SCMs – Where We Are & Where We Are Going

Larry Sutter Ph.D., P.E.
Michigan Technological University
Points to be Discussed Today

- Why are SCMs so important?
- What’s the problem?
- What can we expect in the future?
- What can we do to keep producing quality concrete?
Disclosure

- I am not here representing one material or a single provider.

But...
Sounded like a pop-punk band name...
Available... but depreciated term
Available in MI as a plate, not as an SCM
Disclosure

• Fly ash has been a main focus for me, particularly testing and specifications

• I love all SCMs and want to see optimal SCM use in ALL concrete

• Doesn’t mean I won’t tick some body off today… Sorry in advance…
What is an SCM?

- **cementitious material, supplementary, (SCM)** - an inorganic material that *contributes to the properties* of a cementitious mixture *through hydraulic* or *pozzolanic* activity, or both

  - **DISCUSSION**—Some examples of supplementary cementitious materials are *fly ash, silica fume, slag cement, rice husk ash, and natural pozzolans*. In practice, these materials are used in combination with portland cement. (ASTM C125)
<table>
<thead>
<tr>
<th>Effects</th>
<th>Fly ash</th>
<th>Slag</th>
<th>Silica fume</th>
<th>Natural Pozzolan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced</td>
<td><img src="%E2%86%92" alt="Up" /></td>
<td><img src="%E2%86%92" alt="Up" /></td>
<td><img src="%E2%86%92" alt="Up" /></td>
<td><img src="%E2%86%92" alt="Up" /></td>
</tr>
<tr>
<td>No/Little Effect</td>
<td><img src="%E2%86%90" alt="Green" /></td>
<td><img src="%E2%86%90" alt="Green" /></td>
<td><img src="%E2%86%90" alt="Green" /></td>
<td><img src="%E2%86%90" alt="Green" /></td>
</tr>
<tr>
<td>Increase</td>
<td><img src="%E2%86%91" alt="Red" /></td>
<td><img src="%E2%86%91" alt="Red" /></td>
<td><img src="%E2%86%91" alt="Red" /></td>
<td><img src="%E2%86%91" alt="Red" /></td>
</tr>
<tr>
<td>Varies</td>
<td><img src="%E2%86%91" alt="Black" /></td>
<td><img src="%E2%86%91" alt="Black" /></td>
<td><img src="%E2%86%91" alt="Black" /></td>
<td><img src="%E2%86%91" alt="Black" /></td>
</tr>
<tr>
<td>Strength Gain</td>
<td><img src="%E2%86%93" alt="Red" /></td>
<td><img src="%E2%86%93" alt="Red" /></td>
<td><img src="%E2%86%93" alt="Red" /></td>
<td><img src="%E2%86%93" alt="Red" /></td>
</tr>
<tr>
<td>Freeze-Thaw and Deicer-Scaling Resistance</td>
<td><img src="%E2%86%91" alt="Black" /></td>
<td><img src="%E2%86%91" alt="Black" /></td>
<td><img src="%E2%86%91" alt="Black" /></td>
<td><img src="%E2%86%91" alt="Black" /></td>
</tr>
<tr>
<td>Drying Shrinkage and Creep</td>
<td><img src="%E2%86%90" alt="Green" /></td>
<td><img src="%E2%86%90" alt="Green" /></td>
<td><img src="%E2%86%90" alt="Green" /></td>
<td><img src="%E2%86%90" alt="Green" /></td>
</tr>
<tr>
<td>Permeability</td>
<td><img src="%E2%86%93" alt="Red" /></td>
<td><img src="%E2%86%93" alt="Red" /></td>
<td><img src="%E2%86%93" alt="Red" /></td>
<td><img src="%E2%86%93" alt="Red" /></td>
</tr>
<tr>
<td>Alkali-Silica Reactivity</td>
<td><img src="%E2%86%93" alt="Red" /></td>
<td><img src="%E2%86%93" alt="Red" /></td>
<td><img src="%E2%86%93" alt="Red" /></td>
<td><img src="%E2%86%93" alt="Red" /></td>
</tr>
<tr>
<td>Chemical Resistance</td>
<td><img src="%E2%86%91" alt="Black" /></td>
<td><img src="%E2%86%91" alt="Black" /></td>
<td><img src="%E2%86%91" alt="Black" /></td>
<td><img src="%E2%86%91" alt="Black" /></td>
</tr>
<tr>
<td>Carbonation</td>
<td><img src="%E2%86%90" alt="Green" /></td>
<td><img src="%E2%86%90" alt="Green" /></td>
<td><img src="%E2%86%90" alt="Green" /></td>
<td><img src="%E2%86%90" alt="Green" /></td>
</tr>
<tr>
<td>Concrete Color</td>
<td><img src="%E2%86%93" alt="Red" /></td>
<td><img src="%E2%86%93" alt="Red" /></td>
<td><img src="%E2%86%93" alt="Red" /></td>
<td><img src="%E2%86%93" alt="Red" /></td>
</tr>
</tbody>
</table>

