Change is Coming!

Dan King
Peter Taylor

Portland Cement is 200(ish) years old!

- 1817 – Louis Vicat
- 1822 – Egor Cheliev
- 1824 – Joseph Aspdin

![Joseph Aspdin Plaque](image1.png)

Coplay, PA – 1892
Portland Cement is 200(ish) years old!

- The U.S. cement industry exploded at the turn of the 20th century
- ASTM Committee C first met in 1902 and published the initial Standard Specification on Cement in 1904
  - Specific gravity
  - Fineness
  - Setting time
  - Volume
  - Chemical requirements

American specifications were largely standardized by the 1920s
- Portland cement can be produced in a similar way using the same types of materials and processes all over the world
Portland Cement is 200(ish) years old!

• Since the 1920s, cement hasn’t changed a lot:
  • Composition has been adjusted
  • SCMs have been introduced
    • Slag cement (1896)
    • Fly ash (1943)
  • Demands were driven by:
    • (Early age) strength
    • Cost
Mandate for Change

• Increased recognition of the impacts of climate change and the need to reduce greenhouse gas emissions

Images: National Climate Assessment

Mandate for Change

• Governments around the world have made net zero pledges:

Images: National Climate Assessment
Roadmap for Change

• The cement and concrete industries have responded with their own plans to reach net zero carbon emissions

Images: PCA, ACPA

Roadmap for Change

• Towards net zero concrete:
  • Designs that use less concrete
  • Mixtures that use less cement
  • Cements that use less clinker

  • Reduce construction impacts
  • Reduce use phase impacts

Image: PCA
### Blended Cements

- **Portland Limestone Cements (Type IL)**
  - Up to 15% ground limestone
- A variety of SCMs are already used in blended cements today
- Greater use and variety of blended cements is on the horizon
- Future blends may consist of just 50% clinker, or even less

### Future of SCMs

- Calcined clay
- Recycled ground glass (ASTM C1866)
- Harvested fly ash
- Carbon Upcycling
  - Grind materials in presence of CO₂
- Terra CO₂
  - Synthetic fly ash
- Carbon Limit
  - Non-calcined mineral admixture with catalyst
- Fortera
  - Reactive calcium carbonate

Source: Sutter
Alternative Cements

- Ecocem
  - Contains high levels of limestone and slag
- Solidia
  - “Lower proportion of limestone and lower production temperatures”
- CarbonBuilt
  - “Patented materials” cured in CO$_2$
- Brimstone
  - Portland cement from calcium silicate
- Sublime
  - “Portland cement produced from non-carbonate rock by proprietary electrical-chemical processes”

Source: Sutter

New Admixtures and Other Materials

- Admixtures
  - Nano-stuff
  - Rheology modifiers
  - Rate modifiers
- Internal curing – hold and release water
  - LWFA
  - SAP
Adapting to Changes in Cementitious Materials

• A large variety of new cementitious materials and blends appear viable for use in concrete
• Potential for a high degree of variation in terms of what products become available in a given market based on:
  • Producer
  • Geographic region
  • Application
  • Scale
  • Plant capacity

For 100+ years, we’ve been able depend on Portland cement that met a relatively narrow specification all over the world

We’re going to need to be ready not just for changes to the materials themselves, but to a market with much more variation between products
Adapting to Changes in Cementitious Materials

- Can we adapt to these changes?

Impacts on Users

- Physical requirements for cements have been pretty limited
- Is this still the right list of requirements? Are there other requirements that we need to add?

Source: ASTM C1157
Impacts on Users

- Requirements for SCMs have often been even more straightforward
- Even for familiar products like fly ash and slag, the products will change as production or reclamation processes change

**TABLE 1 Physical Requirements**

<table>
<thead>
<tr>
<th>Item</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fineness:</td>
<td>Amount retained when wet screened on a 45-μm (No. 325) sieve, max %</td>
</tr>
<tr>
<td>Specific surface by air permeability, Test Methods C204 shall be determined and reported although no limits are required.</td>
<td>...</td>
</tr>
<tr>
<td>Air Content of Slag Mortar, max %</td>
<td>12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Slag Activity Index</th>
<th>28-Day Index, min %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 80</td>
<td>75</td>
</tr>
<tr>
<td>Grade 100</td>
<td>95</td>
</tr>
<tr>
<td>Grade 120</td>
<td>115</td>
</tr>
</tbody>
</table>

Source: ASTM C989

**Impacts on Users**

- Questions moving forward:
  - Do we understand the chemistry?
  - The old rules may no longer apply

TGA Testing
### Impacts on Designers

**Concrete materials properties for Pavement ME design:**
- How will changes to the cement system change our pavement designs?
- Do we have all of the measurement tools we need to assess these changes?

