CONCRETE AGGREGATES
Portland Cement Concrete

In concrete mixtures the proportions of cement paste & aggregates is controlled by the following factors:

1) Suitable workability & placeability of fresh mass.
2) Adequate strength & durability of hardened product.
3) Minimum cost of the final product
The aggregate occupies ~70-75% of the volume of concrete, so its quality is of great importance.

Aggregates may affect the following properties of concrete:
- Strength
- Durability
- Structural Performance
- Economy
Aggregates have 3 main functions in concrete:

1) To provide a mass of particles which are suitable to resist the action of applied loads & show better durability than cement paste alone.

2) To provide a relatively cheap filler for the cementing material.

3) To reduce volume changes resulting from setting & hardening process & from moisture changes during drying.
The properties of concrete are affected by the properties of aggregate:

1. The mineral character of aggregate affects the strength, durability, elasticity of concrete.
2. The surface characteristics of aggregate affects the workability of fresh mass & the bond between the aggregate & cement paste in hardened concrete. If it is rough, workability decreases & bond increases.
3. The grading of aggregate affects the workability, density & economy.
4. The amount of aggregate in unit volume of concrete
Higher aggregate amount/unit volume of concrete

- Results in less volume changes during setting & hardening or moisture changes. (increase in volume stability)
- Increase in strength & durability
- Decrease in cost

It is a common practice to use as much aggregate as possible in concrete
However, all aggregates are not inert:

- **The physical action**: swelling & shrinkage
- **The chemical action**: alkali-agg. Reaction
- **The thermal action**: expansion & contraction

Like the other ingredients of concrete, aggregates must also be chosen with certain care to end up with a satisfactory concrete.
CLASSIFICATION OF AGGREGATES

According to Source:

1. **Natural aggregate**: Native deposits with no change in their natural state other than washing, crushing, & grading. (sand, gravel, crush stone)

2. **Artificial aggregates**: They are obtained either as a by-product or by a special manufacturing process such as heating. (blast furnace slag, expanded perlite)
According to Petrological Characteristics:

1. **Igneous rocks**: are formed by solidification of molten lava. (granite)
2. **Sedimentary rocks**: are obtained by deposition of weathered & transported pre-existing rocks or solutions. (limestone)
3. **Metamorphic rocks**: are formed under high heat & pressure alteration of either igneous & sedimentary rocks (marble).
According to Unit Weight:

1. **Heavy weight agg.**: Hematite, Magnetite
   Specific Gravity, $G_s > 2.8$

2. **Normal weight agg.**: Gravel, sand, crushed stone
   $2.8 < G_s < 2.4$

3. **Light weight agg.**: Expanded perlite, burned clay
   $G_s < 2.4$
Normal-Weight Aggregate

**ASTM C 33**

**Most common aggregates**
- Sand
- Gravel
- Crushed stone

Produce normal-weight concrete 2200 to 2400 kg/m$^3$
Lightweight Aggregate (1)

ASTM C 330

Expanded
- Shale
- Clay
- Slate
- Slag

Produce structural lightweight concrete
1350 to 1850 kg/m³
Lightweight Aggregate (2)

- Pumice
- Scoria
- Perlite
- Vermiculite
- Diatomite

Produce lightweight insulating concrete—250 to 1450 kg/m³
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/m³
According to Size:

1. **Fine aggregate**: \( d \leq 5 \text{ mm} \)
2. **Coarse aggregate**: \( d > 5 \text{ mm} \)

Aggregates containing a whole range of particles are named as “all-in” or “pit-run” aggregates.
Fine Aggregate

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

- Gravel and crushed stone
- $\geq 5$ mm
- Typically between 9.5 and 37.5 mm
## Aggregate Characteristics and Tests

<table>
<thead>
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<th>Characteristic</th>
<th>Test</th>
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<td>Freeze-thaw resistance</td>
<td>ASTM C 666 (AASHTO T 161), ASTM C 682, AASHTO T 103</td>
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<td>Sulfate resistance</td>
<td>ASTM C 88 (AASHTO T 104)</td>
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<td>Particle shape and surface texture</td>
<td>ASTM C 295, ASTM D 3398</td>
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<td>Grading</td>
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<td>Fine aggregate degradation</td>
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<td>Void content</td>
<td>ASTM C 1252 (AASHTO T 304)</td>
</tr>
<tr>
<td>Bulk density</td>
<td>ASTM C 29 (AASHTO T 19)</td>
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</table>
## Aggregate Characteristics and Tests

