Aggregates

Sections 5.1-5.5†

† Mamlouk, M.S., and Zaniewski, J.P. (2006). ***Materials for Civil and Construction Engineers***, 2nd ed., Prentice Hall

What we are going to talk about …

- Types of aggregates
- Shape and texture
- Moisture conditions
- Specific gravity
- Bulk Unit Weight
- Gradation
- Fineness modulus

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What Are Aggregates?

- Granular material used
  - with a cementing medium to form mortar or concrete
  - alone as foundation material or fill

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Why Aggregates?

- Filler to reduce the cost
- Greater volume stability than paste
- ***Therefore one tries to maximize the amount of aggregate in the mix... To a certain extent!***

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Sources

- Natural aggregates (sand and gravel)
  - Dredged from pits, rivers, lakes, or seabed
  - Mixture of rocks & minerals (quartz)
  - Rounded in shape and smooth in texture
- Crushed stone
  - Produced by mechanically crushing rock
  - Granite, sandstone, limestone & dolomite
  - Angular in shape & rough in texture
- Synthetic (steel slags, expanded clay)
- Recycled concrete & clay bricks

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Uses

- Portland cement concrete (PCC)
- Hot-mix asphalt concrete (HMAC)
- Drainage layer
- Foundation fill
- Road base & unpaved roads



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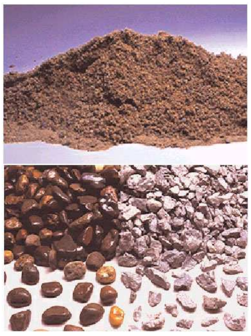
Types of Aggregates Based on Size

- <u>Fine aggregates</u>
  - Natural sand or crushed stone
  - Particles ≤ 4.75 mm
- <u>Coarse aggregates</u>
  - Gravels or crushed stone
  - Particles > 4.75 mm, but usually 10 – 40 mm



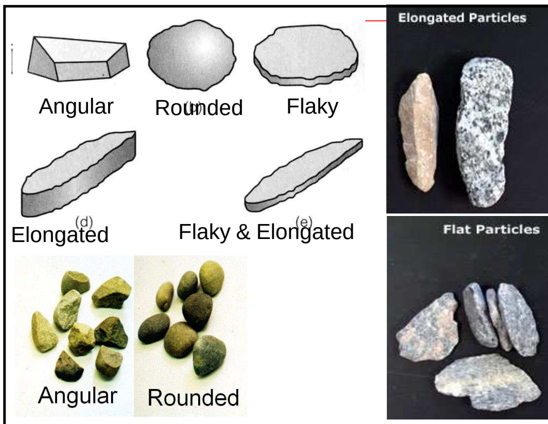
(From "Design and Control of Concrete Mixtures" by Cement Association of Canada)

Aggregates Types Based on Density

- Lightweight
  - Natural (volcanic) & manufactured (by expanding under heat)
  - Specific gravity 0.20 – 2.50
  - Bulk density Fine < 1120 kg/m^3, coarse < 880 kg/m^3
- Normal-weight
  - Crushed stone, gravel & ordinary sand
  - Specific gravity 2.60 – 2.85
  - Bulk density 1520 – 2400 kg/m^3 (typically 2200-2400)
- Heavyweight
  - Mineral iron ores & barite
  - Specific gravity 4.00 – 5.00
  - Bulk density 2400 – 3040 kg/m^3

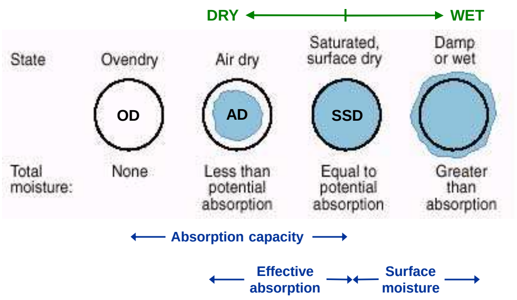
Shape

- 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



Moisture Conditions of Aggregates

The SSD condition is the better choice as a reference state



(From "Design and Control of Concrete Mixtures" by Cement Association of Canada)

