Aggregates for Concrete

Fine Aggregate
- Sand and/or crushed stone
- < 5 mm (0.2 in.)
- F.A. content usually 35% to 45% by mass or volume of total aggregate

Coarse Aggregate
- Gravel and crushed stone
- ≥ 5 mm (0.2 in.)
- Typically between 9.5 and 37.5 mm (3/8 and 1½ in.)

Rock and Mineral Constituents in Aggregates

1. Minerals
2. Igneous rocks
3. Metamorphic rocks
4. Sedimentary rocks

Rock and Mineral Constituents in Aggregates

1. Minerals
   - Silica
     - Quartz, Opal
   - Silicates
     - Feldspar, Clay
   - Carbonate
     - Calcite, Dolomite

Rock and Mineral Constituents in Aggregates

1. Minerals
   - Sulfate
     - Gypsum, Anhydrite
   - Iron sulfide
     - Pyrite, Marcasite
   - Iron oxide
     - Magnetite, Hematite
### Rock and Mineral Constituents in Aggregates

#### 2. Igneous rocks
- Granite
- Syenite
- Diorite
- Gabbro
- Peridotite
- Pegmatite
- Volcanic glass
- Felsite
- Basalt

#### 3. Sedimentary rocks
- Conglomerate
- Sandstone
- Claystone, siltstone, argillite, and shale
- Carbonates
- Chert

#### 4. Metamorphic rocks
- Marble
- Metaquartzite
- Slate
- Phyllite
- Schist
- Amphibolite
- Hornfels
- Gneiss
- Serpentinite

### Normal-Weight Aggregate

**ASTM C 33**

Most common aggregates
- Sand
- Gravel
- Crushed stone

Produce normal-weight concrete
2200 to 2400 kg/m³ (140 to 150 lb/ft³)

### Lightweight Aggregate (1)

**ASTM C 330**

Produce structural lightweight concrete
1350 to 1850 kg/m³ (90 to 120 lb/ft³)

- Expanded
  - Shale
  - Clay
  - Slate
  - Slag

### Lightweight Aggregate (2)

- Pumice
- Scoria
- Perlite
- Vermiculite
- Diatomite

Produce lightweight insulating concrete— 250 to 1450 kg/m³ (15 to 90 lb/ft³)
### Heavyweight Aggregate

**ASTM C 637, C 638 (Radiation Shielding)**
- Barite
- Limonite
- Magnetite
- Ilmenite
- Hematite
- Iron
- Steel punchings or shot

Produce high-density concrete up to 6400 kg/m$^3$ (400 lb/ft$^3$)

### Aggregate Characteristics and Tests (1)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abrasion resistance</td>
<td>ASTM C 121 (AASHTO T 901), ASTM C 535, ASTM C 779</td>
</tr>
<tr>
<td>Freeze-thaw resistance</td>
<td>ASTM C 666 (AASHTO T 161), ASTM C 662, AASHTO T 103</td>
</tr>
<tr>
<td>Sulfate resistance</td>
<td>ASTM C 88 (AASHTO T 104)</td>
</tr>
<tr>
<td>Particle shape and surface texture</td>
<td>ASTM C 295, ASTM D 3398</td>
</tr>
<tr>
<td>Fine aggregate degradation</td>
<td>ASTM C 117 (AASHTO T 711), ASTM C 136 (AASHTO T 721)</td>
</tr>
<tr>
<td>Void content</td>
<td>ASTM C 1252 (AASHTO T 304)</td>
</tr>
<tr>
<td>Bulk density</td>
<td>ASTM C 29 (AASHTO T 191)</td>
</tr>
</tbody>
</table>

### Aggregate Characteristics and Tests (2)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative density</td>
<td>ASTM C 127 (AASHTO T 851) — fine aggregate ASTM C 129 (AASHTO T 642) — coarse aggregate</td>
</tr>
<tr>
<td>Absorption and surface moisture</td>
<td>ASTM C 70, ASTM C 127 (AASHTO T 851), ASTM C 128 (AASHTO T 642), ASTM C 566 (AASHTO T 2250)</td>
</tr>
<tr>
<td>Strength</td>
<td>ASTM C 39 (AASHTO T 221), ASTM C 78 (AASHTO T 97)</td>
</tr>
<tr>
<td>Def. of constituents</td>
<td>ASTM C 123, ASTM C 294</td>
</tr>
<tr>
<td>Aggregate constituents</td>
<td>ASTM C 40 (AASHTO T 210), ASTM C 87 (AASHTO T 711), ASTM C 112 (AASHTO T 110), ASTM C 122 (AASHTO T 113), ASTM C 142 (AASHTO T 112), ASTM C 295</td>
</tr>
</tbody>
</table>

### Grading of Aggregate

Grading is the particle-size distribution of an aggregate as determined by a sieve analysis using wire mesh sieves with square openings.

