Aggregates for Concrete
Aggregates for Concrete

Significance:

- Cost
- Provide dimensional stability
- Influence hardness, abrasion resistance, elastic modulus
Aggregates for Concrete

Aggregate Type

- **Coarse aggregate** > 3/16 in. - 4.75 mm (No. 4 sieve)

- **Fine aggregate** < 3/16 in. and > 150 (No. 200 sieve)
Aggregates for Concrete

Aggregate Type - mineralogy

- **Igneous Rocks**
  - *Intrusive (plutonic):* coarse-grained; granite
  - *Shallow Intrusive:* fine-grained; riolite, andesite, basalt
  - *Extrusive:* fine-grained; tuff, pumice, basalt hard,
  - Tough, strong: excellent aggregate.
Aggregate Type - mineralogy

- **Sedimentary Rocks** (cost effective - near the surface), about 80% of aggregates
  - Natural sand and gravel
  - Sandstone, limestone (dolomite), chert, flint, graywacke
- **Metamorphic Rocks**: slate, gneiss
- Excellent to poor

P.K. Mehta and P.J. M. Monteiro, *Concrete: Microstructure, Properties, and Materials*
Aggregates for Concrete

Production

P.K. Mehta and P.J.M. Monteiro, Concrete: Microstructure, Properties, and Materials
## Aggregates for Concrete

### Density

<table>
<thead>
<tr>
<th>Aggregate Type</th>
<th>Density (pcf)</th>
<th>Concrete Density (pcf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal weight aggregate</td>
<td>110</td>
<td>150</td>
</tr>
<tr>
<td>Lightweight Aggregate</td>
<td>&lt; 70</td>
<td>90-115</td>
</tr>
<tr>
<td>perlite - thermal insulators</td>
<td></td>
<td></td>
</tr>
<tr>
<td>expanded shales - structural concrete</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heavyweight Aggregate</td>
<td>115-200</td>
<td>&lt;200</td>
</tr>
</tbody>
</table>
Aggregates for Concrete

Lightweight aggregate spectrum

1.0 pcf = 16.02 kg/m³
1.0 psi = 0.00069 MPa
Internal curing of concrete

• Very promising technique
  • *Curing water provided by saturated lightweight aggregate*
  
• Internal water: curing from the “inside-out”

• Mix-proportioning procedure developed by Dale Bentz at NIST
Internal curing of concrete

![Graph showing microstrain over time for w/c=0.3 HPM slag blended cement. The graph compares control and internal curing (IC) treatments. The microstrain decreases over time, with the IC treatment showing a smaller decrease than the control. The graph is labeled with time in days (0, 7, 14, 21, 28, 35, 42, 49, 56) on the x-axis and microstrain on the y-axis. The source of the data is D. Bentz.](image-url)

Source: D. Bentz

P.K. Mehta and P.J.M. Monteiro, Concrete: Microstructure, Properties, and Materials
Industrial by-products

- **Slags**: by-product of metallurgic industries
- Not a high quality aggregate because it has some impurities
- Not used for prestressed concrete
- Used for blocks
- *Much more value as a cementing material*
Aggregates for Concrete

Industrial by-products used in concrete

- **Fly-ash**: by-product of burning coal (72 million ton/y in USA, 600-700 million ton/yr globally)

- Sintered or pelletized fly-ash has been used for LWA

- Good to be used in combination with P.C.
  - *Much more value as a pozzolanic material*
Industrial by-products used in concrete

- **Aggregate from recycled concrete** (demolished concrete buildings)
  - Aggregate is contaminated with cement paste, gypsum, etc.
  - Cost of crushing, grinding, dust control, and separation of undesirable constituents
  - Silt, clay increase water requirement (wash them out)
Industrial by-products used in concrete

- Aggregates from Municipal Wastes
- Not appropriate
Aggregates for Concrete

Aggregate characteristics that affect concrete properties

- Parent Rock
- Prior Exposure and Processing Factors
- Particles Characteristics
  - Size
  - Shape
  - Texture
- Concrete Mix Proportioning
- Porosity/Density
- Microstructure
  - Mineralogical Composition
  - Crushing Strength
  - Abrasion Resistance
  - Elastic Modulus
  - Soundness
- Properties of Plastic Concrete
  - Consistency
  - Cohesiveness
  - Unit Weight
- Properties of Hardened Concrete
  1. Ultimate Strength
  2. Abrasion resistance
  3. Dimensional Stability
  4. Durability

P.K. Mehta and P.J. M. Monteiro, Concrete: Microstructure, Properties, and Materials
Characteristics controlled by porosity

- **Density**

  - **I) Apparent specific density**: Density of the material including the internal pores.

