BENEFICIAL USE OF FLY ASH, BOTTOM ASH, AND OTHER COAL COMBUSTION PRODUCTS

By
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Reduce, reuse, and recycle for sustainable developments.

Minimize use of manufactured materials.

Maximize environmental benefits: clean air, clean water, and resource conservation.
Basic Approach

Recycle. Recycle as is.

Recycle without additional processing, (i.e., without adding any cost to it).
Basic Approach

WASTE is wasted if you waste it, otherwise it is a resource. Resource is wasted if you ignore it and do not conserve it with holistic best practices and reduce societal costs. Resource is for the transformation of people and society.

Focus on turning brown fields into green fields of the 21st Century.
CLEAN AIR
CLEAN WATER
and
RESOURCE CONSERVATION

“The earth, the sea (water), and the air are the concern of every nation.” President John F. Kennedy, fall 1963, in a speech to the U.N. General Assembly.
Introduction

• Over 5 billion tonnes of non-hazardous by-product materials are produced each year in USA (2000). At an average cost of $30 per tonne, it would cost B$150 to throw it all away.

• These by-products are from agricultural sources, domestic/post-consumer sources, industrial sources, and materials processing sources.
Coal Ash (CCPs)

- Over 120 million-tonnes of non-hazardous coal combustion products (CCPs) are produced each year in USA (2007). At an average disposal cost of $30 per tonne, it would cost $3.6 billion to throw it all away.
- CCPs are produced by coal-burning power plants to generate electricity and other industrial plants/boilers to generate steam/energy.
- These by-products generally can be used as a partial substitution of cement and many other everyday construction needs.
Coal Ash (CCPS/CCBs)
Coal Combustion Residuals

Fly ash & Bottom ash
Cyclone boiler slag, Cenospheres
FGD Materials (dry or wet/sludge)
FBC/AFBC & PFBC Materials
Spray Dryer Absorber/Clean-Coal Ash
Co-generation ash (coal, wood, petroleum coke, etc.)
Coal Combustion Products (CCPs)

• Develop recycling technology for high-volume applications of coal combustion products (CCPs) generated by using both conventional and clean-coal technologies.

• Fly ash (Class F, since 1930s, and Class C, since early 1980s), bottom ash, cyclone-boiler slag, and clean-coal ash (CCA - since late 1980s, ash derived from SOx control technologies, including FBC/AFBC/PFBC boilers, as well as dry- or wet-FGD materials from SOx/NOx control technologies).
Figure 2. Examples of Class C and Class F fly ash.
Bottom Ash, 20 X Magnification
Cyclone Boiler Slag, 100 X Magnification
Coal Combustion Products

- Fly ash
- Bottom ash
Under a microscope, fly ash particles look like tiny ball bearings. Hard and round, these particles are so small that in laboratory tests for fineness, the ash can be sifted through screens with more than 100,000 openings per square inch. Silica is the primary compound in fly ash.
Fly ash particles (Magnification, 1000 X)
The precise properties of power plant ash are dependent upon the kind of coal each utility burns. Coal mined in the western United States, for example, produces fly ash that has more lime and less silica than ash from eastern coal.
## Chemical Composition