Moisture Conditions of Aggregates

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

Important for proportioning concrete
negative free moisture – aggregates will absorb water

Moisture States of Aggregates

- What happens when
  - **MC > AC**
    - extra water will be added to the paste and the w/c ratio of the concrete will be higher than desired
  - **MC < AC**
    - water will be removed from the paste so that the w/c is effectively lowered and the workability of the concrete decreased

Moisture Content

- Amount of water in an aggregate particle

$$MC = \frac{W_{AGG} - W_{OD}}{W_{OD}} \times 100 \ (\%)$$

  - W_{OD} ≡ weight at OD
  - W_{AGG} ≡ weight of aggregate in stockpiled conditions

Absorption Capacity

- Maximum amount of water an aggregate can absorb

$$AC = \frac{W_{SSD} - W_{OD}}{W_{OD}} \times 100 \ (\%)$$

  - W_{SSD} ≡ weight at SSD
  - W_{OD} ≡ weight at OD

Effective Absorption

- Amount of water required to bring an aggregate from AD to SSD

$$EA = \frac{W_{SSD} - W_{AD}}{W_{SSD}} \times 100 \ (\%)$$

  - W_{SSD} ≡ weight at SSD
  - W_{AD} ≡ weight at AD

Surface Moisture

- Amount of water on the surface of an aggregate particle

$$SM = \frac{W_{WET} - W_{SSD}}{W_{SSD}} \times 100 \ (\%)$$

  - W_{SSD} ≡ weight at SSD
  - W_{WET} ≡ weight at wet conditions

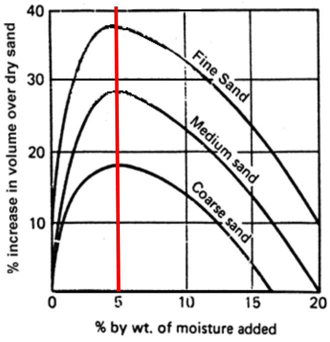
Example 1

- A sample of sand has the following properties:
  Wet mass = 625.2 g
  Dry mass = 589.9 g
  Absorption = 1.6%

Determine:
(a) Total moisture content
(b) Surface moisture

Bulking

- % increase in volume of an aggregate over its dry volume
- Depends on:
  - moisture content
  - particle size
- Because of bulking, aggregates batched by weight



Specific Gravity (***Relative Density***)

- Not an indicator of aggregate quality but important for mix design
- Used to establish weight-volume relationships
- Ratio of the mass (weight) of a unit volume of a material at a specific temp. to the mass (weight) of the ***same*** volume of gas-free distilled water at that temp

Specific Gravity (***Relative Density***)

$$SG = \frac{\text{weight of material}}{\text{volume of material} \times \text{unit weight of water}}$$

- ✓ "Density" could be used but SG is usually used
- ✓ Weight of material depends on moisture level
- ✓ Unit weight of water = 1 g/cm^3 = 1000 kg/m^3, 0.01 MN/m^3,10 KN/m^3

Three types of SG for mix design

- Bulk dry
- Bulk surface saturated
- Apparent SG

Bulk Specific Gravity

- Volume of pores included in total volume

$$BSG = \frac{\text{density of particles (solid volume + pore volume)}}{\text{density of water}}$$

- ✓ Related to MC
- ✓ Since mass and volume can change with MC

$$BSG_{OD} = \frac{W_{OD}}{W_{SSD} - W_{SW}}$$

$$BSG_{SSD} = \frac{W_{SSD}}{W_{SSD} - W_{SW}}$$

$$W_{SSD} - W_{SW} = \left(V_{solid} + V_{\substack{\text{impermeable}\\\text{voids}}} + V_{\substack{\text{permeable}\\\text{voids}}}\right)\gamma_w$$

