The Use of Fly Ash for In-Situ Recycling of Asphalt Concrete Pavements

Presented by:
Tim Muehlfeld, PE
We Energies

Workshop on Green Construction Materials
Using Coal Combustion Products
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Milwaukee, Wisconsin
Asphalt Deterioration
Alligator Cracking

Potholes
Cold In Place Recycling of Asphalt
Full Depth Reclamation
Basic Procedure

- Existing layers of hot mix asphalt (HMA) are pulverized, graded and compacted for use as base layer
- Cementitious Class C fly ash or Pozzolanic Class F fly ash with a CaO additive is integrated in-situ
- A new surface layer is applied
Case Study #1

The CIR process was tested on a 2.4 km (1.5 mile) portion of road in Mequon, Wisconsin during the Summer of 1997.
Background on Highland Avenue

• Two lane rural road approximately 12.9 km (8 mile) long in Southeastern Wisconsin

• Average Daily Traffic of 1150 cars/day (AADT 1150)

• Light truck traffic

• Average asphaltic surface thickness was 140 mm (5-1/2 inches)

• Average aggregate base thickness was between 178 mm and 457 mm (7 and 18 inches)
CIR Process

- Initial Pavement Pulverization
- Fly Ash Binder Addition
- Repulverization/Mixing
- Reshaping and Compacting
- New HMA Wearing Surface
• Pulverize existing HMA pavement to a depth of 203 mm (8 inches)
• Grade and compact materials following standard procedures
Pleasant Prairie Class C fly ash is applied over the surface of the pulverized CIR base by a spreader truck at a rate of 19 kg/sq m (35 lb/sq yd)
Water applied at rate of 36.2 ltrs/sq m (8 gal/sq yd) and base is repulverized to incorporate moistened fly ash into base.
Repulverized base is compacted and shaped with a grader.
The 203 mm (8 inch) thick stabilized base is graded and compacted to 178 mm (7 inches)

The pavement is completed with a 102 mm (4 inch) HMA surface
Fly Ash Content

- 5.5% - 8.5% FA
- 4.0% - 6.0% MC
Compactive Effort

- **Standard Proctor**
  2191 kg/cu meter
  (136.8 pcf) max dry density

- **Marshall Compaction**
  35 blows
Structural Number

- Pre-Construction (8/97) - 2.1
- Post-Construction (6/99) - 2.9
- (10/03) - 3.7
Fly Ash Content vs. Resilient Modulus

Resilient Modulus (ksi)

Fly Ash Content (%)

- 5.5
- 7.0
- 8.5

Resilient Modulus (ksi)

0 200 400 600 800 1000 1200

5.5 7.0 8.5

Fly Ash Content (%)
Final Mix Design

- 7% Fly Ash
  154 kg/cu m (9.6 pcf) <=> 35 lb/sy

- 5% MC
  109 kg/cu m <=> 36 liter/sq m
  (6.8 pcf <=> 8 gal/sy)
Case Study #2

• CTH JK, Waukesha, Wisconsin;
• Year 2000 ADT: 5050
• Year 2021 ADT: 8080
• Existing Pavement: 127mm (5”) AC + 178mm (7”) CABC
Laboratory Tests

• Class C Fly Ash
  6% and 8% by weight of CIPR

• Cold In-place Recycled Materials
  68 percent gravel;
  26 percent sand;
  6 percent silt and clay
Test Results

- **Moisture-Density (ASTM D1557)**
  - Optimum Moisture 5.5%
  - 2.28 g/cm³ (143 pcf) --- 6% fly ash
  - 2.29 g/cm³ (144 pcf) --- 8% fly ash

- **Moisture-Strength (ASTM D1633)**
  - Optimum Moisture 5%
  - 1.72MPa (249 psi) --- 6% fly ash
  - 2.62MPa (380 psi) --- 8% fly ash
County Highway JK Project

- Pulverize Existing HMA Pavement to a Depth of 127mm (5”)
- Spraying Water
- Repulverized to a Depth of 305mm (12”)
Pulverization and Addition of Water
Transfer of Fly Ash
Project Execution

• Add 6% Fly Ash
• Add 5% Water
• Compact Immediately After Mixing
• 152mm (6”) HMA Surfacing
Application of Fly Ash
Fly Ash Application
Pavement Evaluation

• Falling Weight Deflectometer
• Seven Sensors: 0, 0.3 (12”), 0.46 (18”), 0.61 (24”), 0.91 (36”), 1.22 (48”), and 1.52 m (60”) from the Center of Loading
• Impact Load 40 KN (9000 lbs)
• Performed in the Outer Wheel Path Every 30 m (100’)
Falling Weight Deflectometer
Pavement Deflection