<table>
<thead>
<tr>
<th>Oxides</th>
<th>Cement, Type I</th>
<th>St. Helen’s Ash</th>
<th>VPP Class F Ash</th>
<th>Columbia Unit #1 Fly Ash</th>
<th>P-4 Class C Ash</th>
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<tbody>
<tr>
<td>%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SiO₂</td>
<td>20.1</td>
<td>62.2</td>
<td>48.2</td>
<td>44.8</td>
<td>32.9</td>
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<td>Al₂O₃</td>
<td>4.4</td>
<td>17.6</td>
<td>26.3</td>
<td>22.8</td>
<td>19.4</td>
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<td>CaO</td>
<td>57.5</td>
<td>5.7</td>
<td>2.7</td>
<td>17.0</td>
<td>28.8</td>
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<tr>
<td>MgO</td>
<td>1.6</td>
<td>2.2</td>
<td>1.1</td>
<td>5.1</td>
<td>4.8</td>
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<tr>
<td>Fe₂O₃</td>
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<td>5.6</td>
<td>10.6</td>
<td>4.2</td>
<td>5.4</td>
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<td>TiO₂</td>
<td>0.27</td>
<td>0.79</td>
<td>1.2</td>
<td>1.0</td>
<td>1.6</td>
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<td>K₂O</td>
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<td>1.2</td>
<td>2.3</td>
<td>0.43</td>
<td>0.34</td>
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<td>Na₂O</td>
<td>0.22</td>
<td>4.6</td>
<td>1.1</td>
<td>0.29</td>
<td>1.9</td>
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<td>Moisture</td>
<td>0.2</td>
<td>0.42</td>
<td>0.39</td>
<td>0.13</td>
<td>0.80</td>
</tr>
<tr>
<td>LOI</td>
<td>1.1</td>
<td>0.60</td>
<td>7.9</td>
<td>0.27</td>
<td>0.65</td>
</tr>
</tbody>
</table>
Of all the uses for fly ash, the best known are as an additive in portland cement concrete and as a supplementary cementitious material. In both of these applications, fly ash increases strength and durability, adding years to the life of the product.
Energy Conservation

About six million BTUs are needed to produce one ton of cement. Use of fly ash saves that energy and conserves dwindling resources.
Fly ash is a pozzolan. A pozzolan is an inert siliceous material that in the presence of moisture will combine with calcium hydroxide to produce a cementitious material with excellent structural properties.
COMUNE DI POZZUOLI

MANUTENZIONE STRAORDINARIA DEL MANUFATTO (CHALET) ADIBITO A BAR E VENDITA SOUVENIRS

CHIUSURA DUN ZIO ATTIVITA' 10/11/200

11:00
Portland Cement + Water

Free Lime, Ca(OH)₂

Fly Ash

Cementitious Material
SEM Images of BCN60, 7 days
Why Be Interested in Fly Ash?

The answer to this question is short, simple, and clear: a good fly ash, properly used as an ingredient, produces a better concrete at lower cost. Concrete employing fly ash is better in many important ways than concrete without fly ash. It provides the contractor and building owner with a more durable product, easier to handle, place, and finish. It helps to increase business and profit for the ready-mix plant operator.
Reduces Heat of Hydration

Fly ash reaction generates heat more slowly than the faster reacting portland cement. Some researchers have also shown that substitution can also slow the hydration of portland cement itself. This combination minimizes heat generation in concrete, especially in mass concrete.
Resists Sulfate Attack

Fly ash combines with lime (CaOH\(_2\)), making it less available to react with sulfates. The resulting cementitious material also blocks concrete bleed channels which can hinder further entry of the aggressive soluble sulfates. This combination will often times improve a concrete’s resistance to sulfate attack.
Resists Alkali Aggregate

Many fly ashes react with available alkalies in the concrete making them less available to react with the aggregates.
Improves Workability

The spherical shape and small size of fly ash particles combine to lubricate the concrete mixture, reducing water demand for a given slump.
Fly ash concrete requires less water than plain concrete at any given slump; and, high workability enables placement at lower slumps. Reduction in water content means more strength and less shrinkage and improved durability.
BENEFITS of FLY ASH in CONCRETE

- Increased Ultimate Strength
- Reduced Permeability
- Improved Durability
- Reduced Shrinkage
- Increased Abrasion Resistance
- Lower Concrete Cost
BENEFITS OF CCPs UTILIZATION

- Avoids Disposal Costs
- Conserves Landfill Capacity
- Reduces Construction Costs
- Enhances Environment from Minimizing Disposal
- Virgin and Manufactured Construction Materials Conserved for Higher Priority Use
High Tech Use of Fly Ash

