Fundamentals of Concrete
Concrete Components

- Cement
- Water
- Fine Aggregate
- Coarse Aggregate
Range in Proportions

- **Mix 1**
  - Cement: 15%
  - Water: 18%
  - Air: 8%
  - Fine agg.: 28%
  - Coarse agg.: 31%

- **Mix 2**
  - Cement: 7%
  - Water: 14%
  - Air: 4%
  - Fine agg.: 24%
  - Coarse agg.: 51%

- **Mix 3**
  - Cement: 15%
  - Water: 21%
  - Air: 3%
  - Fine agg.: 30%
  - Coarse agg.: 31%

- **Mix 4**
  - Cement: 7%
  - Water: 16%
  - Air: 1%
  - Fine agg.: 25%
  - Coarse agg.: 51%

**Legend**
- Air-entrained concrete
- Non-air-entrained concrete
Advantages of Reducing Water Content:

- Increased strength
- Lower permeability
- Increased resistance to weathering
- Better bond between concrete and reinforcement
- Reduced drying shrinkage and cracking
- Less volume change from wetting and drying
Workability

— that property of freshly mixed concrete that determines its working characteristics, i.e. the ease with which it can be mixed, placed, compacted and finished.
Cross Section of Hardened Concrete

Concrete made with siliceous rounded gravel

Concrete made with crushed limestone
Workability
Factors Affecting Workability

- Method and duration of transportation
- Quantity and characteristics of cementing materials
- Concrete consistency (slump)
- Aggregate grading, shape & surface texture
- % entrained air
- Water content
- Concrete & ambient air temperature
- Admixtures
Effect of Casting Temperature on Slump

![Casting Temperature vs Slump](image)

- **Casting temperature, °F**
  - 32
  - 52
  - 72
  - 92

- **Slump, mm**
  - 0
  - 50
  - 100
  - 150
  - 200

- **Slump, in.**
  - 0
  - 2
  - 4
  - 6
  - 8

- **Casting temperature, °C**
  - 0
  - 10
  - 20
  - 30
  - 40

- **Cement A**
- **Cement B**
Bleeding and Settlement
Consolidation
Effect of Voids in Concrete on Modulus of Elasticity, Compressive Strength, and Flexural Strength
Hydration
— is the chemical reaction between the cement and water in which new compounds with strength producing properties are formed.

Heat of Hydration
— is the heat given off during the chemical reaction as the cement hydrates.
Setting Times at Different Temperatures

Penetration resistance, MPa

Cured at 32°C (90°F)

23°C (73°F)

10°C (50°F)

Initial Set

Final Set

Penetration resistance, 1000 psi

Time, hr

0 2 4 6 8 10 12 14

0 1 2 3 4 5 6 7

Fundamentals of Concrete
Curing

— maintenance of a satisfactory moisture content and temperature in concrete for a suitable period of time immediately following placing & finishing so that the desired properties may develop.

- Time
- Temperature
- Moisture
Effect of Curing on Strength Development

**Graph:**
- **Y-axis:** Compressive strength, MPa
- **X-axis:** Age at test, days
- Lines represent different curing conditions:
  - Moist-cured entire time
  - In air after 28 days moist curing
  - In air after 7 days moist curing
  - In laboratory air entire time

**Legend:**
- Moist-cured entire time: Blue line
- In air after 28 days moist curing: Red line
- In air after 7 days moist curing: Green line
- In laboratory air entire time: Orange line

**Title:**
Fundamentals of Concrete
Effect of Casting and Curing Temperature on Strength Development

![Graph showing the effect of casting and curing temperature on strength development.](image)

- Compressive strength, MPa
- Casting/curing temperature, °C °F
  - 10/10 (50/50)
  - 23/10 (73/50)
  - 23/23 (73/73)
  - 32/32 (90/90)
- Age, days
Concrete Strength Gain Versus Time for Concrete Exposed to Outdoor Conditions

Outdoor exposure - Skokie, Illinois
150-mm (6-in.) modified cubes
Type I cement
Rel. Humidity of 150 x 300-mm (6 x 12-in.) Cylinders Moist Cured for 7 days

Cement content: 270 kg/m³ (454 lb/cu yd)
Normal-density concrete
w/c ratio: 0.66

- 75 mm (3 in.) depth
- 45 (1³/₄)
- 20 (³/₄)
- 6 (¹/₄)

Relative humidity, percent

Time of drying, days

Fundamentals of Concrete
Drying Shrinkage and Mass Loss of 150 x 300-mm (6 x 12-in.) Cylinders Moist Cured for 7 days

- Cement content: 270 kg/m³ (454 lb/yd³)
- Normal-density concrete
- w/c ratio: 0.66

Shrinkage, millionths

Mass loss, kg

Time of drying, days
— is defined as the measured maximum resistance of a concrete or mortar specimen to an axial load, usually expressed in MPa (psi) at an age of 28-days.

