Aggregates for Concrete

Chapter 05
What is Aggregate?

- Aggregates are the natural or artificial inorganic granular materials used with a cementing medium to form mortar or concrete.
- In concrete, the cement paste covers the aggregate particles surfaces, fills the voids between them, and bonds the particles together.
- The aggregate occupies ~70-75% of the volume of concrete, so its quality is of great importance.
Aggregate uses in civil engineering

- 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
### Importance of General Aggregate Properties in Different CE Applications

(Meininger and Nichols, 1990)

<table>
<thead>
<tr>
<th>Property</th>
<th>Portland Cement Concrete</th>
<th>Asphalt Concrete</th>
<th>Base</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PHYSICAL</strong></td>
<td></td>
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<tr>
<td>Particle shape (angularity)</td>
<td>M</td>
<td>V</td>
<td>V</td>
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<tr>
<td>Particle shape (flakiness, elongation)</td>
<td>M</td>
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<tr>
<td>Particle size—maximum</td>
<td>M</td>
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<tr>
<td>Particle size—distribution</td>
<td>M</td>
<td>M</td>
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<tr>
<td>Particle surface texture</td>
<td>M</td>
<td>V</td>
<td>V</td>
</tr>
<tr>
<td>Pore structure, porosity</td>
<td>V</td>
<td>M</td>
<td>U</td>
</tr>
<tr>
<td>Specific gravity, absorption</td>
<td>V</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Soundness—weatherability</td>
<td>V</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Unit weight, voids—loose, compacted</td>
<td>V</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Volumetric stability—thermal</td>
<td>M</td>
<td>U</td>
<td>U</td>
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<tr>
<td>Volumetric stability—wet/dry</td>
<td>M</td>
<td>U</td>
<td>M</td>
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<tr>
<td>Volumetric stability—freeze/thaw</td>
<td>V</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Integrity during heating</td>
<td>U</td>
<td>M</td>
<td>U</td>
</tr>
<tr>
<td>Deleterious constituents</td>
<td>V</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td><strong>CHEMICAL</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Solubility</td>
<td>M</td>
<td>U</td>
<td>U</td>
</tr>
<tr>
<td>Surface charge</td>
<td>U</td>
<td>V</td>
<td>U</td>
</tr>
<tr>
<td>Asphalt affinity</td>
<td>U</td>
<td>V</td>
<td>M</td>
</tr>
<tr>
<td>Reactivity to chemicals</td>
<td>V</td>
<td>U</td>
<td>U</td>
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<tr>
<td>Volume stability—chemical</td>
<td>V</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Coatings</td>
<td>M</td>
<td>M</td>
<td>U</td>
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<tr>
<td><strong>MECHANICAL</strong></td>
<td></td>
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<td></td>
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<tr>
<td>Compressive strength</td>
<td>M</td>
<td>U</td>
<td>U</td>
</tr>
<tr>
<td>Toughness (impact resistance)</td>
<td>M</td>
<td>M</td>
<td>U</td>
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<tr>
<td>Abrasion resistance</td>
<td>M</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Character of products of abrasion</td>
<td>M</td>
<td>M</td>
<td>U</td>
</tr>
<tr>
<td>Mass stability (stiffness, resilience)</td>
<td>U</td>
<td>V</td>
<td>V</td>
</tr>
<tr>
<td>Polishability</td>
<td>M</td>
<td>M</td>
<td>U</td>
</tr>
</tbody>
</table>

*V – Very important; M – Moderately important; U – Unimportant or importance unknown
Role of Aggregates in Concrete

-serve as an inexpensive filler

-impart higher volume stability by restricting shrinkage of the paste to a certain extent.
Aggregate greatly affect the durability and structural performance of concrete.
Aggregate Properties Affecting Concrete Properties

- Grading (Particle Size Distribution)
- Maximum aggregate size ($D_{\text{max}}$)
- Shape and surface texture of the particles
- Water absorption capacity
- Unit weight
- Specific gravity
- Mechanical properties (strength, hardness, E modulus, etc.)
- Thermal properties
- The amount of deleterious materials in the aggregates.
Classification of Aggregates
Source

