



Royal Institute of Technology, Stockholm

# Road Aggregates Characterization

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### Do you know about...?

Source	Percentage
Kroosberg (Crushed bedrock)	60.4%
Naturgrus (Sand and gravel)	27.1%
Övrigt (Others)*	10.4%
Morän (Fill)	2.1%

Application	Percentage
Väg (Road construction)	57%
Fyllnad (Filling)	16%
Övrigt (Other uses)	15%
Betong (Concrete)	12%

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## Aggregates

- Aggregate is the major component of all materials used in road construction



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## Aggregates

- ◆ is a broad category of coarse particulate material used in construction
  - ◆ include sand, gravel, crushed stone, slag, recycled concrete and geosynthetic aggregates
  - ◆ components of composite materials such as concrete and asphalt concrete
  - ◆ serves as reinforcement to add strength to the overall composite material
  - ◆ are widely used in drainage applications such as foundation drains, retaining wall drains, and road side edge drains
  - ◆ are also used as base material under foundations, roads

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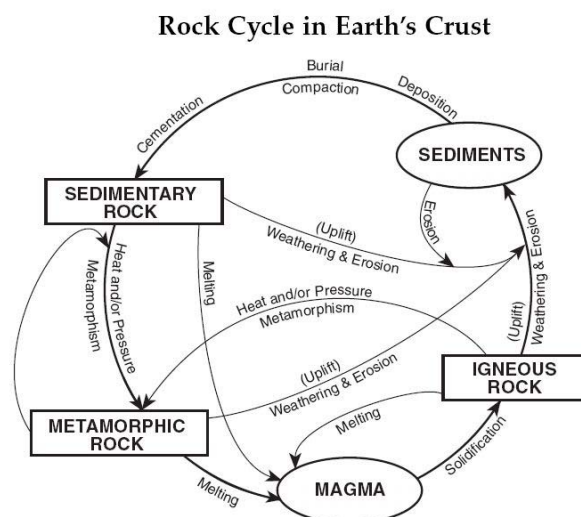
## Where do we use Aggregates in Highway Engineering?

- ◆ Asphalt – wearing course, base course
  - ◆ high fracture resistance
  - ◆ good interlocking
  - ◆ hardness
  - ◆ surface friction
  - ◆ light reflective
- ◆ Base Material
  - ◆ good fracture resistance
  - ◆ good interlocking
  - ◆ drainage
- ◆ Sub-Base Material
  - ◆ medium fracture resistance
  - ◆ good interlocking
  - ◆ drainage

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## Where do Aggregates come from?



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## Classification

### 1. Igneous rocks

- ◆ Origin :- Natural aggregates
- ◆ Grain size
  - ◆ Coarse grained
  - ◆ Medium grained
  - ◆ Fine grained
- ◆ Composition
  - ◆ Acidic > 66% of silica.
  - ◆ Intermediate 55 to 66% silica.
  - ◆ Basic < 55% silica.

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## Classification

### 2. Sedimentary rocks

- ◆ Calcareous
  - ◆ Chalk, Lime stone
- ◆ Siliceous
  - ◆ Sandstone
  - ◆ Flint, chert
- ◆ Argillaceous
  - ◆ Clay, shell etc.

### 3. Metamorphic rocks

- ◆ Artificial aggregate - by product of industrial processes  
eg. Blast furnace slag

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## Sources of Aggregates

### ◆ Gravel

- ◆ Rock quarry
- ◆ On site material
- ◆ Gravel pit
- ◆ Mines
- ◆ Slag from ore processing

### ◆ Sand and Filler

- ◆ Rock quarry
- ◆ On site material
- ◆ Sand pit
- ◆ Dredging (river and salt water)
- ◆ Processes mine material

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## Rock Quarry



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## Gravel Pit



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## On Land Dredging



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## Marine Dredging



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## Aggregate Production at Quarries

