Understanding Cement and Its Application

Ben Blankenship
Technical Services Manager
Ash Grove Cement Co.

www.ASHGROVE.com
Outline

• Cement Hydration
• Cement Types and Specifications
• Applications of Various Types of Cements
• Other Products That Utilize Cement
Understanding a Concrete Mix

What is Concrete Made of?

Components of Concrete

- 6% air
- 11% cement
- 41% gravel or crushed stone
- 26% sand
- 16% water
CEMENT HYDRATION
What the heck is Hydration anyway?!!!

- **Hydration** - Merriam – Webster Dictionary’s Definition:
  - “to cause to take up or combine with water or the elements of water”

- A **chemical reaction** between water and cement
  - Chemical Reaction – a process in which a substance is changed into one or more new substances
Chemistry is Everywhere!

- Concrete is no exception!
  - Hydration reaction between water and cement in concrete is primarily dependent on 2 things:
    1. Water / Moisture
       - Water is the fuel for the reaction
       - Without water the reaction cannot take place!
    2. Temperature / heat
       - The rate of the chemical reaction is governed by temperature
Chemical Compounds of Portland Cement

Belite (C2S)  Alite (C3S)
Cement Chemistry

- $C_3S$ – (Alite) Primarily responsible for early age strength development (up to 28 days).
- $C_2S$ – (Belite) Primarily responsible for later age strength development (beyond 28 days).
- Alite and Belite crystals are formed in a metallic flux of Aluminum and Iron oxides (liquid) in the kiln.
- Two Aluminum compounds are produced during this process, which do not contribute to strength:
  - $C_3A$ – Reacts vigorously with water initially
    - Gypsum added to cement to control this reaction
  - $C_4AF$ – Has an influence on cement color
Other Components

• Alite and Belite crystals are formed in a metallic flux of Aluminum and Iron oxides (liquid) in the kiln.

• Two Aluminum compounds are produced during this process, which do not contribute to strength:
  • C3A
  • C4AF
Scanning-Electron Micrograph of Powdered Cement
SEMs of Hardened Cement Paste
Hydration Products

• CSH – Calcium Silicate Hydrate
• CaOH – Calcium Hydroxide

www.ASHGROVE.com
Cold influence on Cement Hydration

- $\text{C}_3\text{A}$, $\text{C}_4\text{AF}$, $\text{C}_3\text{S}$, $\text{C}_2\text{S}$

$$2\text{C}_3\text{S} + 6\text{H} = \text{C}_3\text{S}_2\text{H}_3 + 3\text{CH}$$
$$2\text{C}_2\text{S} + 4\text{H} = \text{C}_3\text{S}_2\text{H}_3 + \text{CH}$$

- $\text{C}_3\text{S}_2\text{H}_3$ “calcium silicate hydrate” glue
Heat of Hydration

At 73°F normal 3-Day heat of cement is

\[ \sim 240[C_3S] + 50[C_2S] + 880[C_3A] + 290[C_4AF] \text{ (J/g)} \]

49% 22% 76% 77%

At 50°F normal 3-Day heat of cement is

\[ \sim 122[C_3S] + 22[C_2S] + 450[C_3A] + 140[C_4AF] \text{ (J/g)} \]

26% 10% 35% 37%

(42 J/g to heat water 18°F)
Strength Development of Paste

MPa

20 40 60 80 100

c\textsubscript{3}S

c\textsubscript{2}S
c\textsubscript{3}A
c\textsubscript{4}AF
days

www.ASHGROVE.com
<table>
<thead>
<tr>
<th>Temperature (F)</th>
<th>3-Day Compressive Strength (% of 70°F)</th>
<th>Setting Time (Hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>100</td>
<td>6</td>
</tr>
<tr>
<td>60</td>
<td>77</td>
<td>8</td>
</tr>
<tr>
<td>50</td>
<td>58</td>
<td>10</td>
</tr>
<tr>
<td>40</td>
<td>33</td>
<td>14</td>
</tr>
<tr>
<td>30</td>
<td>20</td>
<td>19</td>
</tr>
</tbody>
</table>
Types of Portland Cement

ASTM C 150 (AASHTO M 85)

I  Normal
IA  Normal, air-entraining
II  Moderate sulfate resistance
IIA  Moderate sulfate resistance, air-entraining
III  High early strength
IIIA  High early strength, air-entraining
IV  Low heat of hydration
V  High sulfate resistance
Blended Cements ASTM C 595

