Pavement Materials & Design

Aggregates Blending

Introduction

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Aggregate Production

The Hashemite University

https://www.youtube.com/watch?v=iChSAX816aw

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Aggregate Production

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Aggregate classifications by size

الجامعة الهاشمية The Hashemite University

Local classification

العدسية

الفولية

الجوزية

رمل

الناعمة (السمسية)

الحمصية

Imagez source: https://www.slideserve.com/avel/4803086

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Aggregates

1.2.2.2 Properties

Properties of Aggregates

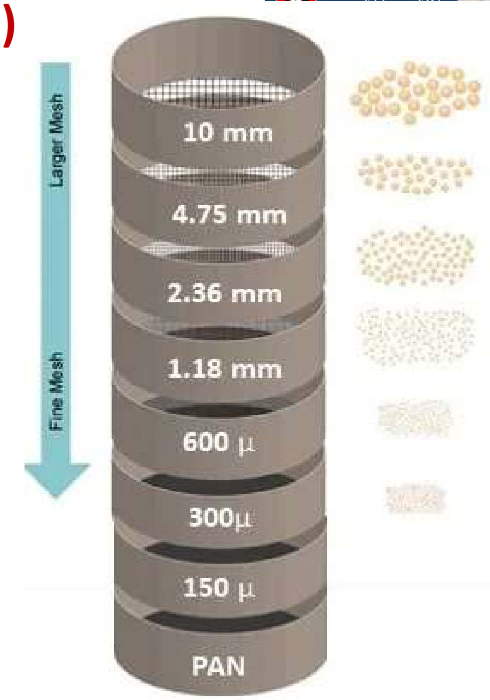
1. Particle size and gradation.
2. Hardness or resistance to wear
3. Durability or resistance to weathering.
4. Chemical stability
5. Particle shape and surface texture.
6. Freedom from deleterious particles or substances.
7. Specific gravity & absorption.

Particle size distribution (gradation)

- Gradation
  - *Blend of particle sizes in the mix.*
  - *It is the most important property of an aggregate*
- Gradation affects on the following properties of asphalt mixes
  1. *Stiffness*
  2. *Stability*
  3. *Durability*
  4. *Permeability*
  5. *Workability*
  6. *Fatigue resistance*
  7. *Frictional resistance*
  8. *Resistance to moisture damage*
  9. *Economy of pavement structure.*

Particle size distribution (gradation)

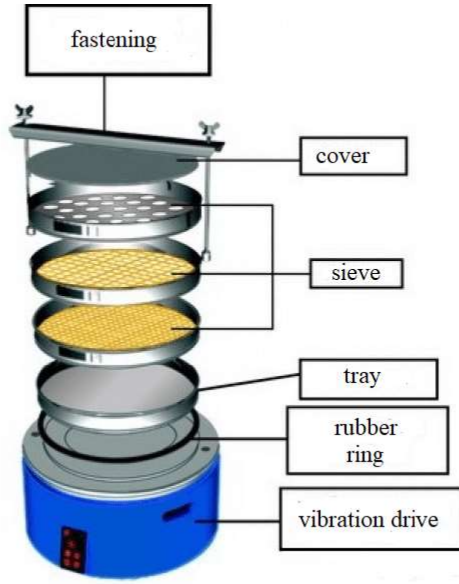
- Gradation is evaluated by passing the aggregates through a series of sieves
  - *Called “Sieve analysis”*
- Sieve analysis:
  - *Determination of particle size distribution of fine and coarse aggregates by sieving,*
  - *Expressed as %*
  - *Grain size analysis data are plotted on aggregate gradation chart*



https://civiconcepts.com/blog/sieve-analysis

Aggregate

Mechanical Sieve



https://www.researchgate.net/publication/349246117_Mathematical_Modeling_of_Coal_Dust_Screening_by_Means_of_Sieve_Analysis_and_Coal_Dust_Combustion_Based_on_New_Methods_of_Piece-Linear_Function_Approximation/figures?lo=1&utm_source=google&utm_medium=organic

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Aggregate

Mechanical Sieve

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Sieve Analysis example

Example -1

- A sieve analysis test was performed on a sample of fine aggregate and produced the following results

Sieve, mm	4.75	2.36	2.00	1.18	0.60	0.30	0.15	0.075	pan
Amount retained, g	0	33.2	56.9	83.1	151.4	40.4	72.0	58.3	15.6

- Calculate the percent passing each sieve
- Draw a 0.45 power gradation chart with the use of a spreadsheet program.

Example 1 – Solution

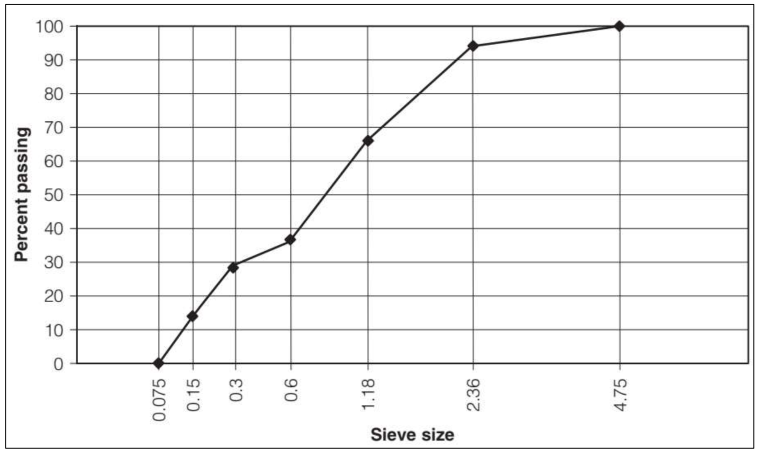
Percent passing each sieve

Sieve size	Amount Retained, g (a)	Cumulative Amount Retained, g (b)	Cumulative Percent Retained (c) = (b) × 100/Total	Percent Passing* (d) = 100 − (c)
4.75 mm (No. 4)	0	0	0	100
2.36 mm (No. 8)	33.2	33.2	6	94
2.00 mm (No. 10)	56.9	90.1	18	82
1.18 mm (No. 16)	83.1	173.2	34	66
0.60 mm (No. 30)	151.4	324.6	64	36
0.30 mm (No. 50)	40.4	365.0	71	29
0.15 mm (No. 100)	72.0	437.0	86	14
0.075 mm (No. 200)	58.3	495.3	96.9	3.1
Pan	15.6	510.9	100	
Total	510.9			

Example 1 – Solution

Draw a 0.45 power gradation chart

1	2	3
Sieve Size (mm)	Sieve to the 0.45 Power	Percent Passing
4.75	2.02	100
2.36	1.47	94
2	1.37	82
1.18	1.08	66
0.6	0.79	36
0.3	0.58	29
0.15	0.43	14
0.075	0.31	3.1



Aggregate

Aggregate classifications- by size based on

- **ASTM standard**
  - *Coarse aggregate:*
    - Aggregate retained on Sieve No. 4 (4.75 mm)
  - *Fine aggregate:*
    - Aggregate passing Sieve No. 4 (4.75 mm) and retained on Sieve No. 200 (0.075 mm)
  - *Mineral fillers/dust/fines:*
    - Aggregate passing Sieve No. 200 (0.075 mm)