- Blasting of bedrock
- Primary crushing stage
  - Jaw crusher
- Secondary crushing stage
  - Gyratory or cone crusher
  - Screen
- Tertiary crushing stage
  - Cone crusher
  - Impact crusher (VSI)
  - Screens

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## Blasting



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## Crushing



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## Source Aggregate Characterization

- Gradation
- Toughness and Abrasion Resistance
- Particle Shape and Surface Texture
- Durability and Soundness
- Cleanliness and Deleterious Materials

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## Aggregate Gradation

- In a gradation and size analysis, a sample of dry aggregate of known weight is separated through a series of sieves with progressively smaller openings
- Once separated, the weight of particles retained on each sieve is measured and compared to the total sample weight
- Particle size distribution is then expressed as a percent retained/passing by weight on each sieve size

Percent retained

Percent passing



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## Aggregate Gradation

- Aggregate gradation influences almost every important property including:
  - Stiffness
  - Stability
  - Durability
  - Permeability
  - Workability
  - fatigue resistance
  - skid resistance and
  - resistance to moisture damage

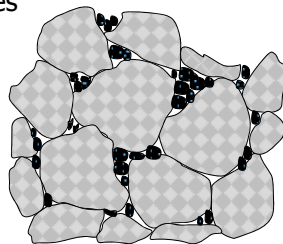
(Roberts et al., 1996)

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## Aggregate Gradation

- It is often expressed in graphical form
  - Using concepts of **Maximum density gradation**
  - A special graph referred to as the FHWA (Federal Highway Administration) 0.45 power graph.
- This gradation would involve a particle arrangement where successively smaller particles are packed within the voids between larger particles



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## Fuller and Thompson's Equation (Interactive Equation)

- A widely used equation to describe a **maximum density gradation** for a given maximum aggregate size. It is developed by **Fuller and Thompson in 1907**.

$$p = \left( \frac{d}{D} \right)^n * 100$$

Where:

- P = percent passing (%)
- d = aggregate size being considered
- D = maximum aggregate size
- n = parameter which adjusts curve for fineness or coarseness (for maximum particle density  $n \approx 0.5$  according to Fuller and Thompson)

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## The 0.45 Power Maximum Density Graph

- In the early 1960s, the FHWA introduced the standard gradation graph used in the HMA industry today
- This graph uses Fuller and Thompson's equation with  $n = 0.45$  and is convenient for determining the maximum density line and adjusting gradation (Roberts et al., 1996)
- This graph is slightly different than other gradation graphs because it uses the sieve size raised to the nth power (usually 0.45) as the x-axis units. Thus, a plot of Fuller and Thompson's maximum density equation with  $n = 0.45$  appears as a straight diagonal line

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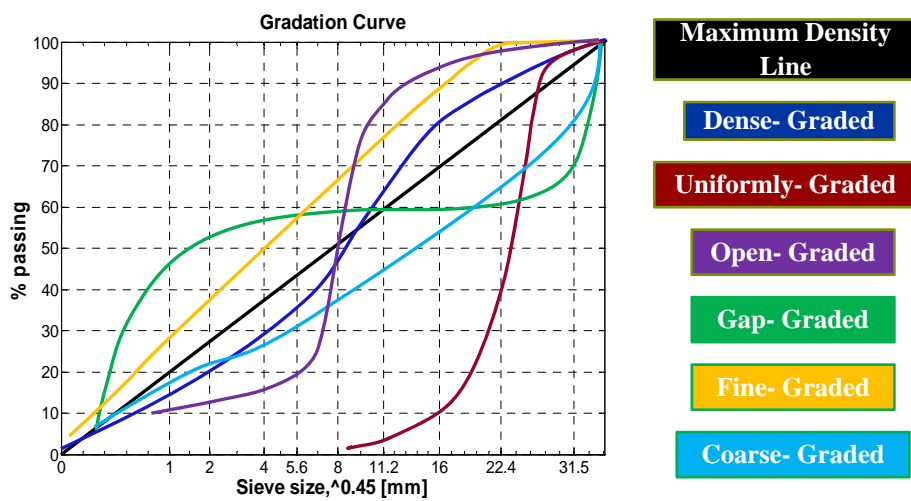
## Calculations for a 0.45 Power Gradation Curve

