5.1 Aggregate Sources

• Natural:
  - natural sand & gravel pits, river rock
  - quarries (crushed)

• Manufactured & recycled materials:
  - pulverized concrete & asphalt
  - steel mill slag
  - steel slugs
  - expanded shale
  - styrofoam
5.2 Geological Classifications

- Igneous
- Sedimentary
- Metamorphic

All three classes of rock are used successfully in CE applications.

Check physical, chemical, and mechanical properties, supplemented by mineralogical examination.

Historical performance in a similar design.
5.4 Aggregate Uses

- Under foundations and pavements
  - Stability
  - Drainage
- As fillers
  - Portland Cement Concrete
    - 60-75% of volume
    - 80-85% of weight
  - Hot Mix Asphalt
    - 80%-90% of volume
    - 90-96% of weight
Aggregate Mining

Quarry

Sand from river deposit
5.5 Aggregate Properties

- Shape and texture
- Soundness
- Toughness
- Absorption
- Specific gravity
- Strength and modulus
- Gradation
- Deleterious materials and cleanness
- Alkaline reactivity
- Affinity for asphalt

Superpave consensus properties
Typical source properties
Needed for PCC and HMA mix design
Particle Shape & Surface Texture

• Shape = angular, rounded, flaky, or elongated

• Flaky and elongated are bad because of easy breakage and difficulty compacting in thin asphalt layers

  ➢ High friction (angular, rough) for **strength & stability of asphalt**

  ➢ Low friction (rounded, smooth) for **workability of concrete**
Angular

Rounded

Flaky

Elongated

Flaky & Elongated

Angular

Rounded


Soundness & Durability

Resist weathering

- Water freezing in voids fractures & disintegrates aggregates
- Test method uses “salt solution” to simulate freezing

• Prepare sample
  - Minimum mass
  - Specified gradation

Soak 16 hrs – dry 4 hrs
Repeat cycle 5 times

Measure gradation

\[
Loss = \left( \frac{M_B - M_A}{M_B} \right) \times 100
\]
**Toughness & Abrasion Resistance**

- Resist **load** damage
  - During construction
  - Traffic loads

- LA abrasion test

**LA abrasion test procedure**

- Prepare sample
- Minimum mass original
- Specified gradation
- Charge drum w/ sample
- Steel spheres
- 500 revolutions
- Sieve

\[
\text{Loss} = \left( \frac{M_{\text{original}} - M_{\text{final}}}{M_{\text{original}}} \right) \times 100
\]
**Aggregate Moisture States**

- **Bone dry** – dried in oven to constant mass
  - $W_s$
  - Moisture content: $M = \frac{W_m - V_s}{W_s} \times 100$

- **Air dry** – moisture condition state undefined
  - $W_m$

- **Saturated surface dry** – moisture condition state undefined
  - $W_{SSD} = W_s + W_p$

- **Moist** – moisture condition state undefined
  - $W_m$

**Absorption**

- Absorption is the moisture content when the aggregates are in the SSD condition

- Free moisture is the moisture content in excess of the SSD condition.

**Percent free moisture** = $M - A$

- **Important for proportioning concrete**
  - Negative free moisture – aggregates will absorb water
  - Positive free moisture – aggregates will release water
Specific Gravity

The mass of a material divided by the mass of water whose volume is equal to the volume of the material at a specific temperature, or

\[
G = \frac{\text{Mass Solid}}{\text{Volume}} \div \frac{\text{Mass Water}}{\text{Volume}}
\]

- \( G = \frac{\rho}{\rho_w} \)
- \( \rho_w \) = density of water at specified temperature
- @ 4°C, \( \rho_w \) is:
  - 1000 kg/m\(^3\) = 1 g/ml = 1 g/cc
  - 62.4 lb/ft\(^3\) (remember to stay consistent with force and mass units for measurements and the issue of force and mass will go away as G is a ratio)
Effects of Voids