Aggregate classifications by size

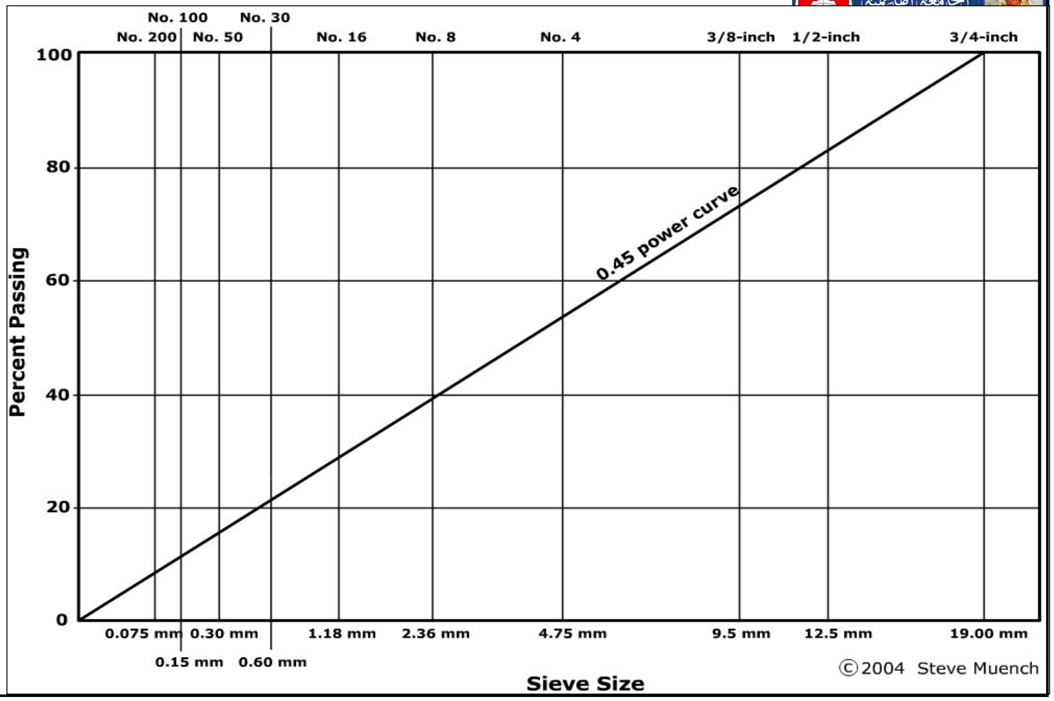


Image source: http://www.pavementinteractive.org/wp-content/uploads/2011/07/Gradation_terms.swf

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Maximum Aggregate Size

- Two parameters are used to represent the maximum aggregate size
  1. *Nominal Maximum Aggregate Size (NMAS)*
     - is the smallest sieve that retains some of the aggregate particles but generally not more than 10 percent by weight (according to ASTM standard)
  2. *Maximum aggregate size*
     - The smallest sieve through which 100 percent of the aggregate sample particles pass (or retained 0) (according to ASTM standard)

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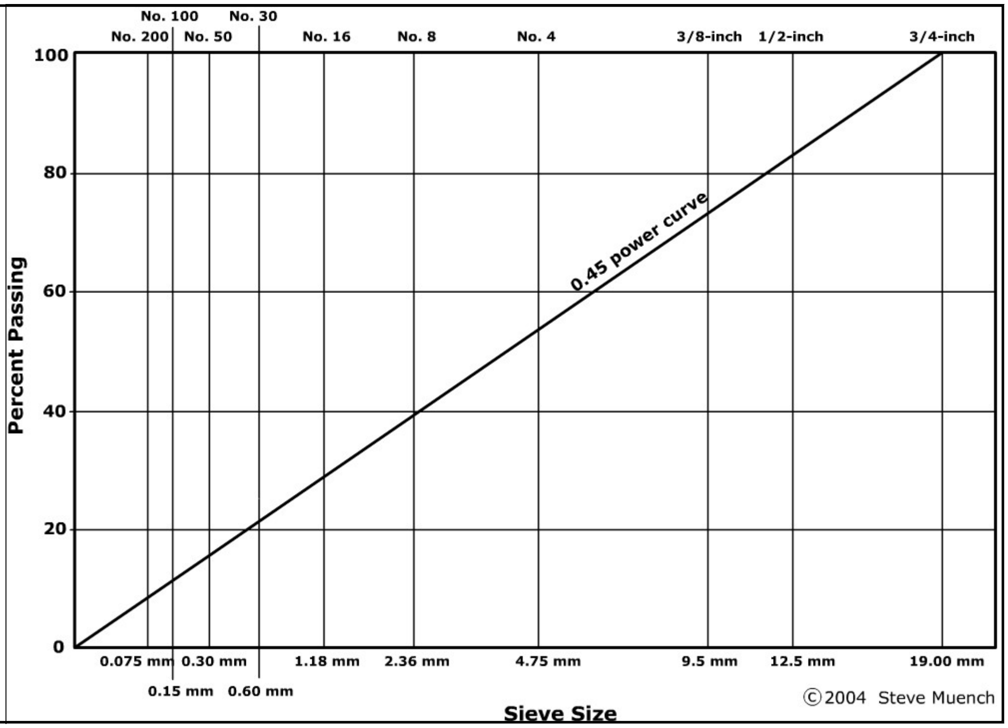
Aggregate gradation

Maximum density line



http://www.pavementinteractive.org/wp-content/uploads/2011/07/Gradation_terms.swf

Aggregate

Typical Gradations

- ❑ *Dense or well-graded.*
  - ➢ *Refers to a gradation that is near* ***maximum density****.*
  - ➢ *The most common HMA mix designs in the U.S. tend to use dense graded aggregate.*
- ❑ *Properties*
  - ➢ Good interlock
  - ➢ Low permeability

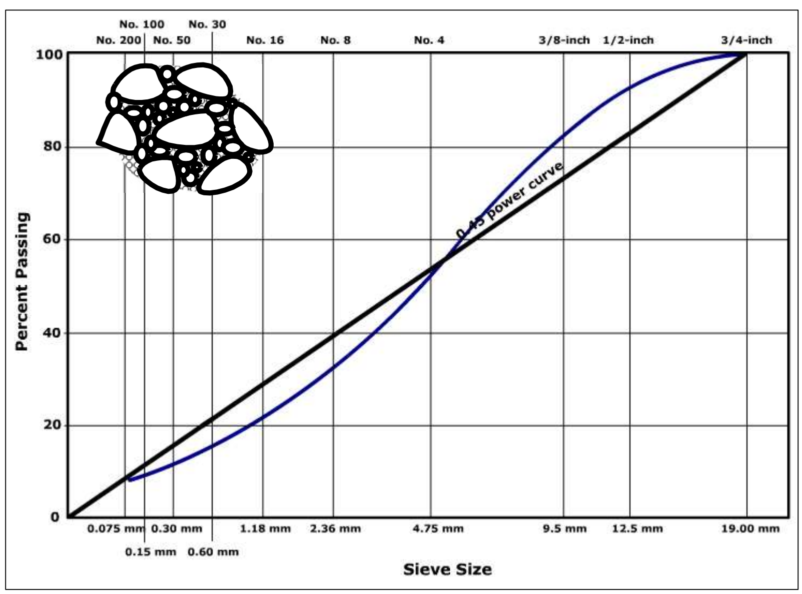
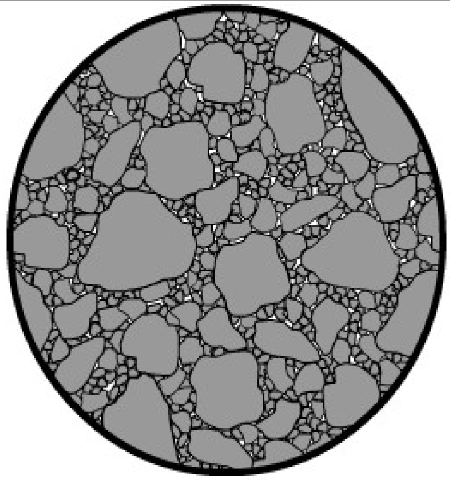


Image source: https://pavementinteractive.org/reference-desk/materials/aggregate/gradation-and-size/

Dense-graded asphalt Mixtures



Dense graded HMA contains all sizes of aggregate particles. There are enough fine particles to effectivly separate many of the coarse particles. Therefore, stress transmission through the HMA structure relies on both the coarse and fine particles. VMA is generally between 11 and 17%, air voids are generally near 4%, and asphalt binder content can range between 4.5 to 6%.

