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Concrete Technology

Aggregates for Concrete



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Definitions and Importance of Aggregates

- Aggregate is a rock like material
- Used in many civil engineering and construction applications including:
 - Portland cement concrete
 - Asphalt concrete
 - Base materials for roads
 - Ballast for railroads
 - Foundations
 - Plaster, mortar, grout, filter materials, etc.
- Over 2,000,000,000 tons/yr
- Over \$8,000,000,000/yr
- Directly employs over 70,000 persons

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Aggregates

- ASTM (American Society of Testing and Materials) C 125 & D 8 are standard definitions
- Granular material such as:
 - Sand & Gravel (~900,000,000 tons per year)
 - Crushed stone (~1,200,000,000 tons per year)
 - Iron ore blast furnace and other slags
 - Manufactured (lightweight and heavy weight)
 - Reclaimed (Crushed portland cement concrete, clay bricks, etc.)

Aggregates Types - Gravel

GRAVEL

- Naturally occurring, water born pieces of rock, in buried or current stream beds
- Normally rounded with smooth surfaces, other properties dependent on parent rock
- Crushed gravel is larger gravel particles that have been reduced in size by a crusher
- May be washed to remove undesirable material
- May be screened to divide into desired size groupings

Aggregates Types - Sands

SANDS

- Naturally occurring, water or wind born pieces of rock in buried or current stream beds or dunes
- Often rounded with smooth surfaces, other properties dependent on parent rock
- May be washed to remove undesirable material
- May be screened to divide into desired size groupings

Aggregates Types

Crushed Stone or Manufactured Mineral Aggregate

- Rock layers quarried and processed through a crushing and screen plant to reduce to desired size and divide into desired size groupings
- Limestones and dolomites (~ 70%, Hard to Soft)
- Granites (~15%, Hard)
- Sandstones (~2%, Soft)
- **Normal Weight**
 - Gravels, Sands, Normal Crushed Stone, Bulk Specific Gravity - 2.4 to 2.9, Bulk Density (of Bulk Unit Weight) - 1520 to 1680 kg/m³ (95 to 105 pcf), Most commonly used
- **Light Weight**
 - Manufactured or Natural, Bulk Density Less than 1120 kg/m³ (70 pcf), Most commonly used in lightweight concrete, many must be screened to get the desired size distribution, and some must be crushed

Concrete Aggregates

Introduction

- It is economical to put as much aggregate into a concrete mix as possible while not sacrificing other properties.
- However, Economy is not the only reason for using aggregate; it also confers greater volume stability and better durability than cement paste alone.

Aggregates in Concrete

- Influences dimensional stability, elastic modulus, durability, workability, and cost of concrete.
- Classification
 - Coarse Aggregate (CA)
 - Size: 4.75 mm (3/16 in.) to 50 mm (2 in.) (retained on No. 4 sieve)
 - Fine Aggregate (FA)
 - Size: <4.75 mm; >75 μ m (0.003 in.) (retained on No. 200 sieve)
 - Mass concrete may contain up to 150-mm (\approx 6 in.) coarse aggregate.

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Aggregates in Concrete

- **Natural mineral aggregates**, i.e., sand and gravel have a bulk density of 95 to 105 lbs/ft³ (1520 - 1680 kg/m³) and produce Normal-Weight concrete (NWC).
 - NWC unit weight: 150 lbs/ft³ (2400 Kg/m³)
- Aggregates with bulk densities less than 70 lbs/ft³ (1120 Kg/m³) are called Lightweight.
- Aggregates weighing more than 130 lbs/ft³ (2080 Kg/m³) are called heavyweight.

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Classification of Natural Aggregates

- Rocks are classified according to origin into three major groups:
 1. Natural Mineral Aggregates - Sand, gravel, and crushed rock derived from natural sources.
 - (a) **Igneous Rocks** - formed on cooling of the magma (molten rock matter).
Granite, basalt: hard, tough, strong → Excellent aggregates
 - (b) **Sedimentary Rocks** - Stratified rocks (cost effective—near the surface; about 80% of aggregates; Natural sand and gravel)
Limestone, sandstone → Excellent to poor
 - (c) **Metamorphic Rocks** - Igneous or sedimentary rocks that have changed their original texture, crystal structure, or mineralogy composition due to physical and chemical conditions below the earth's surface.
Marble, schist, slate → Excellent to poor

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Classification of Natural Aggregates

- Synthetic Aggregates
 - Thermally processed materials, i.e. expanded clays and shale.
 - Aggregates made from industrial by-products, i.e. blast-furnace slag & fly ash.
- Recycled Aggregates
 - Made from municipal wastes and recycled concrete from demolished buildings and pavements.
 - **Problems:** Cost of crushing, grading, dust control, and separation of undesirable constituents.

