CHAPTER 4

AGGREGATES
4. AGGREGATES

4.1 Introduction

• Aggregates occupy at least three quarters of volume of concrete.
• Quality is especially important.
• Cheaper than the cement, put into the mix as much as possible.
• Higher volume stability and better durability than the cement paste alone.
4.2 General Classification of Aggregates

a) According to Production Methods

• **Natural Aggregates:**
  – Taken from native deposits without any change in their natural states during production except for crushing, grading or washing.
  – Example: sand, gravel, crushed stone, lime rock.

• **By-Product Aggregates:**
  – Comprise blast-furnace slags and cinders, fly ash, etc. Cinders are residue of coal or wood after burning.
Processed Aggregates:

– Heat treated, expanded materials with lightweight characteristics.
– Example: Perlite, burnt clays, shales, processed fly ash.

Colored Aggregates:

– Glass, ceramics, manufactured marble for decorative and architectural purposes.
b) According to Petrological Characteristics

• **Igneous Rocks:**
  
  Solidification of molten lava forms igneous rocks.
  
  • Example: Quartz, granite, basalt, obsidian, pumice, tuff.

• **Sedimentary Rocks:**
  
  Obtained by the deposition of weathered and transported pre-existing rocks.
  
  • Example: Sandstone, limestone, shale.
  
  • IMPORTANT: If these are hard and dense, OK. If not, high absorption capacity gives unsatisfactory results.
Sedimentary Rocks

- Limestone
- Chert
- Arkose
- Shale
- Sandstone
- Conglomerate
Formation of PUMICE
Basalt
• **Metamorphic Rocks:**

Formed at a depth under high heat and pressure by the alterations of either igneous rocks or sedimentary rocks.

• **Example:** Marble, slate, schist.

• **IMPORTANT:** If hard and dense, OK. If laminated, undesirable.
c) According to Particle Size

1) Fine Aggregate (sand):
Fine aggregate includes the particles that all passes through 4.75 mm sieve and retain on 0.075 mm sieve.

2) Coarse Aggregate (gravel):
Coarse aggregate includes the particles that retain on 4.75 mm sieve.

Silt: sizes 0.002-0.075 mm

Clay: sizes smaller than 0.002 mm
d) According to Their Unit Weights:

1) Normal Weight Aggregates:
   • Sand, gravel and crushed stone.
   • Concrete produced by these aggregates: 2160 to 2560 kg/m$^3$.

2) Light Weight Aggregates:
   • Slag, slate and other light stones.
   • Concrete produced by them: 240 to 1440 kg/m$^3$.
   • This concrete is normally used for insulation purposes.

3) Heavy Weight Aggregates:
   • Hemotite, barite magnetite, steel and iron punchings.
   • Concrete produced by them: 2800 to 6400 kg/m$^3$. 
4.4 Mechanical Properties of Aggregates

4.4.1 Bond of Aggregate

- Bond is the interlocking of the aggregate and the paste owing to the roughness of the surface of the former.

- A rough surface, such as that of crushed particles, results in a better bond; better bond is also usually obtained with softer, porous and mineralogically heterogeneous particles.

- No accepted test exists.

- Generally, when bond is good, a crushed concrete specimen should contain some aggregate particles broken right through, in addition to the more numerous ones pulled out from their sockets.
4.4.2 Strength of Aggregate

• NOTE:
  Comp. strength (concrete) < Comp. strength (aggregate)

• The crushing strength of aggregate cannot be tested with any direct test. There are some indirect tests to inform us about the crushing strength of aggregate.
  – Test method: Crushing value test

Other Mechanical Properties of Aggregates:

a) Impact value: Impact value of aggregates measures the toughness of particles by impact.
b) **Abrasion**: Abrasion of aggregates measures the resistance of aggregates against wearing.

- It is an important property of concrete in roads and in floor surfaces subjected to heavy traffic. The most frequently used test method is the Los Angeles Abrasion Test.