Source: Portland Cement Association
Hydraulic Reaction (Hydration)

- Reaction of hydraulic cementitious materials with water results in production of calcium silicate hydrates (C-S-H) and calcium hydroxide (CH), also ettringite and other hydrated aluminate phases (C-A-H)
  - Examples: portland cement, slag cement, Class C fly ash

- **Hydraulic Reaction:**
  
  \[
  \text{Hydraulic Cement} + \text{Water} \rightarrow \text{C-S-H} + \text{C-A-H} + \text{CH}
  \]

- **C-S-H** provides strength – **desirable** product

- **CH** provides little strength and is soluble, also is a reactant in many MRD mechanisms – **undesirable** product
Pozzolanic Reaction

- Pozzolans consume calcium hydroxide (CH) through the pozzolanic reaction
  - Examples: fly ash, silica fume, natural pozzolans, ground glass
  - **Hydraulic Reaction:**
    \[
    \text{Hydraulic Cement} + \text{Water} \rightarrow \text{C-S-H} + \text{CH}
    \]
  - **Pozzolanic Reaction:**
    \[
    \text{Pozzolan} + \text{CH} + \text{Water} \rightarrow \text{C-S-H}
    \]
  + Increases strength
  + Increases paste density
  + Reduces alkali (ASR mitigation)
  + Reduces rate of heat evolution attributed to hydration reaction
  - Slows rate of strength development
General Characteristics - Composition

- **Coal Fly Ash**
- **Slag Cement**
  - *Not a pozzolan*
  - *Consumes CH through its hydration reaction*
- **Silica Fume**

After Glasser et al., 1987
General Characteristics – Particle Size & Shape

Portland Cement

Slag Cement

Fly Ash

Silica Fume
Silica Fume – Particle Size & Shape
General Characteristics – Particle Size & Shape

Portland Cement

Slag Cement

Natural Pozzolan
General Characteristics – Particle Size & Shape

Portland Cement

Slag Cement

Natural Pozzolan

Natural Pozzolan
Natural Pozzolan – Particle Size & Shape
SCMs – What’s our options?

• Many materials can be used
  – fly ash, slag cement, natural pozzolans, ground glass, silica fume

• Each has strengths and weaknesses

• Market availability often dictates what alternatives we have to fly ash, if any

• Fly ash has been our “go-to” material
Why do we use fly ash?

• Clearly the “go-to” SCM for many years

1. Fly ash improves the properties of concrete and offers other advantages

2. Reserves – there is nothing else available that provides the same performance and advantages, and is available in comparable quantities
Why do we use fly ash?

