CHAPTER

2

Prentice Hall

**REINFORCED CONCRETE**

*A Fundamental Approach - Fifth Edition*

# CONCRETE-PRODUCING MATERIALS

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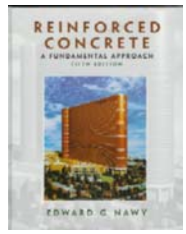
**SPRING 2004**

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**ENCE 454 – Design of Concrete Structures**

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## Introduction

- Concrete is produced by the collective mechanical and chemical interaction of a large number of constituent materials.
- The concrete-producing material include:
  – Cement;
  – Fine and coarse aggregate;
  – Water;
  – Air; and
  – Admixtures

# Portland Cement

- Manufacture
  - The raw materials that make cement are:
  1. Lime ($CaO$), from limestone
  2. Silica ($SiO_2$), from clay
  3. Aluminum ($Al_2O_3$), from clay

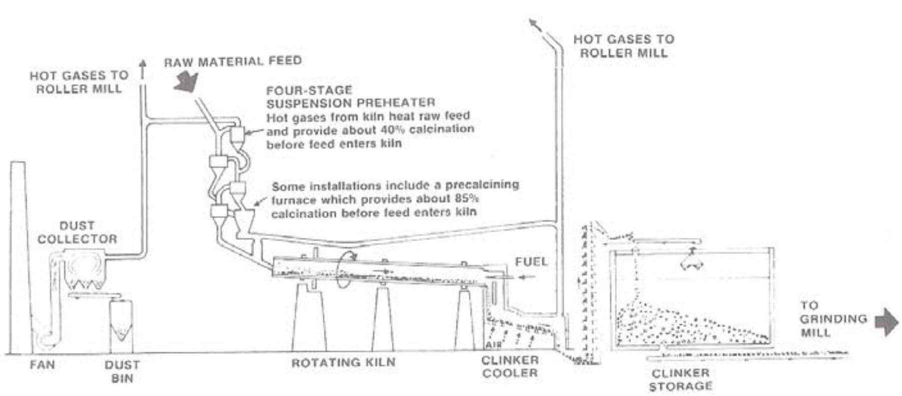

Specific Gravity:
3.12 and 3.16

Weight:
94 lb/ft$^3$ (for commercial sack)



# Portland Cement (cont'd)

- Manufacture
  - The Process of Manufacture



# Portland Cement (cont'd)

- Strength

Table 1. Properties of Cement

| Component | Rate of Reaction | Heat Liberated | Ultimate Cementing value |
|---|---|---|---|
| Tricalcium, $C_3S$ | Medium | Medium | Good |
| Dicalcium, $C_2S$ | Slow | Small | Good |
| Tricalcium aluminate, $C_3A$ | Fast | Large | Poor |
| Tetracalcium aluminoferrate, $C_4AF$ | Slow | Small | Poor |



# Portland Cement (cont'd)

- Average Percentage Composition
  - Since there are different types of cement for various needs, it is necessary to study the percentage variation in the chemical composition of each type in order to interpret the reasons for variation.
  - Table 2, studied in conjunction with Table 1, gives concise reasons for the differences in reaction of each type of cement when in contact with water.

# Portland Cement (cont'd)

- Average Percentage Composition

Table 2. Percentage Composition of Portland Cement

| Type of Cement | Component (%) | | | | | | | General Characteristics |
|---|---|---|---|---|---|---|---|---|
| | $C_3S$ | $C_2S$ | $C_3A$ | $C_4AF$ | $CaSO_4$ | CaO | MgO | |
| Normal: I | 49 | 25 | 12 | 8 | 2.9 | 0.8 | 2.4 | All-purpose cement |
| Modified: II | 45 | 29 | 6 | 12 | 2.8 | 0.6 | 3.0 | Comparative low heat liberation; used in large structures |
| High early strength: III | 56 | 15 | 12 | 8 | 3.9 | 1.4 | 2.6 | High strength in 3 days |
| Low heat: IV | 30 | 46 | 5 | 13 | 2.9 | 0.3 | 2.7 | Used in mass concrete dams |
| Sulfate resisting: V | 43 | 36 | 4 | 12 | 2.7 | 0.4 | 1.6 | Used in sewers and structures exposed to sulfates |



# Portland Cement (cont'd)

- Influence of fineness of Cement on Strength Development
  - Size of particles affects rate of reaction of cement with water.
  - The surface area of the particles of finely ground cement is greater than that of coarsely ground cement.
  - Therefore, greater rate of reactions with water and a more rapid hardening process.

# Portland Cement (cont'd)

- Influence of Cement on the Durability of Concrete
  - Concrete can be disintegrated due to cycles of
    - Wetting
    - Freezing
    - Thawing
    - Drying
  - Cracks can be developed because of these cycles.



