In-situ Reclamation of Flexible Pavements Using Coal Combustion Byproducts

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Asphalt Pavement Rehabilitation

- **Trends:**
  - **increasing traffic demand (loads & volumes)**
  - **decreasing budgets**
  - **continuing need for a safe, efficient, cost-effective transportation system**

- **Highway Department Choices:**
  - **Replace distressed road with new one** (expensive, wastes scarce resources)
  - **Replace distressed roads by recycling existing pavement and other by-products into a new pavement** (less expensive, greener)

- **Recycling / reclamation of existing pavements must be a priority**
Objective

Demonstrate effective use of Class F fly ash in combination with lime or lime kiln dust (LKD) in Full Depth Reclamation of asphalt pavements.
• FDR is a flexible pavement reclamation process. The full pavement section (wearing surface, base/subbase, and a pre-determined portion of underlying soil) is uniformly pulverized, blended with chemical additives (e.g. cement, fly ash, lime, emulsion) and compacted to construct a new stabilized base. An asphalt overlay can then be placed.

• Short of conventional re-construction, FDR is the only cost-effective pavement rehabilitation procedure that corrects base and subbase problems.
Why Use Fly Ash in FDR Work?

- Fly ash provides Silica and Alumina needed for cementious reaction with lime to increase strength, stiffness, and durability of stabilized base layer.

- Fly ash act as mineral filler to fill the voids in the granular pulverized pavement mix, thus reducing permeability of the FDR stabilized layer.
Nine sections were designed and constructed using six mixes:

- **Station 1:** 2% Cement with 7.2 liters per square meter emulsion, 20 cm stabilization depth (0.48 km)
- **Station 2:** 5% Cement, 30 cm stabilization depth (1.3 km)
- **Station 3:** 3% Lime Kiln Dust with 6.3 liters per square meter emulsion, 20 cm stabilization depth (1.1 km)
- **Station 4:** 13 cm Mill and Fill (Two 0.16 km sections at the north and south ends of the project, and a 1.1 km as well as 0.16 km sections near the middle of the project) Control Sections
- **Station 5:** 5% Lime Kiln Dust with 5% Fly Ash, 20 cm stabilization depth (1 km)
- **Station 6:** 4% Lime with 6% Fly Ash, 20 cm stabilization depth (1.1 km)
Warren County Pavement Sections (0.65 km)

Two sections were designed and constructed (2006):

• Station 1: 13 cm Mill and Fill - Control (0.13 km)

• Station 2: 4% Lime with 6% Fly Ash, 30 cm stabilization depth (0.52 km)
FDR Construction

1. Milling of Asphalt Surface (Warren County)

2. Placing of Fly Ash, Lime, & LKD (Warren County)

3. Train of equipment (front to back: water truck, mixer and compactor) Delaware County

4. Teeth of Mixer (Delaware County)
5. Material before mixing (left) and after mixing (right), Delaware County

6. Compaction of FDR base layer (Delaware County)

7. Final FDR base layer ready for asphalt overlay (Warren County)

8. Asphalt overlay (Warren County)
Pavement Instrumentation

- Pressure Cell
- Tensiometer
- Shallow LVDT Reference Plate

08/02/2006
Asphalt strain gauge
Falling Weight Deflectometer (FWD) Testing by Ohio DOT

Delaware site before FDR
Measured Deflections
(Warren County)

Location (km from start)

Deflection (mm)

- Section 2
  - Fly Ash & Lime

- Section 1
  - Control

07/06 Before FDR
09/06 1 Month after FDR
10/07 14 Months
04/08 20 Months
07/09 35 Months
03/10 43 Months
Measured Deflections  
(Warren County)

Location (km from start)

Section 2  
Fly Ash & Lime

Section 1  
Control

Deflection (mm)

07/06 Before FDR  
04/08 20 Months  
07/09 35 Months  
03/10 43 Months
Measured Deflections
(Warren County)

Location (km from start)

Section 2
Fly Ash & Lime

Section 1
Control

Deflection (mm)

07/06 Before FDR
09/06 1 Month after FDR
10/07 14 Months
07/09 35 Months
Average Backcalculated Moduli of FDR Layer from FWD Testing (Delaware County)

- Typical Resilient Modulus values (Mechanistic Empirical Pavement Design Guide 2004, FHWA)
- Outlying data points removed
### Average Backcalculated Moduli of FDR Layer from FWD Testing
(Warren County)

<table>
<thead>
<tr>
<th>Section</th>
<th>Elastic Modulus of base layer (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1, control</td>
<td></td>
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<tr>
<td>S2, fly ash and lime</td>
<td></td>
</tr>
</tbody>
</table>

