Properties of Portland Cement Concrete
Concrete Ingredients

- Gravel: 40%
- Sand: 25%
- Water: 20%
- Cement: 10%
- Air: 5%

Paste

Mortar

- Gravel
- Sand
- Water
- Cement
- Air
Concrete Strength

1. Aggregate

2. Cement/Aggregate Bond

3. Cement Paste
Water-Cement Ratio

![Graph showing the relationship between water/cement ratio and compressive strength. The graph indicates a decrease in compressive strength as the water/cement ratio increases.](image)
Water-Cement Ratio (Volume)

\[
w/c = \frac{\text{gallons of water}}{\text{sacks of cement}} \quad \text{(gallons/sack)}
\]

1 sack of cement = 1 ft\(^3\) bulk = 94 lb
Water-Cement Ratio

\[ \frac{w}{c} = \frac{\text{mass of water}}{\text{mass of cement}} \quad \text{(dimensionless)} \]

\[ \frac{w}{cm} = \frac{\text{mass of water}}{\text{mass of cement} + \text{SCMs}} \]
Water-Cement Ratio

0.25 = Full Hydration
Water-Cement Ratio

Compressive Strength

Water/Cement Ratio

Vibrated

Rodded
Water-Cement Ratio

0% Hydration

100% Hydration
Cement Paste Strength

The diagram shows the relationship between the compressive strength (MPa) of cement paste and the air content (percent) of the paste. A negative correlation is observed, where an increase in air content is associated with a decrease in compressive strength.
Freeze-Thaw Durability
Freeze-Thaw Durability
Air Entrainment
Air Entrainment

(data from tests on mortar cubes)
Air Requirements

Optimum Air Content = 9% of Mortar Volume

NMAS = 3"
1½"
¾"
⅜"

CIVL 3137
Properties Affected by Air Content

- durability
- consistency
- strength
- bleeding
Air Entrainment
Air Entrainment
Important Properties

- workability
- harshness
- compressive strength
- tensile / flexural strength
- stiffness
- durability
- permeability
- shrinkage / creep
Workability

workability (n.) the ease with which the concrete ingredients (gravel, sand, cement, water) can be mixed, transported, placed, consolidated, and finished with minimum loss of homogeneity.
Workability

Workability refers to the fluidity of the concrete and how easily it can be transported, placed, and consolidated without inhomogeneity.

Workability = consistency + cohesion

Consistency refers to the stickiness of the concrete and how easily it can be placed and finished without inhomogeneity.
Inhomogeneity

**segregation** (*n.*) the tendency for the gravel particles to separate from the rest of the ingredients.

**bleeding** (*n.*) the tendency for the mixing water to separate from the rest of the ingredients.
Causes of Segregation

improper placement

too much mixing water

over-vibration
Causes of Bleeding

too little cement

too much water

over-vibration

over-working
Concrete Strength

![Graph showing the relationship between strength (Mpa) and w/c ratio (by mass) for 28-day, 7-day, 3-day, and 1-day, with lines for air-entrained and non-air-entrained concrete.](image-url)
Strength Gain Over Time

![Graph showing the relationship between age and compressive strength for different water-to-cement ratios (w/c). The graph indicates that as the w/c ratio increases from 0.3 to 0.7, the compressive strength increases over time.](image-url)
Concrete Maturity

![Graph showing compressive strength versus maturity, with key points at 1d, 3d, 7d, 14d, and 28d. The log function line is indicated.]
Tensile Strength

\[ f_t \approx 0.1f'_c \]
Tensile Strength

\[ f_t = 6.7 \sqrt{f'_c} \quad (f'_c \text{ in psi}) \]
Beam Flexure Test

\[ L/3 \]
Modulus of Rupture

\[ \text{MOR} = \frac{PL}{bd^2} \]
Concrete Behavior

![Stress-Strain Curve for Concrete](image)

- $f'_c$: 5700 psi
- Stress (psi)
- Strain ($\times 10^{-4}$)
Beam Flexure Test

\[ \text{MOR} = \frac{PL}{bd^2} \]

Assumed stress distribution

Actual stress distribution

Compression

Neutral axis

Tension

\( f_t \)
Flexural Strength

\[ \text{MOR} = 8.4 \sqrt{f'_c} \quad (f'_c \text{ in psi}) \]

\[ f_t = 6.7 \sqrt{f'_c} \quad (f'_c \text{ in psi}) \]

\[ \text{MOR} \approx 1.25 f_t \quad \text{or} \quad f_t \approx 0.8 \text{ MOR} \]
Flexural Strength

[Graph showing relationship between tensile and compressive strengths]
Stiffness and Strength
Stiffness and Strength

Source: ACI Manual of Concrete Practice

\[ E = 33w^{1.5} \sqrt{f'_c} \]

- \( E \) = elastic modulus in lb/in\(^2\)
- \( w \) = unit weight in lb/ft\(^3\)
- \( f'_c \) = compressive strength in lb/in\(^2\)
Stiffness and Strength

\[ E = 57,000 \sqrt{f'_c} \]

Typical test data
Stiffness and Strength
Durability

Sources of Deterioration

- Alkali-Silica Reaction
  - aggregate type
  - cement type
- Freeze-Thaw Cycles
  - air content
  - w/c ratio
- Sulfate Attack
  - cement type
Shrinkage / Creep

Sources of Volume Change

- Temperature Changes
- Drying Shrinkage
- Creep Strains
## Coefficient of Thermal Expansion

<table>
<thead>
<tr>
<th>Aggregate Type</th>
<th>Coefficient (10^-6 in/in/°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>6.6</td>
</tr>
<tr>
<td>Sandstone</td>
<td>6.5</td>
</tr>
<tr>
<td>Gravel</td>
<td>6.0</td>
</tr>
<tr>
<td>Granite</td>
<td>5.3</td>
</tr>
<tr>
<td>Basalt</td>
<td>4.8</td>
</tr>
<tr>
<td>Limestone</td>
<td>3.8</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>5.5</strong></td>
</tr>
</tbody>
</table>
Example

How much strain would develop in a granitic concrete due to a 60°F temperature change?
Example

\[ \varepsilon = 3.6 \times 10^{-4} \]
## Drying Shrinkage Coefficient

<table>
<thead>
<tr>
<th>Tensile Strength (psi)</th>
<th>Shrinkage Coefficient (in/in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 or less</td>
<td>0.0008</td>
</tr>
<tr>
<td>400</td>
<td>0.0006</td>
</tr>
<tr>
<td>500</td>
<td>0.00045</td>
</tr>
<tr>
<td>600</td>
<td>0.0003</td>
</tr>
<tr>
<td>700 or more</td>
<td>0.0002</td>
</tr>
<tr>
<td>Typical</td>
<td>0.0006</td>
</tr>
</tbody>
</table>
Example

How much will a typical 14-ft pavement slab shrink during curing if it is unrestrained?
Example

How much tensile stress will develop in the slab in the previous example if it is restrained?