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Classification of Natural Aggregates

- Another description of aggregates is given in ASTM C294 which classifies aggregates as follows:
 - Silica minerals, (e.g., quartz, opal, chalcedony, tridymite, cristobalite), Feldspars, Micaceous minerals, Carbonite minerals, Sulphides, Ferromagnesian minerals, Zeolites, Tron oxides, & clay minerals.
- These mineralogical classifications are of help in recognizing properties of aggregates

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Aggregate Characteristics Affecting Concrete Behavior

1. Characteristics controlled by porosity

A. Density

- I) **Apparent specific gravity**: Density of the material including the internal pores.
- II) **Bulk density** (dry-rodded unit weight) weight of aggregate that would fill a unit volume; affects the following concrete behavior: mix design, workability, and unit weight.

Free Moisture and Absorption of Aggregates

- The moisture content and absorption of aggregates are important in calculating the proportions of concrete mixes since any excess water in the aggregates will be incorporated in the cement paste and give it a higher water/cement ratio than expected.
- All moisture conditions are expressed in terms of oven dry unit weight.
- Figure 1, on the next slide, shows a schematic representation of the moisture conditions of aggregates.

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Aggregate Characteristics Affecting Concrete Behavior

B. Absorption and Surface Moisture

The figure shows four circular diagrams representing aggregate moisture states. Each diagram has a small red wedge at the top representing surface moisture. 1. Oven Dry (OD): The circle is white, indicating no water in accessible pores. 2. Air Dry (AD): The circle is white with a small red wedge at the top, indicating pores are partially filled. 3. Saturated Surface Dry (SSD): The circle is grey with a small red wedge at the top, indicating pores are saturated and the surface is dry. 4. Wet: The circle is black with a small red wedge at the top, indicating pores are filled and the surface is wet.

Oven Dry (OD)
No water in accessible pores

Air Dry (AD)
Pores Partially Filled

Saturated Surface Dry (SSD)
Saturated Surface Dry

Wet
Pores filled & Surface Wet

Fig. 1: Schematic Representation of Moisture in Aggregate

Moisture conditions of aggregates:

- **Oven-dry Condition:** All free moisture, whether external surface moisture or internal moisture, driven off by heat.
- **Air dry:** No surface moisture, but some internal moisture remains.

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Absorption and Surface Moisture (Cont'd)

- **Saturated-surface dry condition (SSD):** Aggregates are said to be **SSD** when their moisture states are such that during mixing they will neither absorb any of the mixing water added; nor will they contribute any of their contained water to the mix. Note that aggregates in SSD condition may possess "bound water" (water held by physical-chemical bonds at the surface) on their surfaces since this water cannot be easily removed from the aggregate.
- **Damp or Wet condition:** Aggregate containing moisture in excess of the SSD condition.
 - The Free Water, which will become part of the mixing water, is in excess of the SSD condition of the aggregate.
- Absorption and surface moisture affects the following concrete behaviors: mix-design, strength / abrasion resistance.

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Absorption and Surface Moisture (Cont'd)

State	Oven dry	Air dry	Saturated, surface dry	Damp or wet
Total Moisture	None	Less than potential absorption	Equal to potential absorption	Greater than absorption

Moisture conditions of aggregates

Oven dry

Air dry

Saturated, surface dry

Damp or wet

Granite aggregate at various moisture conditions

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Aggregate Characteristics Affecting Concrete Behavior

C. Soundness

- Aggregate is considered **unsound** when volume changes in the aggregate induced by weather, such as alternate cycles of wetting and drying or freezing and thawing, result in concrete deterioration.
- Depends on: porosity, flaws and contaminants.
 - Pumice- (10% absorption) - no problem with freezing and thawing.
 - Limestone - breaks: use smaller aggregates (critical size)
 (**critical aggregate size**: size below which high internal stresses capable of cracking the particle will not occur)

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Aggregate Characteristics Affecting Concrete Behavior

2. Characteristics dependent on prior exposure and processing factors

A. **Aggregate size**

- Maximum size of aggregate (**MSA**):
 - $MSA < 1/5$ of the narrowest dimension of the form in which concrete is to be placed.
 - Also: $MSA < 3/4$ of the maximum clear distance between the re-bars
- Aggregate size affects the following concrete properties: water demand, cement content, microcracking (strength).

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Aggregate Characteristics Affecting Concrete Behavior

B. **Aggregate Grading** (distribution of particles of granular materials among various sizes)

- Depends on: proportions of coarse and fine aggregates
- Affects: Paste content (cost economy), workability.