  - **II) Bulk density** (dry-rodded unit weight) weight of the aggregate that would fill a unit volume: affects the following concrete behavior: mix design, workability, and unit weight.
Absorption and Surface Moisture

- Affects the following concrete behavior:
  - Mix-design,
  - Soundness,
  - Strength/abrasion resistance.
Aggregates for Concrete

<table>
<thead>
<tr>
<th>State</th>
<th>Oven dry</th>
<th>Air dry</th>
<th>Saturated, surface dry</th>
<th>Damp or wet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Moisture</td>
<td>None</td>
<td>Less than potential absorption</td>
<td>Equal to potential absorption</td>
<td>Greater than absorption</td>
</tr>
</tbody>
</table>

**Moisture conditions of aggregates (a)**

- Oven dry
- Air dry
- Saturated, surface dry
- Damp or wet

Granite aggregate at various moisture conditions (b)

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Aggregates for Concrete

Bulking

Percent increase in volume over dry, rodde, sand

Percent of moisture added by mass to dry, rodde sand

Fine sands

Medium sands

Coarse sands

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Soundness

- Aggregate is considered unsound when volume changes in the aggregate induced by weather such as alternate cycles of wetting and drying or freezing and thawing result in concrete deterioration.

- Depends on: porosity, flaws and contaminants

- Pumice- (10% absorption) - no problem with freezing and thawing

- Limestone- breaks use smaller aggregate (critical size)
Aggregates for Concrete

Particle size

- **Size**: Affects the following concrete properties: water demand, cement content, microcracking.

- **Grading**
  - Depends on: proportions of coarse and fine aggregate
  - Affects: paste content (cost economy), workability
What is the best packing you can achieve with spheres?
Reduction of voids

(a)

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Reduction of Voids

Gravel
- No. 4 - 3/8in
- No. 4 - 3/4in
- No. 4 - 1 1/2in
- 3/8in - 3/4in
- 3/8in - 1 1/2in

Granite

Percentage of Sand in Mixed Aggregates

P.K. Mehta and P.J.M. Monteiro, Concrete: Microstructure, Properties, and Materials
Shape and Surface Texture

- Round, angular, elongated, flaky

- Rough-textured and elongated particles require more cement paste to produce workable concrete mixtures, this increasing the cost.
## Surface Texture

- **Depends on**
  - Rock hardness,
  - Grain size,
  - Porosity,
  - Previous exposure

- **Affects**
  - Workability,
  - Paste demand,
  - Initial strength
## REQUIREMENTS FOR STRUCTURAL LIGHTWEIGHT CONCRETE

<table>
<thead>
<tr>
<th></th>
<th>Air-dried, 28-day unit weight, max. [lb/ft(^3) (kg/m(^3))]</th>
<th>28-day splitting tensile strength, min. [psi (MPa)]</th>
<th>28-day compressive strength, min. [psi (MPa)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>All lightweight aggregates</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>110 (1760)</td>
<td>320 (2.2)</td>
<td>4000 (28)</td>
<td></td>
</tr>
<tr>
<td>105 (1680)</td>
<td>300 (2.1)</td>
<td>3000 (21)</td>
<td></td>
</tr>
<tr>
<td>100 (1600)</td>
<td>290 (2.0)</td>
<td>2500 (17)</td>
<td></td>
</tr>
<tr>
<td>Combination of normal sand and lightweight aggregate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>115 (1840)</td>
<td>330 (2.3)</td>
<td>4000 (28)</td>
<td></td>
</tr>
<tr>
<td>110 (1760)</td>
<td>310 (2.1)</td>
<td>3000 (21)</td>
<td></td>
</tr>
<tr>
<td>105 (1680)</td>
<td>300 (2.1)</td>
<td>2500 (17)</td>
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</tr>
</tbody>
</table>
### APPROXIMATE RELATIONSHIP BETWEEN AVERAGE COMpressive STRENGTH AND CEMENT CONTENT

<table>
<thead>
<tr>
<th>Compressive strength [psi (MPa)]</th>
<th>Cement Content [lb/yd³ (kg/m³)]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All-lightweight</td>
</tr>
<tr>
<td>2500 (17)</td>
<td>400-510 (240-305)</td>
</tr>
<tr>
<td>3000 (21)</td>
<td>440-560 (260-335)</td>
</tr>
<tr>
<td>4000 (28)</td>
<td>530-660 (320-395)</td>
</tr>
<tr>
<td>5000 (34)</td>
<td>630-750 (375-450)</td>
</tr>
<tr>
<td>6000 (41)</td>
<td>740-840 (440-500)</td>
</tr>
</tbody>
</table>
Fracture surface from concrete cylinders after splitting tension test

- Concrete made with lightweight aggregate
- Concrete made with rounded flint aggregate
Effect of replacing lightweight fines by natural sand

(a) Creep Strain $\times 10^{-6}$

(b) Drying Shrinkage Strain $\times 10^{-6}$

150 by 300 mm cylinders of 35 MPa concrete

- No. 1 - no replacement
- No. 2 - 1/3 replaced
- No. 3 - 2/3 replaced
- No. 4 - 100% replaced
Case Study

- **Aggregates Containing Pyrite**
- What is the maximum amount of pyrite which can be tolerated in aggregates to be used in concrete? Do you know of any clearly identified cases where pyrite was held responsible for major deterioration of concrete?