- **Los Angeles Abrasion Test**: The aggregate of specified grading is placed in a cylindrical drum, mounted horizontally. A charge of steel balls is added and the drum is rotated a specified number of revolutions. The tumbling and dropping of the aggregate and the balls result in abrasion and attrition of the aggregate. The resulting grading should be compared with the standard limitations.
Los Angeles Abrasion Test
Aggregate Impact Value Test

Hammer

aggregates

counter

Total 54
4.5 Physical Properties

4.5.1 Specific Gravity

• The specific gravity of an aggregate is a characteristic of the material, which needs to be determined in making calculations of mix design of concrete.
4.5.2 Porosity and Absorption of Aggregates

• The porosity of aggregate, its permeability, and absorption influence the bonding between aggregate and cement paste, the resistance of concrete to freezing and thawing and resistance to abrasion.

• When all the pores in the aggregate are full it is said to be saturated.
• If just the surface of aggregate is dry then it is said saturated-surface-dry.

• If the aggregate in saturated surface dry condition allowed to stand free in dry air, some water from pores will evaporate and it is said to be air-dry condition. (See Fig. 4.1)
water absorption:

Determined by measuring the increase in weight of an oven-dried sample when immersed in water, for 24 hours. (The surface water being removed).

The ratio of the increase in weight to the weight of dry sample, expressed as a percentage is termed absorption.

- Water absorption $= W_{\text{wet}} - W_{\text{dry}}$

At the time of setting of concrete the aggregate is in a saturated-surface-dry condition.
Moisture Content of Aggregate

• Moisture content is the water in excess of that saturated surface dry state.
• Total water content of a moist aggregate is equal to the sum of absorption and moisture content.
Figure 4.1 Different moisture conditions of aggregate
<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><strong>Total Moisture</strong></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
4.5.5 Deleterious Substances in Aggregates

a) **Organic Impurities:**
   - Consists of products of decay of vegetable matter. The organic impurities may interfere with the process of hydration of cement. This affects the rate of gaining strength.

b) **Clay and Other Fine Materials:**
   - Found as surface coatings which interfere with the bond between aggregate and the cement paste. Affects the strength and durability of concrete.

**Other types of fine material:**
Silt and crusher dust.
Affect the bond between cement paste and aggregates.

- “BS EN 12620: Aggregates for Concrete” limits the content of all three materials not more than the follows:
  - 15% by weight in crushed sand
  - 3% by weight in natural or crushed gravel
  - 1% by weight in coarse aggregate.
c) **Salt Contamination:**

- Aggregates from the seashore contain salt and have to be washed with fresh water. The aggregate washed even with the sea water do not contain harmful quantities of salts.

- If salt is not removed;
  - It will absorb moisture from the air and cause efflorescence unsightly white deposits on the surface of the concrete.
  - A slight corrosion of reinforcement may also result, but this is not believed to progress to a dangerous degree, especially when the concrete is of good quality and adequate cover to reinforcement is provided.
d) Alkalinity of Aggregates:

- Reactive forms of silica such as opal may occur in some types of rocks, like siliceous limestone.

- The reaction takes place between the siliceous minerals in the aggregate and the alkaline hydroxides derived from the alkalis (Na$_2$O, K$_2$O) in the cement.

- The resulting gel tends to increase in volume in a humid medium and causes cracking of concrete.

- In this case, it is recommended to control the limit of alkalis in the cement.
4.5.6 Soundness of Aggregate

This is the name given to the ability of aggregate to resist excessive changes in volume as a result of changes of physical conditions.

- Aggregate is said to be unsound when volume changes, induced by the freezing and thawing result in deterioration of the concrete.
4.5.7 Sieve Analysis

- Sieve analysis is the name of the operation of dividing a sample of aggregate into fractions, each consisting of particles of the same size.

- In practice each fraction contains particles between specific limits, these being the openings of standard test sieves.
Grading curves & standard limits of aggregates

Your aggregate
Sieves

Sieve openings
Sieve shaker
Pouring aggregate from top of sieves.
Placing in sieve shaker
Sieve shaker
Measuring weight retained on each sieve
<table>
<thead>
<tr>
<th>British standards (millimeters)</th>
<th>American standards</th>
<th>Nominal openings (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>3 in</td>
<td>3</td>
</tr>
<tr>
<td>37.5</td>
<td>1 ½</td>
<td>1.5</td>
</tr>
<tr>
<td>20</td>
<td>¾</td>
<td>0.75</td>
</tr>
<tr>
<td>12.5</td>
<td>½</td>
<td>0.5</td>
</tr>
<tr>
<td>6.3</td>
<td>¼</td>
<td>0.25</td>
</tr>
<tr>
<td>4.75</td>
<td>No 4</td>
<td>0.187</td>
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<tr>
<td>2.36</td>
<td>No 8</td>
<td>0.0937</td>
</tr>
<tr>
<td>1.18</td>
<td>No 16</td>
<td>0.0469</td>
</tr>
<tr>
<td>0.600</td>
<td>No 30</td>
<td>0.0234</td>
</tr>
<tr>
<td>0.300</td>
<td>No 50</td>
<td>0.0117</td>
</tr>
<tr>
<td>0.150</td>
<td>No 100</td>
<td>0.0059</td>
</tr>
<tr>
<td>0.075</td>
<td>No 200</td>
<td>0.0029</td>
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</table>