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Test</th>
</tr>
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<tbody>
<tr>
<td>Relative density</td>
<td>ASTM C 127 (AASHTO T 85)—fine aggregate</td>
</tr>
<tr>
<td></td>
<td>ASTM C 128 (AASHTO T 84)—coarse aggregate</td>
</tr>
<tr>
<td>Absorption and surface moisture</td>
<td>ASTM C 70, ASTM C 127 (AASHTO T 85), ASTM C 128 (AASHTO T 84), ASTM C 566 (AASHTO T 255)</td>
</tr>
<tr>
<td>Strength</td>
<td>ASTM C 39 (AASHTO T 22), ASTM C 78 (AASHTO T 97)</td>
</tr>
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<td>Def. of constituents</td>
<td>ASTM C 125, ASTM C 294</td>
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<tr>
<td>Aggregate constituents</td>
<td>ASTM C 40 (AASHTO T 21), ASTM C 87 (AASHTO T 71), ASTM C 117 (AASHTO T 11), ASTM C 123 (AASHTO T 113), ASTM C 142 (AASHTO T 112), ASTM C 295</td>
</tr>
</tbody>
</table>
SAMPLING

- Tests in the lab is carried out on the samples. So, certain precautions in obtaining a sample must be taken to obtain “representative sample”.

- The main sample is made up of portions drawn from different points. The minimum number of portions, increment, is 10 & they should add up to a weight not less than:
<table>
<thead>
<tr>
<th>Max. Particle Size</th>
<th>Min. Weight of Sample (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 25 mm</td>
<td>50</td>
</tr>
<tr>
<td>25-5 mm</td>
<td>25</td>
</tr>
<tr>
<td>&lt; 5 mm</td>
<td>13</td>
</tr>
</tbody>
</table>

* Details are provided in ASTM D 75 & TS 707
Methods of reducing the amount of sample:

1) **Quartering**:
   - Mix the field sample over three times on a level surface.
   - Shovel the sample to a conical shape.
   - Press the apex & flatten the conical shape.
   - Divide them into four equal quarters.
   - Discard two diagonally opposite quarters & use the remainder.
   - If this remainder is still too large follow the same path.
2) **Splitting:**

- Use the “sample splitter” to divide the aggregate sample into two.
- Sample splitter is a box with an even number of chutes alternately discharging to two sides.
- The width of each chute should be greater than 1.5 times the size of the largest aggregate size.
- If the remainder is still too large follow the same path.
Riffle Sample Splitter

Riffle Bucket and Separate Feed Chute Stand
In addition to petrological character, the external characteristics, i.e. The shape & surface texture of aggregates are of importance.

**Particle Shape**

- **Rounded**: Completely water worn & fully shaped by attrition. (River Gravel)
- **Irregular**: Partly shaped by attrition so it contains some rounded edges. (Land Gravel)
- **Angular**: Has sharp corners, show little evidence of wear. (Crushed Stone)

- **Flaky**: Thickness is relatively small with respect to two other dimensions. (Laminated Rocks)

- **Elongated**: Have lengths considerably larger than two other dimensions.
Rounded aggregates are suitable to use in concrete because flaky & elongated particles reduce workability, increase water demand & reduce strength.

In the case of angular particles, the bond between agg. Particles is higher due to interlocking but due to higher surface area, angular particles increase water demand & therefore reduce workability. As a result, for the same cement content & same workability rounded agg. Give higher strength.
Surface Texture

- This affects the bond to the cement paste & also influences the water demand of the mix.

  - **Smooth:** Bond b/w cement paste & agg is weak.
  - **Rough:** Bond b/w cement paste & agg. is strong.

