Ordinary Portland Cement (OPC): Overview

Anything But Ordinary

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US Cement Industry
US Cement Plants
World Cement Production 2015

Notes:
P - Preliminary
E - Estimate

Cembureau, 2016
Concrete Proportions by Volume

- Up to 8% Air
- 7-15% Cement
- 60-75% Aggregates (Coarse and Fine)
- 14-21% Water
Hydraulic Cement Manufacture
Overview
# Phase Composition

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>Shorthand</th>
<th>Mass (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tricalcium silicate (Alite)</td>
<td>C₃S</td>
<td>48 – 68</td>
</tr>
<tr>
<td>Dicalcium silicate (Belite)</td>
<td>C₂S</td>
<td>6 – 27</td>
</tr>
<tr>
<td>Tricalcium aluminate (Aluminate)</td>
<td>C₃A</td>
<td>0 – 12</td>
</tr>
<tr>
<td>Tetracalcium aluminoferrite (Ferrite)</td>
<td>C₄AF</td>
<td>4 – 13</td>
</tr>
<tr>
<td>Calcium sulfate dihydrate (gypsum)</td>
<td>CSH₂</td>
<td>~ 5</td>
</tr>
</tbody>
</table>
Cement Types
Hydraulic Cements

- Portland
- Blended (or composite)
- Other
Portland Cements

• ASTM C150 (AASHTO M 85)
  • Type I
  • Type II
  • Type II(MH)
  • Type III
  • Type IV
  • Type V
Blended Cement Types

• ASTM C595 (AASHTO M 240)
  • Type IS(X) Portland blast-furnace slag cement
  • Type IP(X) Portland-pozzolan cement
  • Type IL(X) Portland-limestone cements
  • Type IT(AX)(BY) Ternary blended cement

• MS, HS, MH, LH designations can apply as well
2014 US Cement Shipments

- Types I and II
- Type III
- Type V
- Type IS
- Type IP
- Type IL

USGS and PCA data
Compressive Strength

ASTM C109 compressive strength, MPa vs. Time, days.
Cement Hydration
How Cements React with Water

Cement grain

Water
How Cements React with Water

C-S-H

Ettringite

CH
How Cements React with Water

C-S-H

Ettringite

CH
How Cements React with Water

- C-S-H
- Ettringite
- CH
How Cements React with Water

C-S-H
Ettringite
CH
How Cements React with Water
Heat of Hydration

- Stage 1
- Stage 2
- Stages 3 and 4
- Stage 5

C₃S hydration

C₃A hydration
Heat of Hydration

modified from Mindess et al., 2002
Concrete Durability
Corrosion

• $C_3A$ content
• Alkali content
• $w:c$
• (admixtures)
Freeze-Thaw

- Air content and spacing
- Strength
- D-cracking
F-T: Air Void Spacing & Volume

The spacing factor $\bar{L}$ is defined as the maximum distance of any point in the cement paste from the periphery of an air void.

The spacing surface is defined as the surface area of a quantity of air voids that have a volume of 1 mm$^3$.

Thomas & Wilson 2002
Sulfate Attack

• A form of chemical attack
• Internal or external
Alkali-Silica Reactivity

• Discovered 1930s
• Present in most of North America
• Fine and coarse aggregate

• Controllable
  • Aggregate
  • SCMs/blended cements
  • Control alkali loading
  • ASR inhibitors (lithium)
Barriers to Novel Cements
Practical Barriers

• Inertia
• Low profit margins  
  • Low-skilled labor
• Codes and standards  
  • Life safety  
  • Commercial agreements  
  • Appropriate test methods
• Raw materials availability
• Durability concerns  
  • CAC example
Thank you!

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