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Aggregate

Typical Gradations

- **Uniformly graded**
  - Or single size or one size
  - 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
- **Properties**
  - Few points of contact
  - Poor interlock (shape dependent)
  - High permeability

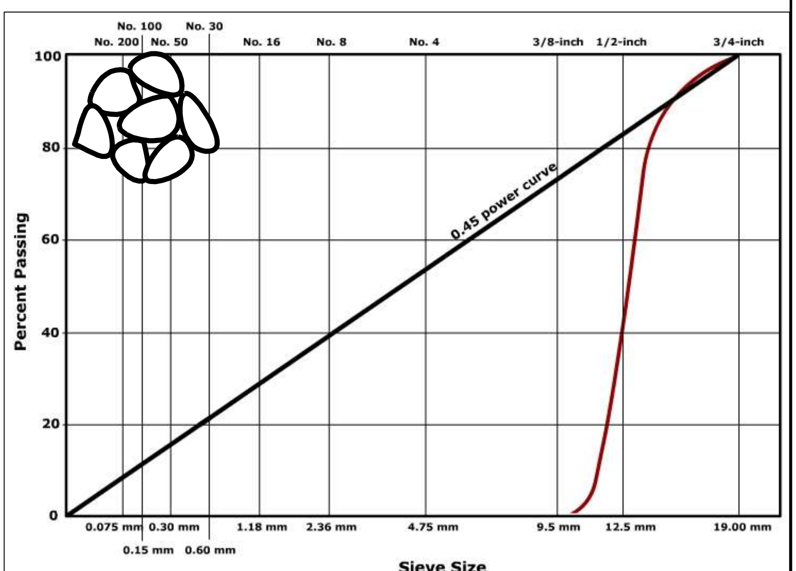

Image source: https://pavementinteractive.org/reference-desk/materials/aggregate/gradation-and-size/

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Aggregate

Typical Gradations

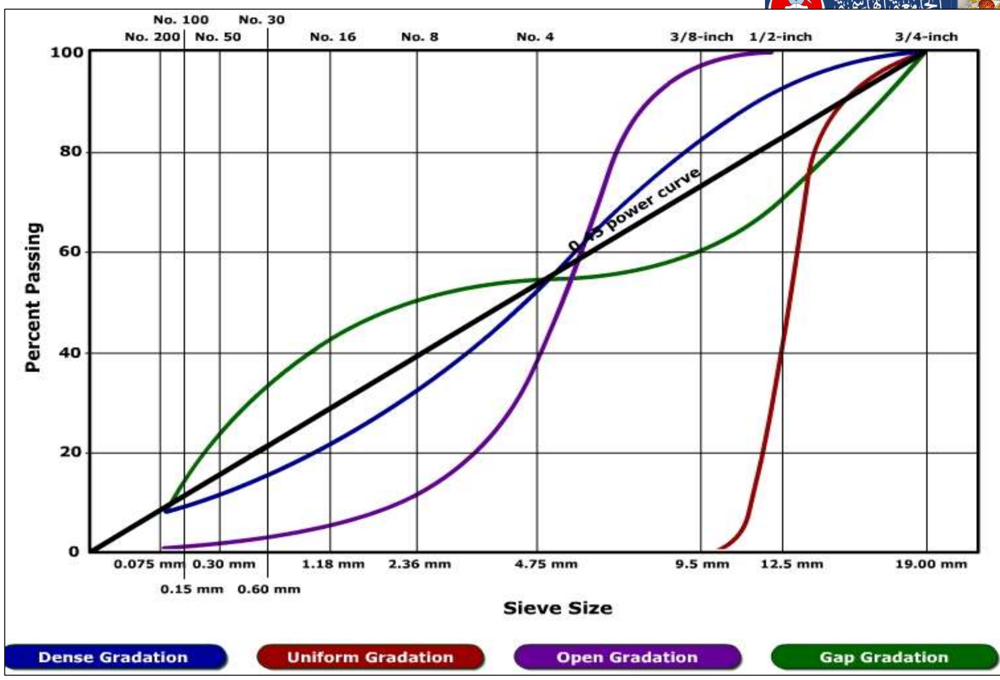

Image source: https://pavementinteractive.org/reference-desk/materials/aggregate/gradation-and-size/

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Aggregate

Gradation specifications (limits)

- Gradation specifications is used to define maximum and minimum cumulative percentages of material passing each sieve

Sieve	Percent Passing
9.5 mm (3/8″)	100
4.75 mm (No. 4)	95–100
2.36 mm (No. 8)	80–100
1.18 mm (No. 16)	50–85
0.60 mm (No. 30)	25–60
0.30 mm (No. 50)	10–30
0.15 mm (No. 100)	0–10

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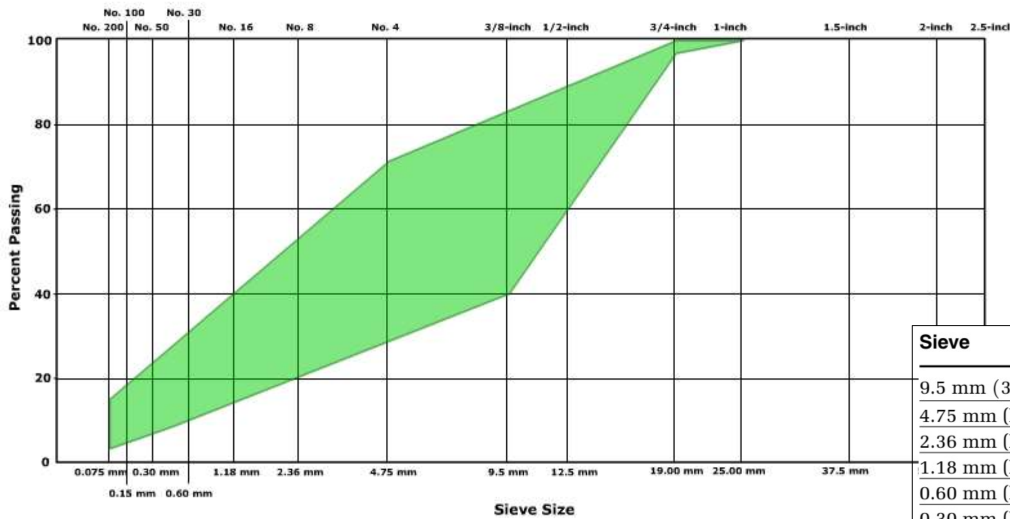
Gradation Specifications

Representative Gradation Specifications for surface Course



Sieve	Percent Passing
9.5 mm (3/8″)	100
4.75 mm (No. 4)	95–100
2.36 mm (No. 8)	80–100
1.18 mm (No. 16)	50–85
0.60 mm (No. 30)	25–60
0.30 mm (No. 50)	10–30
0.15 mm (No. 100)	0–10

Image source: https://pavementinteractive.org/reference-desk/materials/aggregate/gradation-and-size/