- Surface texture is not a very important property from compressive strength point of view but agg. Having rough surface texture perform better under flexural & tensile stresses.
Grading of Aggregates

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 150 μm to 9.5 mm

Coarse aggregate—13 sieves with openings from 1.18 mm to 100 mm
<table>
<thead>
<tr>
<th>TS 706</th>
<th></th>
<th>ASTM C 33</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>125 mm</td>
<td>125 mm</td>
</tr>
<tr>
<td></td>
<td>90 mm</td>
<td>100 mm</td>
</tr>
<tr>
<td></td>
<td>63 mm</td>
<td>90 mm</td>
</tr>
<tr>
<td></td>
<td>31.5 mm</td>
<td>75 mm (3&quot;)</td>
</tr>
<tr>
<td></td>
<td>16 mm</td>
<td>63 mm</td>
</tr>
<tr>
<td></td>
<td>8 mm</td>
<td>50 mm (2&quot;)</td>
</tr>
<tr>
<td></td>
<td>4 mm</td>
<td>37.5 mm (1-1/2&quot;)</td>
</tr>
<tr>
<td></td>
<td>2 mm</td>
<td>25 mm (1&quot;)</td>
</tr>
<tr>
<td></td>
<td>1 mm</td>
<td>12.5 mm (1/2&quot;)</td>
</tr>
<tr>
<td></td>
<td>0.5 mm</td>
<td>9.5 mm (3/8&quot;)</td>
</tr>
<tr>
<td></td>
<td>0.25 mm</td>
<td>4.75 mm (#4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.38 mm (#8)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.19 mm (#16)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.595 mm (#30)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.297 mm (#50)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.149 mm (#100)</td>
</tr>
</tbody>
</table>
- The material is sieved through a series of sieves that are placed one above the other in order of size with the largest sieve at the top.
- Dry agg. is sieved to prevent lumps.
The particle size distribution in an aggregate sample is known as “gradation”.

Strength development of concrete depends on degree of compaction & workability together with many other factors. So, a satisfactory concrete should be compacted to max density with a reasonable work.

On the other hand, in good concrete all aggregate particles must be covered by cement paste.
The grading of aggregate must be so that the workability, density & volume stability of concrete may not be adversely affected by it.

- Fine Particles → higher cost
- Coarse Particles → less workability

- A reasonable combination of fine & coarse aggregate must be used. This can be expressed by maximum density or minimum voids concept.
A cube with a dimension of 2Dx2Dx2D is filled with spheres of diameter D

\[ V_{\text{cube}} = (2D)^3 = 8D^3 \]

\[ 1V_{\text{sphere}} = \left(\frac{4}{3}\right)\pi \left(\frac{D}{2}\right)^3 \approx 0.52D^3 \]

\[ 8 \times V_{\text{sp}} = 8 \times 0.52D^3 \approx 4.2D^3 \] (solid volume)

\[ \text{Void Volume} = 8D^3 - 4.2D^3 = 3.8D^3 \]
Same cube filled with spheres of diameter D/4.

Solid Volume = \( 8 \times 8 \times 8 \times \frac{4}{3} \pi (\frac{D}{8})^3 \approx 4.2D^3 \)

# of spheres

Void Volume \( \approx 3.8D^3 \)

Size of agg. is not important. If an agg. with the same size is used amount of void volume will not change. So, to overcome this different sizes of particles should be used.

However, you should not forget that as agg. get finer, the surface area increases.

More surface area = more paste & water requirement
Reduction of Voids
Factors Affecting a Desired Grading

1) *Surface area of the Aggregate*
   The lower the surface area, the lesser is the paste requirement.

2) *Relative Volume of Agg. in Concrete*
   Higher volume of agg.:
   - economical
   - higher strength, higher volume stability
   - less workability!
3) **Workability**: The ease with which a concrete mixture can be mixed, transported, placed in the form & compacted without any segregation. Workability increases as the amount of paste b/w fine agg. part increases. It also increases as the amount of mortar b/w coarse agg. particles increases.

4) **Segregation**: Separation of the particles with different sizes & specific gravities. The requirements of workability and absence of segregation tend to oppose each other. Thus, these two factors are interrelated. The major of these is workability which, in turn, affects most of the properties of concrete.
Determination of the Grading of Aggregate

- There are two different methods for determining the agg. grading:
  - Fineness Modulus (FM)
  - Granulometry

- The grading of the particles in an agg. sample is performed by “sieve analysis”. The sieve analysis is conducted by the use of “standard test sieves”. Test sieves have square openings & their designation correspond to the sizes of those openings.
1) **Fineness Modulus (FM):**

FM is a single figure which is the sum of cumulative % retained on a series of sieves having a clear opening half that of the preceding one. Usually determined for fine agg.

\[
FM = \frac{\sum (\% \text{ cumulative retained on each sieve})}{100}
\]

- **For Fine Agg.** → #4, #8, #16, #30, #50, #100
  
  \{practical limits → 2-3.5\}

- **For Coarse Agg.** → Fine set + 3/8” + 3/4” + 1 ½” + 3”
  
  \{practical limits → 5.5-8.0\}

- The FM of the mixture of two or more agg. is the weighted average of the FM of that two more agg.
Ex: A 500gr sample of a Fine Agg. was sieved. Determine FM?