W_{SW} = weight of saturated sample in water

Apparent Specific Gravity

- Solid & impermeable pores included in total volume

$$ASG = \frac{\text{density of particles (solid volume)}}{\text{density of water}}$$

$$ASG = \frac{W_{OD}}{W_{OD} - W_{SW}}$$

$$W_{OD} - W_{SW} = \left(V_{solid} + V_{\substack{\text{impermeable}\\\text{voids}}}\right)\gamma_w$$

$$ASG > BSG_{SSD} > BSG_{OD}$$

Porosity

- Volume of pores included in total volume

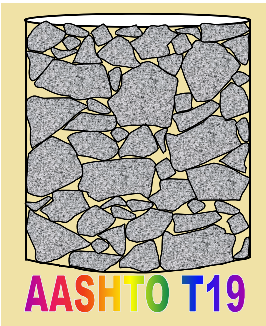
$$\text{Porosity} = \frac{\text{volume of pores}}{\text{total volume of particle}}$$

✓Absorption
✓Freezing characteristics
✓Strength

Bulk Unit Weight

- Needed for proportioning of portland cement concrete
- Weight of a given volume of graded aggregate that has been compacted
- Measures volume that graded aggregate will occupy in concrete
  - solid aggregate particles + voids between them

Procedure for bulk Unit Weight



$$\gamma_{bulk} = \frac{W_s}{V}$$

Voids

- Amount of air between particles
- ***Void content*** → total volume – solid volume of particles

$$V_{solid}\ (\%) = \frac{V_{solid}}{V} \times 100 = \frac{W/\gamma_{solid}}{W/\gamma_{bulk}} \times 100$$
$$= \frac{\gamma_{bulk}}{\gamma_{solid}} \times 100 = \frac{\gamma_{bulk}}{BSG_{OD} \times \gamma_w} \times 100$$

Voids

- If the bulk dry specific gravity is known, the percentage of voids can be determined:

$$\text{Void content (\%)} = \frac{(BSG_{OD} \times \gamma_w) - \gamma_{bulk}}{BSG_{OD} \times \gamma_w} \times 100$$

Example 2

- A sample of coarse aggregate is placed on a rigid bucket & rodded with a tamping rod to determine its unit weight. The following data is obtained:

volume of bucket = 0.009 m^3
weight of empty bucket = 82.3 N
weight of bucket filled w/ dry rodded coarse agg = 248.6 N

(a) Calculate the dry-rodded unit weight
(b) If BSG_{OD} = 2.630, calculate the % of voids

Example 3

The weight of a sample of coarse aggregate was measured under various conditions with the following results:

- Oven-dry weight in air, W_{OD} = 1076.3 g
- Air-dry weight in air, W_{AD} = 1083.3 g
- Saturated-surface-dry weight in air, W_{SSD} = 1089.2 g
- Weight of saturated sample in water, W_{SW} = 681.5 g

Calculate:

Air-dry moisture content
Absorption capacity
Effective absorption
Bulk specific gravity
Saturated surface-dry bulk specific gravity
Apparent specific gravity

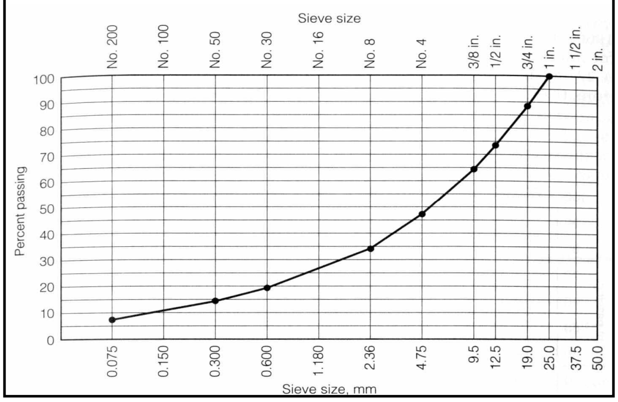
Size Gradation

- Particle size distribution of an aggregate sample
- Determined by ***sieve analysis*** (CSA A23.2-2A)
- Grading expressed as % of material passing each sieve