Particle Size (mm)	% Passing
19.0	$P = \left(\frac{19.0}{19.0}\right)^{0.45} = 1.000$ (100.0%)
12.5	$P = \left(\frac{12.5}{19.0}\right)^{0.45} = 0.833$ (83.3%)
9.5	$P = \left(\frac{9.5}{19.0}\right)^{0.45} = 0.732$ (73.2%)
2.00	$P = \left(\frac{2.00}{19.0}\right)^{0.45} = 0.363$ (36.3%)
0.300	$P = \left(\frac{0.300}{19.0}\right)^{0.45} = 0.154$ (15.4%)
0.075	$P = \left(\frac{0.075}{19.0}\right)^{0.45} = 0.082$ (8.2%)

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## The 0.45 Power Maximum Density Graph



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## Coarse Aggregate and their Sieve Sizes

Sieve Designation	Opening (in)	Opening (mm)
3 in	3.00	75.0
2 in	2.00	50.0
1½ in	1.50	37.5
1 in	1.00	25.0
¾ in	0.75	19.0
½ in	0.50	12.5
⅜ in	0.375	9.50

- Retained on 4.75 mm (No.4) ASTM D692
- Retained on 2.36 mm (No.8) Asphalt Institute
- Retained on 2.00 mm (No.10) HMA Book

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## Fine Aggregate and their Sieve Sizes

Sieve Designation	Opening (in)	Opening (mm)
No. 4	0.187	4.75
No. 8	0.0937	2.36
No. 16	0.0469	1.18
No. 30	0.0234	0.60
No. 50	0.0117	0.30
No. 100	0.0059	0.15
No. 200	0.0030	0.075

Passing 4.75 mm (No.4) ASTM D1073

Retained on 2.36 mm (No.8) Asphalt Institute

- **Mineral filler**
  - At least 70% pass 0.075 mm ASTM D242

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## Maximum and Nominal Aggregate Sizes

%P	%R
100	0
100	0
92	8
72	20
65	7
48	17
36	12
22	14
15	7
9	6
4	5
0	4

### Nominal maximum size

One size larger than the first sieve to retain more than 10 %

### Maximum size

One size larger than nominal maximum size

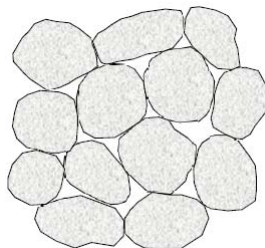
%P	%R
100	0
99	1
88	11
72	16
65	7
48	17
36	12
22	14
15	7
9	6
4	5
0	4

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## Uniformly Graded Aggregate

● **Uniformly graded** refers to a gradation that contains most of the particles in a very narrow size range. The curve is steep and only occupies the narrow size range specified. All the particles are the same size.

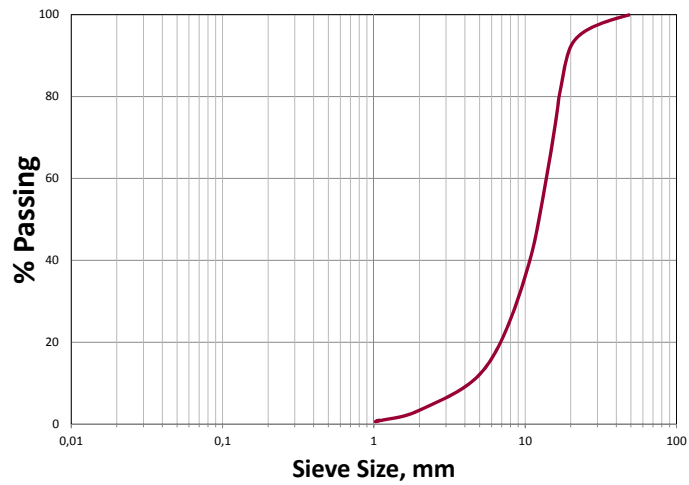


- Particle-to-particle contact
- High void content
- Low but variable density
- High stability if confined
- Low stability when unconfined
- Difficult to compact