**ASTM C 33**
- Fine aggregate—7 standard sieves with openings from 120 µm to 9.5 mm (No. 100 to 3/8 in.)
- Coarse aggregate—13 sieves with openings from 1.18 mm to 100 mm (0.046 in. to 4 in.)

### Range of Particle Sizes

### Fine-Aggregate Grading Limits

<table>
<thead>
<tr>
<th>Sieve size</th>
<th>Percent passing by mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5 mm</td>
<td>100</td>
</tr>
<tr>
<td>4.75 mm</td>
<td>95 to 100</td>
</tr>
<tr>
<td>2.36 mm</td>
<td>80 to 100</td>
</tr>
<tr>
<td>1.18 mm</td>
<td>50 to 65</td>
</tr>
<tr>
<td>900 µm</td>
<td>25 to 60</td>
</tr>
<tr>
<td>300 µm</td>
<td>5 to 30 (AASHTO 10 to 30)</td>
</tr>
<tr>
<td>150 µm</td>
<td>0 to 10 (AASHTO 2 to 10)</td>
</tr>
</tbody>
</table>

---

[Images of aggregate characteristics and grading are included here.]
Maximum Size vs. Nominal Maximum Size of Aggregate

- Maximum size — is the smallest sieve that all of a particular aggregate must pass through.
- Nominal maximum size — is the standard sieve opening immediately smaller than the smallest through which all of the aggregate must pass.
- The nominal maximum-size sieve may retain 5% to 15%

Nominal Maximum Size of Aggregate

Size should not exceed —

- 1/5 the narrowest dimension between sides of forms
- 3/4 clear spacing between rebars and between rebars and the form
- 1/3 depth of slabs

Coarse Aggregate Grading

<table>
<thead>
<tr>
<th>Size No. 57</th>
<th>25 to 4.75 mm (1 in. to No. 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sieve size</td>
<td>Percent passing by mass</td>
</tr>
<tr>
<td>37.5 mm (1½ in.)</td>
<td>100</td>
</tr>
<tr>
<td>25.0 mm (1 in.)</td>
<td>90 to 100</td>
</tr>
<tr>
<td>12.5 mm (1/2 in.)</td>
<td>25 to 60</td>
</tr>
<tr>
<td>6.35 mm (No. 6)</td>
<td>15 to 10</td>
</tr>
<tr>
<td>1.18 mm (No. 8)</td>
<td>5 to 5</td>
</tr>
</tbody>
</table>

Grading Limits

Reduction of Voids

Dispersion of Aggregates
Fineness Modulus (FM)

- Obtained by adding the sum of the cumulative percentages by mass of a sample aggregate retained on each of a specified series of sieves and dividing the sum by 100.
- The specified sieves are: 150 µm (No. 100), 300 µm (No. 50), 600 µm (No. 30), 1.18 mm (No. 16), 2.36 mm (No. 8), 4.75 mm (No. 4), 9.5 mm (3/8 in.), 19.0 mm (3/4 in.), 37.5 mm (1½ in.), 75 mm (3 in.), and 150 mm (6 in.).

<table>
<thead>
<tr>
<th>Sieve size</th>
<th>Percentage of individual fraction retained, by mass</th>
<th>Percentage passing by mass</th>
<th>Cumulative percentage retained, by mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.5 mm (3/32 in.)</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>4.75 mm (No. 4)</td>
<td>2</td>
<td>98</td>
<td>2</td>
</tr>
<tr>
<td>2.36 mm (No. 8)</td>
<td>13</td>
<td>87</td>
<td>15</td>
</tr>
<tr>
<td>1.18 mm (No. 16)</td>
<td>20</td>
<td>80</td>
<td>35</td>
</tr>
<tr>
<td>600 µm (No. 30)</td>
<td>20</td>
<td>80</td>
<td>55</td>
</tr>
<tr>
<td>300 µm (No. 50)</td>
<td>24</td>
<td>76</td>
<td>79</td>
</tr>
<tr>
<td>150 µm (No. 100)</td>
<td>18</td>
<td>82</td>
<td>97</td>
</tr>
<tr>
<td>Pan</td>
<td>3</td>
<td>0</td>
<td>—</td>
</tr>
</tbody>
</table>

Total 100 0 283

Fineness modulus = 283 ÷ 100 = 2.83
**Moisture Conditions**

- **State**
  - None
  - Less than potential absorption
  - Equal to potential absorption
  - Greater than absorption

**Bulking of Sand**

- **Figure**: Graph showing the percent increase in weight for dry and saturated sand with respect to moisture added.