<table>
<thead>
<tr>
<th>Sieve</th>
<th>Amount Retained on (gr)</th>
<th>Amount Retained on (%)</th>
<th>% Cumulative Retained on</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/8&quot;</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>#4</td>
<td>30</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>#8</td>
<td>80</td>
<td>16</td>
<td>22</td>
</tr>
<tr>
<td>#16</td>
<td>100</td>
<td>20</td>
<td>42</td>
</tr>
<tr>
<td>#30</td>
<td>120</td>
<td>24</td>
<td>66</td>
</tr>
<tr>
<td>#50</td>
<td>125</td>
<td>25</td>
<td>91</td>
</tr>
<tr>
<td>#100</td>
<td>35</td>
<td>7</td>
<td>98</td>
</tr>
<tr>
<td>Pan</td>
<td>10</td>
<td>2</td>
<td>100</td>
</tr>
</tbody>
</table>

FM = \( \frac{6+22+42+66+91+98}{100} = 3.25 \)

- Pan is not included.
- Only standard sieves are included, if we were given #10 sieve you should not use that in calculations
Ex: Determine the FM for the 1000gr sample of Coarse Agg.

<table>
<thead>
<tr>
<th>Sieve</th>
<th>Amount Retained on (gr)</th>
<th>Amount Retained on (%)</th>
<th>% Cumulative Retained on</th>
</tr>
</thead>
<tbody>
<tr>
<td>2&quot;</td>
<td>70</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>1 1/2&quot;</td>
<td>230</td>
<td>23</td>
<td>30</td>
</tr>
<tr>
<td>3/4&quot;</td>
<td>350</td>
<td>35</td>
<td>65</td>
</tr>
<tr>
<td>3/8&quot;</td>
<td>250</td>
<td>25</td>
<td>90</td>
</tr>
<tr>
<td>#4</td>
<td>100</td>
<td>10</td>
<td>100</td>
</tr>
</tbody>
</table>

\[
\text{FM} = \frac{\text{Fine Set} + 3/8" + 3/4" + 1 1/2" + 3"}{100} = 7.85
\]
Ex: The fine agg. with the FM=3.25 and the coarse agg. with the FM=7.85 are available. Combine them in such a way that the FM becomes 6.8

\[
X : \text{Volume of Fine agg.}.
\]

\[
\frac{3.25X + 7.85(100-X)}{100} = 6.8 \quad \rightarrow \quad X = 23
\]

*23% of fine agg. and 77% of coarse agg. should be mixed.*
2) **Granulometry:**

- The FM is not always representative of the gradation of an aggregate sample and various gradation curves may give the same FM.

- In the gradation curves, the vertical axis represents the % passing & the horizontal axis represents the sieve opening.

- A logarithmic scale is used for horizontal axis.
A good aggregate gradation for a particular concrete is the one that leads to a workable, dense & uniform concrete, without any segregation of particles.
There is no single “ideal” grading curve. Instead, standards provide upper & lower limits.
<table>
<thead>
<tr>
<th>ASTM Requirement for FA</th>
<th>% Passing</th>
</tr>
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<tbody>
<tr>
<td>Sieve</td>
<td></td>
</tr>
<tr>
<td>3/8&quot;</td>
<td>100</td>
</tr>
<tr>
<td>#4</td>
<td>95-100</td>
</tr>
<tr>
<td>#8</td>
<td>80-100</td>
</tr>
<tr>
<td>#16</td>
<td>50-85</td>
</tr>
<tr>
<td>#30</td>
<td>25-60</td>
</tr>
<tr>
<td>#50</td>
<td>10-30</td>
</tr>
<tr>
<td>#100</td>
<td>2-10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ASTM Requirement for CA</th>
<th>% Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sieve</td>
<td>1 1/2&quot;- #4</td>
</tr>
<tr>
<td>3&quot;</td>
<td>–</td>
</tr>
<tr>
<td>2 1/2&quot;</td>
<td>–</td>
</tr>
<tr>
<td>2&quot;</td>
<td>100</td>
</tr>
<tr>
<td>1 1/2&quot;</td>
<td>95-100</td>
</tr>
<tr>
<td>1&quot;</td>
<td>–</td>
</tr>
<tr>
<td>3/4&quot;</td>
<td>35-70</td>
</tr>
<tr>
<td>1/2&quot;</td>
<td>–</td>
</tr>
<tr>
<td>3/8&quot;</td>
<td>10-30</td>
</tr>
<tr>
<td>#4</td>
<td>0-5</td>
</tr>
<tr>
<td>#6</td>
<td>–</td>
</tr>
</tbody>
</table>