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## Uniformly Graded Aggregate

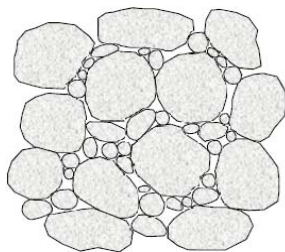


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## Open-Graded Aggregate

● **Open graded** refers to a gradation that contains only a small percentage of aggregate particles in the small range

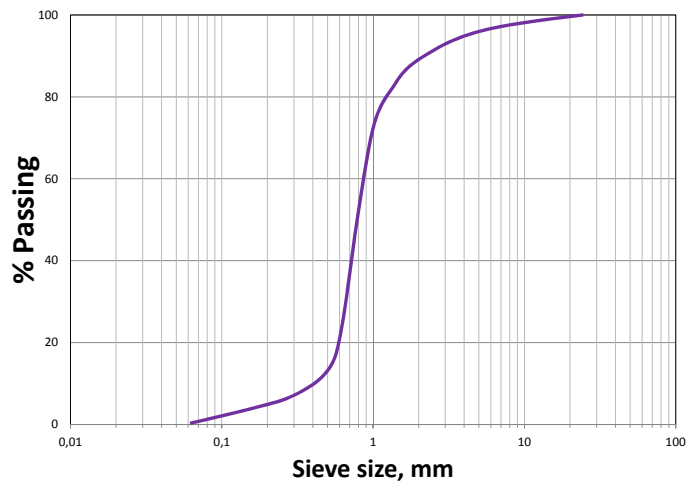


- Few particle-to-particle contact
- High void content
- Low but variable density
- High stability if confined
- Low stability when unconfined
- Difficult to compact

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## Open-Graded Aggregate

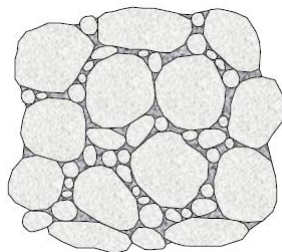


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## Dense-Graded Aggregate

● **Dense or well-graded** refers to a gradation that is near the 0,45 power curve for maximum density and contains optimum amount of aggregates from all ranges.



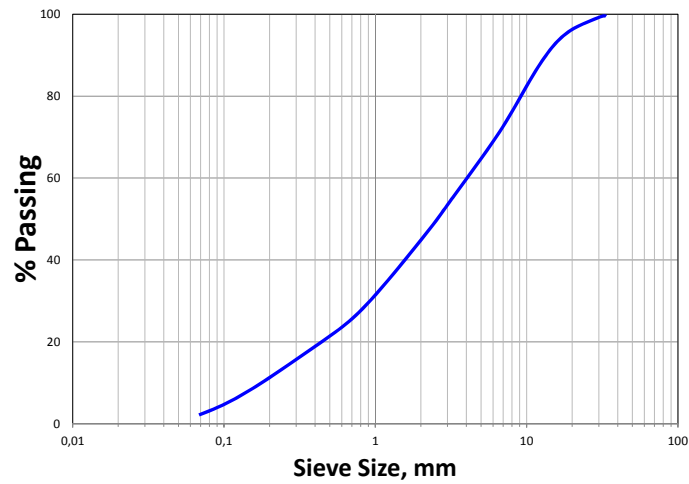
- Particle-to-particle contact
- Low void content
- High density
- High stability if confined
- High stability when unconfined
- Difficult to compact