- It works
  - Cement replacement
  - Improves concrete performance
  - Ancillary benefits
Cement Replacement

• Reduces cost – 3:5:6
  – If we cannot reduce cost with an SCM, concrete producers will turn to straight cement… but…
  – We **MUST** meet performance criteria (e.g., ASR mitigation, protection from sulfate attack)

and consider…

• Sustainability goals
  – Reduces GHG
  – Reduces embodied energy

![CO2 and embodied energy chart](chart.png)
Performance – Key Reason for Use

• Since its first use in the 1940’s fly ash has been recognized as improving concrete properties
Properties of Cements and Concretes Containing Fly Ash*

By Raymond E. Davis¹, Roy W. Carlson², J. W. Kelly³, and Harmer E. Davis⁴

Members American Concrete Institute
1937 – Davis et al. identified:

Concretes containing properly constituted fly-ash cements when compared with concretes containing portland cements exhibit:

(1) About the same water requirement to produce a given consistency

(2) Somewhat lower compressive strength at early ages but substantially higher compressive strength at later ages under normal conditions of moist curing
1937 – Davis et al. identified:

Concretes containing properly constituted fly-ash cements when compared with concretes containing portland cements exhibit:

(3) Compressive strengths which are substantially higher at early ages when cured at higher temperatures

(4) Shrinkage which is likely to be no more and may be less

(5) Lower heat of hydration
1937 – Davis et al. identified:

Concretes containing properly constituted fly-ash cements when compared with concretes containing portland cements exhibit:

(6) About the same or somewhat less resistance of freezing and thawing

(7) Greater resistance to sulfate action
Calorimetry – 2014 Research
Strength – 2014 Research
Sorptivity of 15% MgCl$_2$ into Different 0.45 w/c Concrete Mixtures

![Graph showing sorptivity](image-url)
ASTM C1293

Prism expansion at 24 months (%)

Percent replacement of cement with fly ash (% wt)

0.141% Expansion for Control @ 24 Months
So what’s the problem?
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
- Scheduled for closure at the end of 2019
The Problem

• Fly ash supplies have been challenged by 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
Ash Production is Dropping
Source: U.S. Energy Information Administration, 2018
So What’s Up With Fly Ash?

- Domestic fly ash production (new production) will be slightly decreasing over the next 20 years and beyond
  - Domestic production should stabilize (next 5 years) – reductions in coal–fired power will plateau
  - Fewer plants, running at a higher percentage of capacity
  - Suppliers believe that although total reserves may decrease, the volume of quality ash as a percentage or total production will increase due to dry handling – no more ponding
- Recovered ash from landfills/ponds will become a significant fraction of the total reserves
So What Else is Up With Fly Ash?

• Challenges
  – Pollution control measures will effect “fresh” ash
    • Powdered Activated Carbon
    • Trona
  – Competing with other markets for the material
  – Lower supply – consider ash once rejected?
  – Recovered Ash – A New Frontier
Options

• What will replace fly ash if needed?
  – Slag cement (*existing solution*)
  – Natural pozzolans (*existing solution*)
  – Recovered fly ash (*emerging solution*)
  – Ash Imports (*emerging solution*)
  – Lower quality fly ash (*last resort*)
  – New Materials (colloidal silica, ground glass)
  – Straight cement

Are existing tests and specifications adequate?
Options

• Slag Cement
  – Currently used, excellent solution
  – Geographically limited
  – Good performance as a cement replacement and as an ASR mitigator
    • Higher replacement levels required compared to ash
  – Concerns about scaling? Make Curing Great Again!
Slag Cement - Hydration

- Slag cement is hydraulic and produces calcium silicate hydrate (C-S-H) as a hydration product.
- Slag cement reacts slower than portland cement.
  - Hydration of portland cement produces C-S-H and CH.
  - CH reacts with the slag cement, breaking down the glass phases and causing the material to react with water and form C-S-H.
- Slag cement is not pozzolanic.
  - It does consume CH by binding alkalis in its hydration products.
  - Provides the benefits of a pozzolan.
Slag Cement - Specification

- ASTM C989 (AASHTO M 302) *Standard Specification for Slag Cement for Use in Concrete and Mortars*
- Classifies the material under three categories: Grade 80, Grade 100, and Grade 120
- The grade classification refers to the relative strength of mortar cubes using the SAI test with a 50% replacement of OPC
  - Uses standard reference cement
  - 75% of the Control 28-day strength = Grade 80
  - 95% of the Control 28-day strength = Grade 100
  - 115% of the Control 28-day strength = Grade 120
• Because slag cement is slower to react, concrete setting time may increase compared to OPC concrete