Reduction of voids

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Aggregate Characteristics Affecting Concrete Behavior

Fineness Modulus (FM):

- Index of fineness of an aggregate.
- It is computed by adding the cumulative percentages of aggregate retained on each of the specified series of sieves, and dividing the sum by 100 [smallest size sieve: No. 100 (150 μm)].
- Note: The higher the FM, the coarser the aggregate.

Aggregate Characteristics Affecting Concrete Behavior

B. Aggregate Grading (Cont'd)

- The fineness modulus can be considered as a weighted average size of a sieve on which the material is retained, keeping in mind that the sieves are counted from the finest.
- For instance, a fineness modulus of 4.00 can be interpreted to mean the the fourth sieve, No. 16 in the US series, is the average size.
- It is important to note that the fineness modulus is just one number which only characterizes the average size of the aggregate, and different gradings may have the same fineness modulus.

Aggregate Characteristics Affecting Concrete Behavior

C. Shape and Surface Texture

Rough-textured and elongated particles require more cement paste to produce workable concrete mixtures, thus increasing the cost.

- Shape:
 - **Round** - losing edges and corners.
 - **Angular** - well defined edges and corners.
 - **Elongated**- when length is considerably larger than the other two dimensions.
 - **Flaky** or **flat**- when thickness is small relative to two other dimensions.

Aggregate Characteristics Affecting Concrete Behavior

C. Shape and Surface Texture (Cont'd)


- Surface Texture- the degree to which the aggregate surface is smooth or rough- (based on visual judgement).
 - Depends on: rock hardness, grain size, porosity, previous exposure.
 - Affects: Workability, paste demand, initial strength.

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Specific Gravity

- The **specific gravity** (relative density) of an aggregate is the ratio of its weight to the weight of an equal volume of water.
- Most natural aggregates have specific gravities between 2.4 and 3.0 as shown in the next slide.

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Specific Gravity of Rock Groups

Rock Group	Average Specific Gravity	Range of Specific Gravities
Basalt	2.80	2.6-3.0
Flint	2.54	2.4-2.6
Granite	2.69	2.6-3.0
Gritstone	2.69	2.6-2.9
Hornfels	2.82	2.7-3.0
Limestone	2.66	2.5-2.8
Porphyry	2.73	2.6-2.9
Quartzite	2.62	2.6-2.7

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Unit Weight of Aggregate in Bulk

- The **Dry-Rodded** Unit Weight of an aggregate is the weight required to fill a contained or a specified unit volume, after it has been rodded to attain maximum packing.
- ASTM C29 gives the common methods of determining the Dry-Rodded Unit Weight that is also sometimes called the “bulk unit weight of aggregates” since the voids between the particles are included. It is important to note that the Dry- Rodded Unit Weight is NOT THE SAME AS SPECIFIC GRAVITY.

Quality Requirements for Aggregates

- The durability requirements for aggregate can be organized into deleterious substances and reactive aggregates. The deleterious substances are listed below:
 - Substances causing a chemical reaction.
 - Substances which undergo disruptive expansion.
 - Clay and other surface coatings.
 - Aggregate particles with flat or elongated shape.
 - Structurally soft and/or weak particles.

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Reactive Aggregates

- One of the most important examples of reactive aggregates is the Alkali-aggregate reaction in which alkali hydroxides react with the reactive silicates to form alkali silica gels which subsequently absorb water from their surroundings through osmosis.
 - This leads to internal stresses in hardened concrete until its tensile strength is reached and it cracks.
 - If the reactive aggregates cannot be avoided another method to control the alkali-aggregate reaction is to limit the alkali content of the portland cement to 0.6% or less (expressed as the *Na O* equivalent of the total alkalis) whenever reactive aggregates are to be used for making concrete.
 - Another method consists of adding to concrete a finely ground pozzolanic materials.

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Influence of Aggregate on Concrete Strength

- The rougher the surface of the aggregate and the greater the area in contact with the cement paste, the stronger a concrete will be.
- Rounded particles result in lower strength than crushed aggregates.
- Larger size aggregates lead to lower strength in concrete.

Maximum size of aggregate (mm)	390 (660) kg/m³	330 (560) kg/m³	280 (470) kg/m³	170 (280) kg/m³
9.5	35	30	22	8
19	36	31	24	10
38	37	32	26	12
76	36	31	28	15
152	30	28	28	18

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Influence of Aggregate on Concrete Strength

- In lean mixes large aggregate give the best value for strength but in rich mixes, it is the smaller aggregates that results in higher strength.

