Ash an Expert...
A Prelude to Alternative SCMs

Bud Werner – CTL|Thompson, Inc.
Thomas Adams – American Coal Ash Association (ACAA)
Mark Van Kluenen – Skyway Cement Company
Tom McNamee – Master Builders Solutions
Joe Thomas – Magnatics/NPA
Jonathan Dennis – GCC of America, Inc.

April 27, 2021

A Brief History of Hydraulic Cement in Construction

Bud Werner – CTL|Thompson, Inc.
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Hydraulic Cement

- Definition (ACI) – A binding material that sets and hardens by chemical reaction with water and is capable of doing so underwater.
  - Portland cement.
  - Natural cement.
  - Slag cement.
  - Class C fly ash.
  - Plaster of Paris

Ancient Building with Earthen Materials
Stones Alone
Stacked Stone Process

- Incredibly labor intensive
- Very slow process
- The “contractor” undoubtedly was looking for a better way.

Ancient Building with Earthen Materials
Stones With Mortar

Egypt 2000BC
China 200BC-1600AD
Ancient Building with Earthen Materials
Stones With Mortar

**Egypt 2000 BC**
- Some of the stones were found to be bedded with calcined gypsum (300°C).
- Modern day term for this is Plaster of Paris.
- Controversy surrounds all the theories of pyramid construction.

**China 200BC – 1600 AD**
- Methods varied with age.
- Ming Dynasty construction included use of Plaster of Paris with a “rice pectin” admixture, one of few documented organic admixtures.

Ancient Building with Earthen Materials
Concrete and Mortar

- Roman Structures (Pantheon / Colosseum and many others)
- Built with calcined Limestone (840°C-900°C) ground up and mixed with about 85% volcanic ash from Mount Vesuvius, from near Puzzuoli. Ash became known as “pozzolana”.
- Combination was later called “Natural Cement”
Ancient Building with Earthen Materials
Concrete and Mortar

Crete
Santorini

- Greeks used calcined lime and Santorin Earth, a volcanic tuff from major modern eruptions on Thera.
- They also ground up ceramics to use as pozzolan

The Advent of Portland Cement

Eddystone Rock Lighthouse
- In 1756 the third of 4 lighthouses built in this location was completed. Although it later was undermined, it was never totally removed.
- John Smeaton experimented with production of lime by including some clay in the feed – and found it improved its strength properties.
- Trass (Rhine region volcanic material) was combined with the Smeaton cement.
- In spite of Smeaton’s experiment, not much improvement was made to his lime for about 100 years.
The Advent of Portland Cement

- In 1842, Joseph Aspdin patented Portland Cement.
- He calcined limestone, broke it up and mixed it with clay and water, calcined it yet again and ground it up.
- It is called Portland Cement because of Aspdin's observation that the hardened cement resembled stone bluffs surrounding the Isle of Portland.
- This new product did not take off quickly. Aspdin's son took over its promotion. A man named Charles Johnson noticed that when some of the clinkers were "over burned", they made excellent cement when ground up. Modern day cement is calcined at about 1450°C.

The Use of Portland Cement in the Past 150 Years

- People started putting stones and sand in mortar.
- Germany formed their own “Portland Cement Assn.” in about 1870
- The world started to be more scientific in its development – better tools and more scientific understanding.
  - Petrography was instrumental in understanding the Bogue reactive component composition of cement (C₃S,C₂S,C₃A,C₄AF)
  - Thermal analyses became a useful tools.
- ASCE began formulating test methods to assess it.
- ASTM formed Committee C1 on Cement.
Early Standards

- British Standard for Portland Cement – 1904
- First ASTM standard for Portland Cement – 1904
- ASTM Standard for Natural Cement (C10) – 1904
- First ASTM Standard C150 for Portland Cement – 1940
- Carnegie Institute, US Bureau of Standards, and (after 1926) the Portland Cement Institute did a lot of study and research on Portland Cement during the first part of the 20th Century.
- The British “Cement and Concrete Association was formed after WWII

Advent of GGBFS (Slag Cement)

- By-product of iron production.
- Mixed with calcined lime in the 1700’s to make mortar
- Iron ore is heated to 1500 °C to separate iron from the ore.
- Molten slag is granulated by quenching when dumped from the furnaces.
- Thus, we get “ground, granulated blast-furnace slag”
  - Now called “SLAG CEMENT”
Advent of Fly Ash

- Not as old as natural pozzolans.
- It gained attention in the 1950’s and 1960’s as powerplants became more sophisticated and the ash was cleaner and finer.
- USBR, COE, TVA all used it in water resource, hydraulic power and/or flood control structures in the mid 1900’s.
- Originally Class F ash was used. The Class C ash was later as the Powder River Basin and similar lignite/sub-bituminous coals were mined for power plants.

