Harvested Fly Ash

Larry Sutter Ph.D., P.E., F.ASTM, F.ACI
Materials Science & Engineering
Michigan Technological University

Background

- We expect one key property from concrete: Longevity
- Service demands have increased
  - Use of aggressive deicing chemicals
- We have increased our expectations for reduced environmental impact and lower initial and lifecycle costs
- SCMs assist us in meeting these goals
- **Coal Fly Ash is our go-to SCM**
### Effects of SCMs on Properly Cured Hardened Concrete

<table>
<thead>
<tr>
<th></th>
<th>Fly ash</th>
<th>Slag</th>
<th>Silica fume</th>
<th>Natural Pozzolan</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reduced</strong></td>
<td><img src="down_arrow.png" alt="Arrow Down" /></td>
<td><img src="down_arrow.png" alt="Arrow Down" /></td>
<td><img src="down_arrow.png" alt="Arrow Down" /></td>
<td><img src="down_arrow.png" alt="Arrow Down" /></td>
</tr>
<tr>
<td><strong>No/Little Effect</strong></td>
<td><img src="right_arrow.png" alt="Arrow Right" /></td>
<td><img src="right_arrow.png" alt="Arrow Right" /></td>
<td><img src="right_arrow.png" alt="Arrow Right" /></td>
<td><img src="right_arrow.png" alt="Arrow Right" /></td>
</tr>
<tr>
<td><strong>Increase</strong></td>
<td><img src="up_arrow.png" alt="Arrow Up" /></td>
<td><img src="up_arrow.png" alt="Arrow Up" /></td>
<td><img src="up_arrow.png" alt="Arrow Up" /></td>
<td><img src="up_arrow.png" alt="Arrow Up" /></td>
</tr>
<tr>
<td><strong>Varies</strong></td>
<td><img src="left_arrow.png" alt="Arrow Left" /></td>
<td><img src="left_arrow.png" alt="Arrow Left" /></td>
<td><img src="left_arrow.png" alt="Arrow Left" /></td>
<td><img src="left_arrow.png" alt="Arrow Left" /></td>
</tr>
</tbody>
</table>

- **Strength Gain**
- **Abrasion Resistance**
- **Freeze-Thaw and Deicer-Scaling Resistance**
- **Drying Shrinkage and Creep**
- **Permeability**
- **Alkali-Silica Reactivity**
- **Chemical Resistance**
- **Carbonation**
- **Concrete Color**
So what’s the problem?

The Problem

- Fly ash supplies are challenged by coal-fired power plant closures and conversions to natural gas
- Fly ash spot shortages have been reported in many U.S. markets
- Concerns center on the fact that no other material is available with the reserves that fly ash historically has provided
Coal-fired Power Plants are Being Retired

Navajo Generating Station

- 2250 megawatt net coal-fired powerplant
- Largest coal fired electrical generating station west of the Mississippi
- Produces approximately 500,000 tons a year of Class F fly ash
- Closed 2020
Coal-fired Power Plants are Being Retired

Source: U.S. Energy Information Administration, 2021

Electric Power Generation by Fuel Type

Source: U.S. Energy Information Administration, 2021
So What’s Up With Fly Ash?

- Domestic fly ash production (new production) will continue decreasing over the next 20 years and beyond
  - Domestic use of coal for electrical power generation is predicted to continue decreasing
  - Fewer plants, running at a higher percentage of capacity
  - Suppliers believe that although total reserves will decrease, the volume of quality ash as a percentage of total production will increase due to dry handling – no more ponding
- Harvested ash from landfills/ponds will become a significant fraction of the total reserves
So What’s Up With Fly Ash?

- Domestic fly ash production (new production) will continue decreasing over the next 20 years and beyond
  - Domestic use of coal for electrical power generation is predicted to continue decreasing
  - Fewer plants, running at a higher percentage of capacity
  - Suppliers believe that although total reserves will decrease, the volume of quality ash as a percentage of total production will increase due to dry handling – no more ponding
- Harvested ash from landfills/ponds will become a significant fraction of the total reserves

Harvested Ash

- With diminishing production, ash marketers are turning to landfills & ash ponds to recover fly ash
  - Most harvested sources are Class F ash
  - Limited research to date on performance of harvested ash
- All harvested sources will require processing
  - Drying
  - Sizing
  - Blending
- Could lead to more uniformity - or less - depending upon source and degree of processing
Coal Fly Ash

• **Benefits**
  - Improved workability
  - Decreased heat of hydration
  - Reduced cost
  - Potential increased sulfate resistance and alkali-silica reaction (ASR) mitigation
  - Increased late strength, and decreased shrinkage and permeability