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## Dense-Graded Aggregate

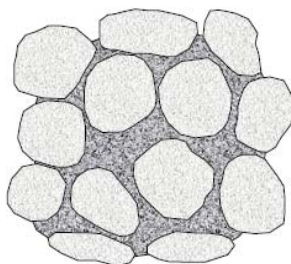


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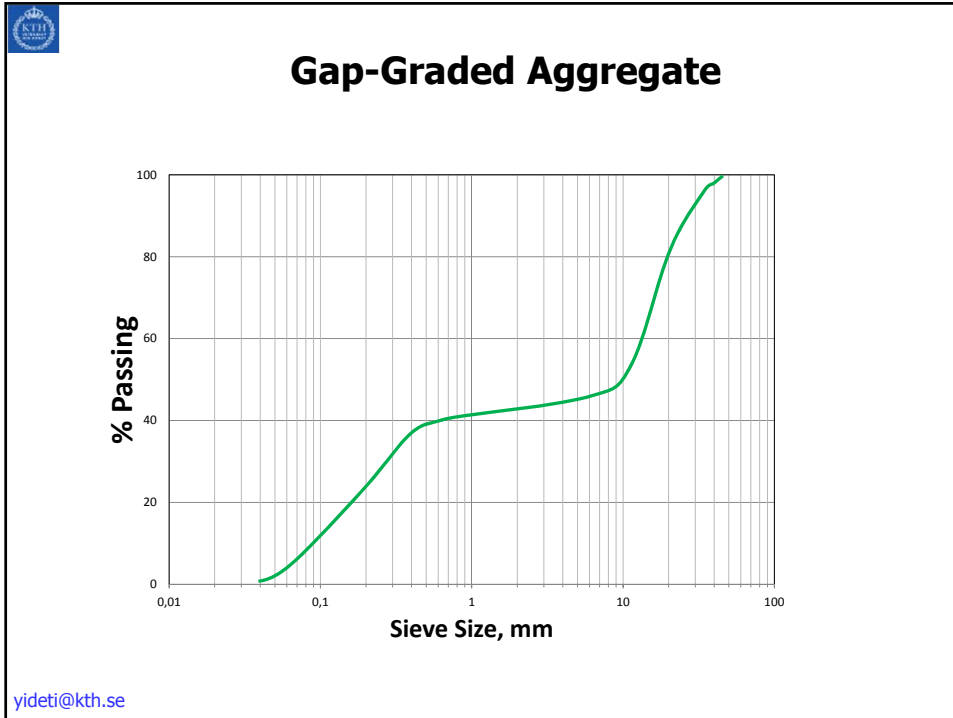
## Gap-Graded Aggregate

● **Gap graded** refers to a gradation that contains only a small percentage of aggregate particles in the mid-size range. The curve is flat in the mid-size range



- No particle-to-particle contact
- High void content
- Lower density
- Low stability if confined
- Low stability when unconfined
- Easy to compact

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**Example Percentage Passing Calculation**

Sieve Designation	Aggregate weight retained (g)	Aggregate percent retained (%)	Cumulative weight retained (g)	Cumulative percent retained (%)	Cumulative percent passing (%)
12.5	0	0	0	0	100
9.5	480	4.8	480	4.8	95.2
4.75	1540	15.6	2020	20.4	79.6
2.36	2240	22.6	4260	43	57
1.18	1300	13.1	5560	56.1	43.9
0.6	1650	16.7	7210	72.8	27.2
0.3	740	7.5	7950	80.3	19.7
0.15	720	7.3	8670	87.6	12.4
0.075	930	9.4	9600	97	3
0	300	3	9900	100	0
Total	9600				

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## Toughness/Abrasion Resistance

- Common test methods for characterizing aggregate toughness/abrasion resistance
  - Los Angeles Abrasion (AASHTO T96, ASTM C131)
  - Aggregate Impact Value (British)
  - Aggregate Crushing Value (British)
  - Micro-Deval Abrasion (French/Canadian)
  - Degradation in the SHRP Gyrotory Compactor

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## Los Angeles Abrasion test