- Most general use concrete
  20 to 40 MPa
  (3000 to 6000 psi)

- High-strength concrete by definition
  70 MPa or greater
  (10000 psi or greater)
Compressive Strength Test Specimen Sizes

- **Mortar** — 50 mm (2 in.) cubes
- **Concrete** — 150 x 300 mm (6 x 12 in.) cylinders
Strength Development of Concretes in Percent of 28-Day Strength
Ratios — W/CM and W/C

- **Water-cementing materials ratio (w/cm)**
  — ratio of mass of water to mass of cementing materials in a concrete mix expressed as a decimal. The water is exclusive to that absorbed by the aggregate.

- **Water-cement ratio (w/c)**
  — ratio of mass of water to mass of cement in a concrete mix expressed as a decimal.
Typical Relationships of Strength to W/C-Ratio

28-day strength
Moist cured cylinders

Compressive strength, MPa

Water-cement ratio

Compressive strength, psi
Testing of Compressive Strength
Approximations of Concrete Strengths

- **Compressive strength** ($f'_c$)
  - 7-day — 75% of 28-day
  - 56 and 90-day — 10% - 15% > 28-day

- **Flexural Strength (Modulus of Rupture)**
  - normal density — 8% - 12% of $f'_c$

- **Tensile Strength**
  - direct tensile — 8% -12% of $f'_c$
  - splitting tensile — 8% -14% of $f'_c$
# Observed Average Density of Fresh Concrete (Metric)

<table>
<thead>
<tr>
<th>Maximum size of aggregate, mm</th>
<th>Air, %</th>
<th>Water, kg/m³</th>
<th>Cement, kg/m³</th>
<th>Density, kg/m³</th>
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</thead>
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<tr>
<td></td>
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<td></td>
<td>2.55</td>
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<td>2259</td>
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<td>75</td>
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<td>121</td>
<td>242</td>
<td>2307</td>
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</tbody>
</table>

Relative density of aggregate

- Cement, kg/m³
- Water, kg/m³
- Relative density of aggregate
## Observed Average Density of Fresh Concrete (Inch-Pound)

<table>
<thead>
<tr>
<th>Maximum size of aggregate, in.</th>
<th>Air, %</th>
<th>Water, lb/yd³</th>
<th>Cement, lb/yd³</th>
<th>Density, lb/ft³</th>
<th>Relative density of aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>¾</td>
<td>6.0</td>
<td>283</td>
<td>566</td>
<td>2.55</td>
<td>137, 139, 141, 143, 145</td>
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<td>1½</td>
<td>4.5</td>
<td>245</td>
<td>490</td>
<td>2.60</td>
<td>141, 143, 146, 148, 150</td>
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<tr>
<td>3</td>
<td>3.5</td>
<td>204</td>
<td>408</td>
<td>2.70</td>
<td>144, 147, 149, 152, 154</td>
</tr>
</tbody>
</table>
Fundamentals of Concrete

E and Density—Approx. Values

- **Modulus of Elasticity (E)**
  - normal concrete — 14,000 to 41,000 MPa (2 to 6 million psi)

- **Density**
  - normal concrete — 2200 to 2400 kg/m³ (137 to 150 lb/ft³)
  - reinforced concrete — 2400 kg/m³ (150 lb/ft³)
  - low density insulating concrete — as little as 240 kg/m³ (15 lb/ft³)
  - high density concrete — up to 6000 kg/m³ (375 lb/ft³) (radiation shielding, counterweights)
Watertightness / Permeability

- **Watertightness**
  — the ability of concrete to hold back or retain water without visible leakage.