**Natural Aggregates** are taken from native deposits with no change in their natural state during production other than crushing, grading, or washing e.g. sand, gravel, crushed stone, pumice

**Artificial Aggregates** are those materials obtained either as a by-product of an unrelated industrial process or by a special manufacturing process like heat treatment. e.g. blast-furnace slag, expanded perlite, expanded vermiculite, burned clay.
● **Natural:**
  - natural sand & gravel pits, river rock
  - quarries (crushed)

● **Artificial aggregates:**
  - pulverized concrete & asphalt
  - steel mill slag
  - steel slugs
  - expanded shale
  - styrofoam
Aggregate stokpilling
Materials of Construction - Aggregates

NATURAL
- Gravel
- Crushed stone
- Natural sand
- Crushed sand

ARTIFICIAL
- Expanded clay
- Slag
- Expanded perlite
Concrete with gravel aggregates

Concrete with crushed stone aggregates
Specific Gravity or Unit Weight

Normal-weight aggregates: 2.4 < Specific Gravity < 2.8.

Lightweight aggregates: Specific Gravity < 2.4.
  e.g. expanded perlite, pumice……

Heavyweight aggregates: Specific Gravity > 2.8.
  e.g. crushed hematite and magnetite (Heavyweight concrete is used for radiation shielding).

The dry loose unit weight of normal-weight aggregates ranges from 1120 to 1760 kg/m³.
Size of Particles

According to Turkish Standards: (TS 706 EN 12620)
fillers < 63 μm < fine aggregates < 4 mm < coarse aggregate < 63 mm

According to American Standards: (ASTM C33)
fillers < No.100 (0.149 mm) < fine aggregates < No.4 (4.75 mm) < coarse aggregate < 4 inch (100mm)

Aggregates consisting of both coarse and fine particles are called combined or mixed aggregates. Natural mixed aggregates taken from the deposits and used as they occur are called all-in aggregates or pit-run aggregates.
Size of Particles

- **Fine aggregate** material passing a sieve with 4 mm (4.75 mm in ASTM standards) openings.

- **Coarse aggregate** material retained on a sieve with 4mm (4.75 mm in ASTM standards) openings.

- **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%
Materials of Construction - Aggregates

Coarse 15-25 mm
Coarse 5-15 mm
Fine 0-4 mm
Filler <0.063 µm
Particle shape and surface texture

The shape and surface texture of the individual aggregate particles determine how the material will pack into a dense configuration and also determines the mobility of the stones within a mix.

There are two considerations in the shape of the material: **angularity** and **flakiness**.
**Shape:**

Rounded particles have no original faces left; they are fully water-worn or completely shaped by attrition, e.g. river gravel.

Angular particles possess well-defined edges; they show little evidence of wear, e.g. crushed stone.

Flaky particles are those which have small thickness relative to the other two dimensions.

Elongated particles are those which have lengths considerably larger than the other two dimensions.
Surface Texture

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

- **Smooth**: Cement paste & agg bond is weak, less water demand for same workability
- **Rough**: Cement paste & agg bond is strong, more water demand for same workability

Surface texture is not a very important property from compressive strength point of view but aggregates having rough surface texture perform better under flexural & tensile stresses.
SMOOTH  ROUGH
Aggregate Standards

The requirements for normal weight aggregates are given in below standards:

- TS 706 EN 12620- Aggregates for Concrete
- ASTM C33 Concrete Aggregates
Sampling of Aggregates

A **sample** is a representative small portion from a larger whole or group of materials.

It is essential that a truly **representative sample** of the material be obtained for testing purposes. Sampling is as important as testing.

Relatively large aggregate samples are obtained from a stockpile and represent the whole supply of aggregates are called **field samples** or **main samples**.

Field samples should consist of accumulations of a number of small portions, called **sample increments**, that are taken at random from different parts of the whole mass.
Sampling of Aggregates

Too fine particles

Sampling

Too coarse particles
Field Sample vs Test Sample

- Field samples are supposed to be sufficiently large amounts of aggregates for full representation of the whole supply. Specifications require only a portion of the field sample for the test sample.

