Use of Industrial By-Products in Sustainable Construction Practices

by

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Presented at the International Conference on Sustainable Construction Materials and Technologies,
Coventry, U.K., June 11 - 13, 2007
Sustainable Development

According to the World Commission on Environment and Development, Brundtland Report 1987, sustainability means “Meeting the needs of the present without compromising the ability of the future generations to meet their own needs.”
Spaceship Earth

Center for By-Products Utilization
Concrete is environmentally very friendly material.
Introduction

• Concrete is the world’s most consumed manmade product.

• To produce one tonne of portland cement, 1.5 tonnes of raw materials are needed. Therefore each year, production of 1.5 billion tonnes of cement consumes at least 2.3 million tonnes of raw materials.
Environmental Issues

The production of one ton of portland cement releases approximately one ton of $\text{CO}_2$ and other greenhouse gases (GHGs) into the atmosphere.
Reduction of CO$_2$ Emissions by Increased use of Fly Ash

- Replacing 15% of cement worldwide by SCM will reduce CO$_2$ emissions by 250 million tonnes.
Long-Term Evaluation of Concrete Pavements Using Fly Ash

Materials

- Cement (ASTM C150, Type I)
- Fly Ash (ASTM C 618, Type C)
- Fly Ash (ASTM C 618, Type F)
- Sand (ASTM C 33)
- Coarse Aggregate (ASTM C 33)
- Admixtures (WRA, HRWRA, and AEA)
A total of six different mixtures of high-volumes of fly ash concrete, used for pavement construction, were evaluated in this project. These pavements were constructed in 1984 - 1991.
CONCRETE MIXTURES

Three different high-volumes of Class C fly ash concrete mixtures were used:

- 74% Class C (1984)
- 50% Class C (1990)
- 19% Class C (1990)
CONCRETE MIXTURES

Three different high-volumes of Class F fly ash concrete mixtures were used:

- 67% Class F (1991)
- 53% Class F (1991)
- 40% Class F (1990)
Compressive Strength versus Age

Compressive Strength, MPa

Age

- A-1 70% Class C Fly Ash
- B-5 50% Class C Fly Ash
- C-4 19% Class C Fly Ash
- D-2 67% Class F Fly Ash
- E-3 53% Class F Fly Ash
- F-6 35% Class F Fly Ash
Compressive Strength
(as compared with 28-day age):

74% Class C, 18 years, +200%
50% Class C, 12 years, +80 %
19% Class C, 12 years, +90%
67% Class F, 11 years, +189%
53% Class F, 11 years, +117%
40% Class F, 12 years, +72%
Rate of Strength Gain for Concrete with Class C or Class F Fly Ash

Ratio of Compressive strengths at Seven or Eight Years and 28-day

Class C Fly Ash
Class F Fly Ash
The rate of early-age strength gain of Class C fly ash concrete mixtures was higher compared to Class F fly ash concrete mixtures. This was primarily attributed to greater reactivity of Class C fly ash compared to Class F fly ash.
## Chloride-Ion Penetration for Concrete Cores

<table>
<thead>
<tr>
<th>ASTM C1202 Charge Passed (coulombs)</th>
<th>ASTM C1202 Chloride ion Penetrability</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;4000</td>
<td>High</td>
</tr>
<tr>
<td>2,000-4,000</td>
<td>Moderate</td>
</tr>
<tr>
<td>1,000-2,000</td>
<td>Low</td>
</tr>
<tr>
<td>100-1,000</td>
<td>Very Low</td>
</tr>
<tr>
<td>&lt;100</td>
<td>Negligible</td>
</tr>
</tbody>
</table>
Chloride-Ion Penetration for Core Specimens
Long-term pozzolanic strength contribution of Class F fly ash was somewhat greater compared to Class C fly ash. Consequently, long-term compressive strengths of Class F fly ash concrete pavements were higher than that for Class C fly ash concrete pavements.
USE OF WOOD ASH IN CONCRETE

Wood ash is generated by the pulp and paper industry, saw mills, and wood products industry.
Approximately 3.6 million dry tonnes of wood ash are produced each year.