Advent of Silica Fume

- First tested in 1952
- Mostly not collected until the 1970’s.
- By-product of the silicon chip production process.
- Extremely fine in comparison to other pozzolans. (100 times finer than most)
- It became commonly used in the 1980’s.
- There is a limited supply.
Advent of Metakaolin

• Just a natural pozzolan on steroids.
• Kaolin clay calcined to 700 °C ±50?
• Ground very fine, finer than cement, not as fine as silica fume.
• Used in high performance concrete.
• I remember it first becoming available in the 1970’s.
• No separate ASTM specification for it was ever published.

Fly Ash State of Affairs

Thomas Adams – American Coal Ash Association (ACAA)
thadams@acaa-usa.org
A Prelude to Alternative SMCs

ACAA Mission

- The mission of the American Coal Ash Association is to encourage beneficial use of CCP in ways that are
  - environmentally responsible,
  - technically sound,
  - commercially competitive,
  - supportive of a sustainable global community.

What is the state of supply today and why?

- On a national level, some regions are experiencing a significant gap between supply and demand.
- Primary reason for this gap: demand has been increasing while coal-fueled generation has been decreasing
- About 6 years ago, coal fueled about 50% of the generation of electricity
- Today, coal accounts for 20% to 25% of generation
- Base-load generation has declined
- Coal plants are now running mostly in very hot and very cold weather conditions
State of Supply - continued

- 2009: U.S. Environmental Protection Agency (EPA) started an attempt to regulate fly ash and other coal combustion products (CCP) as a hazardous waste.
- Many older coal-fueled plants began to hit retirement age or became uneconomical to retrofit to meet increasingly stringent EPA standards.
- Combustion stream injections made some fly ash unsuitable for use in concrete.
- Fracking caused a rapid increase in supplies of natural gas.
- As natural supplies increased, gas prices decreased dramatically.
- Fossil fuels became a primary target of environmental activists.

There is fly ash not in use

- *Each year millions of tons of fly ash produced goes to disposal rather than into beneficial use.*
- Primary Reason #1 – Dislocation
- Primary Reason #2 – Quality
- 2015 to 2019 185.9 m tons of fly ash produced
- 2015 to 2019 108.7 m tons of fly ash used in all beneficial uses
- 2015 to 2019 69.4 m tons of fly ash used in concrete
- 2015 to 2019 **77.2 m tons of fly ash not used**
Fly Ash Production Forecast

Figure 1. Various Scenarios for Fly Ash Production, 1974 to 2039

Table 1. Fly Ash Forecast Scenarios (in millions short tons)

<table>
<thead>
<tr>
<th>Fly Ash Production</th>
<th>Volume 2018</th>
<th>Projected Volume 2039</th>
<th>Projected Total Change</th>
<th>Projected Avg. Annual Growth Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline Forecast</td>
<td>36.2</td>
<td>30.8</td>
<td>-14.9%</td>
<td>-0.8%</td>
</tr>
<tr>
<td>High Growth Scenario</td>
<td>36.2</td>
<td>44.8</td>
<td>23.8%</td>
<td>1.0%</td>
</tr>
<tr>
<td>Low Growth Scenario</td>
<td>36.2</td>
<td>24.9</td>
<td>-31.2%</td>
<td>-1.8%</td>
</tr>
<tr>
<td>Fly Ash Utilization</td>
<td>20.1</td>
<td>27.8</td>
<td>38.3%</td>
<td>1.6%</td>
</tr>
</tbody>
</table>
What is “harvesting”?