• Curing is always essential for achieving a quality product; it is more critical with slag-cement-based concrete given the prolonged set time
  – The slower reaction rate, especially at lower temperatures, is often overlooked, and this can lead to durability issues such as scaling when not properly cured

• A slower reaction rate and associated lower heat evolution makes slag cement an ideal ingredient for mass concrete placement where control of internal temperatures is critical to achieving durability
  – Up to 80% replacement of OPC with slag cement is used for mass concrete
Slag Cement

- Slag cement is effective at mitigating ASR
  - Requires higher replacement rates than Class F ash (e.g., > 50%)

- ASR mitigation stems from a number of mechanisms
  - Slag cement binds alkalis in C-S-H reaction products
  - Increased hardened cement paste density
    - Lower permeability
    - Improves resistance to ASR and external sulfate attack
Options

• Natural Pozzolan
  – With decreased fly ash supplies, natural pozzolan reserves once overlooked are now being tapped
  – Similar to Class F ash in performance
  – WITH NEW SOURCES - VERIFY PERFORMANCE

• Need a pozzolanic activity test!
  – Geographically limited – primarily in western U.S.
Natural pozzolanic materials

- Global distribution: natural pozzolans vs. volcanics
Natural Pozzolans

- Examples of natural pozzolans include
  - Volcanic ashes
  - Some diatomaceous earths
  - Opaline cherts and shale
  - Tuffs
  - Pumicite
  - Various calcined clays and shales
- Some natural pozzolans can be used as mined
- Most require processing such as drying, calcining, or grinding
Recovered Ash

- Significant volumes of high quality fly ash have been disposed of.
- Not all is recoverable, but a large fraction is.

Approximately 2000 million short tons 1974 - 2013
Recovered Ash

- Significant volumes of high quality fly ash have been disposed of
- Not all is recoverable, but a large fraction is

Approximately 650 million short tons 1974 – 2013
~33% utilization – 1350 million short tons disposed
Recovered Ash

• With diminishing production, ash marketers are turning to landfills & ash ponds to recover fly ash
  – Most recovered sources are Class F ash – Class C possible
  – Limited research to date on performance of recovered ash

• All recovered sources will require processing
  – Drying, sizing, and blending
  – Could lead to more uniformity if processed properly
Recovered Ash

• Concerns
  – Uniformity – ash in ponds will stratify based on density; strata in land fills/ponds will represent different coal sources and burning conditions
  – Weathering – Does storage alter the chemical or physical nature of the ash?
  – Adulteration – many land fills/ponds hold bottom ash, scrubber residue, and other wastes in addition to ash
  – Infiltration – clays and other materials may infiltrate and co-deposit
  – Testing – do current specifications provide tests & limits that will adequately screen recovered ash?
Recovered Ash

• Concerns (continued)
  – Current federal and state regulations create pressure to close disposal ponds quickly, leaving insufficient time to recover and use the ash – also restrict opening closed landfills
  – Power producers have little to no incentive to use ash beneficially under current regulations.

• Benefits
  – 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
Coal awaits transport at a Japanese port. Almost all of the nation’s supply is imported. BLOOMBERG/GETTY IMAGES

Bucking global trends, Japan again embraces coal power

By Dennis Normile | May 2, 2018, 5:00 PM

Most of the world is turning its back on burning coal to produce electricity, but not Japan. The nation has fired up at least eight new coal power plants in the past 2 years and has plans for an additional 36 over the next decade—the biggest planned coal power expansion in any developed nation (not including China and India). And last month, the government took a key step toward locking in a national energy plan that would have coal provide 26% of Japan’s electricity in 2030 and abandons a previous goal of slashing coal’s share to 10%.
China coal power building boom sparks climate warning

By Matt McGrath
Environment correspondent

26 September 2018

Top Stories

US meets Saudi prince despite criticism
The US treasury chief's meeting in Riyadh comes amid an outcry over the murder of Jamal Khashoggi.