Up to 70% of the wood ash produced is landfilled.
Disposal of Wood Ash in Landfills

- Cost
- Decreasing landfill space
- Unknown future liabilities
Objectives

• Sustainable development for the pulp and paper industry

• Determine the feasibility of using wood ash in concrete
MICROGRAPH OF WOOD FLY ASH
PARTICLE SIZE DISTRIBUTION OF A TYPICAL WOOD FLY ASH
## Average Concrete Mixture Proportions from Full-scale Manufacturing

<table>
<thead>
<tr>
<th>Mixture Number</th>
<th>C-1</th>
<th>C-2</th>
<th>C-3</th>
<th>C-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement, (kg/m³)</td>
<td>302</td>
<td>285</td>
<td>260</td>
<td>263</td>
</tr>
<tr>
<td>Wood FA, (kg/m³)</td>
<td>0</td>
<td>20</td>
<td>31</td>
<td>47</td>
</tr>
<tr>
<td>Class C FA, (kg/m³), A</td>
<td>30</td>
<td>60</td>
<td>77</td>
<td>80</td>
</tr>
</tbody>
</table>
## Average Concrete Mixture Proportions from Full-scale Manufacturing (Cont’d)

<table>
<thead>
<tr>
<th>Mixture Number</th>
<th>C-1</th>
<th>C-2</th>
<th>C-3</th>
<th>C-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>[W/(C+A)]</td>
<td>0.40</td>
<td>0.41</td>
<td>0.47</td>
<td>0.45</td>
</tr>
<tr>
<td>SSD Fine Aggregate, (kg/m³)</td>
<td>835</td>
<td>820</td>
<td>780</td>
<td>805</td>
</tr>
<tr>
<td>SSD Coarse Aggregate, (kg/m³)</td>
<td>970</td>
<td>980</td>
<td>950</td>
<td>950</td>
</tr>
<tr>
<td>AEA, (L/m³)</td>
<td>1.3</td>
<td>1.4</td>
<td>1.3</td>
<td>1.3</td>
</tr>
</tbody>
</table>
Wood Ash Concrete Test Results

• 28-day compressive strength approximately 33 MPa.

• 365-day compressive strength over 42 MPa.
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AVERAGE COMPRESSIVE STRENGTH FOR CONCRETE MIXTURES FROM FULL-SCALE MANUFACTURING
All concrete mixtures from full-scale manufacturing achieved strength of more than 28 MPa at the age of 7 days. Therefore, concrete made with wood FA and Class C coal fly ash can be used for many structural application.
Relative Dynamic Modulus versus Freezing and Thawing Cycles for Full-Scale Manufacturing

- Mixture C-1
- Mixture C-2
- Mixture C-3
- Mixture C-4
Use of Foundry Sand in Concrete

Mined foundry sands are silica sand of graded size used for making molds. Sand molds are made to cast a hollow shape in which molten metal is poured to cast a metal product. Sand in the mold is bonded by clay (green sand) or chemicals (clay-bonded or chemically-bonded).
Foundry Sand (cont’d)

Green-sand molds are used to produce about 90% of casting volume in the USA. Green sand is composed of silica sand (85 - 95%); bentonite clay (4 - 10%) as a binder; an additive (2 - 10%) to improve the casting surface finish; and water (2 - 5%).
In modern foundry practice, sand is typically reused through several production cycles. Typically 10% or so of sand is discarded during each reuse cycle. Such sand is available for other recycling options. Wisconsin alone produces over 500,000 tonnes of foundry by-products.
Large-Volume Recycling Options for Used Foundry Sand

- Portland cement concrete
Materials

Three types of sand
- Regular Concrete Sand (RCS)
- Used Foundry Sand (UFS)
- Clean Foundry Sand (CFS)

Type I Cement (ASTM C 150)

Class C Fly Ash (ASTM C 618)
• Foundry sands (used or clean) did not pass all ASTM C 33 requirements for fine aggregate.