- The large field sample has to be properly reduced to a convenient size for conducting tests on the aggregates (test sample).
Amount of Field Samples

For fine aggregate; min 10-15 kg (various standards)

For coarse aggregate; coarse aggregate sample size (in kg) ≥ 2 × \(D_{\text{max}}\) (in mm)

Acc. to Turkish standard: \(M = 6\sqrt{D_{\text{max}}\rho_b}\)

\(\rho_b\): loose bulk density (t/m\(^3\))

\(M\): mass of sample (kg), \(D_{\text{max}}\): max. agg. size
Reducing Field Samples to Test Samples
Splitting Method

A **sample splitter** divides the aggregate into two equal sizes. A box with even number of chutes alternatively discharging to the left and to the right. The chutes have equal widths ($>1.5 \text{ D}_{\text{max}}$). The aggregate sample that is discharged into the splitter is collected in two receptacles, one on each side. One half of the aggregate is discarded and the other half is used as the test sample or for further splitting.
Quartering Method

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.
GRADING (PARTICLE SIZE DISTRIBUTION)

Grading → particle size distribution.
Grading of aggregates is dividing aggregate sample into various size fractions.
The presence of different size groups in an aggregate provides more compact fitting of the particles in concrete. In other words, the void spaces between the particles are reduced.

1.  

\[
V_{\text{sphere}} = \frac{4}{3}\pi\left(\frac{D}{2}\right)^3 = 0.52D^3
\]
\[
V_{\text{occ}} = 8 \times 0.52D^3 = 4.2D^3
\]
\[
V_{\text{total}} = (2D)^3 = 8D^3
\]
\[
V_{\text{voids}} = (8 - 4.2)D^3 = 3.8D^3
\]

2.  

\[
V_{\text{sphere}} = \frac{4}{3}\pi\left(\frac{D}{8}\right)^3
\]
\[
= 8.18 \times 10^{-3} D^3
\]
\[
V_{\text{occ}} = 512(8.18 \times 10^{-3}D^3) = 4.2D^3
\]
\[
V_{\text{total}} = (2D)^3 = 8D^3
\]
\[
V_{\text{voids}} = (8 - 4.2)D^3 = 3.8D^3
\]

3.  

8 large
200 small
spheres

\[
V_{\text{occupied}} = (4.2 + 1.6)D^3 = 5.8D^3
\]
\[
V_{\text{total}} = 8D^3
\]
\[
V_{\text{voids}} = (8 - 5.8)D^3 = 2.2D^3
\]
Reduction of Voids
Why grading is needed?

1) concrete should have sufficient strength and acceptable durability during service life,

2) concrete should possess the desired amount of workability, i.e. concrete should be sufficiently plastic (in fresh state) to be easily mixed, transported, placed, compacted, and finished without segregation.

3) concrete should be economical.
Why we need grading?

The function of the cement paste in a concrete is;
- covering the surfaces of the aggregate particles,
- filling the spaces between them,
- binding the particles together.

Therefore, a compact fitting of aggregate particles reduces the paste requirement and leads to economical concrete with high strength and durability.
Why we need grading?

If the aggregates do not have good grading, the desired workability cannot be achieved. In such a case, if the amount of water is increased with the purpose of having more workable concrete, then the W/C ratio of the mix will be increased, causing the strength and durability of the concrete to be decreased.

So the grading of the aggregate particles affects the water requirement and the workability of fresh concrete; it also affects the strength and durability of hardened concrete.
Test Sieves

Grading of aggregate is determined by sieve analysis using standard wire mesh sieves with square openings.

Standard test sieves according to Turkish standards (TS EN 933-1):
63 mm, 31.5 mm, 16 mm, 8 mm, 4 mm, 2 mm, 1 mm, 0.5 mm, 0.25 mm and 0.125 mm

Standard ASTM sieves (ASTM C33):
90 mm (3.5 in.), 75 mm (3 in.), 63 mm (2.5 in.), 50 mm (2 in.), 37.5 mm (1.5 in.), 25 mm (1 in.), 19.5 mm (3/4 in.), 12.5 mm (1/2 in.), 9.5 mm (3/8 in.), 4.75 mm (No.4), 2.38 mm (No.8), 1.19 mm (No.16), 0.595 mm (No.30), 0.297 mm (No.50), and 0.149 mm (No.100).