1 hour ago

Trump: US will build up nuclear arsenal

1 hour ago

May says 95% of Brexit deal now agreed

2 hours ago
Countries in and around the Middle East are adding coal-fired power plants

Planned coal-fired capacity additions from a number of countries in and around the Middle East will add 41 gigawatts (GW) of new electric generating capacity over the next decade, based on announced projects and projects currently in the permitting process. Another 3 GW of coal-fired capacity is currently under construction in these countries. About 12 GW of coal-fired generating capacity—or about half of the region’s coal-fired generating fleet—has come online since 2006.
Imports

- Certainly in the near term, and potentially long term, imports will become a significant source.
- Imports are already a significant contributor in some markets.
- China is COMMITTED to keeping shipping costs low, making imports cost effective.
- Issues of quality must be addressed.
Increased Need for Testing

• In general, inconsistent performance has caused ASTM & AASHTO to re-evaluate specifications

• Items under consideration
  – Revise classification
    • Use CaO instead of SUM (approved at ASTM); CaO more predictive of key properties
  – Move to ASTM C1567 for assessing ASR mitigation (done)
  – Pozzolanic and cementitious activity (major need)
    • Current SAI is inadequate in many cases
  – Particle size – need better test (major need)
  – Adsorption potential (tests have been developed)
    • Use adsorption based tests rather than LOI
New Materials – Ground Glass

- Total Production (~ 11 million tons/year in U.S.)
  - Container Glass (~ 3 million tons/year in U.S.)
  - E-Glass (100,000 lbs/year in U.S.)
  - Recycling capacity exceeds generation (U.S. EPA)

- Primary Processing – Grinding
  - -325 mesh
  - Composition is uniform
# Nominal Glass Composition

<table>
<thead>
<tr>
<th></th>
<th>Bottle Glass</th>
<th>Plate Glass</th>
<th>Display Glass</th>
<th>E-Glass</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>71</td>
<td>71</td>
<td>63</td>
<td>60</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>1.8</td>
<td>0.4</td>
<td>18</td>
<td>12.5</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0.6</td>
<td>0.4</td>
<td>0.0</td>
<td>0.4</td>
</tr>
<tr>
<td>B₂O₃</td>
<td>0.01</td>
<td>0.02</td>
<td>2.0</td>
<td>0.0</td>
</tr>
<tr>
<td>MgO</td>
<td>0.90</td>
<td>3.9</td>
<td>2.5</td>
<td>2.9</td>
</tr>
<tr>
<td>CaO</td>
<td>11</td>
<td>9.3</td>
<td>0.1</td>
<td>21</td>
</tr>
<tr>
<td>Na₂O</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>0.75</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.5</td>
<td>0.05</td>
<td>0.0</td>
<td>0.06</td>
</tr>
</tbody>
</table>
Colloidal Silica

- Class F Fly Ash

After J. Belkowitz, Intelligent Concrete LLC

- Colloidal Silica

Bottom Ash

- ASTM and AASHTO will begin discussing a “Class B” for bottom ash
- Mimics the properties of the fly ash from the same coal but attributes are subdued, relative to the fly ash
  - Contributes to concrete properties
  - Mitigates ASR
- Angular – increased water demand (no big deal)
- Commonly comingled with fly ash in recovered materials
More cement?

- Once 3:5:6 doesn’t apply (e.g., 6:6:6) the cement replacement advantage is diminished
- Sustainability goals are important only if incentivized (i.e., carbon tax)
- A higher cement content (particularly low alkali) is not out of reality **IF** the mixture meets performance
  - ASR mitigation
  - Sulfate attack prevention
Standard Practice for

Determining the Reactivity of Concrete Aggregates and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete Construction

AASHTO Designation: R 80-17

Technical Section: 3c, Hardened Concrete
ASR Risk Mitigation - ASTM

• Standard guides for identifying reactive aggregates and recommending mitigation strategies

• USE THEM!
Proper Testing is Needed

- Many specifiers use existing ASR tests incorrectly
  - Accelerated mortar beam tests are intended to evaluate a material performance, not a mixture performance
  - Expansion values based on the prescribed mass (volume) of aggregate
  - Results cannot be recombined
  - Running ASTM C1260 (AASHTO T 303) and ASTM C1293 in any way other than how they were designed is a waste of time and money – and will lead to errors
  - Empirical tests must be done empirically
Proper Testing is Needed

- Even with recovered and import ash, it is difficult to envision a market – near term – where fly ash is not equal to or greater than cement in price.