* Changes with max aggregate size
* Gap Graded agg.  
No particles between #30 & #16

* Single sized agg.  
Most of the particles are between #30 & #16

---

(a) Continuous  
Uniform  
Gap

(b) Increasing cumulative percentage passing  
Increasing particle size/sieve opening
Handling & Stockpiling of Agg.

- Handling and stockpiling of coarse aggregates may easily lead to segregation. To overcome this segregation, CA are handled and stockpiled in different size fractions, such as 5-15\text{mm}, 15-25\text{mm}, and these aggregates are mixed in specified proportions only when fed into the mixer.

Segregation: separation of particles having different sizes.
Aggregate Stockpiling
Stock Pile Segregation
Aggregate Proportions
Specific gravity is the ratio of the weight of a unit volume of material to the weight of the same volume of water at 20º to 25ºC.

\[ G = \frac{Wt}{Wt_w} = \frac{\gamma}{\gamma_{H2O}} \]

where:
- \( G \) = specific gravity
- \( Wt \) = weight of material
- \( V \) = volume
- \( Wt_w \) = weight of water
SPECIFIC GRAVITY OF AGG.

\[ \text{Sp.Gr.} = \frac{\text{Weight of Agg.} \ (W_A)}{\text{Weight of an equal volume of water} \ (V_A \times \rho_w)} = \frac{W_A}{V_A \times \rho_w} = \frac{\rho_A}{\rho_w} \]

- Sp.Gr. is used in certain computations for concrete mix design or control work, such as, absolute volume of aggregate in concrete. **It is not a measure of the quality of aggregate.**
Volume of Aggregate?
MOISTURE CONDITION OF AGGREGATES

Four Moisture Conditions

- OD (Original Dry)
- Air Dry
- SSD (Saturated Surface Dry)
- Wet

Absorption vs. Surface Moisture Content

Total Moisture Content
Apparent Specific Gravity

\[ G_a = \frac{W_{OD}}{(V_s + V_{ip}) \gamma_{H_2O}} \]

where:

- \( G_a \) = apparent specific gravity of solids (aggregate)
- \( W_{OD} \) = oven dry weight of aggregate
- \( V_s \) = volume of solids
- \( V_{ip} \) = volume of impermeable pores
- \( \gamma_w \) = unit weight of water (1 g/ml)
**Bulk Specific Gravity**

\[
G_{b(ssd)} = \frac{W_{ssd}}{(V_s + V_{ip} + V_{pp}) \cdot \gamma_{H_2O}}
\]

\[
G_{b(od)} = \frac{W_{OD}}{(V_s + V_{ip} + V_{pp}) \cdot \gamma_{H_2O}}
\]

- \(W_{t_{OD}}\) = oven dry weight of aggregate
- \(V_s\) = volume of solids
- \(V_{ip}\) = volume of impermeable pores
- \(V_{pp}\) = volume of water permeable pores
- \(\gamma_w\) = unit weight of water (1 g/ml)
Determination of Sp. Gr. of Aggregates

Archimedes Principle

\[ G_a = \frac{W_{OD}}{W_{OD} - W_{SW}} \]
1) **Coarse Agg.**

- Aggs are oven dried at 105±5°C overnight & the weight is measured as (A)→oven dry weight
- Aggs are soaked in water for 24 hours
- Aggs are taken out from water & rolled in a large absorbent cloth, until all visible films of water are removed & then weighed (B)→saturated surface dry weight
- Aggs are then weighed in water (C)
% Absorption = \frac{B-A}{A} \times 100