These sieves have square openings, too. The numbers by which some of the ASTM sieves are designated indicate the number of openings per linear inch, e.g. a No.100 sieve has 100 x 100 openings per square inch. (1 inch = 25.4 mm.)
Materials of Construction - Aggregates
Sieve Analysis

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.

To avoid lumps of fine aggregate classified as large particles and also to prevent clogging of the finer sieves the aggregates should be dried before screening.

A shaker is usually used for the shaking operation. The mechanical sieving operation takes 10-15 min.
At the end of the sieving operation, the fractions of the aggregate sample retained on each sieve are weighed and calculations are made as follows:

<table>
<thead>
<tr>
<th>Standard sieve size (mm)</th>
<th>Weight Retained (g)</th>
<th>Percent Retained</th>
<th>Cumulative % Retained</th>
<th>% Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>63,0</td>
<td>0</td>
<td>0,0</td>
<td>0,0</td>
<td>100,0</td>
</tr>
<tr>
<td>31,5</td>
<td>5200</td>
<td>26,0</td>
<td>26,0</td>
<td>74,0</td>
</tr>
<tr>
<td>16,0</td>
<td>2220</td>
<td>11,1</td>
<td>37,1</td>
<td>62,9</td>
</tr>
<tr>
<td>8,0</td>
<td>4580</td>
<td>22,9</td>
<td>60,0</td>
<td>40,0</td>
</tr>
<tr>
<td>4,0</td>
<td>1780</td>
<td>8,9</td>
<td>68,9</td>
<td>31,1</td>
</tr>
<tr>
<td>2,0</td>
<td>2020</td>
<td>10,1</td>
<td>79,0</td>
<td>21,0</td>
</tr>
<tr>
<td>1,0</td>
<td>1200</td>
<td>6,0</td>
<td>85,0</td>
<td>15,0</td>
</tr>
<tr>
<td>0,5</td>
<td>1400</td>
<td>7,0</td>
<td>92,0</td>
<td>8,0</td>
</tr>
<tr>
<td>0,25</td>
<td>1020</td>
<td>5,1</td>
<td>97,1</td>
<td>2,9</td>
</tr>
<tr>
<td>0,125</td>
<td>350</td>
<td>1,8</td>
<td>98,9</td>
<td>1,2</td>
</tr>
<tr>
<td>Pan</td>
<td>230</td>
<td>1,2</td>
<td>100,0</td>
<td>0,0</td>
</tr>
<tr>
<td>Total</td>
<td>20000</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
In the grading curve, the vertical axis represents the % passing, and the horizontal axis represents the sieve openings (in logarithmic scale).
A good aggregate grading is the one that leads to:
- workable,
- dense,
- uniform concrete,
without any segregation of the particles.
There is no single "ideal" grading curve that can provide all of the required properties for a concrete satisfactorily.
**Fineness Modulus**

The fineness modulus of an aggregate sample is an empirical factor obtained by adding the cumulative percentages of aggregates retained on each of a specified series of standard sieves and dividing by 100.

\[
FM = \frac{\text{Cumulative % Retained on Standard Sieves}}{100}
\]
Standard sieves for determination of FM

For fine aggregate
Metric sieves: 0.125, 0.25, 0.50, 1, 2, 4 mm
ASTM sieves: No.100, No.50, No.30, No.16, No.8, No.4

For coarse aggregate (or combined aggregate)
Metric sieves: Fine set + 8, 16, 32, 63 mm
ASTM sieves: Fine set + 3/8”, 3/4”, 1 ½”, 3”
The higher the fineness modulus, the coarser the aggregate.

Two aggregates with the same fineness modulus can have quite different gradation curves.