- Year 2002
- Year 2001

Deflection, mils

Station, feet

Year 2002
Year 2001

D0
D60
D0
D60
Modulus Increase

- $1.24 \text{GPa (180 ksi)}$ in 2001
- $1.84 \text{GPa (267 ksi)} : 49\%$ Increase in 2002
- $2.27 \text{GPa (329 ksi)} : 83\%$ Increase in 2003
Layer Coefficient

- Fly Ash Stabilized CIR Base Course:
  0.16 → 0.23 → 0.245

- Untreated CIR Base Course
  0.13
After One Year
After Two Years
After Three Years
Future Research

• Strength Gain;

• Freeze-thaw Durability; and

• Dry Shrinkage Induced Cracks
Energy Use and Materials

**Full-Depth Reclamation vs. New Base**

- **Number of Trucks Needed**: 12 (New Base) vs. 180 (Full-Depth Reclamation)
- **New Roadway Material tons (metric tons)**: 300 (New Base) vs. 300 (Full-Depth Reclamation) [Note: The figure suggests a possible error in the comparison as both values are the same.]
- **Material Landfilled cubic yard (m³)**: 0 (New Base) vs. 2,700 (2,100) (Full-Depth Reclamation)
- **Diesel Fuel Consumed gallon (liter)**: 500 (1,900) (New Base) vs. 3,000 (11,400) (Full-Depth Reclamation)

Based on 1 mile (1.6 km) of 24-foot (7.3-m)-wide 2-lane road, 6-inch (150-mm) base
Conclusions

- Rehabilitates deteriorated asphalt roads
- Improves ride quality
- Improves structural capacity
- Strength gain
- Construction time is reduced
- Less traffic disruption
- Improved safety
Conclusions

• Incorporates fly ash into cold in-place recycled (CIR) asphalt pavements
• Recycles old road materials
• Saves virgin resources
• Reduces trucking
Strength Performance Results of “Eco-Pad”
A High Recycled Content
In-Situ Mixed Concrete Pavement
In-Situ Mixed Concrete Process

- Grade and compact sub-grade
- Place 3” (75mm) thick layer of fine aggregate (bottom ash)
- Place 5” (125mm) layer coarse aggregate (RCC)
- Pulverization / mixing
- Pre-blended 50/50 fly ash & portland cement addition: range 15% to 20% by mass of total concrete
- Pulverization / mixing
- Add water: optimum range 6% to 10%
- Reshaping and compacting
Costs for In-Situ Mixed Concrete Eco-Pad

- **Approximate cost range for 8” (200mm) Eco-Pad:** $2.00/sf ($22.00/m²) to $2.50/sf ($28.00/m²) (excludes base)
- **Depends on:**
  - Cost of byproduct and recycled materials
  - Amount of binder
  - Availability of pre-blended binder
  - Slab thickness
  - Size of project and mobilization costs
Pleasant Prairie Power Plant Eco-Pad
Coal Combustion Bottom Ash
Eco-Pad Coarse Aggregate: Recycled Crushed Concrete
# Eco-Pad Combined Aggregate

<table>
<thead>
<tr>
<th>Aggregate Blend RC/BA</th>
<th>60/40 Blend</th>
<th>70/30 Blend</th>
<th>Field Blend</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sample 1</td>
<td>Sample 2</td>
<td>Sample 1</td>
</tr>
<tr>
<td>Grain size Analysis, [mm, in. or sieve#]</td>
<td>60/40-1</td>
<td>60/40-2</td>
<td>70/30-1</td>
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<tr>
<td>37.5 [1½]</td>
<td>100</td>
<td>100</td>
<td>-</td>
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<tr>
<td>25.0 [1]</td>
<td>97.4</td>
<td>97</td>
<td>100</td>
</tr>
<tr>
<td>19.0 [¾]</td>
<td>91.0</td>
<td>89.5</td>
<td>96</td>
</tr>
<tr>
<td>12.5 [½]</td>
<td>78.7</td>
<td>75.3</td>
<td>84.7</td>
</tr>
<tr>
<td>9.0 [3/8]</td>
<td>72.0</td>
<td>67.7</td>
<td>78.3</td>
</tr>
<tr>
<td>4.75 [#4]</td>
<td>58.3</td>
<td>52.1</td>
<td>66.6</td>
</tr>
<tr>
<td>2.00 [#10]</td>
<td>49.1</td>
<td>41.9</td>
<td>58.7</td>
</tr>
<tr>
<td>0.850 [#20]</td>
<td>40.7</td>
<td>33.5</td>
<td>50.3</td>
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<tr>
<td>0.425 [#40]</td>
<td>31.3</td>
<td>25.4</td>
<td>40.4</td>
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<tr>
<td>0.150 [#100]</td>
<td>12.8</td>
<td>10.5</td>
<td>20.1</td>
</tr>
<tr>
<td>0.075 [#200]</td>
<td>6.6</td>
<td>5.6</td>
<td>10.6</td>
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Bulk Storage and Blending Facility in Milwaukee, Wisconsin, U.S.A.
## Cementitious Materials