- **The Los Angeles (L.A.) abrasion test** is a common test method used to indicate aggregate toughness and abrasion characteristics (**AASHTO T96, ASTM C131**)
- Resistance of coarse aggregate abrasion and mechanical degradation during handling, construction and use
- For the L.A. abrasion test, the portion of an aggregate sample retained on the 1.70 mm sieve is placed in a large rotating drum that contains a shelf plate attached to the outer wall
- A specified number of steel spheres are then placed in the machine and the drum is rotated for 500 revolutions at a speed of 30 - 33 revolutions per minute (RPM)

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## Los Angeles Abrasion test

- The material is then extracted and separated into material passing and retained on the 1.70 mm sieve
- The retained material is then weighed and compared to the original sample weight. The difference in weight is reported as a percent of the original weight and called the "percent loss"



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## Los Angeles Abrasion test

Aggregate Type	L.A Abrasion value
<b>General Values</b>	
Hard, igneous rocks 10	
Soft limestone's and sandstones 60	
<b>Ranges for Specific Rocks</b>	
Basalt	10 - 17
Dolomite	18 - 30
Gneiss	33 - 57
Granite	27 - 49
Limestone	19 - 30
Quartzite	20 - 35

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## Aggregate Crushing Value

- The aggregate crushing value indicates the ability of an aggregate to resist crushing
- The lower the figure the stronger the aggregate, i.e. the greater its ability to resist crushing
- The aggregate passing 12.5 mm sieve and retained on 10 mm sieve is selected for standard test
- Compression testing machine with a load of 40 tonnes is applied for 10 minutes



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## Aggregate Crushing Value

- The aggregate crushing value is defined as a ratio of the weight, of fines passing the specified sieve (2.36 mm) to the total weight of the sample expressed as a percentage.
  - Aggregate crushing value > 35 weak for pavement
  - Aggregate crushing value < 10 exceptionally strong

Rock group      Crushing value

- Basalt                      14
- Granite                     20
- Lime stone                24
- Quartzite                  16

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## Aggregate Impact Value

- Toughness of an aggregate is its resistance to failure by impact

Rock group      Impact value

- Basalt                      15
- Granite                    19
- Lime stone                23
- Quartzite                 21



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## Durability/Soundness

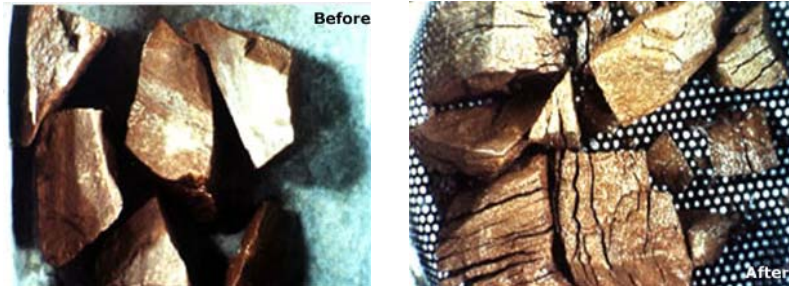
- AASHTO T 104 and ASTM C 88
- Estimates resistance of aggregate to breakdown or disintegration when subjected to weathering action
- Successively wetting and drying aggregate in saturated solutions of either **sodium sulfate or magnesium sulfate solution**
- Result is total percent loss over various sieve intervals for a prescribed number of cycles
  - Maximum loss values typically range from 10 to 20 % per 5 cycles



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## Soundness



Before

After

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## Cleanliness and Deleterious Materials

- Deleterious material is the mass percent of contaminants such as clay lumps, shale, wood, mica, and coal in the blended aggregate
- Aggregates must be relatively clean when used in HMA or PCC
- **To test for clay lumps or friable particles**
  - A sample is first washed and dried to remove material passing the 0.075-mm (No. 200) sieve. The remaining sample is separated into different sizes and each size is weighed and soaked in water for 24 hours
  - Particles that can be broken down into fines with fingers are classified as clay lumps or friable material. The amount of this material is calculated by percentage of total sample weight
  - The test can be performed for both fine and coarse aggregates

