mixed and field compacted specimens
Laboratory Evaluation: Performance Tests

- Rutting
  - Georgia Loaded Wheel Test, GLWT

- Low Temperature Cracking
  - Thermal Stress Restrained Specimen Test, TSRST

- Stripping
  - Tensile Strength Ratio, TSR (Lottman Test, 15 cycles)
Georgia Loaded Wheel Test (GLWT)

- Cylindrical specimen 3” tall, 6” diameter
- 100# load on a pneumatic linear hose pressurized to 100 psi
- 150°F inside the chamber
- Load applied by an aluminum wheel onto the hose, which rests on the specimen
- Rut depths measured at pre-determined numbers of cycles
Georgia Loaded Wheel Tester
Georgia Loaded Wheel Tester
Thermal Stress Restrained Specimen Test (TSRST)

- Evaluates low temperature cracking
- Specimen is cooled, developing tensile stresses
  - 10” long by 2” diameter specimen
  - Ends restrained
  - Specimen cooled at 16°F/hr
  - Temperature and load at failure recorded
Thermal Stress Restrained Specimen Test
Thermal Stress Restrained Specimen Test
TSRST Failure Temperatures

-40
-30
-20
-10
0

Lab Mixed and Compacted
Plant Mixed and Field Compacted

°F

Control
DJ
JB
LR
TSRST Failure Stresses

- Lab Mixed and Compacted
- Plant Mixed and Field Compacted

Tensile Stress, psi

- Control
- DJ
- JB
- LR
Indirect Tensile Strength Test

- Lottman Test
  - 15 cycles
- AASHTO T 283
  - Modified Lottman
  - Single cycle
Indirect Tensile Strength Test

- Specimens in subsets
  - One tested dry
  - One tested after conditioning

- Conditioning
  - Vacuum out air and replace with water
  - Leave in water at 140°F for 24 hours
  - Freeze at 5°F then back to 140°F water for 24 hours
  - May repeat for multiple cycles
Tensile Strength Ratio (TSR)

Specimens compressed between bearing plates on the diameter of the specimen until cracks appear, indicating tensile failure

$$\text{TSR} = \frac{S_c}{S_d}$$

- $S_c$ = tensile strength of conditioned subset
- $S_d$ = tensile strength of unconditioned subset

WYDOT considers a TSR > 75% a pass
Tensile Strength Retained: Lab Mixes

Cycles

TSR

0 4 8 12 16

100%
90%
80%
70%
60%
50%

Control
DJ
JB
LR
Tensile Strength Retained: Plant & Field Mixes

![Graph showing Tensile Strength Retained for different mixes over cycles](image_url)
Field Evaluation

CITY OF GILLETTE
WARLOW DRIVE
(GURLEY AVE. TO CITY LIMITS)
(01EN80)

PROJECT FUNDING:
State Grant Funding: $271,000
Local 1% Sales Tax: $450,000

Contractor: Cundy Asphalt Paving Construction, Inc.
Engineer: Consolidated Engineers, Inc.

SEP 24 2002
Hot Plant

- 15% bottom ash added through its own cold feed bin
- Lime slurry added
Construction

- Mill 3” of existing 8” of asphalt pavement
- Additional milling at wide cracks
  - Place PavePrep® fabric
  - Place 3/4” hot mix and compact
- Tack and paving fabric
- Place 3” of plant mix
- Four 800’ test sections
  1 – Control, 3 – 15% bottom ash
Rotomilled Surface
Milled Pavement and PavePrep®
Placing hot mix over PavePrep®
Compacting over patched areas
Tack and Paving Fabric
Compaction
Finished Pavement
Post-Construction Field Evaluation

- **FWD Testing**
  - Measure of structural integrity of the pavement
  - Tested before and after the overlay

- **Pavement Condition Index (PCI)**
  - Measure of pavement performance
  - To be performed
Falling Weight Deflectometer (FWD)
FWD Load Plate Deflections

Deflection, mils

Green: After Overlay
Red: Before Overlay
FWD 12" Sensor Deflections

Green: After Overlay

Red: Before Overlay
Pavement Condition Index (PCI)

<table>
<thead>
<tr>
<th>PCI</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 - 85</td>
<td>Excellent</td>
</tr>
<tr>
<td>85 - 70</td>
<td>Very Good</td>
</tr>
<tr>
<td>70 - 55</td>
<td>Good</td>
</tr>
<tr>
<td>55 - 40</td>
<td>Fair</td>
</tr>
<tr>
<td>40 - 25</td>
<td>Poor</td>
</tr>
<tr>
<td>25 - 10</td>
<td>Very Poor</td>
</tr>
<tr>
<td>10 - 0</td>
<td>Failed</td>
</tr>
</tbody>
</table>

Pavement surface condition survey
ASTM D 6433
## PCI: Warlow Drive

<table>
<thead>
<tr>
<th>Survey</th>
<th>PCI</th>
<th>Pavement Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Paving: October 2002</td>
<td>54</td>
<td>Fair</td>
</tr>
<tr>
<td>6 months: April 2003</td>
<td>99</td>
<td>Excellent</td>
</tr>
<tr>
<td>12 months: October 2003</td>
<td>90</td>
<td>Excellent</td>
</tr>
</tbody>
</table>
Economic Considerations

- Increased asphalt costs
  - 0.5% to 1.5% asphalt content increase

- Reduced aggregate costs
  - 15% of aggregate replaced with bottom ash

- Does higher asphalt content lead to improved durability?
  - Similar benefits to using fewer gyrations for low volume roads during Superpave mix design
Asphalt contents for bottom ash mixes are 0.5% to 1.5% higher than for the control mixes.
Summary: Performance Tests

- GLWT indicates that the Control and LR sections should have better rut resistance.
- TSRST results are inconclusive in predicting thermal cracking.
  - The lab mix results indicate thermal cracking at higher temperatures for the bottom ash mixes, but this is not reflected in the field mix results.
- TSR indicates the JB bottom ash may be more vulnerable to stripping.
FWD results indicate better structural improvements for the JB and DJ mixes than for the control and LR mixes.

Evaluating the long-term performance of the test sections should give an indication of how bottom ash pavements perform:
- FWD
- Pavement Condition Index (PCI)
Implementation

If the performance of the bottom ash pavements is similar to other pavements, initial material costs will dictate whether bottom ash pavements are cost effective.

- Bottom ash cost
  - Purchase
  - Haul
  - Disposal

- Aggregate and asphalt costs
  - Purchase
  - Haul
Questions?