- **Permeability**
  — amount of water migration through concrete when the water is under pressure or the ability of concrete to resist penetration by water or other substances (liquids, gas, ions, etc.)
Relationship between Hydraulic Permeability, W/C-Ratio, and Initial Curing

- Non-air-entrained concrete
- Specimens: 100 x 200 mm (4 x 8 in.) cylinders
- Water pressure: 20 MPa (3000 psi)
- Curing:
  - 1 day moist, 90 days in air
  - 7 days moist, 90 days in air

Graph showing the relationship between hydraulic permeability and water-cement ratio.
Effect of W/C-Ratio and Curing Duration on Permeability of Mortar

- **Non-air-entrained concrete**
  - Specimens: 25 x 150 mm (1 x 6 in.) mortar disks
  - Pressure: 140 kPa (20 psi)

**Graph:**
- Leakage, kg/(m² • h), average for 48 hours
- Leakage, spf per hour
- Period of moist curing and age at test, days

- **w/c ratio:**
  - 0.80
  - 0.64
  - 0.50
Effect of W/C-Ratio and Air Content on the Total Charge at the End of the Rapid Chloride Permeability Test

![Graph showing the cumulative charge in coulombs against the water to cement ratio for different air contents (2%, 4%, and 6%). The graph indicates a positive correlation between the water to cement ratio and the cumulative charge.](image-url)
Effect of Compressive Strength and Aggregate Type on the Abrasion Resistance of Concrete
Effect of Hard Steel Troweling and Surface Treatments on the Abrasion Resistance of Concrete (ASTM C 779)
Measuring Abrasion Resistance of Concrete
Specimens Subjected to 150 Cycles of Freezing and Thawing

- Non-air-entrained
- High water-cement ratio
- Air-entrained
- Low water-cement ratio
Relationship Between Freeze-Thaw Resistance, W/C-Ratio, and Different Concretes and Curing Conditions (1)

![Graph showing the relationship between freeze-thaw resistance, W/C-ratio, and different concretes and curing conditions.](image)

- **Type I cement**
- **Fog cured 14 days, Dried 76 days at 50% RH**
- **Air-entrained concrete**
- **Non-air-entrained concrete**

Cycles of freezing and thawing to 25% loss in mass

Water-cement ratio, by mass
Fundamentals of Concrete

Relationship Between Freeze-Thaw Resistance, W/C-Ratio, and Different Concretes and Curing Conditions (2)

Cycles of freezing and thawing to 25% loss in mass

Fog cured 28 days
No drying period

- Air-entrained concrete
- Non-air-entrained concrete

Type I cement

Water-cement ratio, by mass
Alkali- Aggregate Reactivity (AAR)

— is a reaction between the active mineral constituents of some aggregates and the sodium and potassium alkali hydroxides and calcium hydroxide in the concrete.

- Alkali-Silica Reaction (ASR)
- Alkali-Carbonate Reaction (ACR)
Alkali-Silica Reactivity (ASR)

- Control ASR with:
  - Fly ash
  - Slag
  - Calcined clay
  - Blended cement
- Limit concrete alkali content
- Test for effectiveness
Effect of Fly Ash on Alkali-Aggregate Reactivity

Type II cement, alkali = 1.00%
Class F fly ash
Rhyolitic reactive aggregate
ASTM C 227 mortar bars

Expansion at 30 months, percent

Fly ash dosage, percent

Failure criterion
Corroded Steel Due to Carbonation
Methods to Reduce Corrosion of Embedded Steel by Chlorides

- Use low w/cm ratio concrete
- Moist cure
- Reduce permeability with SCM’s
- Increase concrete cover
- Corrosion inhibitors
- Epoxy-coated reinforcing steel
- Concrete overlays
- Surface treatments
- Cathodic protection
Reducing Corrosion by Chlorides Using Epoxy-Coated Rebars
Sulfate Attack

- Use low w/c
- Use sulfate resistant cement
Concrete Beams After Seven Years of Exposure to Sulfate-Rich Wet Soil
Average 16-yr Ratings of Concrete Beams in Sulfate Soils

Rating:
1.0 = no deterioration
5.0 = severe deterioration

![Diagram showing the relationship between water-cement ratio and visual rating for different ASTM types of concrete](image)
Concrete Exposed to Seawater
Secondary Ettringite Deposits in Void
Heat Induced Delayed Expansion
Videos 1/2

Concrete Fundamentals

Workability
Videos 2/2

Concrete Durability

Fact: Compressive strength alone does not determine the concrete's durability.

Freeze-Thaw