- Type IP - Portland Pozzolan Cement
- Type IS - Portland Slag Cement
- Type IT - Ternary Blended Cement
- Type IL – Limestone Cement
Special C 595 Subcategories (Type Suffixes)

- (MS) -- moderate sulfate resistance
- (A) -- air entraining
- (MH) -- moderate heat of hydration
- (LH) -- low heat of hydration
Portland and Blended Hyd. Cements
ASTM C 1157

• Type GU--General use
• Type HE--High early strength
• Type MS--Moderate sulfate resistance
• Type HS--High sulfate resistance
• Type MH--Moderate heat of hydration
• Type LH--Low heat of hydration
• Option (R)--Low reactivity with reactive aggregates
<table>
<thead>
<tr>
<th>Feature</th>
<th>C 150</th>
<th>C 595</th>
<th>C 1157</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Auto. Exp.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Setting</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Alkalies</td>
<td>Optional</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Chemistry</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Fineness</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Ingredient</td>
<td>Yes</td>
<td>Yes</td>
<td>No (bc)</td>
</tr>
</tbody>
</table>
General Use

- C 150 Type I or II
- C 595 Types IP, IS
- C 1157 Type GU
Moderate or Low Heat for Massive Elements

- C 150 Type II (moderate heat option)
- C 595 Types IP(MH), IS(MH)
- C 1157 Types MH, LH
The current state-of-the-art is to use a pozzolan to lower the heat of mass concrete.
High-Early Strength for Rapid Placement, Repair, & Cold Weather

- ASTM C 150 Type III
- ASTM C 1157 Type HE
Type III High Early Strength Cements
Sulfate Resistance

- ASTM C 150 Type II or V
- ASTM C 595 Type IP(MS) or IS(MS)
- ASTM C 1157 Type MS or HS
Type II & Type V Sulfate Resistant Cements
Outdoor Sulfate Test

Type V Cement
W/C-ratio = 0.65

Type V Cement
W/C-ratio = 0.39
Performance of Concretes Made with Different W/C-Ratios in Sulfate Soil

Higher water to cement ratio concrete is more permeable to water-borne sulfates.
Performance of Concretes Made with Different Cements in Sulfate Soil

Similar water to cement ratios and cement contents

![Graph showing performance of concretes with different cements over age.](image)

- **ASTM Type V**
  - w/c = 0.37
- **ASTM Type II**
  - w/c = 0.38
- **ASTM Type I**
  - w/c = 0.39

Cement content = 390 kg/m$^3$ (658 lbs/yd$^3$)

**Age, years**

**Visual rating**
Cement For Soil Stabilization

- Cement is used to provide stabilization to poor compacting and expansive soils.
- Cement is used for "sandy" soils, while lime is a better option for soils with a higher clay content.
- Very effective especially with asphalt.
Masonry and Mortar Cement

- Masonry cements consist of a mixture of portland cement or blended cements with plasticizing materials such as limestone, hydrated, or hydraulic lime and other materials to enhance set, water retention, workability, and durability.
- Meet requirement of ASTM C 91 (Masonry) and ASTM C 1329 (Mortar).
- Type N, S, and M
Gunite or Shotcrete

- Pneumatically projected onto a surface at high velocity
- Applied by wet or dry process
  - Dry – Pre blended cement and aggregate are propelled through a hose by compressed air and water is introduced at the nozzle.
  - Wet – Pre-mixed material is pumped to nozzle where compressed air is added to increase velocity of material
- Commonly used in swimming pools
Concrete Block (CMU), Pavers, Brick, Tile, etc.

- Cement and Sand are “dry” cast into a mold and vibrated to consolidate
- Very low moisture content
- Curing is critical
Oil Well Cement

- API Specification 10A includes 8 classes from A through H
- 3 grades
  - Grade O – Ordinary
  - Grade MSR – Moderate Sulfate Resistant
  - Grade HSR – High Sulfate Resistant
- Each class is applicable for use at a certain range of well depth, temperature, pressure, and sulfate environment
- Conventional ASTM C 150 cements can be used for some applications
Precast and Prestressed Concrete

- Concrete is cast and cured in a controlled environment to achieve very high field performance and durability characteristics
- Often use SCC Mixes
Questions?!!!