• **Concerns**
  - Air-entraining admixture adsorption by residual carbon in the fly ash
  - Slow initial strength gain (Class F)
  - Fly ash variability
  - **How reactive is it?**

Harvested Coal Fly Ash

✓ **Benefits**
  - Improved workability
  - Decreased heat of hydration
  - Potential increased sulfate resistance and alkali-silica reaction (ASR) mitigation
  - Increased late strength, and decreased shrinkage and permeability

✓ **Concerns**
  - Air-entraining admixture adsorption by residual carbon in the fly ash
  - Slow initial strength gain (Class F)
  - Fly ash variability
  - **How reactive is it?**
Harvested Ash

- Significant volumes of high-quality fly ash have been disposed
  - Approximately 2000 million short tons produced 1974 - 2013
  - Approximately 650 million short tons used 1974 – 2013
  - ~33% utilization – 1350 million short tons disposed
- Not all is recoverable, but a large fraction is

Harvested Ash – Production & Beneficiation

- Harvesting operations vary depending on the source characteristics
  - Standards are being developed to guide harvesting operations
    - ASTM E3183 Standard Guide for Harvesting Coal Combustion Products Stored in Active and Inactive Storage Areas for Beneficial Use
  - Provides a framework for characterization of the site, planning and scoping of a harvesting project, the site design and approval process (as applicable), and the implementation of harvesting
  - Does not address processing the material to meet ASTM C618 or AASHTO M 295
Harvested Ash – Production & Beneficiation

- With very few exceptions, harvested ash will be processed for use in concrete
  - Drying
    - Needed to meet moisture limits
  - Screening or air classification, or both
    - Primarily to address comingled bottom ash
  - Grinding (last resort)
    - Bottom ash, cemented particles
  - Post-treatment
  - Carbon removal or mitigation

Harvested Ash – Production & Beneficiation

- More on carbon removal
  - Many ashes were landfilled originally due to excessive carbon content
  - Beneficiation Methods
    - Triboelectrostatic separation
    - Carbon Burnout
    - Passivation
Harvested Ash – Production & Beneficiation

• More on carbon removal
  • Many ashes were landfilled originally due to excessive carbon content

• Triboelectrostatic separation

Source: http://www.indmin.com/events/download.ashx/document/speaker/8819/a5000080081a56A0J/Presentation
Harvested Ash – Production & Beneficiation

• More on carbon removal
  • Many ashes were landfilled originally due to excessive carbon content

• Carbon Burnout
  • Reburn with coal feed
  • Fluidized bed combustion
  • STAR™ Staged Turbulent Air Flow (SEFA)

Harvested Ash – Production & Beneficiation

• More on carbon removal
  • Many ashes were landfilled originally due to excessive carbon content

• Passivation
Harvested Ash – Production & Beneficiation

• More on carbon removal
  • Many ashes were landfilled originally due to excessive carbon content
  • Passivation

Passivation treatments render the surface of carbon non-adsorptive
Harvested Ash – Production & Beneficiation

- In the near term, harvested ash will be sourced from mono-fills where only fly ash was deposited
- Long term, fly ash co-mingled with other materials will be harvested, requiring more extensive processing
- Mixtures of fly ash and bottom ash will be produced
- Testing – primarily reactivity testing – will become more important to ensure uniformity

A Little More on Bottom Ash

- A common “concern” expressed – inclusion of bottom ash
- Bottom ash is chemically similar to fly ash from the same combustion process, and performs in a similar manner
- Grinding improves bottom ash performance and ground bottom ash has been shown to perform as well or in some cases better than fly ash from the same combustion process
- Coarse bottom ash can be separated by sieving; fine bottom ash cannot be separated from fly ash and will be a component of some harvested materials
## Bottom Ash – Example Data

<table>
<thead>
<tr>
<th>Oxide Content (% wt.)</th>
<th>FA-A</th>
<th>GBA-A</th>
<th>FA-B</th>
<th>GBA-B</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>36.72</td>
<td>43.61</td>
<td>57.1</td>
<td>59.99</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>18.2</td>
<td>16.12</td>
<td>20.83</td>
<td>18.43</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>5.69</td>
<td>9.57</td>
<td>4.75</td>
<td>6.45</td>
</tr>
<tr>
<td>SO₃</td>
<td>1.78</td>
<td>0.65</td>
<td>0.41</td>
<td>0.48</td>
</tr>
<tr>
<td>CaO</td>
<td>25.64</td>
<td>20.42</td>
<td>10.3</td>
<td>9.44</td>
</tr>
<tr>
<td>Na₂O</td>
<td>1.66</td>
<td>1.08</td>
<td>0.3</td>
<td>0.26</td>
</tr>
<tr>
<td>MgO</td>
<td>5.82</td>
<td>4.96</td>
<td>2.46</td>
<td>2.15</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.43</td>
<td>0.39</td>
<td>1.03</td>
<td>0.91</td>
</tr>
</tbody>
</table>