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Gradation Specifications

Representative Gradation Specifications for Base Course

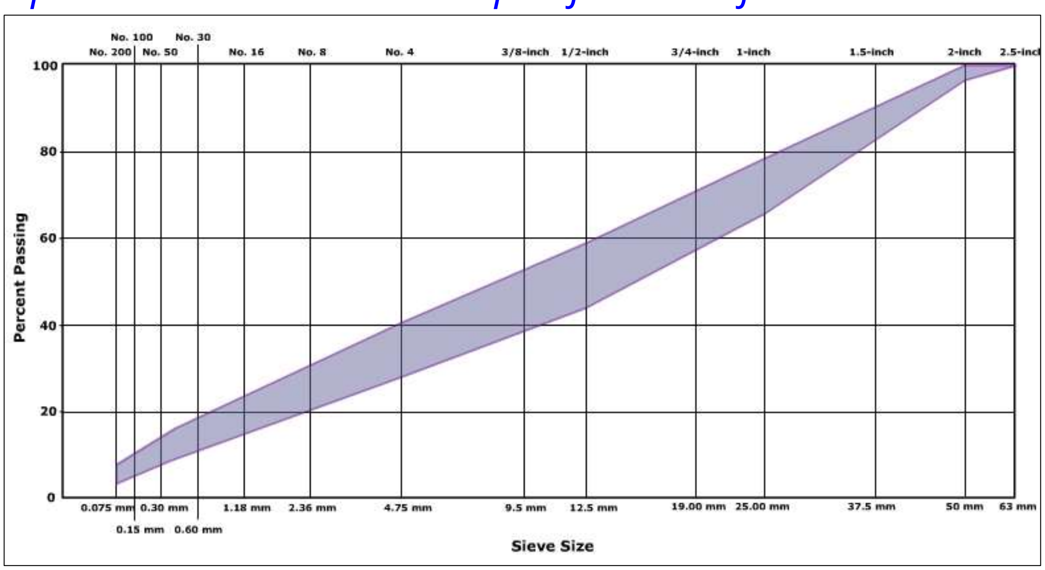

Image source: https://pavementinteractive.org/reference-desk/materials/aggregate/gradation-and-size/

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Gradation Specifications

Representative Gradation Specifications for Subbase Course

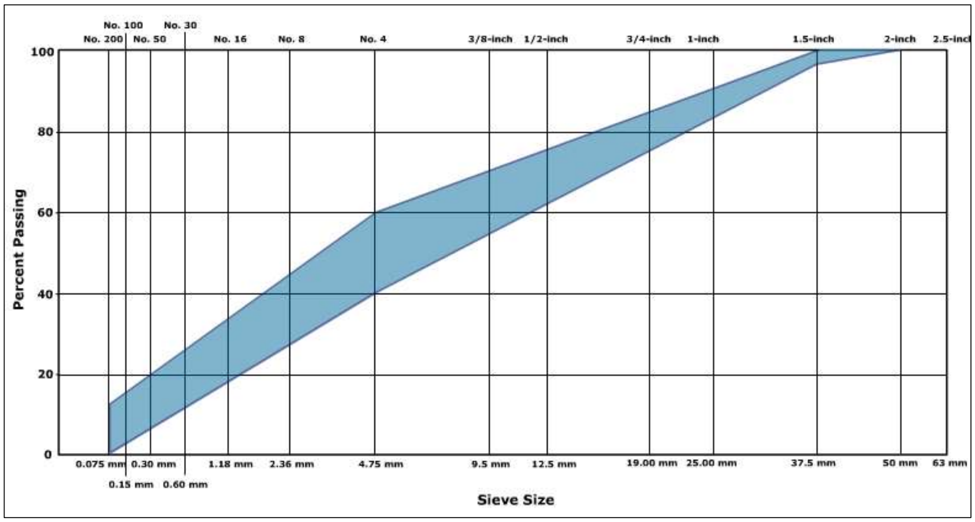

Image source: https://pavementinteractive.org/reference-desk/materials/aggregate/gradation-and-size/

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Gradation Specifications

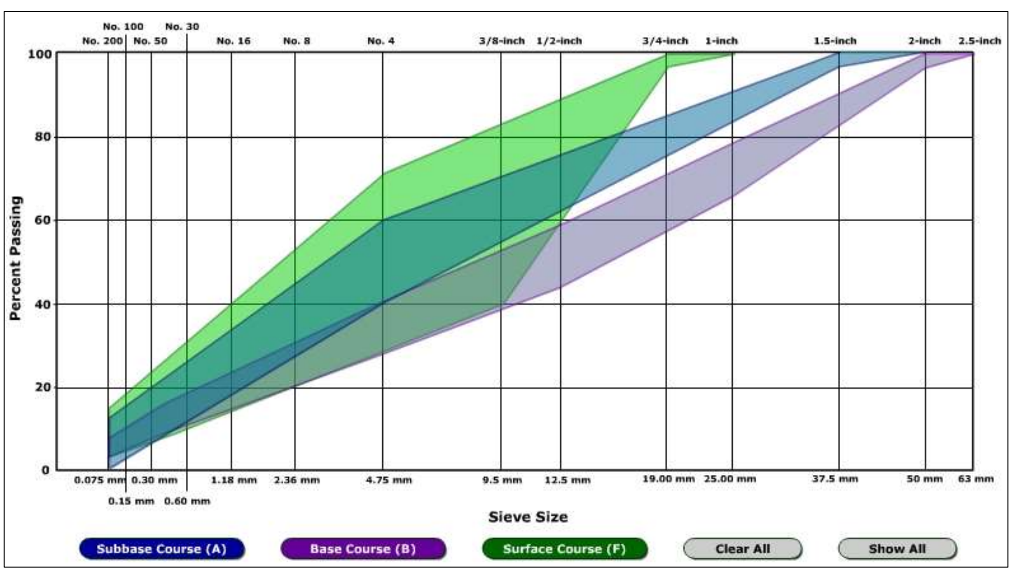

Image source: https://pavementinteractive.org/reference-desk/materials/aggregate/gradation-and-size/

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Aggregate

Aggregate blending

- A single aggregate source is generally **unlikely to meet gradation** requirements for Portland cement or asphalt concrete mixes
  - Thus, blending of aggregates from two or more sources would be required to satisfy the specifications.
- A trial-and-error process is generally used to determine the proportions
- The basic equation for blending is
  - $P_i = a \times Ai + B \times Bi + C \times Ci$;where
    - P_i = Percent blend materials passing sieve size I
    - A_i , B_i, C_i = Percent of aggregates from stockpiles A, B, C passing sieve size I
    - a,b, and c = devimal fraction by weight of aggregates from stockpiles A, B, C used in the blend

      * a + b+ c = 1.0

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Aggregate blending

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Example -3

- Determine a blend of the two aggregates shown in the table below, which will meet the specifications

Sieve	12.5 mm (1/2 in.)	9.5 mm (3/8 in.)	4.75 mm (No. 4)	2.00 mm (No. 10)	0.425 mm (No. 40)	0.180 mm (No. 80)	0.075 mm (No. 200)
Specification	100	95–100	70–85	55–70	20–40	10–20	4–8
Target gradation	100	98	77.5	62.5	30	15	6
% Passing Agg. A (A_i)	100	100	98	90	71	42	19
% Passing Agg. B (B_i)	100	94	70	49	14	2	1

