CHAPTER 6
Portland Cement, Mixing Water and Admixtures
Portland Cement

• PC is named after the limestone & chalk cliffs on the Isle of Portland, where it was first made in the early 1800s.
• There are many types of cement, but portland cement is so prevalent that in construction cement is always assumed to mean portland cement.
• Cement paste = cement + water
  ➢ Glue (or binder) that bonds aggregates together to make concrete

• Mortar = cement paste + sand

• Concrete = cement + water + sand + aggregates:
  ➢ Portland cement (7.5% - 15% of volume)
  ➢ Water
  ➢ Aggregates (60% - 75% volume)
  ➢ Air voids (1% - 15% of volume)
  ➢ Sometimes admixtures
6.1 Cement Production

1. Crushing and grinding of raw materials
   - Calcium Oxide (calcareous material)
     - limestone, chalk, or oyster shells
   - Silica & Alumina (argillaceous material)
     - clay, shale, blast furnace slag

2. Heat and melt in a kiln at 1400-1650°C (2500-3000°F) which forms cement clinker

3. Add gypsum (delays set time) to clinker and pulverize to fine powder
   - \(7 \times 10^{11}\) particles / lb
     - small particles produce a large surface area for more complete hydration
6.2 Chemical Composition of PC

• **Calcination** in the kiln changes molecular structure of ingredients.

• **Main compounds:**
  - tricalcium silicate (C\(_3\)S)
  - dicalcium silicate (C\(_2\)S)
  - tricalcium aluminate (C\(_3\)A)
  - tetracalcium aluminoferrite (C\(_4\)AF)

• **Minor compounds:** small percent but can have strong influences:
  - magnesium oxide
  - titanium oxide
  - manganese oxide
  - sodium oxide
  - potassium oxide

• **Alkalis** (Na\(_2\)O, K\(_2\)O) react with silica causing disintegration & expansion of concrete
Alkali-Silica Reactivity
6.3 Fineness

• Smaller cement particles have more surface area to react with water
  ➢ fineness controls the rate of hydration (heat & strength gain)
  ➢ too fine is more expensive and can be harmful

• Surface area measured indirectly (cm²/g)

Blaine test – Measures air permeability against known standard material

Wagner Turbidimeter – Measures sedimentation rate suspended in kerosene - finer settles slower
6.4 Specific Gravity

- \( G_{\text{cement}} \approx 3.15 \)
  - Measured for cement particles without air voids
- Bulk unit weight (weight required to fill a container) is highly variable.
- Cement should not be measured by volume.
6.5 Hydration

- Chemical reaction of cement with water

- “Hardening” – is not setting or drying
  - Drying = evaporation = no water
    - stops reaction
    - stops strength gain

- Mechanisms:
  - **Through-solution**: dominates early stage of hydration
  - **Topochemical**: solid-state reaction at cement surface

- Hydration rate: aluminates > silicates → needs balance
• Hydration of C\textsubscript{3}S & C\textsubscript{2}S: produces C-S-H (calcium-silicate-hydrate) \(\rightarrow\) makes paste strong

• Primary Chemical Reaction Chemical reactions that harden cement paste
  ➢ Fast in the beginning but is long term (decades in dams)
  ➢ Causes heat, which can be a problem if there’s too much

• Structure development in cement paste
6.6 Voids in Hydrated Cement

a) Interlayer hydration space
   - space between atomic layers
   - shrinkage if humidity <11%

b) Capillary voids
   - w/c ratio too high
   - decrease strength and increase permeability

c) Trapped voids
   - large pockets caused by handling
   - decrease strength and increase permeability

d) Entrained air
   - microscopic bubbles caused by admixtures
   - increases durability
### 6.7 Properties of Hydrated Cement

#### Setting

- **Stiffening**: change from plastic to solid (initial and final)
  - *not the same as hardening, which is strength gain*
  - *handling, placing, & vibrating must be completed before initial set*
  - *finishing between initial and final*
  - *curing after final set*

- **False Set**: premature stiffening within a few minutes
  - *due to humidity in cement during storage*
  - *remix without adding water*

- **Quick set & flash set** are different – cannot be fixed
Tests for Initial and Final Set

• penetration of weighted needle

Vicat

Gillmore
Soundness

Ability to retain its volume after setting

• Expansion after setting is measured in the autoclave test at 420°F & 295 psi

Frame for measuring length of sample before and after autoclave conditioning

Autoclave

Sample molds
Compressive Strength of Mortar

ASTM C109

- Average of three 2" mortar cubes
- Proportional to compressive strength of cylinders
- Compressive strength of concrete cannot be accurately predicted from cement strength

Mold

Prepare sample

Compression test

Typical failure
6.8 Water-Cement Ratio

• The most important property of hydrating cement
• Water needed for hydration, $w/c = 0.22-0.25$

• Extra water is needed for workability but causes voids
  ➢ Decreases strength
  ➢ Decreases durability
  ➢ Decreases bond between successive layers
  ➢ Decreases bond between concrete and rebar
  ➢ Increases permeability
  ➢ Increases volume change from wetting and drying
Air Entrained Concrete

Non-air Entrained Concrete
6.9 Types of PC

Standard PC types

• I Normal

• II Moderate Sulfate Resistance
  ➢ Type I/II is both normal & moderate sulfate resistance