---

## Bottom Ash – Example Data

<table>
<thead>
<tr>
<th>Phase (%)</th>
<th>FA-A</th>
<th>GBA-A</th>
<th>FA-B</th>
<th>GBA-B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amorphous</td>
<td>83</td>
<td>53.9</td>
<td>72.7</td>
<td>64.0</td>
</tr>
<tr>
<td>Anorthite - (CaAl₂Si₂O₈)</td>
<td>-</td>
<td>34.3</td>
<td>-</td>
<td>18.6</td>
</tr>
<tr>
<td>Quartz - SiO₂</td>
<td>4.1</td>
<td>2.9</td>
<td>13.9</td>
<td>13.7</td>
</tr>
<tr>
<td>Diopside - (CaMgSi₂O₆)</td>
<td>-</td>
<td>8.1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Hematite - Fe₂O₃</td>
<td>1.2</td>
<td>0.9</td>
<td>0.4</td>
<td>0.3</td>
</tr>
<tr>
<td>Merwinite - Ca₂MgSiO₄</td>
<td>8.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lime - CaO</td>
<td>0.7</td>
<td>-</td>
<td>0.02</td>
<td>-</td>
</tr>
<tr>
<td>Periclase - MgO</td>
<td>2.4</td>
<td>-</td>
<td>0.03</td>
<td>0.2</td>
</tr>
<tr>
<td>Magnesite - MgCO₃</td>
<td>0.3</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Mullite - A₁₂SiO₁₈</td>
<td>-</td>
<td>-</td>
<td>11.4</td>
<td>2.0</td>
</tr>
</tbody>
</table>
Bottom Ash – Example Data

<table>
<thead>
<tr>
<th></th>
<th>C618 Limits</th>
<th>Fly Ash A</th>
<th>Ground Bottom Ash A</th>
<th>Fly Ash B</th>
<th>Ground Bottom Ash B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fineness</td>
<td>34 max</td>
<td>12.9</td>
<td>1.4</td>
<td>10.4</td>
<td>19.6</td>
</tr>
<tr>
<td>7-Day SAI, %</td>
<td>75 min</td>
<td>97</td>
<td>84</td>
<td>79</td>
<td>79</td>
</tr>
<tr>
<td>28-Day SAI, %</td>
<td>75 min</td>
<td>102</td>
<td>94</td>
<td>90</td>
<td>83</td>
</tr>
<tr>
<td>Water Req., %</td>
<td>105 max</td>
<td>94</td>
<td>97</td>
<td>97</td>
<td>97</td>
</tr>
</tbody>
</table>

Bottom Ash – ASTM C1567

![Graph showing the relationship between Average Expansion (%) and Cement Replacement (%). The graph includes data points for different cement replacement percentages and shows a trend for each type of ash.](image-url)
Harvested Ash – Testing

- Testing **for all coal combustion products** needs to be improved – harvested ash is only instigating the change
  - Reactivity
    - R3 test, modified SAI
  - Particle Size Distribution
  - Adsorption Properties
    - Foam Index, Iodine Number, SorbSensor™
  - Uniformity
  - NCHRP 10-104 addressing many of these issues
Harvested Ash

- **Concerns**
  - Current federal and state regulations require near-term closure of disposal ponds, leaving insufficient time to recover and use all available ash.
  - Power producers have little to no incentive to use ash beneficially, closure (cap-in-place) is the lowest cost option.

- **Benefits of landfilled ash**
  - Well over a billion tons of ash in disposal.
  - Proper processing *could* provide a more uniform product.
  - Significant reserves could help limit cost increases although processing will add costs.

A Word on “Off Spec” Ash

- So called “off-spec” ash is being considered for use.
  - Note: Existing ash specifications do not address performance (i.e., meeting the specification does not guarantee performance).

- If performance of a material can be demonstrated – use it.

- Common off-spec issues
  - LOI
  - Fineness

- Materials that are not coal fly ash are not off-spec; they are simply not fly ash – but they may work.

- Verify reserves – Verify Uniformity.
Summary

- Harvested ash is here to stay
- It will perform comparable to fly ash
- It will likely be more expensive due to processing costs
- It could be more uniform if processed properly
  - Specifications need to evolve to ensure this happens
- Bottom ash will be comingled with fly ash – it cannot be avoided
- It is necessary to test and ensure performance
- With luck, we will have ample reserves for the future

Questions?

ilsutter@mtu.edu