- “Harvesting” is the term selected by consensus to describe to process of removing coal ash from disposal – dry and wet – for beneficial uses.
- Why “harvesting’?
- Disposal of coal ash occurs in landfills and surface impoundments (a.k.a. ponds)
- Coal ash comingled with other materials is likely not to be a candidate for processing for concrete manufacture
- Coal ash in monofills is the target
- Over 2.5 billion tons in disposal in the U.S.

Summary

- There are millions of tons of fly ash being produced annually that are not being used.
- Fly ash production is expected to remain fairly constant for the next 15 to 20 years.
- Harvesting will close or eliminate the gap between supply and demand in some regional markets.
- Specification changes can assist with alleviating shortages in some markets.
- Beneficiation technologies are available but can be costly.
Slag Cement in the U.S.

Mark Van Kleunen, LEED AP – Skyway Slag Cement
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2020 US Cement Consumption – 112,000,000 short tons
2019 US Fly ash Consumption For Concrete – 12,600,000 short tons
Slag Comes From an Iron Blast Furnace for Manufacturing Steel

Granulation Process

Slag floating on top

Hot Blast Furnace Slag (BFS)

Slag Diverted to Granulator
High pressure water
6 - 10 tons water/ton slag

Slag is changed to glassy sand like substance known as granulated blast furnace slag - GBFS

Air cooled slag is used for aggregate
Making Slag Cement

Slag cement plant → Granules → Ball Mill → Slag Cement / GGBFS → Finished product

<table>
<thead>
<tr>
<th>Product</th>
<th>Blaine (m²/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slag Cement</td>
<td>500 - 650</td>
</tr>
<tr>
<td>Type III</td>
<td>550 - 650</td>
</tr>
<tr>
<td>Fly Ash</td>
<td>400 - 450</td>
</tr>
<tr>
<td>Type I</td>
<td>350 - 420</td>
</tr>
</tbody>
</table>

Ternary CaO-SiO₂-Al₂O₃ Diagram

- Slag
- Fly Ash
- Natural Pozzolans
- Silica Fume

Strength in Numbers
A 50% cement / 50% slag cement is compared to 100% Reference cement at the various ages.
The reference cement used has a lot to do with determining the grade of slag cement (Alkalies: 0.60 – 0.90% & 5,000 psi @ 28 days).

### Slag-Activity Index ASTM C989/AASHTO M302

<table>
<thead>
<tr>
<th>Min. 28-day</th>
<th>% of Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 100</td>
<td>95</td>
</tr>
<tr>
<td>Grade 120</td>
<td>115</td>
</tr>
</tbody>
</table>

### Slag Cement’s Effect on Concrete Properties

#### General Concrete Properties

<table>
<thead>
<tr>
<th>Fresh Concrete</th>
<th>Hardened Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduces Water Demand</td>
<td>Lower Early Strength</td>
</tr>
<tr>
<td>Improves Workability</td>
<td>Much Higher Later Age Strength</td>
</tr>
<tr>
<td>Slower Bleeding</td>
<td>Much Lower Permeability</td>
</tr>
<tr>
<td>Slightly Lower Air Content</td>
<td>Lowers Chloride Ingress</td>
</tr>
<tr>
<td>Lower Heat of Hydration Mass Concrete</td>
<td>Greatly Reduces ASR Potential</td>
</tr>
<tr>
<td>Slower Setting Time</td>
<td>Greatly Increases Sulfate Resistance</td>
</tr>
<tr>
<td>Improves Finishability</td>
<td>No Difference Freeze Thaw Resistance</td>
</tr>
<tr>
<td>Improves Pumpability</td>
<td>No Difference Abrasion Resistance</td>
</tr>
<tr>
<td>No Difference Plastic Shrinkage</td>
<td>No Difference Drying Shrinkage</td>
</tr>
</tbody>
</table>
### Slag Cement Replacement %’s

