Moving forward with concrete results
Contractor’s Experience in the Use of Fly Ash in Concrete Pavements: A Competitive Advantage

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Wisconsin Concrete Pavement Association
Historical Perspective
1981 WisDOT Standard Specifications

- A-FA Concrete Mix May be used where allowed by the special provisions
- 18 percent max replacement
- Each pound of cement replaced with 1.3 pounds of fly ash
- Not to be used prior to May 15
- Not to be used after September 15
Over 25 years of Specification Evolution
Specification Changes

• A-FA Concrete Mix May be used where allowed by the special provisions

• A-FA must be used “unless documented otherwise”
Specification Changes

• 18 percent max replacement

• 30 percent max replacement
Specification Changes

• Each pound of cement replaced with 1.3 pounds of fly ash

• *Pound for pound cement replacement*
Specification Changes

- Not to be used prior to May 15
- Not to be used after September 15

- At contractor’s discretion, must achieve 3000 psi compressive strength before work can proceed
Two WisDOT Research Projects
Wisconsin DOT Experience with High Fly Ash Content and Reduction of the Fly Ash Replacement Ratio in Concrete Pavements
Background

- Cement Shortages & Price Increases
- Traditional Fly Ash Content = 15-20%
- Favorable High FA Research by Others
WisDOT Pilot Projects

- Field Test Sections
- Laboratory Tests
- 1.3:1 Replacement Ratio
- Up to 40% Fly Ash Content
Laboratory Test Results

• Favorable
  – Compressive Strength
  – Flexural Strength
  – Rapid Chloride Permeability
  – Freeze Thaw Durability

• Unfavorable
  – Scaling of 40% Fly Ash Mixes
Field Performance Results

• No Mix-related Distress in any High Fly Ash Experimental Section
## 1.3:1 Replacement Ratio

<table>
<thead>
<tr>
<th>%Fly Ash</th>
<th>Cement kg/m³</th>
<th>Fly Ash kg/m³</th>
<th>Total kg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>335</td>
<td>0</td>
<td>335</td>
</tr>
<tr>
<td>18.6%</td>
<td>285</td>
<td>65</td>
<td>350</td>
</tr>
<tr>
<td>30%</td>
<td>252</td>
<td>107</td>
<td>359</td>
</tr>
<tr>
<td>40%</td>
<td>223</td>
<td>148</td>
<td>371</td>
</tr>
</tbody>
</table>
Objectives

• Validate data with Wider Range of Materials
• Evaluate Reduced Replacement Ratio
Materials

- 3 Cement Sources
- 4 Fly Ash Sources
- Standard Durable Aggregate
- Air Agent
- Type A Water Reducer
**Mix Proportions**

- Control Grade A with 0% FA
- 1:1 Ratio with 15% FA
- 1:1 Ratio with 30% FA
- 1:1 Ratio with 40% FA
- 1.3:1 Ratio with 18.6% FA (Grd A-FA)
- 1.3:1 Ratio with 30% FA
- 1.3:1 Ratio with 40% FA
Mix Adjustments

• Fly Ash Replacements by Weight
• Volume Adjusted with Fine Agg
• Batches Mixed to Constant Slump
Properties of Fresh Concrete

- Air = 6% +/- 1.5%
- Slump = 50 mm +/- 25 mm
Properties of Hardened Concrete

- Compressive Strength @ 3, 7, 28, 90 & 365 days (AASHTO T22)
- Rapid Chloride Permeability @ 28, 90 & 365 days (AASHTO T277)
- Freeze Thaw Durability (Expansion & Wt Loss @ 300 cycles) (T161 Meth A)
- Drying Shrinkage @ 7, 28, 90 days
FIGURE 1 Compressive Strength by Mix Design and Test Age

Compressive Strength (MPa)

Concrete Age (days)

- PC Control (0%FA)
- 1:1 Ratio (15%FA)
- 1:1 Ratio (30%FA)
- 1:1 Ratio (40%FA)
- 1.3:1 Ratio (18%FA)
- 1.3:1 Ratio (30%FA)
- 1.3:1 Ratio (40%FA)
FIGURE 2  Rapid Chloride Permeability by Mix Design and by Test Age

- PC Control (0%FA)
- 1:1 Ratio (15%FA)
- 1:1 Ratio (30%FA)
- 1:1 Ratio (40%FA)
- 1.3 :1 Ratio (18%FA)
- 1.3 :1 Ratio (30%FA)
- 1.3 :1 Ratio (40%FA)
FIGURE 3 Freeze Thaw Test Data - Expansion by Mix Design

Expansion at 300 Cycles (%) for various replacement ratios and fly ash contents:
- PC Control (0% FA)
- 1:1 Ratio (15% FA)
- 1:1 Ratio (30% FA)
- 1:1 Ratio (40% FA)
- 1.3:1 Ratio (18% FA)
- 1.3:1 Ratio (30% FA)
- 1.3:1 Ratio (40% FA)