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Example -3

Solution

Sieve	12.5 mm (1/2 in.)	9.5 mm (3/8 in.)	4.75 mm (No. 4)	2.00 mm (No. 10)	0.425 mm (No. 40)	0.180 mm (No. 80)	0.075 mm (No. 200)
Specification	100	95–100	70–85	55–70	20–40	10–20	4–8
Target gradation	100	98	77.5	62.5	30	15	6
% Passing Agg. A (A_i)	100	100	98	90	71	42	19
% Passing Agg. B (B_i)	100	94	70	49	14	2	1
30% A_i ($a.A_i$)	30	30	29.4	27	21.3	12.6	5.7
70% B_i ($b.B_i$)	70	65.8	49	34.3	9.8	1.4	0.7
Blend (P_i)	100	96	78	61	31	14	6.4

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Aggregate classifications by size

Local classification

العدسية

الفولية

الجوزية

رمل

الناعمة (السمسية)

الحمصية

Imagez source: https://www.slideserve.com/avel/4803086

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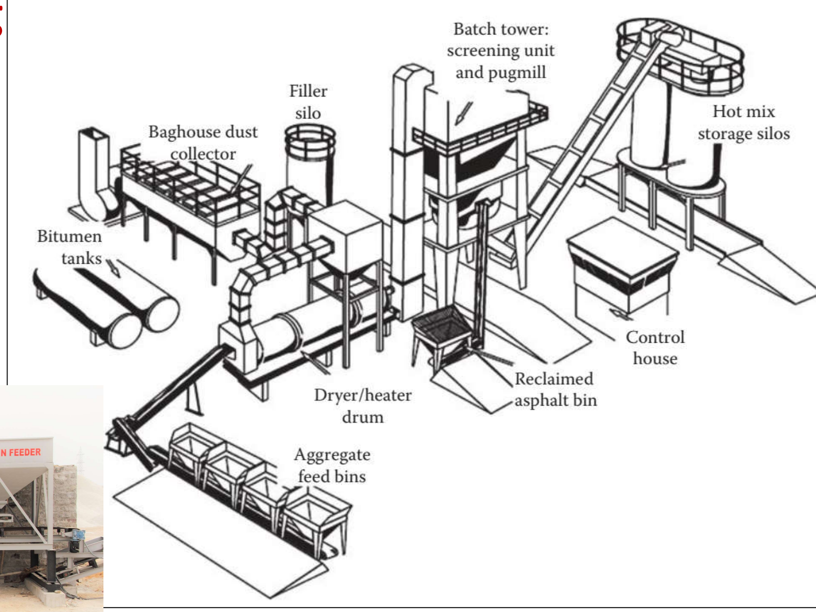
HMA Manufacturing

The batch plant



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HMA Manufacturing

The batch plant

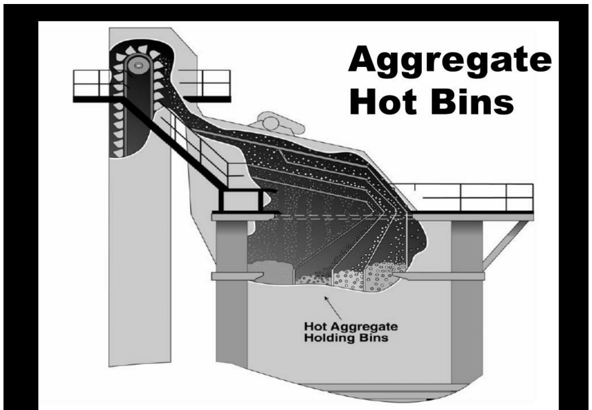
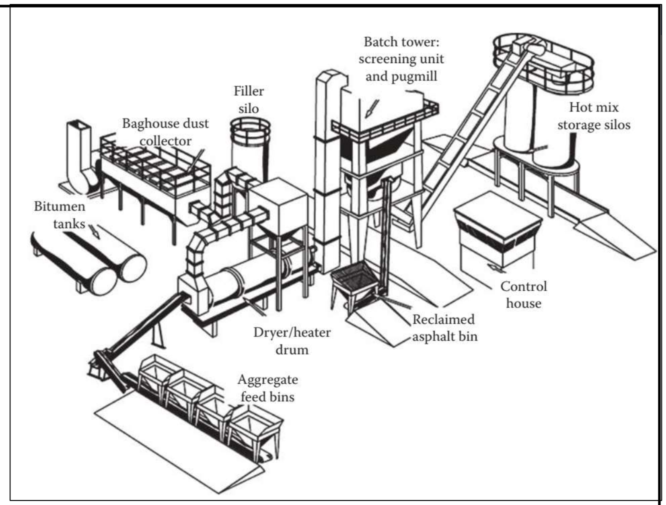


Figure 9.8 Hot bin area.



HMA Manufacturing

https://www.youtube.com/watch?v=n3Yefi-Pt1I

Aggregate class

Local classification

Aggregate Identification		Coarse Agg.	Medium Agg.	Medium-Fine Agg.	Fine Agg.
		Limestone Aggregate			
		حمصية	عدسية	سمسمية	ناعمة
		ركام جيري			
Test Name		Test Result			
- Sieve Analysis: -		% Passing by Weight			
Sieve Number *(Size, mm)*:	1" *(25.4)*	100	100	100	100
	3/4" *(19.0)*	100	100	100	100
	1/2" *(12.7)*	39	98	100	100
	3/8" *(9.50)*	3	32	100	100
	No. 4 *(4.75)*	1	4	18	100
	No. 8 *(2.36)*	1	3	4	66
	No. 20 *(0.85)*	1	3	4	38
	No. 50 *(0.30)*	1	3	4	24
	No. 80 *(0.18)*	1	3	3	20
	No. 200 *(0.075)*	0.6	2.6	3.2	16

Image source: https://www.slideserve.com/avel/4803086

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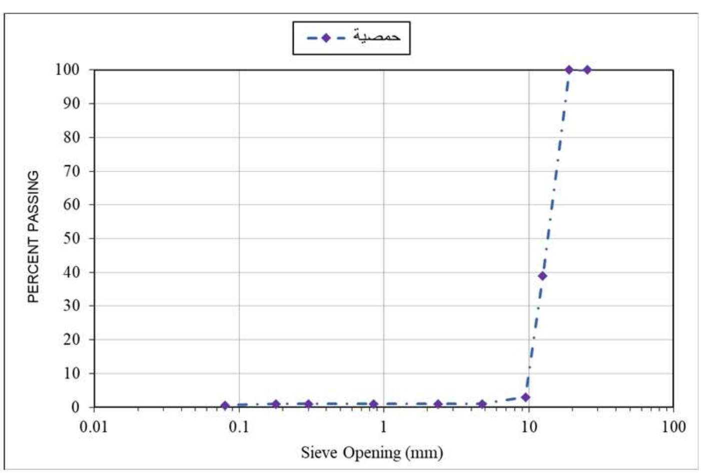
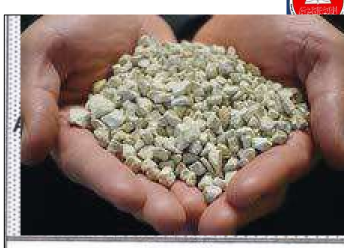
Aggregate classifications by size

Local classification





Test Name		Coarse Agg.
		حمصية
- Sieve Analysis: -		
Sieve Number *(Size, mm)*:	1" *(25.4)*	100
	3/4" *(19.0)*	100
	1/2" *(12.7)*	39
	3/8" *(9.50)*	3
	No. 4 *(4.75)*	1
	No. 8 *(2.36)*	1
	No. 20 *(0.85)*	1
	No. 50 *(0.30)*	1
	No. 80 *(0.18)*	1
	No. 200 *(0.075)*	0.6

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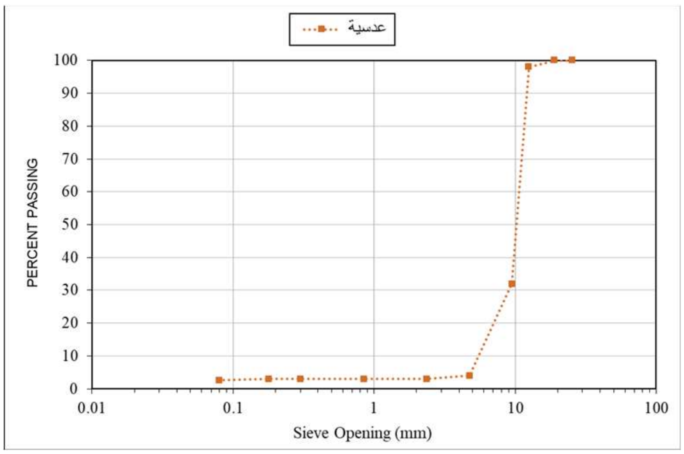
Aggregate classifications by size

Local classification



Medium Agg.