Apparent Specific Gravity = \frac{A}{A-C}

Dry Bulk Specific Gravity = \frac{A}{B-C}

SSD Bulk Sp.Gr. = \frac{B}{B-C}
2) **Fine Agg.**

- Aggs are oven dried to constant weight at 105±5°C. Measure the dry weight as (A)
- Soak them in water for 24hrs
- Stir the sample to bring it to SSD condition. Use the Cone Test for Surface Moisture Determination (Weight as S)
- Fill the aggs in SSD condition into a pycnometer (to a calibrated level) and weight it, (water+pyconometer+agg) (C)
- Fill the pyconometer with water only (to a calibrated level) and weight it (water+pyconometer) (B)
Specific Gravity Test for Sand

| SSD Aggregate (S) | OD Aggregate (A) | Container with H₂O (B) | Container with H₂O and with Aggregate (C) |
% Absorption = \frac{S-A}{A} \times 100

Apparent Specific Gravity = \frac{A}{B+A-C}

Dry Bulk Specific Gravity = \frac{A}{B+S-C}

SSD Bulk Sp.Gr. = \frac{S}{B+S-C}
BULK DENSITY (UNIT WEIGHT)

- The weight of aggregate that will fill a unit volume. Unit weight depends on:
  1. Size distribution
  2. Shape of particles
  3. Compaction
  4. Moisture content → especially for fine agg. at an optimum water content packing efficiency increases.
Unit Weight

Loose

Agg. are dropped to a container at a specified height ($\rho_l = W_1/V$)

Compacted

Agg. are compacted in three layers, each layer is rodded 25 times ($\rho_c = W_2/V$)
MOISTURE CONDITION OF AGGREGATES

State

- Ovendry
  - None

- Air dry
  - Less than potential absorption

- Saturated, surface dry
  - Equal to potential absorption

- Damp or wet
  - Greater than absorption

Total moisture
SIGNIFICANCE OF DETERMINING THE MOISTURE STATE & ABSORPTION CAPACITY

- SSD Condition $\rightarrow$ Equilibrium for Moisture Condition
  1. If total moisture content $= 0$ $\rightarrow$ Agg. is bone-dry (oven dry)
  2. If total moisture content $< \text{absorption capacity}$ $\rightarrow$ It can absorb water
  3. If total moisture content $> \text{absorption capacity}$ $\rightarrow$ There is free water on the surface of agg.
- Mix Design Calculations are Based on Aggs in SSD Condition. Therefore, for aggs not being in that condition corrections have to be made
- w/c ratio $\rightarrow$ w should be “free water”
Porosity or permeability of aggregates and its absorption may affect the following factors:

- The bond between aggregate and cement paste
- Resistance to freezing & thawing of concrete
- Chemical stability
- Resistance to abrasion
- Specific gravity
- Yield of concrete for a given weight of agg.
\[ \% \text{ Absorption} = \frac{W_{SSD} - W_{Dry}}{W_{Dry}} \quad \text{(Absorption Capacity)} \]

\[ W_{Dry} = \frac{W_{SSD}}{1 + \text{Abs. Cap.}} \]

Moisture Content (m) = \[ \frac{W_{agg} - W_{Dry}}{W_{Dry}} \]

\[ W_{agg} = W_{Dry} (1 + m) \]
Dry Bulk Sp.Gr. = \frac{SSD Bulk Sp.Gr.}{1+ \text{Abs. Cap.}}

Wet Bulk Sp.Gr. = \text{Dry Bulk Sp.Gr.} \times (1 + \text{total moisture content})

% Voids = \left( 1 - \frac{Y_{agg}}{G_s \times Y_w} \right) \times 100
DELETERIOUS MATERIALS IN AGGREGATES

- Organic Impurities in natural aggs may interfere with the setting & hardening of concrete. They can be detected by tests, ASTM C40, TS 3673
DELETERIOUS MATERIALS IN AGGREGATES

- **Very Fine Particles:** They can appear in the form of clay and silt or in the form of stone dust → they increase the water requirement or in other words decrease workability.
  - They can appear as coatings on the surface of agg particles → they affect bonding properties.
  - TS 3527 → particles smaller than 63μm
  - ASTM C 117 → #200 sieve (75μm)
DELETERIOUS MATERIALS IN AGGREGATES

- Weak & Unsound Materials *Light weight materials (coals, lignide)*: In excessive amounts may affect durability of concrete. If these impurities occur at or near the surface, they may disintegrate & cause pop-outs & stains.
DELETERIOUS MATERIALS IN AGGREGATES

- **Soft particles**: they are objectionable because they affect the durability adversely. They may cause pop-outs & may brake up during mixing and increase the water demand.