- In a world where fly ash will cost as much – or more – than cement, the days of overdosing is over (This breaks my heart by the way).

- Optimal use of SCMs will become critical to extend sources and minimize costs.
What about tests and specifications?

- Existing tests and specifications provide little information on performance.
- As recovered materials and other materials become more common, new tests and specifications are required that measure performance attributes (i.e., pozzolanic activity, hydraulic activity) or properties (i.e., particle size, adsorption).
- Need to let go of historic limits established in a completely different concrete world that mean little now.
- Need to get more materials in the market – without sacrificing performance and quality – to bolster supplies.
Tentative Specifications for
RAW OR CALCINED NATURAL POZZOLANS FOR USE AS
ADMIXTURES IN PORTLAND CEMENT CONCRETE

ASTM Designation: C 402 – 58 T

These Tentative Specifications have been approved by the operating commit-
tees and accepted by the Society in accordance with established pro-
duces, for use pending adoption as standard. Suggestions for revision
should be addressed to the Society at 500 Race St., Philadelphia 3, Pa.

Scope

1. These specifications cover raw or
   calcined natural pozzolans for use as
   admixtures in portland cement concrete.

Note 1 – The user should recognize that
   replacement of a portion of the portland cement
   by pozzolans may reduce early strength of the
   concrete. Care should be exercised to insure
   strength adequate for the intended use of the
   concrete.

Note 2 – Pozzolans may need to reduce the
   air content of concrete. Hence, if a pozzolan is
   added to portland cement for which air admis-
   sion is specified, provision should be made
   to assure use of sufficient air-entraining agent
   to attain the specified amount of air.

Definition

2. Pozzolan is defined by the Defini-
tions of Terms Relating to Hydraulic
Cement (ASTM Designations: C 2199)
as a siliceous or siliceous and aluminous
material which in itself possesses little
or no cementitious value but will, after
diving form and in the presence of
moisture, chemically react with
silica and alumina at ordinary temperature
in form compounds possessing cement-
ous properties (Note 3).

Note 3 – The natural pozzolans that are
   employed as admixtures for portland cement
   concrete include such materials as cinders
   from coke ovens, oil shale, asphaltic waste,
   coal fly ash, and other similar products
   which may or may not be processed by selec-
tion and various materials requiring calcina-
tion to induce satisfactory properties such as
sintered clays and shales.

Chemical Requirements

A. The pozzolan shall conform to the
   chemical requirements prescribed in
   Table I.

Table I – CHEMICAL REQUIREMENTS

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Minimum Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica dioxide (SiO₂)</td>
<td>70.0</td>
</tr>
<tr>
<td>Alumina oxide (Al₂O₃)</td>
<td>8.0</td>
</tr>
<tr>
<td>Magnesia oxide (MgO)</td>
<td>5.0</td>
</tr>
<tr>
<td>Total lime (CaO, MgO)</td>
<td>5.0</td>
</tr>
<tr>
<td>Moisture content</td>
<td>10.0</td>
</tr>
</tbody>
</table>

B. The water demand of the pozzolan
   when mixed with portland cement
   at a water-cement ratio of
   0.5 shall be determined using the
   test prescribed in ASTM Designation:
   C 267.

C. The specific gravity of the pozzolan
   shall be determined using the test
   prescribed in ASTM Designation:
   C 128.

D. The pozzolan shall be packaged in
   containers of such size that they
   will be conveniently handled on
   job sites.

Physical Requirements

4. The pozzolan shall conform to the
   physical requirements prescribed in
   Table II.

Table II – PHYSICAL REQUIREMENTS

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Minimum Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water demand</td>
<td>5.0</td>
</tr>
<tr>
<td>Moisture content</td>
<td>5.0</td>
</tr>
<tr>
<td>Compressive strength</td>
<td>2500 lbs.</td>
</tr>
</tbody>
</table>

Packaging and Handling

5. The pozzolan shall be packaged in
   containers of such size that they
   will be conveniently handled on
   job sites.