<table>
<thead>
<tr>
<th>Chemical Data</th>
<th>Class C Fly Ash</th>
<th>Slag Cement</th>
<th>Portland Cement Type I / II</th>
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</thead>
<tbody>
<tr>
<td>SiO₂ %</td>
<td>40.3</td>
<td>35.7</td>
<td>20.7</td>
</tr>
<tr>
<td>Al₂O₃ %</td>
<td>18.9</td>
<td>10.0</td>
<td>4.8</td>
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<tr>
<td>Fe₂O₃ %</td>
<td>5.2</td>
<td>0.6</td>
<td>2.7</td>
</tr>
<tr>
<td>SiO₂⁺ Al₂O₃⁺ Fe₂O₃ %</td>
<td>64.5</td>
<td>46.3</td>
<td>28.2</td>
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<tr>
<td>CaO %</td>
<td>21.6</td>
<td>38.6</td>
<td>65.4</td>
</tr>
<tr>
<td>MgO %</td>
<td>3.8</td>
<td>11.2</td>
<td>2.5</td>
</tr>
<tr>
<td>SO₃ %</td>
<td>1.9</td>
<td>2.4</td>
<td>2.4</td>
</tr>
<tr>
<td>LOI %</td>
<td>0.4</td>
<td>-</td>
<td>1.6</td>
</tr>
<tr>
<td>Na₂O %</td>
<td>1.8</td>
<td>0.4</td>
<td>-</td>
</tr>
<tr>
<td>K₂O %</td>
<td>1.2</td>
<td>0.4</td>
<td>-</td>
</tr>
<tr>
<td>Available Alkalis (as equivalent Na₂O%)</td>
<td>1.3</td>
<td>-</td>
<td>0.5</td>
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</tbody>
</table>
Cementitious Materials

<table>
<thead>
<tr>
<th>Physical Data</th>
<th>Class C Fly Ash</th>
<th>Slag Cement</th>
<th>Portland Cement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fineness, retained on sieve #325 (0.045mm) (%)</td>
<td>13.6</td>
<td>1.0</td>
<td>5.3</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>2.52</td>
<td>2.95</td>
<td>3.15</td>
</tr>
<tr>
<td>Strength Activity Index 7 day (% of control)</td>
<td>106</td>
<td>103</td>
<td></td>
</tr>
</tbody>
</table>
Optimum Moisture = 12.6%
Optimum Moisture = 12.4%
Optimum Moisture = 11.2%

Binder Content vs. Compressive Strength

Compressive Strength (psi)

Portland Cement + Fly Ash Content (% of total concrete mass)
Moisture – Density Relationship

15% 50FA/50PC + 5” RC + 3” BA

Graph showing the relationship between moisture content and dry density for the given material mix. The graph indicates an optimum moisture content for maximum dry density, with Gs = 2.7.
Moisture – Strength Relationship

15% 50FA/50PC + 5” RC + 3” BA

Moisture % vs. Compressive Strength (psi at 7 days)
Transfer pre-blended fly ash & portland cement via tanker truck to vane feeder
Apply cementitious materials after mixing aggregates with the pulverizer.
Vane spreader minimizes dusting and regulates volume of fly ash

Edge Berm prevents spilling
In-situ Mixing of Pre-Blended
50% FA / 50% PC
Compaction with pad foot roller
Grading Operations
Final Finish with Smooth Roller
Pre-Blended

50% Fly Ash / 50% Slag Cement
Saw Cutting Control Joints
Dowels for extruded 2’ high curb
Field QC /QA

Moisture and density

Molding cylinders for compressive strength using standard proctor equipment
Field QC /QA

Molding cylinders for compressive strength using standard proctor equipment
Field molded cylinders
Eco-Pad Compressive Strength
(Field Molded Samples, Air Dried)

Days

Avg. Compressive Strength (psi)

365
34.5 MPa
27.6 MPa
20.7 MPa
13.8 MPa
6.9 MPa
0 MPa

7 Day cure at 100° F

7
28
56
180

#1 PC/FA
#2 SC/FA
#3 SC/FA
Eco-Pad after 1 year of service
Surface after 1 year of service
Cores at 1 year of service
Eco-Pad Compressive Strength (Core Samples, Air Dried)
Benefits of In-Situ Mixed Concrete Eco-Pad

- Reduce construction costs
- Resource conservation
- Co-utilize byproducts such as bottom ash, recycled concrete, foundry sand, ground granulated blast furnace slag
- Use on-site materials
- Impervious surface
- Potential process for pervious concrete
Questions ???