<table>
<thead>
<tr>
<th>Application</th>
<th>Slag Cement %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete paving</td>
<td>25 – 50 %</td>
</tr>
<tr>
<td>Exterior flatwork not exposed to deicer salts</td>
<td>20 – 35 %</td>
</tr>
<tr>
<td>Exterior flatwork exposed to deicer salts with (w/cm &lt; 0.45)</td>
<td>10 – 15 %</td>
</tr>
<tr>
<td>Interior flatwork</td>
<td>25 – 50 %</td>
</tr>
<tr>
<td>Footings</td>
<td>30 – 65 %</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Application</th>
<th>Slag Cement %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Masonry/Pavers</td>
<td>20 – 50 %</td>
</tr>
<tr>
<td>ICF</td>
<td>25 – 60 %</td>
</tr>
<tr>
<td>High strength</td>
<td>25 – 50 %</td>
</tr>
<tr>
<td>Tilt-up panels</td>
<td>25 – 50 %</td>
</tr>
<tr>
<td>ASR mitigation</td>
<td>25 – 50 %</td>
</tr>
<tr>
<td>Lower permeability</td>
<td>25 – 50 %</td>
</tr>
<tr>
<td>Mass concrete</td>
<td>25 – 70 %</td>
</tr>
<tr>
<td>Sulfate Resistance</td>
<td></td>
</tr>
<tr>
<td>Type II equivalence</td>
<td>25 – 50 %</td>
</tr>
<tr>
<td>Type V equivalence</td>
<td>35 – 65 %</td>
</tr>
</tbody>
</table>

### Improved Reflectivity

<table>
<thead>
<tr>
<th>Solar Reflectance</th>
<th>Portland</th>
<th>Fly Ash</th>
<th>Slag Cement</th>
<th>Slag + White Portland</th>
<th>White Portland</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.20</td>
<td>0.53</td>
<td>0.54</td>
<td>0.64</td>
<td>0.62</td>
<td>0.69</td>
</tr>
<tr>
<td>0.30</td>
<td></td>
<td></td>
<td>0.50</td>
<td>0.62</td>
<td></td>
</tr>
<tr>
<td>0.40</td>
<td></td>
<td></td>
<td>0.46</td>
<td>0.62</td>
<td></td>
</tr>
<tr>
<td>0.50</td>
<td></td>
<td></td>
<td></td>
<td>0.62</td>
<td></td>
</tr>
<tr>
<td>0.60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.70</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Greening

- "Greening" is a temporary blue-green color showing on the surface of concrete containing slag in the first few days after placement.
- Occurs in small percentage of concrete made with slag, disappears within a week of exposure to air and sunlight (oxidizes).

Effect on Initial Set Time

<table>
<thead>
<tr>
<th>Condition</th>
<th>Initial Time of Set (Min to 500 psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>85-90°F</td>
<td>100% Portland</td>
</tr>
<tr>
<td>73°F</td>
<td>35% Slag, 65% Fly Ash</td>
</tr>
<tr>
<td>55°F</td>
<td>45% Slag, 55% Fly Ash</td>
</tr>
<tr>
<td>1% CaCl</td>
<td>20% Fly Ash</td>
</tr>
<tr>
<td>2% CaCl</td>
<td>20% Slag, 80% Fly Ash</td>
</tr>
</tbody>
</table>
Effect on Strength

- Higher 28-day compressive strengths
  - 1,000-2,000 psi higher
- Lower early strengths
- Typically matches portland strengths ~7 days
- Optimum strength replacement 35%-40%

![Graph showing the effect of slag cement on compressive and flexural strength](image)

Effect of Slag Cement on Concrete Permeability

![Graph showing the effect of slag cement on chloride ion penetrability](image)

Chloride Ion Penetrability (ASTM C1202)

- Low Permeability < 2000 Coulombs
- Very Low Permeability < 1000

<table>
<thead>
<tr>
<th>Slag Replacement of T-I Portland Cement</th>
<th>Charge Passed, Coulombs</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>1,000</td>
</tr>
<tr>
<td>25%</td>
<td>2,000</td>
</tr>
<tr>
<td>50%</td>
<td>3,000</td>
</tr>
</tbody>
</table>

- $w/cm = 0.45$
- $w/cm = 0.55$
- $w/cm = 0.70$
Effect of Slag Cement on ASR

ASR Expansion of Concrete, ASTM C1293

Potentially deleterious expansion > 0.04% @ 2 years

Siliceous Limestone Greywacke Sandstone Granite

Expansion at 2 Years, %

0.00 0.05 0.10 0.15 0.20 0.25 0.30

100% Portland 25% Slag 35% Slag 50% Slag 65% Slag

Silica Fume

Tom McNamee – Master Builders Solutions
Tom.mcnamee@mbcc-group.com
Silica Fume Products