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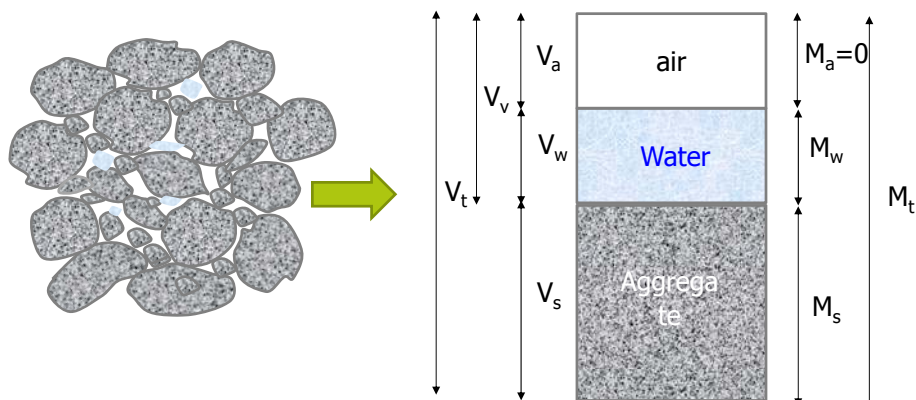
## Volumetric relationships of Aggregate Materials

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## Phase Diagram

To compute mass (or weight) and volume of the three different phases



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**Phase Diagram**

- M= mass of unbound materials
- V = volume
- s= solid solids
- w= water
- a= air
- v = voids
- t = total

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**Gravimetric water content (w)**

● Gravimetric water content (w) is a measure of the water present in the granular mix by weight . It is defined as the ratio of the mass of water,  $M_w$  to the mass of the solids,

$$w = \frac{M_w}{M_s} * 100\%$$

- Expressed as percentage
- Range from 0 to 100 %

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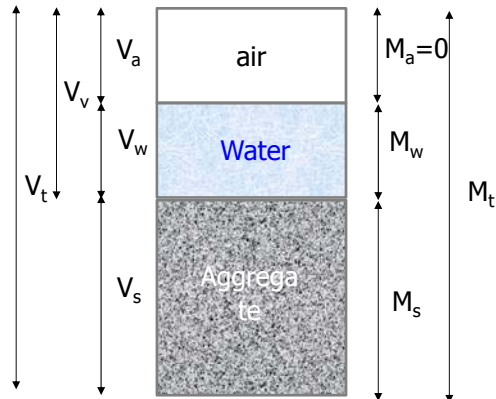


## Volumetric water content ( $\theta_v$ )

- **Volumetric water content ( $\theta_v$ )** is defined as the ratio of the volume of water,  $V_w$  to the total volume of the aggregate,  $V_t$

$$\theta_v = \frac{V_w}{V_t} * 100\%$$

- Expressed as percentage
- Range from 0 to 100 %



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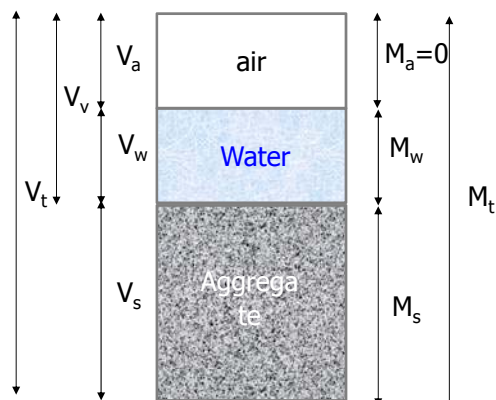


## Porosity ( $n$ )

- **Porosity ( $n$ )** is defined as the ratio of the volume of voids over the total volume of aggregate mix

$$n = \frac{V_v}{V_t} * 100\%$$

- Theoretical range : 0 to 100 %



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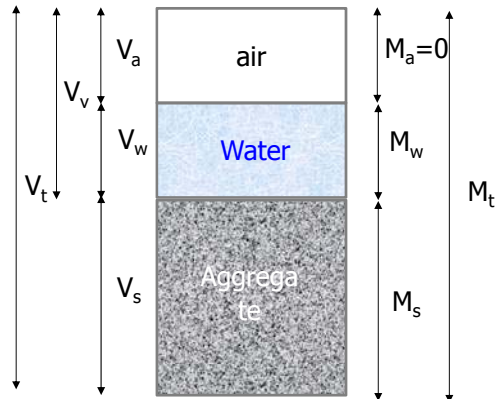