- **Salt contamination**: Most important effects are:
  - Corrosion of reinforcement
  - Efflorescence: presence of white deposits on the surface of concrete.
SOUNDNESS OF AGGREGATES

Soundness is the ability of agg to resist volume changes to environmental effects.
- Freezing & Thawing
- Alternate Wetting & Drying
- Temperature Changes
SOUNDNESS OF AGGREGATES

Aggs are said to be unsound when volume changes induced by the above, results in deterioration of concrete. This effect may be:

- Local scaling
- Extensive surface cracking
- Disintegration over a considerable depth
To detect unsound particles, aggs are treated with Na$_2$SO$_4$ or MgSO$_4$ solutions.

- 18 hours of immersion
- Dry at 105°C+5°C to constant weight
- After 5 cycles determine the loss in weight of the agg.
According to TS following limits should not be exceeded.

<table>
<thead>
<tr>
<th></th>
<th>Na$_2$SO$_4$</th>
<th>MgSO$_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine Agg.</td>
<td>19%</td>
<td>27%</td>
</tr>
<tr>
<td>Coarse Agg.</td>
<td>15%</td>
<td>22%</td>
</tr>
</tbody>
</table>
ABRASION RESISTANCE

- Especially when concrete is used in roads or floor surfaces subjected to heavy traffic load.

- Hardness, or resistance to wear (abrasion) is determined by Los-Angeles abrasion test.
Los Angeles Abrasion Test:
- The agg with a specified grading is placed inside the L.A. Testing Machine.
- Loose steel balls are placed inside the drum.
- The apparatus is rotated for a specified cycles.
- Finally the loss in weight is determined by screening with #12 sieve.
- Resistant → <10% for 100 revolutions.
- → <50% for 500 revolutions.
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
Alkali-Silica Reaction (ASR)

- 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
Alkali-Silica Reaction (ASR)

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.
Alkali-Silica Reaction (ASR)

Test Methods
- Mortar-Bar Method (ASTM 227)
- Chemical Method (ASTM C 289)
- Petrographic Examination (ASTM C 295)
- Rapid Mortar-Bar Test (ASTM C 1260)
- Concrete Prism Test (ASTM C 1293)
Alkali-Silica Reaction (ASR)

- Controlling ASR
  - Non-reactive aggregates
  - Supplementary cementing materials or blended cements
  - Limit alkalis in cement
  - Lithium-based admixtures
  - Limestone sweetening (~30% replacement of reactive aggregate with crushed limestone)
Effect of Supplementary Cementing Materials on ASR

0.10% expansion limit for evaluating effectiveness of supplementary cementitious materials against AAR
MAX AGG SIZE

- It’s the smallest sieve size through which the entire amount of the agg particles can pass.

- The larger the size of agg, the smaller the surface area to be wetted per unit weight. Thus, extending the grading of agg to a larger max size lowers the water requirement of the mix. So, for the same workability & cement content higher strength will be obtained.
- Optimum max agg size for structural concrete is 25mm.

- Studies have shown that concrete’s made with max agg size greater than 40mm have lower strength. Because of the smaller surface area for the bond between agg to paste. Volume changes in the paste causes larger stresses at the interface.
Standard Limitations for Max Agg Size

- The concrete mix must be so that it can be placed inside the molds and between the reinforcing bars easily without any segregation. So, max agg size ($D_{max}$) should not exceed:

1) $\frac{1}{5}$ of the narrowest dimension of the mold.

$$d = \min (d_1, d_2, d_3)$$

$$D_{max} < \frac{d}{5}$$
2) 1/3 of the depth of the slab

\[ D_{\text{max}} < \frac{h}{3} \]

3) 3/4 of the clear spacing between reinforcement

\[ D_{\text{max}} < \frac{3}{4} S \]

4) \( D_{\text{max}} < 40\text{mm} \)
Example:

1) \(D_{\text{max}} < \frac{1}{5} \min (20, 40) = 4\, \text{cm}\)
2) \(D_{\text{max}} < \frac{1}{3}(9) = 3\, \text{cm}\)
3) \(D_{\text{max}} < \frac{3}{4}(4) = 3\, \text{cm}\)
4) \(D_{\text{max}} < 4\, \text{cm}\)