BENEFITS:
- Increase the Durability of Concrete
- Produce High-Strength Concrete
- Reduces permeability
- Improved Sulfate and Corrosion resistance
- ASR Mitigation
Silica Fume
Mitigating ASR

- Limit alkali content in cement/concrete
- Restrict use of reactive aggregates (shipping in from different source)
- Use supplementary cementitious material
- Slag cement
- Fly ash
- Natural pozzolans
  - Silica fume
  - Metakaolin
  - Use lithium admixture

Silica Fume
Mitigating ASR

- Silica fume is a highly efficient pozzolan
- Combines rapidly with alkalies in pore water
- Incorporates alkalies as substitutes for calcium in the hydrated cement gel
- Reduces diffusion rate of alkalies through the pores of concrete
Silica Fume Dosage Calculator

- Based on the recommendations provided in FHWA-HIF-09-001
  - Report on Determining the Reactivity of Concrete Aggregate and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete Construction
- 4 inputs = dosage calculated
- External Technical Support Group should be contacted as needed

Note: If aggregate supplier or producer has ASTM C 1293 test data, the silica fume dosage can be adjusted / optimized

Silica Fume Concrete Production

- Measuring – Add silica fume
- Batching – Add with 70-90% of batch water, followed by aggregates, cementitious materials and then the remaining amount of water. Batch low slump concrete 1-3 inches
- Adding HRWR – Add at end, mix for 70 revolutions
- Mixing – Minimum of 100 revolutions
Natural Pozzolans

- The word most associated with Roman Concrete is: **Durability**
- Concrete that lasts, often in pristine condition, for thousands of years, as opposed to 40 or 60 if we’re lucky....so, what is this stuff made of?
Natural Pozzolans

There are 2 types of Natural Pozzolans (NP):

- **Raw NP** (Volcanic ejecta-based materials – pumice, pumicite, volcanic ash, etc. Pre-calcined by Mother Nature)
- **Calcined NP** (such as MetaKaolin)
Roman Lime Kiln near Aachen GR
Natural Pozzolans

- **Roman Concrete**: "It's the most durable building material in human history, and I say that as an engineer not prone to hyperbole," Roman monument expert Phillip Brune told the Washington Post. *July 4, 2017, Washington Post*

Physical and Chemical Properties of Natural Pozzolan

- Fly Ash
- Raw Natural Pozzolan
- Metakaolin
<table>
<thead>
<tr>
<th>Chemical Analysis</th>
<th>ASTM / AASHTO Limits</th>
<th>ASTM Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon Dioxide (SiO₂)</td>
<td>59.73 %</td>
<td>70.0% min 50.0% min</td>
</tr>
<tr>
<td>Aluminum Oxide (Al₂O₃)</td>
<td>23.01 %</td>
<td>5.0% max 5.0% max</td>
</tr>
<tr>
<td>Iron Oxide (Fe₂O₃)</td>
<td>4.47 %</td>
<td>D4326</td>
</tr>
<tr>
<td>Sum of Constituents</td>
<td>87.21 %</td>
<td>D4326</td>
</tr>
<tr>
<td>Sulfur Trioxide (SO₃)</td>
<td>0.37 %</td>
<td>3.0% max 3.0% max</td>
</tr>
<tr>
<td>Calcium Oxide (CaO)</td>
<td>4.84 %</td>
<td>C311</td>
</tr>
<tr>
<td>Moisture</td>
<td>0.05 %</td>
<td>6.0% max 6.0% max</td>
</tr>
<tr>
<td>Loss on Ignition</td>
<td>0.85 %</td>
<td>5.0% max 5.0% max</td>
</tr>
<tr>
<td>Available Alkalis, as Na₂Oe</td>
<td>1.36 %</td>
<td>not required</td>
</tr>
<tr>
<td>Physical Analysis</td>
<td></td>
<td>C311</td>
</tr>
<tr>
<td>Fineness, % retained on #325</td>
<td>17.13 %</td>
<td>34% max 34% max</td>
</tr>
<tr>
<td>Strength Activity Index - 7 or 28 day requirement</td>
<td></td>
<td>C311, C109</td>
</tr>
<tr>
<td>7 day, % of control</td>
<td>84 %</td>
<td>75% min 75% min</td>
</tr>
<tr>
<td>28 day, % of control</td>
<td>84 %</td>
<td>75% min 75% min</td>
</tr>
<tr>
<td>Water Requirement, % control</td>
<td>95 %</td>
<td>105% max 105% max</td>
</tr>
<tr>
<td>Autoclave Soundness</td>
<td>0.00 %</td>
<td>0.8% max 0.8% max</td>
</tr>
<tr>
<td>Density</td>
<td>2.25</td>
<td>C604</td>
</tr>
</tbody>
</table>