# Portland Cement (cont'd)

- Influence of Cement on the Durability of Concrete (cont'd)
  - The presence of minute ***air voids*** throughout the cement paste *increases the resistance* of concrete to disintegration.
  - This can be achieved by the addition of *air-entraining admixtures* to the concrete while mixing.

# Portland Cement (cont'd)

- Heat Generation during Initial Set
  - Different types of cement generates different degrees of heat at different rates.
  - The bulkier and heavier in cross section the structure is, the less the generation of heat of hydration that is desired.
  - In dams, piers, and caissons, type IV cement is preferred.
  - Therefore, the type of structure and the prevailing conditions govern the type of cement that will be used.



# Water and Air

- Water
  - Water is used to
    - Precipitate chemical reaction,
    - To wet the aggregates, and
    - To lubricates the mixtures for easy workability.
  - Generally, drinking water can be used in mixing.
  - Water having contamination, silt, oil, sugar, or chemicals can be destructive to the strength and setting properties of cement.

# Water and Air (cont'd)

- Water (cont'd)
  - The proportion of water relative to cement (not to whole mixture) is of great importance:
    - Too much water leaves an uneven honeycombed skeleton in the finished product after hydration.
    - Too little water prevents complete chemical reaction with the cement.
    - The product in both cases is a concrete that is weaker than and inferior to normal concrete.



# Water and Air (cont'd)

- Entrained Air
  - Pores are produced in the hardened concrete due to gradual evaporation of excess water from the mix.
  - If evenly distributed, it can be an improving agent to the finished product.
  - Uniformly distributed air bubbles can be produced through the product by adding air-entraining agents such as vinsol resin.

# Water and Air (cont'd)

- Entrained Air (cont'd)
  - Air entrainment
    - Increases workability,
    - Decreases density,
    - Increases durability,
    - Reduces bleeding and segregation, and
    - Reduces the required sand content in the mix.
  - The optimum air content is 9% of mortar fraction of the concrete.



# Water and Air (cont'd)

- Water/Cement Ratio (*w*/*c*)
  - The ratio of the amount of water to the amount of cement by weight.
  - It is an important measure of concrete strength.
  - The ratio can be expressed in terms of gallons of water per bag of cement.
  - For complete hydration of cement in a mix, a water/cement ratio of **0.35 to 0.40** (or 4 to 4.5 gal per bag) is required.

# Water and Air (cont'd)

- Water/Cementitious Ratio
  - For high-strength high-performance concrete, mineral pozzolanic or chemical admixtures are used to replace part of the cement in a particular mixture design.
  - Therefore, the *w/c* ratio would not be the governing criteria for strength requirement, but the water/cementitious ratio:

$$W/(C+P) \qquad (1)$$



# Aggregates

- Constitute the bulk of the finished product.
- Comprise 60 to 80% of the volume of the concrete.
- So graded that the whole mass of concrete acts as a relatively
  - Solid,
  - Homogeneous, and
  - Dense product.

# Aggregates (cont'd)

- Types
  - Coarse Aggregates:
    - Gravel
    - Crushed stones
    - Blast-furnace slag
  - Fine Aggregates
    - Natural
    - Manufactured sand




# Aggregates (cont'd)

- Coarse Aggregates
  - Natural crushed stone
  - Natural gravel
  - Artificial coarse aggregates
  - Heavyweight and nuclear-shielding aggregates
- Fine Aggregates
  - They ranges in size from No. 4 to No. 100 U.S. standard sieve sizes. They should be free of clay, organic materials, and chemicals.

# Aggregates (cont'd)

- Grading for Normal-weight Concrete Mixtures

Table 3. Grading Req's for Aggr. in Normal-Weight Concrete

| U.S. Standard Sieve Size, in (mm) | Percent Passing | | | | |
|---|---|---|---|---|---|
| | Coarse Aggregate | | | | |
| | No. 4 to 2 in. | No. 4 to 1½ in. | No. 4 to 1 in. | No. 4 to ¾ in. | Fine Aggregate |
| 2 in. (50) | 95–100 | 100 | — | — | — |
| 1½ in. (37.5) | — | 95–100 | 100 | — | — |
| 1 in. (25.0) | 25–70 | — | 95–100 | 100 | — |
| ¾ in. (19.00) | — | 35–70 | — | 90–100 | — |
| ½ in. (12.5) | 10–30 | — | 25–60 | — | — |
| ⅜ in. (9.5) | — | 10–30 | — | 20–55 | 100 |
| No. 4 (4.75) | 0–5 | 0–5 | 0–10 | 0–10 | 95–100 |
| No. 8 (2.36) | 0 | 0 | 0–5 | 0–5 | 80–100 |
| No. 16 (1.18) | 0 | 0 | 0 | 0 | 50–85 |
| No. 30 (600 μm) | 0 | 0 | 0 | 0 | 25–60 |
| No. 50 (300 μm) | 0 | 0 | 0 | 0 | 10–30 |
| No. 100 (150 μm) | 0 | 0 | 0 | 0 | 2–10 |