- **07/06 - Before FDR**
- **09/06 - 3 Weeks after FDR**
- **11/06 - 3 Months**
- **04/07 - 8 Months**
- **07/07 - 11 Months**
- **10/07 - 14 Months**
- **04/08 - 20 Months**
- **07/08 - 23 Months**
- **09/08 - 25 Months**
- **04/09 - 32 Months**
- **07/09 - 35 Months**
- **09/09 - 37 Months**
- **03/10 - 43 Months**

- **Open graded cement stabilized aggregate**
- **Soil cement**
- **Lime stabilized soils or unstabilized dense graded aggregate**

- Typical Resilient Modulus values (Mechanistic Empirical Pavement Design Guide 2004, FHWA)
- Outlying data points were removed
### Structural Layer Coefficients

**Delaware County – Section Line Rd.**

<table>
<thead>
<tr>
<th>Date</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Cement &amp; Emulsion</td>
<td>Cement</td>
<td>LKD &amp; Emulsion</td>
<td>Mill &amp; Fill</td>
<td>LKD &amp; Fly Ash</td>
<td>Lime &amp; Fly Ash</td>
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<tr>
<td></td>
<td>M&lt;sub&gt;R&lt;/sub&gt; (psi)</td>
<td>a&lt;sub&gt;i&lt;/sub&gt;</td>
<td>M&lt;sub&gt;R&lt;/sub&gt; (psi)</td>
<td>a&lt;sub&gt;i&lt;/sub&gt;</td>
<td>M&lt;sub&gt;R&lt;/sub&gt; (psi)</td>
<td>a&lt;sub&gt;i&lt;/sub&gt;</td>
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<tr>
<td><strong>07/06</strong></td>
<td>10,173</td>
<td>0.10</td>
<td>5,900</td>
<td>0.08</td>
<td>22,598</td>
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<td>Before FDR</td>
<td>17,785</td>
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<tr>
<td><strong>10/06</strong></td>
<td>364,033</td>
<td>0.32</td>
<td>755,692</td>
<td>0.41</td>
<td>251,896</td>
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<tr>
<td>3 Weeks</td>
<td>205,180</td>
<td>0.27</td>
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<td><strong>04/07</strong></td>
<td>276,630</td>
<td>0.29</td>
<td>818,369</td>
<td>0.42</td>
<td>271,244</td>
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<td>7 months</td>
<td>301,933</td>
<td>0.30</td>
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<tr>
<td><strong>07/07</strong></td>
<td>188,288</td>
<td>0.26</td>
<td>922,125</td>
<td>0.44</td>
<td>247,354</td>
<td>0.28</td>
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<td>10 months</td>
<td>767,857</td>
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<tr>
<td><strong>10/07</strong></td>
<td>375,183</td>
<td>0.32</td>
<td>886,315</td>
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<td>459,375</td>
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<tr>
<td>13 months</td>
<td>1,154,670</td>
<td>0.47</td>
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<tr>
<td><strong>04/08</strong></td>
<td>272,050</td>
<td>0.29</td>
<td>937,500</td>
<td>0.44</td>
<td>343,125</td>
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<tr>
<td>19 months</td>
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<tr>
<td><strong>07/08</strong></td>
<td>187,438</td>
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<td>935,938</td>
<td>0.44</td>
<td>194,027</td>
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<td>22 months</td>
<td>854,833</td>
<td>0.43</td>
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<tr>
<td><strong>09/08</strong></td>
<td>309,406</td>
<td>0.30</td>
<td>1,232,625</td>
<td>0.48</td>
<td>310,292</td>
<td>0.31</td>
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<tr>
<td>24 months</td>
<td>1,014,972</td>
<td>0.45</td>
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<tr>
<td><strong>04/09</strong></td>
<td>134,338</td>
<td>0.23</td>
<td>787,889</td>
<td>0.42</td>
<td>139,903</td>
<td>0.23</td>
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<tr>
<td>31 months</td>
<td>399,004</td>
<td>0.33</td>
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<tr>
<td><strong>07/09</strong></td>
<td>193,025</td>
<td>0.26</td>
<td>1,125,310</td>
<td>0.47</td>
<td>142,004</td>
<td>0.24</td>
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<td>34 months</td>
<td>728,000</td>
<td>0.41</td>
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<tr>
<td><strong>09/09</strong></td>
<td>370,341</td>
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<td>1,004,056</td>
<td>0.45</td>
<td>117,692</td>
<td>0.22</td>
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<tr>
<td>36 months</td>
<td>1,289,264</td>
<td>0.49</td>
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<tr>
<td><strong>03/10</strong></td>
<td>205,404</td>
<td>0.27</td>
<td>916,072</td>
<td>0.44</td>
<td>132,571</td>
<td>0.23</td>
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<tr>
<td>42 months</td>
<td>525,194</td>
<td>0.36</td>
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</tbody>
</table>