**D-Cracking**

**Drying Shrinkage**

**Harmful Materials (1)**

<table>
<thead>
<tr>
<th>Substances</th>
<th>Effect on concrete</th>
<th>Test designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic impurities</td>
<td>Affects setting and hardening, may cause deterioration</td>
<td>ASTM C 40 (AASHTO T 21)</td>
</tr>
<tr>
<td>Materials finer than the 75-µm (No. 200) sieve</td>
<td>Affects bond, increases water requirement</td>
<td>ASTM C 67 (AASHTO T 71)</td>
</tr>
<tr>
<td>Coal, lignite, or other lightweight materials</td>
<td>Affects durability, may cause stains and popouts</td>
<td>ASTM C 117 (AASHTO T 11)</td>
</tr>
<tr>
<td>Soft particles</td>
<td>Affects durability</td>
<td>ASTM C 235</td>
</tr>
</tbody>
</table>
## Harmful Materials (2)

<table>
<thead>
<tr>
<th>Substances</th>
<th>Effect on concrete</th>
<th>Test designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay lumps and fragile particles</td>
<td>Affects workability and durability, may cause popouts</td>
<td>ASTM C 412 (AASHTO T 113)</td>
</tr>
<tr>
<td>Chert of less than 2.40 relative density</td>
<td>Affects durability, may cause popouts</td>
<td>ASTM C 123 (AASHTO T 113)</td>
</tr>
<tr>
<td>Alkali-reactive aggregates</td>
<td>Causes abnormal expansion, map cracking, and popouts</td>
<td>ASTM C 227, C 299, C 296, C 342, C 586, C 1260, C 1293 (AASHTO T 303)</td>
</tr>
</tbody>
</table>

## Harmful Reactive Substances

### Alkali-silica reactive substances
- Siliceous Cherts
- Quartzes
- Certain siliceous limestones and dolomites
- Opaline shales
- Opal

### Alkali-carbonate reactive substances
- Calcitic dolomites
- Dolomitic limestones
- Fine-grained dolomites
- Certain siliceous limestones and dolomites
- Chalcedonic cherts
- Chalcedony
- Cristobalite
- Macics

## Popouts
- Visual Symptoms
  - Network of cracks
  - Closed or spalled joints
  - Relative displacements

## Iron Particles in Aggregates

## 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 Reaction (ASR)
- Visual Symptoms
  - Network of cracks
  - Closed or spalled joints
  - Relative displacements
Visual Symptoms (cont.)
- Fragments breaking out of the surface (popouts)

Mechanism
1. Alkali hydroxide + reactive silica gel $\rightarrow$ reaction product (alkali-silica gel)
2. Gel reaction product + moisture $\rightarrow$ expansion

Influencing Factors
- Reactive forms of silica in the aggregate,
- High-alkali (pH) pore solution
- Sufficient moisture

If one of these conditions is absent — ASR cannot occur.

Test Methods
- Mortar-Bar Method (ASTM 227)
- Chemical Method (ASTM C 289)
- Petrographic Examination (ASTM C 295)
- Rapid Mortar-Bar Test (ASTM C 1260 or AASHTO T 303)
- Concrete Prism Test (ASTM C 1293)

Controlling ASR
- Non-reactive aggregates
- Supplementary cementing materials or blended cements
- Limit alkali loading
- Lithium-based admixtures
- Limestone sweetening (~30% replacement of reactive aggregate with crushed limestone

Influencing factors
- Clay content, or insoluble residue content, in the range of 5% to 25%
- Calcite-to-dolomite ratio of approximately 1:1
- Increase in the dolomite volume
- Small size of the discrete dolomite crystals (rhombs) suspended in a clay matrix
**Aggregates for Concrete**

**Alkali-Carbonate Reaction**
- Test methods
  - Petrographic examination (ASTM C 206)
  - Rock cylinder method (ASTM C 586)
  - Concrete prism test (ASTM C 1105)

- Controlling ACR
  - Selective quarrying to avoid reactive aggregate
  - Blend aggregate according to Appendix in ASTM C 1105
  - Limit aggregate size to smallest practical

**Recycled-Concrete Aggregate**

**Handling and Storing Aggregates**

**Water Absorption**

- Water absorption in % by weight:
  - 142 μm to 4.75 mm
  - 4.75 mm to 9.5 mm
  - 9.5 mm to 16.0 mm
  - 16.0 mm to 33.0 mm
  - 33.0 mm to 50.0 mm
  - Aggregate size: Recycled, Natural, Lightweight
Aggregates for Concrete

Videos 1/6
- Aggregates
- Grading curves

Videos 2/6
- Void content
- Fineness modulus

Videos 3/6
- Gap graded aggregate
- Particle shape

Videos 4/6
- Unit Weight and Voids
- Specific Gravity

Videos 5/6
- Bulk Density (Unit Weight)
- Specific Gravity

Videos 6/6
- Handling and Storing Aggregates