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# Aggregates (cont'd)

- Grading for Lightweight Concrete Mixtures

Table 4. Grading Req's for Aggr. in Lightweight Concrete

| Size Designation | 1 in. (25.0 mm) | ¾ in. (19.0 mm) | ½ in. (12.5 mm) | ⅜ in. (9.5 mm) | No. 4 (4.75 mm) | No. 8 (2.36 mm) | No. 16 (1.18 mm) | No. 50 (300 μm) | No. 100 (150 μm) |
|---|---|---|---|---|---|---|---|---|---|
| Fine aggregate No. 4 to 0 | — | — | — | 100 | 85–100 | — | 40–80 | 10–35 | 5–25 |
| Coarse aggregate | | | | | | | | | |
| 1 in. to No. 4 | 95–100 | — | 25–60 | — | 0–10 | — | — | — | — |
| ¾ in. to No. 4 | 100 | 90–100 | — | 10–50 | 0–15 | — | — | — | — |
| ½ in. to No. 4 | — | 100 | 90–100 | 40–80 | 0–20 | 0–10 | — | — | — |
| ⅜ in. to No. 8 | — | — | 100 | 80–100 | 5–40 | 0–20 | 0–10 | — | — |
| Combined fine and coarse aggregate | | | | | | | | | |
| ½ in. to 0 | — | 100 | 95–100 | — | 50–80 | — | — | 5–20 | 2–15 |
| ⅜ in. to 0 | — | — | 100 | 90–100 | 65–90 | 35–65 | — | 10–25 | 5–15 |

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# Aggregates (cont'd)

- Grading for Heavyweight and Nuclear-shielding Aggregates

Table 5. Grading Req's for Aggr. in Heavyweight Concrete

| Sieve Size | Percentage Passing: Grading 1: for 1½ in. (37.5 mm) Maximum-size Aggregate | Grading 2: for ¾ in. (19.0 mm) Maximum-size Aggregate |
|---|---|---|
| *Coarse Aggregate* | | |
| 2 in. (50 mm) | 100 | — |
| 1½ in. (37.5 mm) | 95–100 | 100 |
| 1 in. (25.0 mm) | 40–80 | 95–100 |
| ¾ in. (19.0 mm) | 20–45 | 40–80 |
| ½ in. (12.5 mm) | 0–10 | 0–15 |
| ⅜ in. (9.5 mm) | 0–2 | 0–2 |
| *Fine Aggregate* | | |
| No. 8 (2.36 mm) | 100 | — |
| No. 16 (1.18 mm) | 95–100 | 100 |
| No. 30 (600 μm) | 55–80 | 75–95 |
| No. 50 (300 μm) | 30–55 | 45–65 |
| No. 100 (150 μm) | 10–30 | 20–40 |
| No. 200 (75 μm) | 0–10 | 0–10 |
| Fineness modulus | 1.30–2.10 | 1.00–1.60 |

Data in Tables 2.3 to 2.5 reprinted with permission from the American Society for Testing and Materials, Philadelphia, Pa.



# Aggregates (cont'd)

- Unit Weights of Aggregates

Table 6. Unit Weight of Aggregates

| Type | Unit Weight of Dry-rodded Aggregate (lb/ft$^3$) | Unit Weight of Concrete (lb/ft$^3$) |
|---|---|---|
| Insulating concretes (perlites, vermiculite, etc) | 15 – 50 | 20 – 90 |
| Structural lightweight | 40 - 70 | 90 – 110 |
| Normal weight | 70 - 110 | 130 – 160 |
| Heavyweight | > 135 | 180 - 380 |

# Admixtures

- Admixtures are materials other than water, aggregates, or hydraulic cement that are used as ingredients of concrete and that are added to the batch immediately before or during the mixing.
- Their purpose is modify the properties of the concrete, i.e., to make it more suitable for the work at hand, or for economy, or for other purposes such as saving energy.



# Admixtures

- Types of Admixtures
  - Accelerating admixtures
  - Air-entraining admixtures
  - Water-reducing admixtures and set-controlling admixtures
  - Finely divided mineral admixtures
  - Admixtures for no-slump concretes
  - Polymers
  - High-range water-reducing admixtures (HRWRA)