<table>
<thead>
<tr>
<th>Measured Property</th>
<th>Source of Data</th>
<th>Affected by Cement System?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elastic modulus</td>
<td>Test</td>
<td>Yes</td>
</tr>
<tr>
<td>Flexural strength</td>
<td>Test</td>
<td>Yes</td>
</tr>
<tr>
<td>Indirect tensile strength (CRCP only)</td>
<td>Test</td>
<td>Yes</td>
</tr>
<tr>
<td>Unit weight</td>
<td>Test</td>
<td>Yes</td>
</tr>
<tr>
<td>Cement type</td>
<td>Estimate</td>
<td>Yes</td>
</tr>
<tr>
<td>Cementitious material content</td>
<td>Estimate</td>
<td>Yes</td>
</tr>
<tr>
<td>Water to cement ratio</td>
<td>Estimate</td>
<td>Yes</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>Test</td>
<td>Maybe</td>
</tr>
<tr>
<td>Surface shortwave absorptivity</td>
<td>Estimate</td>
<td>Maybe</td>
</tr>
<tr>
<td>PCC zero-stress temperature</td>
<td>Estimate</td>
<td>Maybe</td>
</tr>
<tr>
<td>Ultimate shrinkage</td>
<td>Estimate</td>
<td>Maybe</td>
</tr>
<tr>
<td>Reversible shrinkage</td>
<td>Estimate</td>
<td>Maybe</td>
</tr>
<tr>
<td>Time to develop 50 percent of ultimate shrinkage</td>
<td>Estimate</td>
<td>Maybe</td>
</tr>
<tr>
<td>Air content</td>
<td>Test</td>
<td>No</td>
</tr>
<tr>
<td>Coefficient of thermal expansion</td>
<td>Test</td>
<td>No</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>Test</td>
<td>No</td>
</tr>
<tr>
<td>Heat capacity</td>
<td>Test</td>
<td>No</td>
</tr>
<tr>
<td>Aggregate type</td>
<td>Estimate</td>
<td>No</td>
</tr>
<tr>
<td>Curing method</td>
<td>Estimate</td>
<td>No</td>
</tr>
</tbody>
</table>

### Impacts on Designers

**Concrete properties for structural design:**

<table>
<thead>
<tr>
<th>Measured Property</th>
<th>Source of Data</th>
<th>Affected by Cement System?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive strength</td>
<td>Test</td>
<td>Yes</td>
</tr>
<tr>
<td>Flexural strength</td>
<td>Test</td>
<td>Yes</td>
</tr>
<tr>
<td>Modulus of Elasticity</td>
<td>Test</td>
<td>Yes</td>
</tr>
<tr>
<td>Poisson's ratio</td>
<td>Test</td>
<td>Yes</td>
</tr>
<tr>
<td>Creep</td>
<td>Test</td>
<td>Yes</td>
</tr>
<tr>
<td>Bond to steel</td>
<td>Test</td>
<td>Yes</td>
</tr>
<tr>
<td>Shrinkage</td>
<td>Test</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Impacts on Designers

- How will these new cement systems interact with the surrounding environment, and how durable will they prove?
  - Air void system
  - Fluid transport
  - Chemical attack
  - Aggregate interactions

Impacts on Concrete Producers

- Variability between cement manufacturers and products
- Relationships between concrete properties and mixture proportions may not be the same
  - w/cm
  - Water demand
  - Bleeding
- Admixture effects and interactions
- Hydration rates
Impacts on Contractors

- Rheology
- Finishing
  - Set time
  - Bleed rate
  - Strain capacity
  - Cracking risk
  - Scaling risk
- Sawing
- Curing

How Will We Adapt?

- Users and designers
  - Adoption of performance specifications and requirements
  - Re-think design goals
    - Function
    - Durability
    - Low carbon
  - Communication and cooperation with concrete producers and contractors will be more vital than ever
How Will We Adapt?

• Contractors and concrete producers
  • Materials and mix designs
    • Be ready to handle the variety
    • Build capacity – physical and knowledge
  • Testing and quality control
    • These items have always been important
    • More important than ever moving forward
  • Performance Centered Concrete Construction (P3C)

How Will We Adapt?

• What types of tests and procedures have we overlooked?
  • Cylinder handling
  • Fresh properties tests
  • Test batches
  • Slab mock-ups

Image: Matalkah et al. (2019)
How Will We Adapt?

- The Performance Engineered Mixtures program provides a framework for how to approach the changing landscape

The Sky is Falling?

- While these changes will present challenges, they also present opportunities to advance the state of the practice
- We need to
  - Embrace change
  - Figure out what the questions are
  - Plan to get the answers
  - Plan to implement them
  - Educate practitioners
Integrated Materials and Construction Practices

- There’s never been a better time to make sure we understand the fundamentals of cement and concrete!
- IMCP Training from 12:00 to 4:00 pm on Thursday
  - Dr. Tom Van Dam
  - Dr. Armen Amirkhanian