- Metal Extraction
- Mineral Extraction
- SO₂ Control
- Thermal Insulation
- Heat Resistant Materials
- Rubber Filler
- Plastic Filler
- Metal Filler
- Coagulant
Medium Tech Use of Fly Ash

- Concrete and Cement
- Bricks, Blocks, and Paving Stones
- Ceramic Tiles
- Filler in Asphalctic Mixes
Low Tech Use of Fly Ash

- Structural Fills
- Road Base
- Sludge Stabilization
- Land Reclamation
- Grouting
- Soil Amendment
- Mine Backfills
- Coal Mining Operations
Current Uses

- Concrete
- Bricks, blocks, and paving stones
- Slurry
- Blended Cements
- Aggregates from slag
Manufacturing of bricks with fly ash, with or without bottom ash
Air Content Problems

The fineness of fly ash makes it more difficult to develop and hold entrained air.
Low Early Strength

The lb. per lb. substitution mixture proportioning method may result in lower strengths at early ages. Mixture proportioning should take into consideration form removal sequence and anticipated early loading. Lower early strengths can be readily overcome through the use of appropriate admixtures and/or other adjustments to the mixture.
BOTTOM ASH
## Bottom Ash

<table>
<thead>
<tr>
<th>Compound</th>
<th>PPPP</th>
<th>OCPP</th>
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<tr>
<td>SiO</td>
<td>42.9</td>
<td>50.5</td>
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<tr>
<td>AlO</td>
<td>18.2</td>
<td>19.3</td>
</tr>
<tr>
<td>FeO</td>
<td>7.4</td>
<td>7.5</td>
</tr>
<tr>
<td>CaO</td>
<td>21.8</td>
<td>7.4</td>
</tr>
<tr>
<td>MgO</td>
<td>3.7</td>
<td>1.9</td>
</tr>
<tr>
<td>SO</td>
<td>0.62</td>
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<tr>
<td>NaO</td>
<td>1.6</td>
<td>0.75</td>
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<tr>
<td>KO</td>
<td>0.30</td>
<td>0.74</td>
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<tr>
<td>LOI</td>
<td>2.0</td>
<td>4.2</td>
</tr>
</tbody>
</table>
BTM ASH Used as Base & Sub-base Aggregates
- Roadways, Highways, and Airfields
- Parking lots
- Concrete Slab-on-grade
- Footings and Foundations
BTM ASH is also used as lightweight aggregates in masonry products & architectural concrete products.
Project experience with high-fly ash content concrete
## CONCRETE MIXTURE AND TEST DATA
### 5000 psi (34 MPa) SPECIFIED STRENGTH

<table>
<thead>
<tr>
<th>Mixture No.</th>
<th>P4-13</th>
<th>P4-14</th>
<th>P4-15</th>
<th>P4-16</th>
<th>P4-17</th>
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<tr>
<td>Specified Design</td>
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<td>5000</td>
<td>5000</td>
<td>5000</td>
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<tr>
<td>Strength, psi</td>
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<tr>
<td>Cement, lbs</td>
<td>611</td>
<td>490</td>
<td>428</td>
<td>367</td>
<td>305</td>
<td>245</td>
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<tr>
<td>Fly Ash, lbs</td>
<td>0</td>
<td>145</td>
<td>220</td>
<td>295</td>
<td>382</td>
<td>441</td>
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<tr>
<td>Water, lbs</td>
<td>290</td>
<td>291</td>
<td>289</td>
<td>270</td>
<td>278</td>
<td>268</td>
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<tr>
<td>Sand, SSD, lbs</td>
<td>1450</td>
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<tr>
<td>¾” Aggregates SSD, lbs</td>
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<td>1810</td>
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</table>
As the amount of fly ash increased, the water demand decreased while maintaining the same slump (4” ± 1”).
# CONCRETE STRENGTH TEST DATA