The fineness modulus of fine aggregates is used in calculating the proportions of the materials in a concrete mix since the gradation of fine aggregate has the largest effect on workability of fresh concrete. A fine sand (low fineness modulus) requires much more paste for good workability.

The practical limits for FM are as follows:

- 2-3.5 for fine aggregate
- 5.5-8.0 for coarse aggregate
- 4-7.0 for combined aggregate
Example 1

A 500 g sample of an aggregate was sieved to obtain the following. Determine the FM of the aggregate.

<table>
<thead>
<tr>
<th>Sieve size</th>
<th>Amount retained on (g)</th>
<th>% retained on</th>
<th>% cum. retained on</th>
<th>% passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/8”</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>#4</td>
<td>30</td>
<td>6</td>
<td>6</td>
<td>94</td>
</tr>
<tr>
<td>#8</td>
<td>80</td>
<td>16</td>
<td>22</td>
<td>78</td>
</tr>
<tr>
<td>#16</td>
<td>100</td>
<td>20</td>
<td>42</td>
<td>58</td>
</tr>
<tr>
<td>#30</td>
<td>120</td>
<td>24</td>
<td>66</td>
<td>34</td>
</tr>
<tr>
<td>#50</td>
<td>125</td>
<td>25</td>
<td>91</td>
<td>9</td>
</tr>
<tr>
<td>#100</td>
<td>35</td>
<td>7</td>
<td>98</td>
<td>2</td>
</tr>
<tr>
<td>Pan</td>
<td>10</td>
<td>2</td>
<td>100</td>
<td>0</td>
</tr>
</tbody>
</table>

FM  =  \frac{\text{Cum. % Retained}}{100} = \frac{6+22+42+66+91+98}{100} = 3.25
Example 2

A 1000 g of a coarse aggregate sample was sieved to obtain the following.

<table>
<thead>
<tr>
<th>Sieve size</th>
<th>Amount retained on (g)</th>
<th>% retained on</th>
<th>% cum. retained on</th>
<th>% passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>2&quot;</td>
<td>70</td>
<td>7</td>
<td>7</td>
<td>93</td>
</tr>
<tr>
<td>1 1/2&quot;</td>
<td>230</td>
<td>23</td>
<td>30</td>
<td>70</td>
</tr>
<tr>
<td>3/4&quot;</td>
<td>350</td>
<td>35</td>
<td>65</td>
<td>35</td>
</tr>
<tr>
<td>3/8&quot;</td>
<td>250</td>
<td>25</td>
<td>90</td>
<td>10</td>
</tr>
<tr>
<td>No. 4</td>
<td>100</td>
<td>10</td>
<td>100</td>
<td>0</td>
</tr>
</tbody>
</table>

\[ FM = \frac{30 + 65 + 90 + 100 + (5 \times 100)}{100} = 7.85 \]

Standard sieves for sand
Example-3

How much aggregate of example 1 should be added to the aggregate of example 2 to end up with a combined aggregate of FM of 6.8.

Let's assume that $x = \text{weight of FA in 1 kg of the combined aggregate}$

$3.25(x) + 7.85(1-x) = 6.8$

$X = 0.23$ or 23% of the combined aggregate is FA

77% of the combined aggregate is CA

23 77

$X = \frac{100}{X} = 30\%$ By weight of CA, FA should be mixed with it.
**Maximum Aggregate Size** \((D_{\text{max}})\)

\(D_{\text{max}}\) is determined from the sieve analysis; it is the smallest sieve size through which the entire amount of the aggregate particles can pass.

Conforming the standard grading limits, it is advantageous to use an aggregate with the largest \(D_{\text{max}}\). Because,

- Water requirement of concrete decreases; (drying shrinkage decreases)
- Cement requirement decreases; (economical concrete)
- For a specified workability and constant cement content, the water/cement ratio decreases; therefore, strength increases.

The above listed advantages are valid when the \(D_{\text{max}} < 40\) mm. The optimum \(D_{\text{max}}\) for structural concrete is stated as 25 mm.
Moisture States & Absorption

Aggregate particles may contain two types of voids
- impermeable voids
- permeable voids

Water can get into the permeable voids, or the water in them can get out when the ambient temperature is high.