Total 54
Table 4.4 The weight of reduced samples for sieving.

<table>
<thead>
<tr>
<th>Nominal Size of Material (mm)</th>
<th>Minimum weight of sample to be taken for sieving (kg)</th>
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</thead>
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<tr>
<td>63</td>
<td>50</td>
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<tr>
<td>50</td>
<td>35</td>
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<tr>
<td>40</td>
<td>15</td>
</tr>
<tr>
<td>28</td>
<td>5</td>
</tr>
<tr>
<td>20</td>
<td>2</td>
</tr>
<tr>
<td>14</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>0.5</td>
</tr>
<tr>
<td>6 or 5 or 3</td>
<td>0.2</td>
</tr>
<tr>
<td>Less than 3</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Total 54
The results of a sieve analysis are best reported in tabular form as below:

<table>
<thead>
<tr>
<th>(1) Sieve Sizes (mm)</th>
<th>(2) Weight Retained (gr)</th>
<th>(3) Percentage Retained</th>
<th>(4) Cumulative Percent Retained</th>
<th>(5) Cumulative Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Column 1: Sieve sizes
Column 2: The weights retained on each sieve
Column 3: Percentage of retained weights on each sieve according to the total weight of the sample.
Column 4: Cumulative percentage retained starting from largest sieve to smallest one
Column 5: Cumulative percentage passing from each sieve. It is found by subtracting Column 4 values from 100.
4.5.8 Grading Curves

• Graphical representation (ordinates represent the cumulative percentage passing and the abscissa the sieve opening plotted to a logarithmic scale)

• See at a glance whether the grading of a given sample conforms to that specified or is too coarse or too fine.
4.5.9 Fineness Modulus

- Fineness modulus is the sum of the cumulative percentage retained on the sieves of the standard test sieves.
  Fineness modulus (FM) = (Cum. percent retained / 100)

**Standard test sieves are as follows:**

**Coarse aggregate:**
- 75mm, 38mm, 20mm, 10mm

**Fine aggregate:**
- 4.75mm, 2.36mm, 1.18mm, 0.600mm, 0.300mm, 0.150mm
Limits for FM:

- Fine aggregate: 2.3-3.0
- Coarse aggregate: 5.5-8.0
- Combined aggregate: 4.0-7.0

Total 54
## Example on Sieve Analysis

<table>
<thead>
<tr>
<th>Sieve size (mm)</th>
<th>Mass retained (Grams)</th>
<th>Percentage retained</th>
<th>Cumulative percentage retained</th>
<th>Cumulative percentage passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.00</td>
<td>0</td>
<td>0.0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>5.00</td>
<td>6</td>
<td>2.0</td>
<td>2</td>
<td>98</td>
</tr>
<tr>
<td>2.36</td>
<td>31</td>
<td>10.1</td>
<td>12</td>
<td>88</td>
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<td>1.18</td>
<td>30</td>
<td>9.8</td>
<td>22</td>
<td>78</td>
</tr>
<tr>
<td>0.600</td>
<td>59</td>
<td>19.2</td>
<td>41</td>
<td>59</td>
</tr>
<tr>
<td>0.300</td>
<td>107</td>
<td>34.9</td>
<td>76</td>
<td>24</td>
</tr>
<tr>
<td>0.150</td>
<td>53</td>
<td>17.3</td>
<td>93</td>
<td>7</td>
</tr>
<tr>
<td>&lt;0.150</td>
<td>21</td>
<td>6.8</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Total = 246

Fineness Modulus = \( \frac{\text{Cum.\% retained}}{100} = \frac{(2+12+22+41+76+93)}{100} = 2.46 \)
Problem on sieve analysis