- Voids on the surface of aggregates create multiple definitions of specific gravity
  - Apparent
  - Bulk, Dry
  - Bulk, SSD
Apparent Specific Gravity

\[ G_{sa} = \frac{\text{Mass, oven dry agg}}{\text{Vol of agg}} \]

Functional definition

\[ \text{Apparent Sp. Gr.} = \frac{\text{Dry Weight}}{(\text{Volume Not Accessible to Water})\gamma_w} = \frac{W_s}{(V_s + V_i)\gamma_w} \]
**Bulk Specific Gravity, Dry**

**Surface Voids**

\[
G_{sb} = \frac{\text{Mass, oven dry}}{\text{Vol of agg. + surface voids}}
\]

**Functional definition**

**Bulk Stone**

**Vol. of water-perm. voids**

\[
\text{Bulk Dry Sp. Gr.} = \frac{\text{Dry Weight}}{(\text{Total Particle Volume})\gamma_w} = \frac{W_s}{(V_s + V_i + V_p)\gamma_w}
\]

**Bulk Specific Gravity, ssd**  
*(saturated surface dry)*

**Surface Voids**

Bulk, saturated surface dry Stone

**Functional definition**

Mass, SSD

\[
G_{s, b_{\text{ssd}}} = \frac{\text{Vol. of water-perm. voids}}{\text{Vol of agg. + surface voids}}
\]

**Bulk SSD Sp. Gr.**

\[
\text{Bulk SSD Sp. Gr.} = \frac{\text{SSD Weight}}{(\text{Total Particle Volume})\gamma_w} = \frac{W_s + W_p}{(V_s + V_i + V_p)\gamma_w}
\]

Used for concrete mix design
Effective Specific Gravity

\[ G_{se} = \frac{\text{Dry weight}}{(\text{Volume not accessible to asphalt}) \gamma_w} = \frac{W_s}{(V_s + V_c) \gamma_w} \]

where \( V_c \) is volume of voids not filled with asphalt cement.

Used for hot mix asphalt design.
Coarse Aggregate Specific Gravity by the Book

(ASTM C127)

Bulk Dry Sp. Gr. = \( \frac{A}{B - C} \)

Bulk SSD Sp. Gr. = \( \frac{B}{B - C} \)

Apparent Sp. Gr. = \( \frac{A}{A - C} \)

Absorption (%) = \( \frac{B - A}{A} \)(100)

where

\( A = \) dry weight
\( B = \) SSD weight
\( C = \) submerged weight

Measure dry weight
Fine Aggregate Specific Gravity by the Book
(ASTM C128)

Bulk Dry Sp. Gr. = \frac{A}{B + S - C}

Bulk SSD Sp. Gr. = \frac{S}{B + S - C}

Apparent Sp. Gr. = \frac{A}{B + A - C}

Absorption (%) = \frac{S - A}{A} (100)

where

A = dry weight
B = weight of the pycnometer filled with water
C = weight of the pycnometer filled with aggregate and water
S = saturated surface—dry weight of the sample
Bulk Unit Weight & Voids in Aggregates

• Previous treatment of specific gravity and unit weight were for aggregate particles.
• The voids considered were for the voids at the surface of the particles.
• Sometimes we need to know the mass or weight of aggregate required to fill a volume, e.g. the volume of coarse aggregate in a cubic yard of concrete.

**Bulk unit weight** is the weight of aggregate required to fill a “unit” volume. Typical units are cubic meters and cubic feet.
Procedure Aggregate Bulk Unit Weight

- **Loose**
  - Shovel dry aggregate into container
  - Limit drop < 2" above rim of container
  - Strike off aggregate level with top of container
  - Determine weight of aggregate in container, $W_S$
  - Compute unit weight

- **Compacted**
  - Shovel dry aggregate into container
    - Fill to 1/3 of volume
    - Rod 25 times
    - Repeat 3x to fill container
  - Strike off aggregate level with top of container
  - Determine weight of aggregate in container, $W_S$
  - Compute unit weight

Aggregate Gradation
Aggregate Sizes (Review)

- **Coarse** aggregate material retained on a sieve with 4.75 mm openings
- **Fine** aggregate material passing a sieve with 4.75 mm openings