### Chemical Composition (%)

<table>
<thead>
<tr>
<th>Chemical Composition</th>
<th>ASTM C618-15</th>
</tr>
</thead>
<tbody>
<tr>
<td>(By Wyoming Analytical Laboratories, Inc.)</td>
<td>Class N</td>
</tr>
<tr>
<td>Total Silica, Aluminum, Iron</td>
<td>86.6</td>
</tr>
<tr>
<td>Silicon Dioxide</td>
<td>72.5</td>
</tr>
<tr>
<td>Aluminum Oxide</td>
<td>13.2</td>
</tr>
<tr>
<td>Iron Oxide</td>
<td>0.9</td>
</tr>
<tr>
<td>Sulfur Trioxide</td>
<td>0.1</td>
</tr>
<tr>
<td>Calcium Oxide</td>
<td>1.3</td>
</tr>
<tr>
<td>Moisture Content</td>
<td>7.8</td>
</tr>
<tr>
<td>Loss on Ignition</td>
<td>4.1</td>
</tr>
<tr>
<td>Available Alkalis (as Na₂O):</td>
<td>1.5</td>
</tr>
<tr>
<td>Sodium Oxide</td>
<td>0.76</td>
</tr>
<tr>
<td>Potassium Oxide</td>
<td>1.12</td>
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</tbody>
</table>

### Physical Test Results

<table>
<thead>
<tr>
<th>Physical Test Results</th>
<th>ASTM C618-15</th>
</tr>
</thead>
<tbody>
<tr>
<td>(By Wyoming Analytical Laboratories, Inc.)</td>
<td>Class N</td>
</tr>
<tr>
<td>Fineness, Retained on #325 Sieve</td>
<td>5.7</td>
</tr>
<tr>
<td>Strength Activity Index (%)</td>
<td>89.6</td>
</tr>
<tr>
<td>Ratio to Control @ 7 Days</td>
<td>99.2</td>
</tr>
<tr>
<td>Ratio to Control @ 28 Days</td>
<td>95.4</td>
</tr>
<tr>
<td>Water Requirement, % of Control</td>
<td>115 Max</td>
</tr>
<tr>
<td>Soundness, Autoclave Expansion (%)</td>
<td>0.03</td>
</tr>
<tr>
<td>Drying Shrinkage, Increase @ 28 Days (%)</td>
<td>0.02</td>
</tr>
<tr>
<td>Density Mg/m³</td>
<td>2.40</td>
</tr>
</tbody>
</table>

Comments: Meets ASTM C618-15/ AASHTO M295-11 Type N. Retested SAI.
How does Natural Pozzolan enhance and protect concrete?

- Roman Concrete utilized a balanced cement paste – virtually all of the Calcium Hydroxide was consumed based on the recipe shared by Vitruvius.

Note: Calcium Hydroxide (free lime) in concrete, which is not converted to C-S-H, becomes a volatile, bad actor in concrete... upwards of 25% of free lime is released into the concrete matrix, by weight of cement, as a byproduct of the hydraulic reaction.
How does Natural Pozzolan enhance and protect concrete?

• If 20–30% of cement is replaced with NP, the Portland cement system, like the ageless Roman cement, is now better balanced.