Limestone A

عدسية

جيري

Test Name		Test R
- Sieve Analysis: -		% Passing b
Sieve Number *(Size, mm)*:	1" *(25.4)*	100
	3/4" *(19.0)*	100
	1/2" *(12.7)*	98
	3/8" *(9.50)*	32
	No. 4 *(4.75)*	4
	No. 8 *(2.36)*	3
	No. 20 *(0.85)*	3
	No. 50 *(0.30)*	3
	No. 80 *(0.18)*	3
	No. 200 *(0.075)*	2.6

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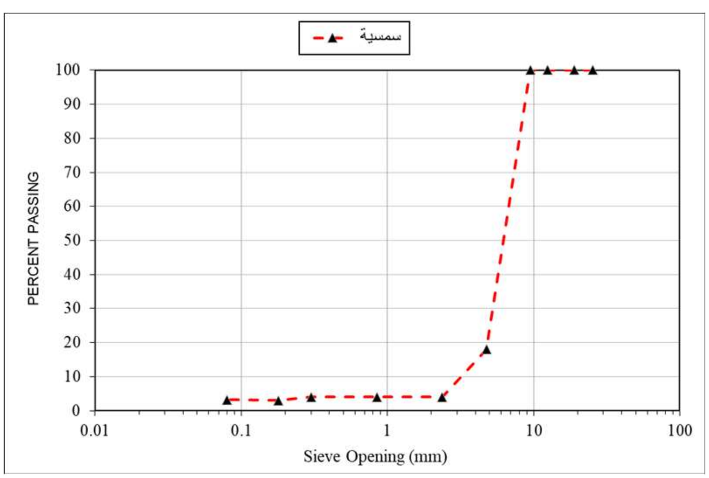
Aggregate classifications by size

Local classification



Medium-Fine Agg.

Aggregate

سمسمية

ركام

Test Name		Result
- Sieve Analysis: -		by Weight
Sieve Number *(Size, mm)*:	1" *(25.4)*	100
	3/4" *(19.0)*	100
	1/2" *(12.7)*	100
	3/8" *(9.50)*	100
	No. 4 *(4.75)*	18
	No. 8 *(2.36)*	4
	No. 20 *(0.85)*	4
	No. 50 *(0.30)*	4
	No. 80 *(0.18)*	3
	No. 200 *(0.075)*	3.2

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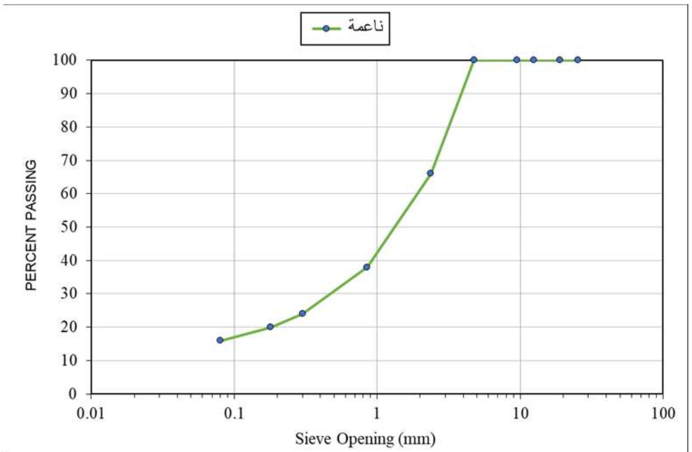
Aggregate classifications by size

Local classification



Test Name		Fine Agg. ناعمة
- Sieve Analysis: -		
Sieve Number *(Size, mm)*:	**1"** *(25.4)*	100
	3/4" *(19.0)*	100
	1/2" *(12.7)*	100
	3/8" *(9.50)*	100
	No. 4 *(4.75)*	100
	No. 8 *(2.36)*	66
	No. 20 *(0.85)*	38
	No. 50 *(0.30)*	24
	No. 80 *(0.18)*	20
	No. 200 *(0.075)*	16

Sieve No. *(Size, mm)*		/ Weight Specification Limits		
1"	(25)	100		
3/4"	(19)	90	-	100
1/2"	(12.5)	71	-	90
3/8"	(9.5)	56	-	80
No. 4	(4.75)	35	-	56
No. 8	(2.36)	23	-	38
No. 20	(0.850)	13	-	27
No. 50	(0.300)	5	-	17
No. 80	(0.180)	4	-	14
No. 200	(0.075)	2	-	8

HMA Mix Design

Asphalt Mixtures Volumetric

Specific Gravity for Aggregates

Aggregate Specific Gravity

- Due to permeable voids in aggregates, three types of S. G. are defined
  - *Apparent (G_{sa})*
    - the ratio of the oven-dry mass of a unit volume of aggregate (including only the impermeable void volumes) to the mass of the same volume of water
  - *Aggregate Bulk Specific Gravity (G_{sb})*
    - the ratio of the oven-dry mass of a unit volume of aggregate (including both the impermeable and water-permeable void volumes) to the mass of the same volume of water
  - *Effective (G_{se})*
    - The ratio of the oven-dry mass of a unit volume of aggregate (including both the impermeable void volumes and the water permeable voids not filled with absorbed asphalt) to the mass of the same volume of water