**AASHTO:**  
\[ a_i = 0.14 \times \left( \frac{M_R}{30,000} \right)^{1/3} \]
### Structural Layer Coefficients

**Warren County - Long Spurling Rd.**

<table>
<thead>
<tr>
<th>Date</th>
<th>Mill &amp; Fill</th>
<th>Lime &amp; Fly Ash</th>
</tr>
</thead>
<tbody>
<tr>
<td>07/06 Before FDR</td>
<td>7,408</td>
<td>3,124</td>
</tr>
<tr>
<td>09/06 3 Weeks</td>
<td>4,966</td>
<td>494,545</td>
</tr>
<tr>
<td>11/06 3 months</td>
<td>24,063</td>
<td>744,513</td>
</tr>
<tr>
<td>04/07 8 months</td>
<td>16,725</td>
<td>223,695</td>
</tr>
<tr>
<td>07/07 11 months</td>
<td>4,827</td>
<td>564,059</td>
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<tr>
<td>10/07 14 months</td>
<td>6,331</td>
<td>1,742,470</td>
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<tr>
<td>04/08 20 months</td>
<td>27,104</td>
<td>620,975</td>
</tr>
<tr>
<td>07/08 23 months</td>
<td>7,789</td>
<td>546,037</td>
</tr>
<tr>
<td>09/08 25 months</td>
<td>17,416</td>
<td>898,196</td>
</tr>
<tr>
<td>04/09 32 months</td>
<td>4,481</td>
<td>300,907</td>
</tr>
<tr>
<td>07/09 35 months</td>
<td>3,340</td>
<td>314,653</td>
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<tr>
<td>09/09 37 months</td>
<td>17,203</td>
<td>390,388</td>
</tr>
<tr>
<td>03/10 43 months</td>
<td>10,147</td>
<td>368,157</td>
</tr>
</tbody>
</table>

**AASHTO:** \( a_i = 0.14 \cdot (M_R/30,000)^{1/3} \)
Delaware Pavements – February 2009

Section 1: Cement + Emulsion
Section 2: Cement
Section 3: LKD + Emulsion

Section 4: Control (Mill & Fill)
Section 5: Fly Ash + LKD
Section 6: Fly Ash + Lime
Section 1: Cement + Emulsion

Section 2: Cement

Section 3: LKD + Emulsion

Section 4: Control (Mill & Fill)

Section 5: Fly Ash + LKD

Section 6: Fly Ash + Lime
Longitudinal Strain Data from Delaware County – 72 km/h

APLF maximum
65 microstrain

<table>
<thead>
<tr>
<th>Station</th>
<th>Mix Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Station 1</td>
<td>Cement &amp; Emulsion</td>
</tr>
<tr>
<td>Station 2</td>
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</tr>
<tr>
<td>Station 3</td>
<td>LKD &amp; Emulsion</td>
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<tr>
<td>Station 4</td>
<td>Control</td>
</tr>
<tr>
<td>Station 5</td>
<td>LKD &amp; Fly Ash</td>
</tr>
<tr>
<td>Station 6</td>
<td>Lime &amp; Fly Ash</td>
</tr>
</tbody>
</table>

Time (10^{-2} sec)
Transverse Strain Data from Delaware County – 72 km/h

APLF maximum 75 microstrain

Station 1 - Cement & Emulsion
Station 2 - Cement
Station 3 - LKD & Emulsion
Station 4 - Control
Station 5 - LKD & Fly Ash
Station 6 - Lime & Fly Ash

Transverse Strain

Time (10^{-2} sec)
Pressure Cell Data from Delaware County 12/06 – 72 km/h

Range of stresses from APLF testing without pavement failure up to 1.5 million ESALs

- Vertical Stress (kpa)
- Time (10^-2 sec)

St. 5 - 5% LKD & 5% Fly Ash
St. 6 - 4% Lime & 6% Fly Ash
Conclusions

• Pavement sections stabilized with fly ash (+LKD/lime) showed comparable stiffness and strength to the cement stabilized sections for up to 3½ years of monitoring (including three seasons of winter)

• The use of fly ash (with LKD or lime) as substitute for traditional cementitious additives in FDR can result in substantial cost savings as well as additional significant environmental benefits

• Fly ash can be easily mixed and compacted using standard FDR construction equipment
Acknowledgements

• Ohio Coal Development Office / Ohio Air Quality Development Authority
• Delaware County Engineer’s Office
• Warren County Engineer's Office
• Muskingum County Engineer’s Office
• Ohio DOT
• Base Construction
• Fly Ash Direct
• Headwater Resources
• Carmeuse NA
• Mintek Resources
• EDP Consultants
• Asphalt Recycling and Reclamation Association
• American Coal Ash Association
• Midwest Coal Ash Association
Outreach

• Asphalt Contractor

• Roads & Bridges

• Better Roads, Ash at Work

• USEPA – C2P2 Case Study 16, Fall 2007