• In other words, much of that 20–25% free-ranging lime by-product in the concrete is consumed, over time - in a reaction with the NP to form additional C-S-H, the binder in concrete – thus densifying the concrete.

How does Natural Pozzolan enhance and protect concrete?

• By converting the free-lime into additional C-S-H, a concrete using NP at a 20–25% replacement of cement will have greater compressive strength than a 100% cement mix design - up to 140% SAI of the straight cement mixes at 1 year.
How does Natural Pozzolan enhance and protect concrete?

- All or most of the free-lime will be converted to C-S-H, providing enhanced strength, reduced permeability, and fortifying the concrete against chemical attack, such as ASR and Sulfate attack.

- The NP converts a bad actor into a good actor, and your concrete will be inoculated from common concrete diseases, giving your customer’s concrete a very long service life....

Benefits of Natural Pozzolans

1. Product consistency: No need to continually adjust your mix design based on product variability.
2. Reduce Carbon Footprint: Almost a pound for pound reduction of embodied carbon for every pound of cement replaced for raw NP and more than ½ pound for calcined NPs.
3. Reduced Heat of Hydration (HOH): Up to 25% or more reduction in HOH based on mix design.
4. Mitigate Chemical Attack: NPs are very effective at mitigating ASR and Sulfate attack, as well as Efflorescence.
5. Reduce Permeability: NPs densify and strengthen concrete. This increases durability & strength and reduces chloride ingress – protecting reinforcement.
6. Air Entrainment Consistency: NPs do not cause variability in air entrainment. LOI in NP is measured bound water, not carbon content.
Emergent NP producers soon to be in production

NP mix design in 18-month ASTM C1012 vs. Control (straight cement) at 18-months
NP production locations USA.

- In production or under construction
- Permitted/Proposed Facility
- Permitted site
Hydraulic Cement

Jonathan Dennis – GCC of America, Inc.
jdennis@gcc.com
Fly Ash – Declining production

CO₂ in Cement Production

Raw materials, energy, and resources

Clinker and cement manufacturing

<table>
<thead>
<tr>
<th>Energy, megajoule/ton</th>
<th>Quarry</th>
<th>Crusher</th>
<th>Transport</th>
<th>Raw mill</th>
<th>Kiln and preheater/precincinator</th>
<th>Cooler</th>
<th>Cement mill</th>
<th>Logistics</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40</td>
<td>5</td>
<td>40</td>
<td>100</td>
<td>3,150</td>
<td>160</td>
<td>285</td>
<td>115</td>
<td>3,895</td>
</tr>
</tbody>
</table>

| CO₂, kilogram/ton | 3    | 1     | 7     | 17   | 479   | 319   | 28 | 49 | 22 | 925 |

Calcination process | Fossil fuels
CO₂ Around the World

Next target?

**SOURCES OF GREENHOUSE GASES**

The largest source of greenhouse gas emissions from human activities is from manufacturing. Cement production is a major contributor.

- **Manufacturing**: 31%
- **Cement**: 19%
- **Iron & Steel**: 19%
- **Chemicals**: 16%
- **Oil & Gas Production**: 13%
- **Electricity**: 27%
- **Other**: 32%
- **Agriculture**: 19%
- **Transportation**: 16%
- **Heating & Cooling**: 7%

SOURCE: RHODIUM GROUP

FORTUNE
How to lower CO2 in Cement

Blended Cement
- Portland Limestone Cement (PLC)
- Natural Pozzolans
- Metakaolin
- Fly Ash
- Slag Cement

Blended Cement & Specifications

Prescriptive

ASTM C150
- Type I
- Type II
- Type III
- Type V

Performance

ASTM C595
- Type IL
- Type IP
- Type IS
- Type IT
- Options A, MS, HS, MH, LH

ASTM C1157
- Type GU
- Type HE
- Type MS
- Type HS
- Type MH
- Type LH
- Options R & A

Flexibility to lower CO2

Least

Most
www.greenercement.com

- CO₂ Calculator
- Specification language
- Instructional & Promotional videos
- Case studies

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Durability and Sustainability

CO₂ - Cement ton

Clinker | Limestone | Pozzolan | CO₂

Type I/II old: 0.88
Type I/II (2004): 0.836
Type IL (10): 0.792
Type IP(25): 0.66
Type IT[25P](10L): 0.572
Fly ash has previously been effective, available, and inexpensive. Other SCMs have struggled to compete economically with it for general construction.
- Shipping (not as many sites for supply)
- Grinding
- Drying/Calcining

Fly ash will continue to be available, but not in excess and for a higher price? Other SCMs are becoming price competitive with fly ash, especially in the West as ASR is a general concern.