• Foundry sands contained higher amounts of fine particles relative to regular concrete sand.
SIEVE ANALYSIS CURVES FOR SANDS

Materials Passing,%

Sieve Size, mm

RCS
UFS
CS (70% RCS+30% UFS)
LL of ASTM
UL of ASTM
Clean Sand

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## Physical Properties of Fine and Coarse Aggregates

<table>
<thead>
<tr>
<th>ASTM</th>
<th>SSD Absorption, (%)</th>
<th>Percent Void</th>
<th>Fineness Modulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>C 128</td>
<td></td>
<td>C 29</td>
<td>C 136</td>
</tr>
<tr>
<td>CS</td>
<td>1.4</td>
<td>33.7</td>
<td>3.57</td>
</tr>
<tr>
<td>CFS</td>
<td>4.5</td>
<td>33.8</td>
<td>2.33</td>
</tr>
<tr>
<td>UFS</td>
<td>5.0</td>
<td>34.8</td>
<td>2.32</td>
</tr>
<tr>
<td>Coarse Aggregate</td>
<td>0.5</td>
<td>44.7</td>
<td>N.A.</td>
</tr>
</tbody>
</table>
Concrete Mixture Proportions

A total of 11 concrete mixtures
- Design compressive strength for all mixtures was 31 MPa
- 1 reference mixture without by-product materials.
- 4 mixtures containing 20 to 40% used or clean foundry sand as a replacement of regular concrete sand.
Concrete Mixture Proportions (Cont’d)

- 6 mixtures containing used or clean foundry sand as a replacement of concrete sand and fly ash as an additional cementitious material.
Concrete Mixture Proportions

- **R0 + 0** – Reference Mixture without by-products
- **U20 + 0** – 20% Sand replaced with UFS. 0% Fly ash
- **U40 + 0** – 40% Sand replaced with UFS. 0% Fly ash
- **C20 + 0** – 20% Sand replaced with CFS. 0% Fly ash
- **C40 + 0** – 40% Sand replaced with CFS. 0% Fly ash
Concrete Mixture Proportions

- **U10 + 17** – 10% sand replaced with UFS. 17% fly ash used in cementitious materials
- **U20 + 20** - 20% sand replaced with UFS. 20% fly ash used in cementitious materials
- **U30 + 22** - 30% sand replaced with UFS. 22% fly ash used in cementitious materials
- **U40 + 25** - 40% sand replaced with UFS. 25% fly ash used in cementitious materials

- **C20 + 14** - 20% sand replaced with CFS. 14% fly ash used in cementitious materials
- **C40 + 14** - 40% sand replaced with CFS. 14% fly ash used in cementitious materials
COMPRESSIVE STRENGTH OF CONCRETE AT 3 DAYS

3 Age, Days

COMPRESSIVE STRENGTH OF CONCRETE AT 3 DAYS
COMPRESSIVE STRENGTH OF CONCRETE AT 28 DAYS

28 Age, Days

COMPRESSIVE STRENGTH OF CONCRETE AT 28 DAYS
ABRASION RESISTANCE OF CONCRETE vs. TIME at 28 DAY AGE
Conclusions

- Up to 40% replacement of regular concrete sand by used foundry sand had compressive strength equivalent to the reference concrete.

- Clean foundry sand up to 40% replacement showed slightly higher strength than the reference concrete.
Conclusions (Cont’d)

• Inclusion of fly ash improved compressive strength of concrete mixtures containing up to 40% foundry sand (used or clean).

• All concrete mixture with up to 40% foundry sand and up to 25% fly ash outperformed the reference mixture.
Acknowledgement

• The UWM Center for By-Products Utilization was established in 1988 with a generous grant from the Dairyland Power Cooperative, LaCrosse, WI; Madison Gas and Electric Company, Madison, WI; National Minerals Corporation, St. Paul, MN; Northern States Power Company, Eau Claire, WI; We Energies, Milwaukee, WI; Wisconsin Power and Light Company, Madison, WI; and Wisconsin Public Service Corporation, Green Bay, WI. Their financial support and additional grant and support from Manitowoc Public Utilities, Manitowoc, WI, and gratefully acknowledged.
THANK YOU

for your interest