Replacement Ratio & (Fly Ash Content)
FIGURE 4 Freeze Thaw Test Data - Weight Loss by Mix Design

Weight Loss at 300 Cycles (g)

PC Control (0%FA) 1:1 Ratio (15%FA) 1:1 Ratio (30%FA) 1:1 Ratio (40%FA) 1:3:1 Ratio (18%FA) 1:3:1 Ratio (30%FA) 1:3:1 Ratio (40%FA)

Replacement Ratio & (Fly Ash Content)
FIGURE 5  Shrinkage by Mix Design and by Test Age

Concrete Age (days)

Shrinkage (microstrain)
Conclusions

• Improved Properties up to 30% FA
• Increased Scaling at 40% FA
• Reduction of Replacement Ratio to 1:1 Did Not Reduce Quality
• 1:1 Mixes with 30% and 40% FA Had Reduced Strength @ 3 & 7 Days
Implementation

- 1:1 Replacement Ratio Allowed
- 30% Max Fly Ash Content Allowed
- Contractors Advised of Early Age Strength Delays
Limitations

- Class C Fly Ash from Western Coal
- Durable Non-reactive Aggregates
High Fly Ash Content in PCC Pavements

State of Wisconsin
Department of Transportation
Bureau of Highway Construction
Introduction

- Fly ash used by WisDOT in A-FA mix for PCC pavements since mid-1980’s
- Interest by WisDOT and industry in identifying an upper boundary for satisfactory fly ash performance
- Standard lab tests did not seem to mirror field experiences of others
Introduction

• Field tests under typical WisDOT conditions needed to assess PCC pavement performance
• Lab test modifications needed to showcase potential of PCC mixes with mineral additives
Testing - 1993 Project

- Slump
- Air Content
- Compressive Strength (3, 7, 28 & 90 days)
- Freeze-thaw Durability (C666 - method A) (28-day wet cure then 28-day air cure) (5% Sodium Chloride solution)
## Mix Designs - 1993

<table>
<thead>
<tr>
<th>Mix Type</th>
<th>Grade A-FA</th>
<th>25% Test Section</th>
<th>30% Test Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement (lbs/cy)</td>
<td>480</td>
<td>450</td>
<td>425</td>
</tr>
<tr>
<td>Fly Ash (lbs/cy)</td>
<td>110</td>
<td>150</td>
<td>180</td>
</tr>
<tr>
<td>F/(C+F)</td>
<td>18.6%</td>
<td>25%</td>
<td>30%</td>
</tr>
<tr>
<td>Aggregate (lbs/cy)</td>
<td>3130</td>
<td>3120</td>
<td>3115</td>
</tr>
</tbody>
</table>
Lessons learned in 1993

• Good Performance - all mixes
• Upper fly ash limit not reached
• Duration of lab tests needed to be increased
Testing - 1995 Projects

- Slump
- Air Content
- Compressive Strength (3, 7, 28, 90 days & 1 year)
- Flexural Strength (28 days)
- Freeze-thaw Durability (same as 1993)
- Rapid Chloride Permeability (T277) (28, 90 days & 1 year)
## Mix Designs - 1995 Projects

<table>
<thead>
<tr>
<th></th>
<th>Grade A-WR</th>
<th>Grade A-FA</th>
<th>25% Test</th>
<th>33% Test</th>
<th>40% Test</th>
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<tbody>
<tr>
<td><strong>Cement</strong> (lbs/cy)</td>
<td>530</td>
<td>480</td>
<td>450</td>
<td>410</td>
<td>375</td>
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<tr>
<td><strong>Fly Ash</strong> (lbs/cy)</td>
<td>0</td>
<td>110</td>
<td>150</td>
<td>200</td>
<td>250</td>
</tr>
<tr>
<td><strong>F/(C+F)</strong></td>
<td>0%</td>
<td>18.6%</td>
<td>25%</td>
<td>33%</td>
<td>40%</td>
</tr>
<tr>
<td><strong>Aggregate</strong> (lbs/cy)</td>
<td>3150</td>
<td>3130</td>
<td>3120</td>
<td>3110</td>
<td>3100</td>
</tr>
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</table>

Workshop on Green Construction Materials Using Coal-Combustion Products - May 1, 2008
Flexural Strength Data - Verona

- A-WR
- A-FA
- 25%FA
- 33%FA
- 40%FA

28-Day
Freeze-Thaw Test Data - Verona

![Graph showing freeze-thaw test data for different materials and percentages of FA (fly ash). The graph includes bars for A-WR, A-FA, 25% FA, 33% FA, and 40% FA, with a vertical axis representing cycles and a horizontal axis representing materials and percentages. The graph indicates the number of cycles for each material after 300 cycles.](image)
Flexural Strength Data - E.C.