Aggregate Specific Gravity

Terms

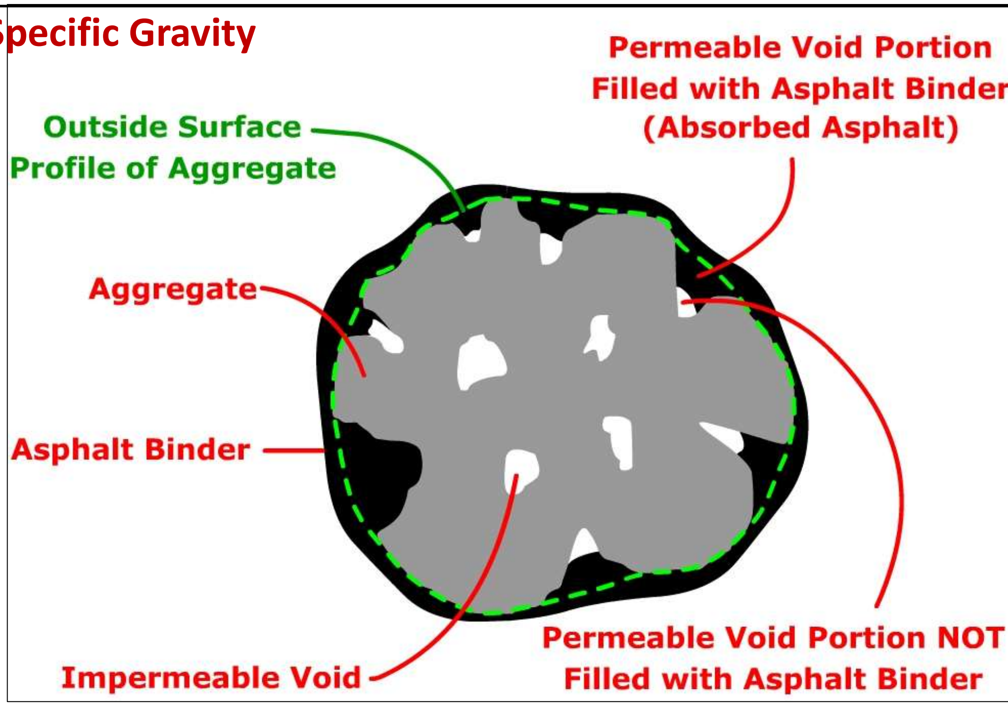


Image source: https://pavementinteractive.org/reference-desk/testing/aggregate-tests/coarse-aggregate-specific-gravity/

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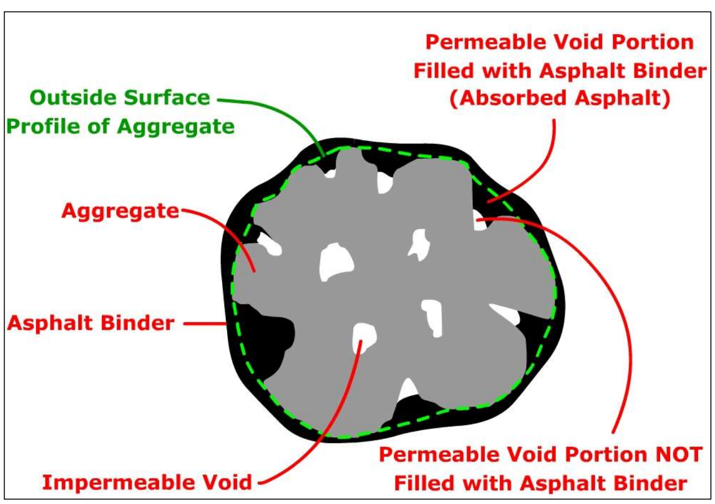
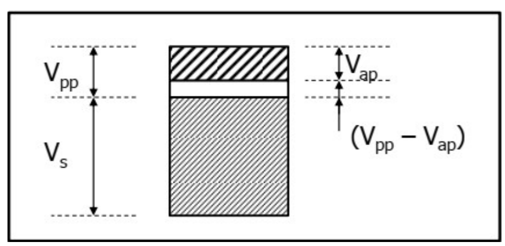
Aggregate Specific Gravity

The Hashemite University





- V_s : Volume of solids
- V_{pp} : Volume of water permeable pores
- V_{ap} : Volume of pores absorbing asphalt
  - *$V_{pp} - V_{ap}$: Volume of water permeable pores not filled with asphalt*

Image source: https://pavementinteractive.org/reference-desk/testing/aggregate-tests/coarse-aggregate-specific-gravity/

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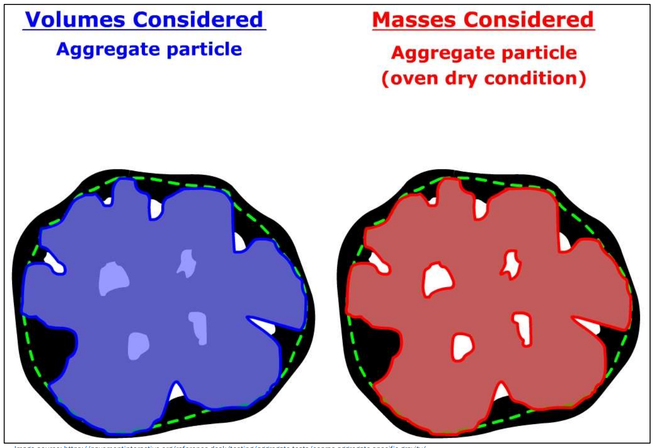
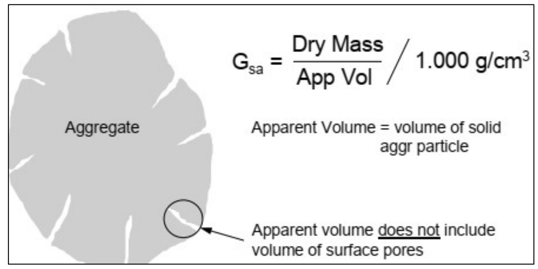
Aggregate Specific Gravity

Apparent Specific Gravity, G_{sa}

- The ratio of the mass in air of a unit volume of an impermeable material at a stated temperature to the mass in air of equal density of an equal volume of gas-free distilled water at a stated temperature





$$G_{sa} = \frac{W_s}{V_s \gamma_w} = \frac{M_s}{V_s \rho_w}$$

Image source: https://pavementinteractive.org/reference-desk/testing/aggregate-tests/coarse-aggregate-specific-gravity/

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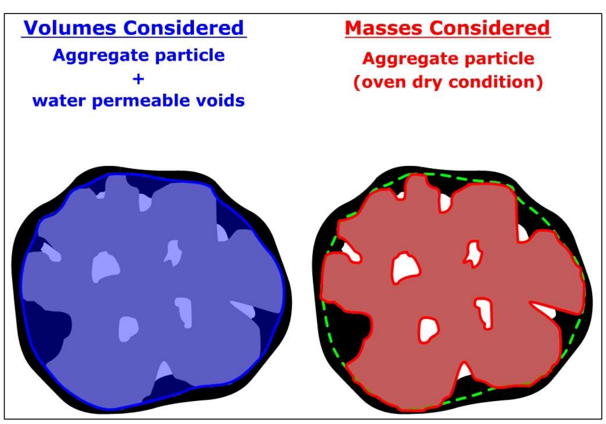
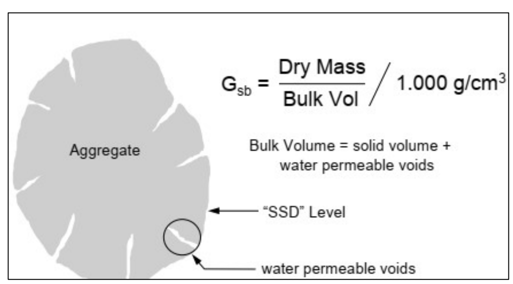
Aggregate Specific Gravity

Bulk Specific Gravity, G_{sb}

- The ratio of the mass in air of a unit volume of a permeable material to the mass in air of equal density of an equal volume of gas-free distilled water at a stated temperature.





$$G_{sb} = \frac{W_s}{(V_s + V_{pp})\gamma_w} = \frac{M_s}{(V_s + V_{pp})\rho_w}$$

Image source: https://pavementinteractive.org/reference-desk/testing/aggregate-tests/coarse-aggregate-specific-gravity/

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Aggregate Specific Gravity

Coarse *Aggregate Specific Gravity*

- Determined in accordance with ASTM C 127
  - Wash **5 kg** of aggregate retained on **No. 4 sieve.**
  - Oven dry to a constant weight.
  - Soak in water for **24 hours.**
  - Decant water.
  - Use pre-dampened towel to get **SSD** condition, weigh and record (**B**)
  - Place the SSD sample in a wire basket, **submerge in water**, then the submerged weight is determined and recorded (**C**)
  - **Oven dry** the sample to a constant weight, weigh and record (A)