(a) Oven-Dry  (b) Air-Dry  (c) Saturated, Surface Dry  (d) Wet

absorption capacity  free water
Moisture Conditions of Aggregates

- **Oven dry** - fully absorbent
- **Air dry** - dry at the particle surface but containing some interior moisture
- **Saturated surface dry (SSD)** — neither absorbing water nor contributing water to the concrete mixture
- **Wet or moist** - containing an excess of moisture on the surface
Total Moisture Content (%) = \( \frac{W_{ps} - W_{od}}{W_{od}} \times 100 \)

\( W_{ps} = \) Weight of the aggregate sample in present state,
\( W_{od} = \) Weight of the aggregate sample in oven-dry state.

Absorption Capacity (%) = \( \frac{W_{SSD} - W_{od}}{W_{od}} \times 100 \)

\( W_{ssd} = \) Weight of the aggregate sample in saturated surface dry condition.

Effective Absorption (%) = \( \frac{W_{SSD} - W_{ad}}{W_{SSD}} \times 100 \)

\( W_{ad} = \) Weight of the aggregate sample in air-dry state.

Surface moisture (%) = \( \frac{W_{wet} - W_{SSD}}{W_{SSD}} \times 100 \)
EXAMPLE

One cubic meter of a concrete mixture consists of

C=300 kg/m³
W=180 kg/m³
FA(SSD)= 700 kg/m³
CA (SSD)= 1200 kg/m³
Σ=2380 kg/m³

The mixture conditions of the aggregates are given below. Calculate the field weights of the ingredients for 1 m³ of the mix.

<table>
<thead>
<tr>
<th></th>
<th>Abs. Cap. (%)</th>
<th>Total moisture (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FA</td>
<td>2.3</td>
<td>4.8</td>
</tr>
<tr>
<td>CA</td>
<td>1.2</td>
<td>0.8</td>
</tr>
</tbody>
</table>
CA is air-dry state:
\[ CA_{AD} = 1200 \left( 1 + 0.008 \right) / \left( 1 + 0.012 \right) = 1195.3 \text{ kg} \]
1200-1195.3=4.7 kg extra water should be added to the mixing water.

FA is in wet state:
\[ FA_{wet} = 700 \left( 1 + 0.048 \right) / \left( 1 + 0.023 \right) = 717.1 \text{ kg} \]
717.1-700=17.1 kg should be subtracted from the mixing water
180+4.7-17.1=167.6 kg

Field weights
C=300 kg/m³
W=167.6 kg/m³
FA(wet)= 717.1 kg/m³
\[ CA \text{ (air-dry)} = 1195.3 \text{ kg/m}^3 \]
\[ \Sigma = 2380 \text{ kg/m}^3 \]
SPECIFIC GRAVITY (Particle density)

Specific Gravity = Density of substance / Density of water

= Weight of substance in air / Weight of an equal vol. water

In the metric system, the density of a substance is numerically equal to the specific gravity.

The specific gravity is expressed as a number, with no unit.

The specific gravity of aggregates are defined in four different ways.
1) Absolute Specific Gravity

Ratio of weight of solid material to volume of solid material excluding all of the pores.

To eliminate the effect of pores the material should be pulverised; the test is laborious and sensitive.

**Absolute specific gravity** = \( \frac{W_s}{(V_s \cdot \gamma_w)} \)

- \( W_s \): weight of solid material
- \( V_s \): volume of solid material
- \( \gamma_w \): unit weight of water (1 g/cm\(^3\))
2. Bulk Specific Gravity, Apparent

Bulk Specific Gravity, Apparent (BSG$_{app}$) is the ratio of weight of oven dry aggregate to the volume of solid material including the impermeable pores.

$$\text{BSG}_{app} = \frac{W_s}{(V_s + V_i) \cdot \gamma_w}$$

where:
- $W_s$: weight of oven dry aggregate
- $V_s$: volume of solid material
- $V_i$: volume of impermeable pores
- $\gamma_w$: specific weight of water

impermeable pores

Ratio of weight of oven dry aggregate to the volume of solid material including the impermeable pores.
3. Bulk Specific Gravity, Dry