- A-FA
- 25% FA
- 33% FA
- 40% FA

28-Day
Permeability Test Data - E.C.

Workshop on Green Construction Materials Using Coal-Combustion Products - May 1, 2008
Freeze-Thaw Test Data - E.C.

A-FA 25%FA 33%FA 40%FA

300 Cycles
CURRENT SPECIFICATIONS
Current Specifications

501.2.6 Fly Ash
(1) Fly ash is defined as a finely divided residue resulting from the combustion of coal in a base loaded electric generating plant, transported from the boiler by flue gases, and later collected, generally by precipitators. Use fly ash in portland cement concrete manufactured by facilities and processes known to provide satisfactory material.

(2) Conform to ASTM C 618 Class C, including the supplemental optional requirements provided, except limit the loss on ignition to a maximum of 2 percent.

(3) Test fly ash by using a recognized laboratory, as defined in 501.2.2(1), 30 days before its proposed use, and every 30 days during the work progress. The manufacturer shall conduct daily uniformity tests on the fly ash. These daily uniformity tests consist of determining the: specific gravity, percent retained on the No. 325 (45 µm) sieve, loss on ignition, moisture content, sulfur trioxide content, and air content of the mortar. The department may reduce the required frequency of the uniformity testing for specific tests on specific fly ash sources if statistical analysis of current data shows no significant probability of exceeding uniformity or specification limits.

(4) Use only one source of fly ash for a bid item of work under the contract, unless the engineer directs otherwise in writing.

(5) Prequalify any proposed fly ash source as follows: The contractor shall obtain a copy of the certified report of tests or analysis made by a qualified independent laboratory, recognized by the department under 501.2.2, showing full and complete compliance with the above specification from the fly ash manufacturer and furnish it to the project engineer. Provide this report to the engineer at least 14 days before using the fly ash.

(6) The manufacturer shall retain all test records for at least 5 years after completing the work, and provide these records upon request.
## Current Specifications

### Quantities for a Nominal Cubic Yard

<table>
<thead>
<tr>
<th>Concrete Grade</th>
<th>Cement (lb)</th>
<th>Class C Fly Ash (lb)</th>
<th>Slag (lb)</th>
<th>Weight Total Agg (lb)</th>
<th>Percent Fine Agg (% Total Agg)</th>
<th>Design Water (gals)</th>
<th>Maximum Water (gals)</th>
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<tr>
<td>A</td>
<td>565</td>
<td>-</td>
<td>-</td>
<td>3120</td>
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<td>27</td>
<td>32</td>
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<tr>
<td>A2</td>
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<td>B-FA</td>
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<td>B-S[10]</td>
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<td>-</td>
<td>2810</td>
<td>50</td>
<td>32</td>
<td>35</td>
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</tbody>
</table>
Additional Costs of Using Fly Ash

- More storage required
- Another material to handle
- Increased admixture demand
- More time before sawing
- Greater risk of volunteer cracking
- More pavement to protect from rain and freezing conditions
- More time before opening to traffic
## EXAMPLE PROJECT

<table>
<thead>
<tr>
<th>Type</th>
<th>Cement Type</th>
<th>Fly Ash Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A Mix</td>
<td>564# cement</td>
<td></td>
</tr>
<tr>
<td>A-FA Mix</td>
<td>480# cement</td>
<td>110# fly ash</td>
</tr>
<tr>
<td>1990’s A-FA</td>
<td>450# cement</td>
<td>150# fly ash</td>
</tr>
<tr>
<td>Current A-FA</td>
<td>395# cement</td>
<td>170# fly ash</td>
</tr>
</tbody>
</table>
## EXAMPLE PROJECT

<table>
<thead>
<tr>
<th></th>
<th>Ash Content</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A-Mix</td>
<td>Zero Ash</td>
<td>$32.43/CY</td>
</tr>
<tr>
<td>A-FA Mix</td>
<td>18% Ash</td>
<td>Save $0.98/CY</td>
</tr>
<tr>
<td>1990’s A-FA</td>
<td>30% Ash</td>
<td>Save $1.30/CY</td>
</tr>
<tr>
<td>Current A-FA</td>
<td>New 30%</td>
<td>Save $3.77/CY</td>
</tr>
</tbody>
</table>
Economic Impact of Using Fly Ash

• PER DAY
  – 15,250 SY per mile = 4237 CY
  – $15,937 per day

• PER PROJECT
  – $160,000 - $210,000 per project savings

• PER YEAR
  – Average of 3,000,000 SY per year the last 10 years
  – So, use of fly ash has an average economic impact of $3,150,000 annually
Contractor’s bottom line:

Can’t afford not to use fly ash or your competitor will be building the project.