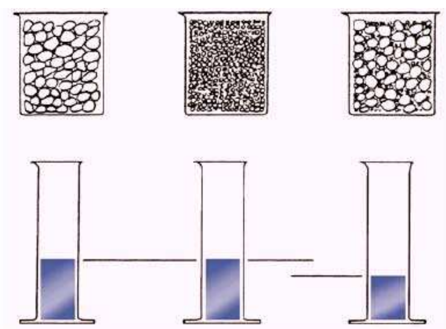
(From "Design and Control of Concrete Mixtures" by Cement Association of Canada)

Range of particle sizes

Gradation – semi log graph



Significance of Gradation



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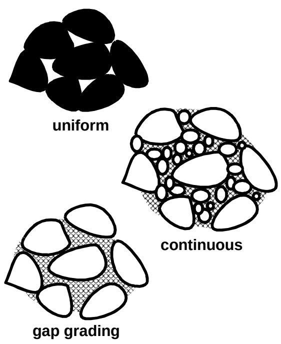
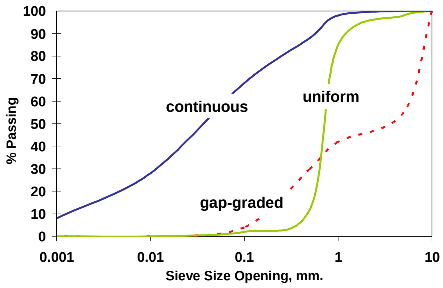
Types of Gradation

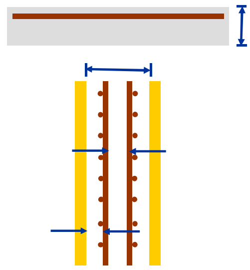
- Uniform (or one-sized)
  - all particles of same size
  - largest volume of voids
  - paste requirement is highest
- Continuous
  - combination of many sizes
  - minimizes volume of voids
  - preferred for efficient use of paste
- Gap
  - missing one or more particle sizes



Grading Curves

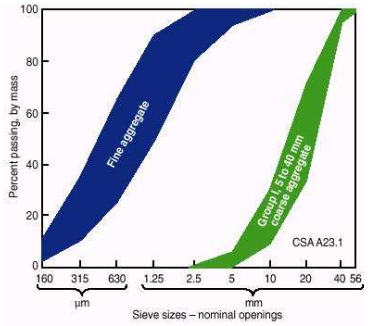


Choice of Aggregate Size



- The maximum aggregate size should be less than the narrowest dimension between forms & reinforcement, between reinforcing bars, or the depth of slab

Grading Limits



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Fineness Modulus

- Gross measure of aggregate gradation
- Usually associated with fine aggregates
- Typical values between 2.3 – 3.1
- Incorporated in ***mix design calculation***

$$FM = \frac{\sum(\text{cumulative \% by mass retained on each sieve})}{100}$$

Fineness Modulus

- The FM is required for mix design since sand gradation has the largest effect on workability.
- The finer the sand (lower FM), the greater the number of particles available to improve workability

Example 4 Fineness Modulus

Sieve size	Weight retained (g)	% Retained	Cumulative % retained
4.75 mm	26	2.6	2.6
2.36 mm	130	13.0	15.6
1.18 mm	240	24.0	39.6
0.60 mm	252	25.2	64.8
0.30 mm	210	21.0	85.8
0.150 mm	138	13.8	99.6
Pan	4		308.0
	1000		**FM = 3.08**

Handling and storing aggregates

Recycled-concrete aggregate

Recycled-concrete aggregate

Water absorption of recycled aggregates (Kerkhoff and Siebel 2001)