**Traditional**
- Maximum aggregate size – the largest sieve size that allows all the aggregates to pass
- Nominal maximum aggregate size – the first sieve to retain some aggregate, generally less than 10%

**Superpave**
- Maximum aggregate size – one sieve size larger than the nominal maximum aggregate size
- Nominal maximum aggregate size – one sieve larger that the first sieve to retain more than 10% of the aggregate
Types of Gradation

Maximum Density Gradation: 0.45 Power Chart

High density gradation (Well Graded)
- has a good mix of all particle sizes which means the aggregates use most of the volume and less cement or asphalt is needed

One-size gradation (Uniform)
- all same size = nearly vertical curve

Gap-graded
- missing some sizes = nearly horizontal section of curve

Open-Graded
- missing small aggregates which fill in holes between larger ones
- lower part of curve is skewed toward large sizes
Types of Gradation on 0.45 Power Graph
This blend of aggregates results in the maximum weight of aggregates that can be placed in a container.

<table>
<thead>
<tr>
<th>Sieve</th>
<th>( P_i = 100\left(\frac{d_i}{D}\right)^{0.45} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 mm (1 in.)</td>
<td>100</td>
</tr>
<tr>
<td>19 mm (3/4 in.)</td>
<td>88</td>
</tr>
<tr>
<td>12.5 mm (1/2 in.)</td>
<td>73</td>
</tr>
<tr>
<td>9.5 mm (3/8 in.)</td>
<td>64</td>
</tr>
<tr>
<td>4.75 mm (No. 4)</td>
<td>47</td>
</tr>
<tr>
<td>2.36 mm (No. 8)</td>
<td>34</td>
</tr>
<tr>
<td>0.60 mm (No. 30)</td>
<td>19</td>
</tr>
<tr>
<td>0.30 mm (No. 50)</td>
<td>14</td>
</tr>
<tr>
<td>0.075 mm (No. 200)</td>
<td>7.3</td>
</tr>
</tbody>
</table>
**ASTM Gradation Specifications**

Control points – the range of allowable percent passing for each “control” sieve

Concrete coarse aggregates
- Size specified by “gradation number”

\[ N_{xy} \]

N gradation size number
small N = large aggregates
range 1 to 8

\[ xy = \text{modifiers for the gradation size.} \]

Concrete fine aggregate control points

<table>
<thead>
<tr>
<th>Sieve</th>
<th>Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.5 mm (3/8)</td>
<td>100</td>
</tr>
<tr>
<td>4.75 mm (No. 4)</td>
<td>95–100</td>
</tr>
<tr>
<td>2.36 mm (No. 8)</td>
<td>80–100</td>
</tr>
<tr>
<td>1.18 mm (No. 16)</td>
<td>50–85</td>
</tr>
<tr>
<td>0.60 mm (No. 30)</td>
<td>25–60</td>
</tr>
<tr>
<td>0.30 mm (No. 50)</td>
<td>10–30</td>
</tr>
<tr>
<td>0.15 mm (No. 100)</td>
<td>2–10</td>
</tr>
</tbody>
</table>
# AASHTO Gradation Specifications

## For Superpave (hot mix asphalt)

<table>
<thead>
<tr>
<th>Sieve Size, mm (in.)</th>
<th>Nominal Maximum Size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>37.5</td>
<td>25</td>
</tr>
<tr>
<td>50 (2 in.)</td>
<td>100</td>
</tr>
<tr>
<td>37.5 (1 1/2 in.)</td>
<td>90–100</td>
</tr>
<tr>
<td>25 (1 in.)</td>
<td>90 max</td>
</tr>
<tr>
<td>19 (3/4 in.)</td>
<td>—</td>
</tr>
<tr>
<td>12.5 (1/2 in.)</td>
<td>—</td>
</tr>
<tr>
<td>9.5 (3/8 in.)</td>
<td>—</td>
</tr>
<tr>
<td>4.75 (No. 4)</td>
<td>—</td>
</tr>
<tr>
<td>2.36 (No. 8)</td>
<td>15–41</td>
</tr>
<tr>
<td>1.18 (No. 16)</td>
<td>—</td>
</tr>
<tr>
<td>0.075 (No. 200)</td>
<td>0.0–6.0</td>
</tr>
</tbody>
</table>