<table>
<thead>
<tr>
<th>BS sieve size (mm)</th>
<th>Weight retained (gr)</th>
<th>Percentage retained (%)</th>
<th>Cumulative percentage retained (%)</th>
<th>Cumulative percentage passing (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>37.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
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<td>0</td>
<td>100</td>
</tr>
<tr>
<td>4.75</td>
<td>454</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>2.36</td>
<td>227</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>1.18</td>
<td>454</td>
<td>0</td>
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<td>0.6</td>
<td>454</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
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<td>Pan</td>
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<td>0</td>
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</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>54</strong></td>
<td><strong>44</strong></td>
<td><strong>54</strong></td>
<td><strong>54</strong></td>
</tr>
</tbody>
</table>
The purpose of sieve analysis is to determine whether or not a particular grading is suitable. The related problem of grading is the combining of fine and coarse aggregates so as to produce desired grading (See Table 4.5, 4.6).

The main factors governing the desired aggregate grading are:
1. the surface area of the aggregate, which determines the amount of water necessary to wet all the solids
2. the relative volume occupied by the aggregate
3. the workability of the mix
4. the tendency to segregation.
4.5.10 Grading Requirements (cont’d)

- The grading of aggregate is a major factor in the workability of a concrete mix.

- Grading affects characteristics of fresh concrete and hardened state: strength, shrinkage and durability.

- Ensure that the grading is kept constant during the concreting work; otherwise variable workability results and as this is usually corrected at the mixer by a variation in the water content, concrete of variable strength is obtained.
Table 4.5: ASTM C33/C 33M Grading Requirements for Fine Aggregates

<table>
<thead>
<tr>
<th>Sieve</th>
<th>Percent passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.5 mm</td>
<td>100</td>
</tr>
<tr>
<td>4.75 mm</td>
<td>95-100</td>
</tr>
<tr>
<td>2.36 mm</td>
<td>80-100</td>
</tr>
<tr>
<td>1.18 mm</td>
<td>50-85</td>
</tr>
<tr>
<td>600 μm</td>
<td>25-60</td>
</tr>
<tr>
<td>300 μm</td>
<td>5-30</td>
</tr>
<tr>
<td>150 μm</td>
<td>0-10</td>
</tr>
</tbody>
</table>
### Table 4.6: ASTM C33/C 33M Grading Requirements for Coarse Aggregates

<table>
<thead>
<tr>
<th>Size mm</th>
<th>100</th>
<th>90</th>
<th>75</th>
<th>63</th>
<th>50</th>
<th>37.5</th>
<th>25</th>
<th>19</th>
<th>12.5</th>
<th>9.5</th>
<th>4.75</th>
<th>2.36</th>
<th>1.18</th>
<th>0.30</th>
</tr>
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<tbody>
<tr>
<td>90-37.5</td>
<td>100</td>
<td>90-100</td>
<td>...</td>
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<td>63-37.5</td>
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<td>4.75-1.18</td>
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<td>...</td>
<td>100</td>
<td>85-100</td>
<td>10-40</td>
<td>0-10</td>
<td>0-5</td>
</tr>
</tbody>
</table>

Total 54
Grading Curves of Aggregates (grading requirement)
• **Gap grading** is a grading in which one or more intermediate size fractions are omitted. (see *Figure 4.2*).

• **Well Graded** means sizes within the entire range are in approximately equal amounts (friction at many points, excellent interlocking, very few voids) (see *Figure 4.2*).
• **Uniform gradation** means a large percentage of the particles are of approximately the same size (poor interlocking, high percentage of voids, friction at few points of contact) (see Figure 4.2).

• **Combined gradation** means fine and coarse aggregates are combined (friction at many points, good interlocking, few voids, economical).
Figure 4.2 Grading of aggregates
Grading of aggregates

(a) Uniform size aggregate:
1. Friction at few points of contact
2. Poor interlocking
3. High percentage of voids

(b) Well-graded aggregate:
1. Friction at many points of contact
2. Excellent interlocking
3. Very few voids

(c) Mixture of coarse and fine aggregate:
1. Friction at many points of contact
2. Good interlocking
3. Few voids
4. Economical preparation

Total 54
Optimized cement paste content for binding the aggregates only in their contact points

Due to filling the interstices with fine mortar there will be a higher compressive strength but also a higher dry density