## Void ratio (e)

● **Void ratio (e)** is defined as the ratio of the volume of voids over the volume of aggregate

$$e = \frac{V_v}{V_s}$$

$$n = \frac{e}{1 + e}$$



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## Degree of saturation (S)

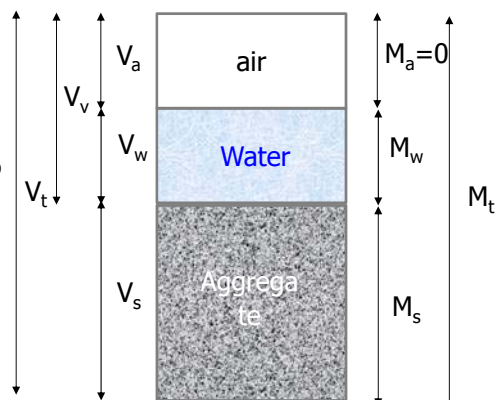
● **Degree of saturation (S)** is the percentage of the void volume filled by water

$$S = \frac{V_w}{V_v} * 100\%$$

- Dry aggregate materials  $S = 0\%$
- Fully saturated  $S = 100\%$
- Unsaturated ( $0\% < S < 100\%$ )

**Note:**

$$G_w = S e$$



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## Densities ( $\rho$ )

- **Densities** is the unit mass of a material
- ◆ Units : g/cm<sup>3</sup>, kg/m<sup>3</sup>, lb/ft<sup>3</sup>, t/m<sup>3</sup>, g/ml,
- ◆ **Density of water** ( $\rho_w = 1.0 \text{ g/cm}^3 = 1000 \text{ kg/m}^3 = 62.4 \text{ lb/ft}^3$ )
- ◆ **Bulk density** ( $\rho_m$ ) is the density of the aggregate materials in the current state.

$$\rho_m = \frac{M_T}{V_T}$$

- ◆ **Dry density** ( $\rho_d$ ) is the density of the aggregate materials in dry state

$$\rho_d = \frac{M_S}{V_T}$$

- ◆ **Solid density** ( $\rho_s$ ) is the density of the aggregate materials in solid state

$$\rho_s = \frac{M_S}{V_S}$$

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## Specific Gravity (G)

- **Specific gravity** is the ratio of density of aggregate mix to the density of water

$$G_S = \frac{\rho_S}{\rho_w} \quad G_S = \frac{M_S}{V_S \rho_w}$$

$$\rho_S = \frac{M_S}{V_S}$$

$$G_S = \frac{\rho_d V_t}{V_S \rho_w}$$

$$\rho_d = \frac{M_S}{V_t} = \frac{G_S}{1+e} \rho_w$$

$$\frac{V_S}{V_t} = \frac{\rho_d}{G_S \rho_w}$$

- Unit volume of aggregate

$$\frac{V_V}{V_t} = 1 - \frac{\rho_d}{G_S \rho_w}$$

- Unit volume of voids

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## Example

1. A cubic meter of aggregate in its natural state weighs 17.75kN, after being dried it weighs 15.08kN. The specific gravity of the aggregate is 2.70. Determine the degree of saturation (S), void ratio (e), porosity (n), and gravimetric water content (w) the aggregate as its natural state.

### Given

Total volume of aggregate  $V_t = 1\text{m}^3$

Total weight of aggregate  $W_t = 17.75\text{kN}$

Dry weight of aggregate  $W_s = 15.08\text{kN}$

Specific gravity of aggregate  $G_s = 2.70$

### Solution (on whiteboard)

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## Questions?