I predict all SCMs will approach and in some cases exceed the cost of Portland cement, so we will see more of them used.
Economics of blended cements

- **Advantages**
  - Handle one cementitious material at batch plant (especially good for portable plants.)
  - Cement manufacturers can chemically and physically optimize the blends.
  - A blend can be prequalified
  - Multiple SCM's in a blend more friendly to concrete suppliers.

- **Disadvantages**
  - Can't customize for multiple types of mixes at one plant
  - Some blends may be more expensive to produce. (Duplicate shipping expense)

---

### Blended Cement & Specifications

<table>
<thead>
<tr>
<th>Prescriptive</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ASTM C150</strong></td>
<td><strong>ASTM C1157</strong></td>
</tr>
<tr>
<td>Type I, Type II, Type III, Type V</td>
<td>Type GU, Type HE, Type MS, Type HS, Type MH, Type LH</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Options</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>A, MS, HS, MH, LH</td>
<td>R &amp; A</td>
</tr>
</tbody>
</table>

**ASTM C595**

- Type IL
- Type IP
- Type IS
- Type IT
- Options A, MS, HS, MH, LH

Flexibility to lower CO₂

Least Flexibility to lower CO₂

Most Flexibility to lower CO₂
What about specs?

• Prescriptive vs. performance
  • It has taken decades for specifiers to understand the nuances of different types of Portland cement.
  • Typical specifiers will not know the difference between a IT(L>P) or IS cement, nor will they know how to specify them. ASTM C-595 will not be particularly useful.
  • ASTM C-1157 offers understandable properties. (Speed of strength gain, sulfate resistance, and heat of hydration potential, and an option for mitigating ASR.) GU, HE, MS, HS, MH, LH, and Option R.
  • However, C-1157 is uncomfortably open ended as to what can be in the cement

What about specs?

• Specifiers will be required to make dramatic changes to their specification documents.
• These are complicated changes, and many of them will not be comfortable with the change unless given lots of guidance.
• CDOT, larger government agencies, might be the first to make these positive changes. Commercial specifications will take many years, even with lots of help.
Thank You!

Now to your Questions

Don’t forget to complete the Poll shared while questions are being answered!

Thank you to our Sponsors!!

Ash an Expert...
A Prelude to Alternative SCMs
Addendum – Fly Ash

Addendum – Slag
Slag cement has little or no effect on drying shrinkage.

**Slag – Drying Shrinkage**

**Slag – Strength Comparison of Slag Cement and Class F Fly Ash**
Slag – Sulfate Resistance ASTM C1012

- Slag – William Preston Memorial Bridge
  - Maryland DOT

- Expansion (Percent) vs. Days
  - Type I
  - Type II
  - 20% Slag*
  - 35% Slag*
  - 50% Slag*

- Expansion (Percent) vs. 6 months
  - Moderate Sulfate Resistance
  - High Sulfate Resistance
Slag – Effect of Slag Cement on Heat of Hydration for Mass Concrete

Can easily achieve internal concrete temperatures < 135°F in summer at 50% - 70% cement replacement

Slag Cement Association  website: www.slagcement.org
Addendum – Silica Fume

Silica Fume –
Hardened Concrete Properties

Rapid Chloride Permeability Test

AASHTO T-277

Chloride permeability
Coulombs Rating
> 4,000 High
2,000-4,000 Moderate
1,000-2,000 Low
100-1,000 Very Low
< 100 Negligible

Rapid chloride permeability, Coulombs

Silica fume %

0 3 6 9 12 15

0 500 1,000 1,500 2,000 2,500 3,000 3,500
Addendum – Natural Pozzolans

Learn More!
Website: Pozzolan.org
Email: Info@pozzolan.org
Tel: 2082522808
Addendum – Cement