6. The pozzolan shall be shipped in
   packages weighing not more than
   400 lbs. Each package shall be
   marked with the name of the
   producer, the name of the
   concrete, and the amount of the
   pozzolan in the package. Similar
   information shall be provided in
   the shipping invoice accompanying
   the shipment of packaged or bulk
   pozzolans.
### TABLE I.—CHEMICAL REQUIREMENTS.

<table>
<thead>
<tr>
<th>Component</th>
<th>Requirement, max, per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon dioxide (SiO₂)</td>
<td>70.0</td>
</tr>
<tr>
<td>plus aluminum oxide (Al₂O₃)</td>
<td></td>
</tr>
<tr>
<td>plus iron oxide (Fe₂O₃)</td>
<td></td>
</tr>
<tr>
<td>Magnesium oxide (MgO)</td>
<td>5.0</td>
</tr>
<tr>
<td>Sulfur trioxide (SO₃)</td>
<td>3.0</td>
</tr>
<tr>
<td>Loss on ignition, max, per cent</td>
<td>10.0</td>
</tr>
<tr>
<td>Moisture content, max, per cent</td>
<td>3.0</td>
</tr>
</tbody>
</table>

### TABLE II.—PHYSICAL REQUIREMENTS.

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Requirement, max, per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fineness:</td>
<td></td>
</tr>
<tr>
<td>Mean particle diameter, microns, max.</td>
<td></td>
</tr>
<tr>
<td>Amount retained when wet-sieved on No. 325 (44-micron) sieve, max, per cent.</td>
<td>12.0</td>
</tr>
<tr>
<td>Pozolanic activity index</td>
<td></td>
</tr>
<tr>
<td>With portland cement, at 28 days, min. percentage of control</td>
<td>75</td>
</tr>
<tr>
<td>With lime, at 7 days, min. psi.</td>
<td>600</td>
</tr>
<tr>
<td>Water requirement, max. percentage of control</td>
<td></td>
</tr>
<tr>
<td>Change of drying shrinkage of mortar bars at 28 days, max. percentage of control</td>
<td>115</td>
</tr>
<tr>
<td>Soundness</td>
<td>0.03</td>
</tr>
<tr>
<td>Autoclave expansion or contraction, max, per cent</td>
<td></td>
</tr>
<tr>
<td>Amount of air-entraining admixture in concrete, ratio to control, max</td>
<td>2.0^c</td>
</tr>
<tr>
<td>Uniformity requirements:</td>
<td></td>
</tr>
<tr>
<td>The specific gravity of individual samples shall not vary from the average established by the ten preceding samples, or by all preceding samples, if the number is less than ten, by more than, per cent.</td>
<td>3</td>
</tr>
<tr>
<td>In addition, when air entrainment is specified for the concrete, the quantity of air-entraining admixture required to produce an air content of 5.0 per cent by volume of mortar shall not vary from the average established by the ten preceding tests, or by all preceding tests if less than ten, by more than, per cent.</td>
<td>20</td>
</tr>
<tr>
<td>Reactivity with cement alkalies:</td>
<td>75</td>
</tr>
<tr>
<td>Reduction of mortar expansion at 14 days, min, per cent</td>
<td></td>
</tr>
<tr>
<td>Mortar expansion at 14 days, max, per cent.</td>
<td>0.020</td>
</tr>
</tbody>
</table>
Wrap-up

• SCMs are needed to produce durable concrete, especially with lower quality aggregates

• Fly ash has been our main SCM

• Fly ash supplies are challenged but not gone – and they are not going away – it’s only logistics

• Cost will almost certainly increase – maybe more than cement
Wrap-up

• Near term solutions to meet the needed volume
  – Recovered ash
  – Imports

• Other solutions
  – Other materials to replace fly ash (slag cement)
  – New materials to supplement fly ash
I’m not a psychic but I will answer any questions?

Larry Sutter

llsutter@mtu.edu