Ratio of weight of the oven dry aggregate to volume of solid material including both permeable and impermeable pores

\[
\text{BSG}_{\text{dry}} = \frac{W_s}{(V_s + V_i + V_p) \cdot \gamma_w}
\]
4. Bulk Specific Gravity, SSD

Ratio of weight of SSD aggregate to volume of solid material including both impermeable and water filled permeable pores

\[ \text{BSG}_{ssd} = \frac{W_s + V_p \cdot \gamma_w}{(V_s + V_i + V_p) \cdot \gamma_w} \]
Determination of CA Specific Gravity
Determination of CA Specific Gravity

- \( BSG_{app} = \frac{A}{(A - C)} \)
- \( BSG_{dry} = \frac{A}{(B - C)} \)
- \( BSG_{SSD} = \frac{B}{(B - C)} \)

- \( A = \) Weight of oven dry agg, in air
- \( B = \) Weight of SSD agg, in air
- \( C = \) Weight of SSD agg, in water

- Absorption capacity, \( \% = \frac{[(B - A) / A]}{100} \)
Determination of FA Specific Gravity
Determination of FA Specific Gravity

\[ BSG_{app} = \frac{A}{A+D-C} \]
\[ BSG_{dry} = \frac{A}{B+D-C} \]
\[ BSG_{SSD} = \frac{B}{B+D-C} \]

\( A = \) Weight of oven dry agg, in air
\( B = \) Weight of SSD agg, in air
\( C = \) Weight of pycnometer filled with aggregate and water
\( D = \) Weight of pycnometer filled with water

Absorption capacity, \( \% = \frac{B-A}{A} \times 100 \)
The specific gravity values are used in design calculations of concrete mixtures to convert the weight of each ingredient into its solid volume or vice versa.

Generally, calculations with reference to concrete aggregates are based on SSD conditions, because the water contained in the pores of aggregate does not take part in the chemical reactions of cement and can therefore be considered as a part of aggregate.
Example 1

A 1000 g sample of coarse aggregate in SSD condition weighed 633 g when immersed in water. The sample weighed 985 g after drying at 105°C. Calculate the SSD bulk specific gravity, absorption capacity and dry bulk specific gravity of the aggregate.

SSD bulk specific gravity = \( \frac{B}{(B-C)} = \frac{1000}{(1000-633)} = 2.72 \)

Absorption capacity (%) = \( \frac{(B-A)}{A} \times 100 = \frac{(1000-985)}{985} \times 100 = 1.52\% \)

Dry bulk specific gravity = SSD bulk sp. gr. / (1 + ab. capacity)

= \( \frac{2.72}{1.0152} = 2.68 \)
Example 2

A 500 g sample of sand in the SSD condition was placed in a container which was then filled with water. The weight of container filled with sample and water was 1697 g. The weight of container filled with water only was 1390 g. Calculate the SSD bulk specific gravity of sand.

\[
\text{SSD bulk sp.gr.} = \frac{B}{B+D-C} = \frac{500}{500 + 1390 - 1697} = 2.59
\]
**Unit weight (Bulk density)**

refers to the weight of aggregates filling up a unit volume; i.e. the volume of the aggregate particles packed together includes not only the solid volume of the particles but also the spaces between the particles.

\[ U = \frac{W_a}{V} \]

U: Unit weight of the aggregate, in t/m$^3$ or g/cm$^3$,

$W_a$: Weight of aggregates filling up a container,

V: Volume of the container.
Unit weight of aggregate depends on:

- gradation of the aggregates,
- shape of the particles,
- moisture state of the aggregate,
- degree of compaction

Depending on the degree of compaction "loose unit weight" or "compacted unit weight" of aggregate can be obtained.

The unit weight reflects the void content between the particles. If an aggregate sample has a high value as its unit weight, this means that the amount of solids occupying a given volume is high or that the space in between the particles is little.

\[
\% \text{ voids between the particles} = [1-\frac{U}{(\text{sp.gr.})\gamma_w}] \times 100
\]