**Mix types – identified by nominal max agg size**

**Five control points per mix type**
Fineness Modulus

• a measure of the gradation fineness

• used for
  ➢ Concrete mix design
  ➢ Daily quality control for concrete mix design

\[
FM = \frac{\sum R_i}{100}
\]

• \( R_i \) = cumulative percent retained on sieve sequence

• #100, 50, 30, 16, 8, 4, and 3/8" sieves

• range of 2.3 - 3.1 for fine aggregate types larger FM being coarser aggregate
Blending Aggregate Gradations

Stockpile aggregates with limited size range controls segregation – determine blend of stockpiles to meet required control points.

Trial & Error Method

\[ P_i = A_i a + B_i b + C_i c \ldots \]

For sieve size \( i \),
\[ P_i = \text{percent in the blend that passes sieve size } i \]
\[ A_i, B_i, C_i \ldots = \text{percent of each stockpile in the blend} \]
\[ a, b, c \ldots = \text{percent of stockpile A, B, C that passes sieve size } i \]

• Use spreadsheet program for trial and error calculations
Properties of Blended Aggregates

- Blended specific gravity:

\[
G = \frac{1}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + \frac{P_3}{G_3} + \ldots}
\]

- Other properties weighted average:

\[
X = \frac{p_1 X_1 + p_2 X_2 + p_3 X_3 + \ldots}{\sum \frac{x_i P_i p_i}{P_i p_i}}
\]
Alkali-Aggregate Reactivity

- Silica in some agg. reacts with the alkalis (Na$_2$O, K$_2$O) in Portland Cement (especially in warm, humid climates)
  - excessive expansion
  - cracking
  - popouts

- Carbonates in aggregate can also react to a lesser extent

- Minimizing reactivity if a reactive aggregate must be used
  - Type II cement – minimizes alkali content of P.C.
  - Keep concrete as dry as possible
  - Fly Ash (Pozzolans) reduce alkali reactivity (not too much)
  - Sweetening – add crushed limestone to the aggregate
Alkali-Aggregate Reactivity

• Tests
  ➢ ASTM C227 – tests expansion potential of cement-agg. combination
    ▪ expansion of mortar bar at specific temp. & humidity
  ➢ ASTM C289 – reactive silicates in agg.
  ➢ ASTM C586 – reactive carbonates in agg.
Asphalt Affinity

• Affects the bond between asphalt binder and aggregate

• Asphalt Stripping (moisture induced damage)
  - water causes asphalt film to separate from agg.
    - reduces durability of Asphalt Concrete (A.C.)
  - Hydrophilic (water-loving)
    - silicates – acidic, negative surface charge
    - more susceptible to stripping
  - Hydrophobic (water-hating)
    - limestone – basic, positive surface charge
    - less susceptible to stripping
  - stripping is also affected by porosity, absorption, coatings, etc.

• Testing
  - ASTM D1664 & D3625 - submerge AC in tepid or boiling water
  - ASTM D1075 – freeze-thaw cycles
5.6 Handling Aggregates

• Minimize **segregation, degradation, and contamination**

• Avoiding Segregation
  - separation into components with similar characteristics
  - any movement of aggregates promotes segregation
    ▪ small drop height
    ▪ build stockpiles in multiple cones
  - fractionalize stockpiles
    ▪ close to single size aggregates in each stockpile
    ▪ batch separately

• Avoiding degradation
  - small drop height
Sampling Aggregates

Random and representative of entire stockpile

- sample from entire width of conveyor belts at several locations
- sample from top, middle, and bottom of stockpile at several locations around stockpile diameter
- use larger sample for testing larger max. size

• Sample splitting or quartering
  - to reduce sample size from large stockpile to small 1-5 kg sample