5000 psi (34 MPa) SPECIFIED STRENGTH

AVERAGE COMPRESSIVE STRENGTH, PSI

<table>
<thead>
<tr>
<th>Test Age, Days</th>
<th>Mixture No.</th>
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<th></th>
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<th></th>
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<tbody>
<tr>
<td></td>
<td>P4-13</td>
<td>P4-14</td>
<td>P4-15</td>
<td>P4-16</td>
<td>P4-17</td>
<td>P4-18</td>
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<tr>
<td>1*</td>
<td>2519</td>
<td>2448</td>
<td>2044</td>
<td>1942</td>
<td>1230</td>
<td>1336</td>
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<tr>
<td>3</td>
<td>2904</td>
<td>2987</td>
<td>2591</td>
<td>2390</td>
<td>314**</td>
<td>116**</td>
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<td>7</td>
<td>3902</td>
<td>4168</td>
<td>3851</td>
<td>3892</td>
<td>3392</td>
<td>205**</td>
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<tr>
<td>28</td>
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<td>56</td>
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<td>91</td>
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<td>7209</td>
<td>7519</td>
<td>8004</td>
<td>9012</td>
<td>8493</td>
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</table>

*AFTER ACCELERATED CURING, USING BOILING WATER METHOD.

**CYLINDERS WERE SOFT WHEN TESTED.
# CONCRETE STRENGTH TEST DATA – 5000 psi (34 MPa) STRENGTH, PLANT NO.2

<table>
<thead>
<tr>
<th>Mixture No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<tbody>
<tr>
<td>Fly Ash, %</td>
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<td>10</td>
<td>15</td>
<td>20</td>
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<td>30</td>
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<td>19 hrs</td>
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<td>22 hrs</td>
<td>2790</td>
<td>3180</td>
<td>3750</td>
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<td>3</td>
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</tbody>
</table>

Center for By-Products Utilization
PROJECT 1: MAY 1984

5” thick slab x 15’ x 20’ = 5 yd³, 70% fly ash replaced for cement.
Frontier Ready Mix Loading Area
Slinger, Wisconsin.
PROJECT 2: SEPTEMBER 1984

24’ wide truck access road.
10” thick x 1400 ft long, = 1000 yd³,
70% fly ash replaced for cement.
Pleasant Prairie Power Plant
Wisconsin, USA.
COMPRESSIVE STRENGTHS

7-day = 1150 PSI
28-day = 2200 PSI
56-day = 3500 PSI
Fly ash is used in large quantities as a fine aggregate in RCCP, and up to 50% of total cementitious materials.
MANUFACTURE OF BLENDED CEMENTS

Raw Material in Production of Cement Clinker
Interground with Clinker
Blended with Cement
HIGH-STRENGTH CERAMIC PRODUCTS

Products with high-flexural strength such as railroad ties, electric line insulators, fence posts, etc.
WATER POLLUTION CONTROL

a) Neutralization of Acidic water
b) Phosphorus Removal from Wastewater
c) Sludge Dewatering
d) Sorbent for Organics
e) Sealing of Contaminated Sediments
Cenospheres are used in metals as a filler. They improve damping and abrasion resistance of the material.
OTHER FILLER
APPLICATIONS

Asphalt Roofing Shingles
Joint Compound
Carpet Backing
Vinyl Flooring
Industrial Coatings, etc.
RECOVERY OF MATERIALS

a) Carbon
b) Magnetite (Fe$_2$O$_3$)
c) Cenospheres
d) Metals: Alumina, Iron Oxide, etc.
Fly Ash Use for Lightweight Aggregates

a) Unfired (Cold Bonded Process)
b) Sintered (Fired) Aggregates
Concrete with Lightweight Aggregates – fly ash used as a pumping aid.
CCP USES MUST BE:

TECHNICALLY PROVEN.
COMMERICALLY EFFECTIVE.
ENVIRONMENTALLY SOUND.
Thank you

More information at