• III High Early Strength
  ➢ becoming cheaper & more common
  ➢ we can strip forms earlier and speed up production

• IV Low Heat of Hydration
  ➢ for large, massive pours to control heat of hydration

• V High Sulfate Resistance

Other cement types: for special uses
6.10 Mixing Water

• Any potable (drinkable) water can be used

• If fresh water isn't available, we may allow some impurities if we still obtain a reasonable concrete mix
  ▪ Example: seawater may be used for plain concrete, but not for reinforced

➢ Acceptable Criteria (ASTM C94)
  ▪ Average 7-day comp. strength of mortar cubes \( \geq 90\% \) of strength of those made with fresh water
  ▪ Should not affect the set time significantly
Disposal and Reuse of Wash Water

- Waste water from ready-mixed plants is a hazardous substance
- Practices prevented or limited by EPA include
  - dumping at the job site
  - dumping at a landfill
  - dumping into a pit at the ready-mix plant
- Can reuse it for mixing new concrete
  - Use chemical stabilizing admixtures
6.11 Admixtures for Concrete

Commonly used to improve properties of fresh and hardened concrete

Types of admixtures

1. Air entrainer
2. Water reducer
3. Retarder
4. Hydration controller
5. Accelerator
6. Specialty admixtures
Air Entrainers

- Produce tiny, dispersed air bubbles into the concrete
  - Water expands as it freezes causing internal stress that cracks the hardened cement paste and greatly reduces durability
  - Air entrainer provides space for the water to go as it expands

- Recommended for all concrete exposed to freezing

- Improve workability, resistance to de-icing chemicals, sulfates, & alkalis

- Decreases strength by about 20% but can be compensated with lower w/c ratio
Thin section of concrete with air voids dyed blue
Air Entrainers (cont’d)

Different from entrapped air which is harmful larger bubbles

- frost resistance improves with decreasing void size
- small voids reduce strength less than large ones

• Air entrainers are usually a liquid poured directly into the truck
• Follow manufacturer’s recommendations for dosage
Water Reducers

- Increase mobility of cement particles
  - Improves workability – measured with slump test

No water reducer

Normal water reducer

Mid range water reducer

High-range water reducer (Superplasticizer)
Without Water Reducer

With Water Reducer

Molecule of Water Reducer
Three Ways to Use Water Reducers

1. improve workability using same w/c ratio
2. increase strength using lower w/c ratio
3. reduce cost at same w/c ratio by reducing both water & cement

<table>
<thead>
<tr>
<th></th>
<th>Cement content kg/m3</th>
<th>Water/Cement Ratio</th>
<th>Slump (mm)</th>
<th>Compressive Strength (Mpa)</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7 day</td>
</tr>
<tr>
<td>Base mix</td>
<td>300</td>
<td>0.62</td>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td>Improve consistency</td>
<td>300</td>
<td>0.62</td>
<td>100</td>
<td>26</td>
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<tr>
<td>Increase strength</td>
<td>300</td>
<td>0.56</td>
<td>50</td>
<td>34</td>
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<tr>
<td>Reduce costs</td>
<td>270</td>
<td>0.62</td>
<td>50</td>
<td>25.5</td>
</tr>
</tbody>
</table>
**Plasticizer (Superplasticizer)**
**High-Range Water Reducer**

- High-range water reducers used same as above:
  - increase slump from 3” to 9”
  - reduce water by 12 - 30% at same slump
- Lasts only 30 - 60 min. with rapid loss of workability
  - added at the jobsite
Retarders

• Delay or retard initial set (increase set time)
  ➢ hot weather for low heat of hydration
  ➢ long haul time
  ➢ time for special finishes
  ➢ may reduce early strength
  ➢ usually doesn't reduce final set time much
Hydration Controllers

• Have the ability to stop and reactivate the hydration process of concrete

• Consist of 2 parts
  1. **stabilizer**: stops the hydration for up to 72 hours
  2. **activator**: reestablishes normal hydration and setting

• Useful in extending the use of ready-mixed concrete when work at the jobsite is stopped for various reasons

• Useful when concrete is being hauled for a long time
Accelerators

• Speed up or accelerate initial & final set (decrease set time)

• Used to
  1. reduce the amount of time before finishing operations begin
  2. reduce curing time
  3. increase rate of strength gain
  4. plug leaks under hydraulic pressure efficiently

• Calcium chloride (CaCl₂) is most common
Specialty Admixtures

- workability agents
- corrosion inhibitors
- damp-proofing agents
- permeability reducing
- fungicidal, germicidal, & insecticidal admix (hospitals, clean rooms, etc.)
- concrete pumping aids
- bonding agents
- grouting agents
- gas-forming agents
- coloring agents
6.12 Supplementary Cementitious Materials

• Fly Ash
  ➢ most commonly used pozzolan in CE structures
  ➢ by-product of the coal industry
  ➢ Class N, F, and C
  ➢ increases workability and extends the hydration process

• Slag Cement
  ➢ made from iron blast furnace slag
  ➢ used as a cementitious material in concrete
Supplementary Cementitious Materials (Cont.)

• Silica Fume
  - byproduct of the production of silicon metal or ferrosilicon alloys
  - increases strength and durability
  - reduces concrete corrosion induced by deicing or marine salts

• Natural Pozzolans
  - Not cementitious, but react with calcium hydroxide to form compounds possessing cementitious properties