- A: Oven-dry wt. of agg.(g)
- B: SSD wt. of agg. (g)
- C: submerged wt. of SSD agg. In water (g

$$G_{sa} = \frac{A}{A-C}$$

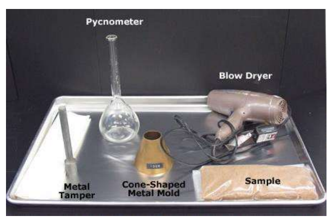
$$G_{sb} = \frac{A}{B-C}$$

$$G_{s,\,SSD} = \frac{B}{B-C}$$

$$\text{Apsorption, \%} = \frac{(B-A)\times 100}{A}$$

Aggregate Specific Gravity

Fine *Aggregate Specific Gravity*



- Determined in accordance with ASTM C 128
  - Fill **flask with water** and record weight as (**B**)
  - Oven-dry **1000 g** of fine aggregate.
  - Soak in water for **24 hours**
  - Spread out and dry (warm air moving current) to **SSD**?
  - Add **500 g of SSD aggregate** (**D**) to pycnometer of **known volume** pre-filled with some water
  - Add more water and **agitate** until **air bubbles** have been **removed**
  - Fill to line and determine the **mass** of the **pycnometer, aggregate** and **water** (**C**)
  - Empty aggregate into pan and **dry to constant mass**
  - Determine **oven dry** mass (**A**)

$$G_{sa} = \frac{A}{B+A-C}$$

$$G_{sb} = \frac{A}{B+D-C}$$

$$G_{s,\,SSD} = \frac{D}{B+D-C}$$

$$\text{Apsorption, \%} = \frac{(D-A)\times 100}{A}$$

- A: Oven-dry wt. of agg. (g)
- B: wt. of flask filled with water (to mark), (g)
- C: wt. of flask + SSD specimen + water (to mark), (g)
- D: SSD wt. (500 ▯ 10 g)

HMA Mix Design

Asphalt Mixtures Volumetric

Specific Gravity for Aggregate Blend

Aggregate Specific Gravity for blend

Aggregate Blend

- A single aggregate source is generally **unlikely to meet gradation** requirements for Portland cement or asphalt concrete mixes
  - Thus, blending of aggregates from two or more sources would be required to satisfy the specifications.
- A trial-and-error process is generally used to determine the proportions
- The basic equation for blending is
  - $P_i = a \times Ai + B \times Bi + C \times Ci$;*where*
    - P_i = Percent blend materials passing sieve size I
    - A_i , B_i, C_i = Percent of aggregates from stockpiles A, B, C passing sieve size I
    - a,b, and c = devimal fraction by weight of aggregates from stockpiles A, B, C used in the blend

      * a + b+ c = 1.0

Aggregate Specific Gravity for blend

Composite G_{sb} for one stockpile

- For stockpiles that include both a coarse and fine fraction
  - *One value must be determined for the stockpile.*
- The average G_{sb} can be calculated as follows:

$$G_{sb} = \frac{P_{coarse} + P_{fine}}{\frac{P_{coarse}}{G_{coarse}} + \frac{P_{fine}}{G_{fine}}}, \text{ where}$$

  - G_{sb} = bulk (dry) specific gravity of the aggregate
  - P_{coarse} = percentage by weight retained on the No. 4 (4.75 mm) sieve
  - P_{fine} = percentage by weight passing the No. 4 (4.75 mm) sieve
  - G_{coarse}= bulk (dry) specific gravity of the coarse fraction
  - G_{fine}= bulk (dry) specific gravity of the fine fraction

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Aggregate Specific Gravity for blend

Composite G_{sb} for one stockpile

- For stockpiles that include More than two aggregate sources
  - *One value must be determined for the stockpile.*
- The average G_{sb} can be calculated as follows:

$$G_{sb} = \frac{P_1 + P_2 + P_3 + \cdots \ldots P_n}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + \frac{P_3}{G_3} + \cdots \ldots \frac{P_n}{G_n} +}, \text{ where}$$

  - G_{sb} = bulk (dry) specific gravity of the aggregate
  - $P_{1,} P_2, P_3, P_n$ = Percentages by weight of aggregates 1, 2, through n
  - $G_{1,} G_2, G_3, G_n = P_{1,} P_2, P_3, P_n$ = Percentages by weight of aggregates 1, 2, through n

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Aggregate Specific Gravity for blend

Absorption (A) for the aggregate blend

- The absorptiveness of aggregate is of significant interest to the mixture designer and specifier.
  - *Absorption can be an indicator regarding aggregate quality along with increased binder demand.*
- The binder absorption is ***typically 40 –80 percent*** of the water absorption rate
- The water absorption rate is calculated by the following equation as outlined in AASHTO T 85

$$Absorption, \% = \frac{B-A}{A} \times 100$$

  - A = mass of the oven-dry test sample
  - B = mass of the saturated surface-dry sample
- The average water absorption for the total aggregate blend as shown in AASHTO T 85 is calculated as follows

$$Absorption\ \% = \frac{P_1 \times A_1 + P_2 \times A_2 + \cdots \ldots P_n \times A_n}{100}, \text{ where}$$

  - P_1, P_2, P_n = Percentages by weight of aggregates 1, 2, through n
  - A_1, A_2, A_n = absorption of aggregates 1, 2, through n

Aggregate Identification		Coarse Agg. 1	Coarse Agg. 2	Medium Agg.	Medium-Fine Agg.	Fine Agg.
		(Basalt)			(Mixed)	
		حصوية 1	حصوية 2	عدسية	سمسمية	ناعمة
		(بازلت)			(خليط)	
Test Name		Test Result				
- Sieve Analysis: -		% Passing by Weight				
Sieve Number (Size, mm):	1" (25)	100	100	100	100	100
	3/4" (19)	99	100	100	100	100
	1/2" (12.5)	1	54	100	100	100
	3/8" (9.5)	1	11	80	98	100
	No. 4 (4.75)	1	1	14	55	98
	No. 8 (2.36)	1	1	2	4	86
	No. 20 (0.850)	1	1	2	3	47
	No. 50 (0.300)	1	1	1	3	27
	No. 80 (0.180)	1	1	1	2	21
	No. 200 (0.075)	0.4	0.6	0.9	1.9	13.5
- Specific Gravity (SG):	Bulk SG. (Oven Dry)	2.748	2.741	2.736	2.718	2.703
	Bulk SG. (SSD)	2.797	2.791	2.788	2.782	2.773
	Apparent SG.	2.890	2.886	2.887	2.903	2.907
- Water Absorption, %		1.8	1.8	1.9	2.3	2.6

And the obtained combined grading was as follows: -

Sieve No. (Size, mm)	% Passing by Weight	
	Combined Grading	Specification Limits
1" (25)	100	100
3/4" (19)	99.9	90 - 100
1/2" (12.5)	84.8	71 - 90
3/8" (9.5)	72.4	56 - 80
No. 4 (4.75)	47.1	35 - 56
No. 8 (2.36)	29.9	23 - 38
No. 20 (0.850)	16.8	13 - 27
No. 50 (0.300)	10.0	5 - 17
No. 80 (0.180)	7.8	4 - 14
No. 200 (0.075)	5.2	2 - 8

Hot Bin Components			Hot Bin Proportions, %
Coarse Agg. 1	(Hot Bin 1)	حصوية 1	7.0
Coarse Agg. 2	(Hot Bin 2)	حصوية 2	18.0
Medium Agg.	(Hot Bin 3)	عدسية	21.0
Medium-Fine Agg.	(Hot Bin 4)	سمسمية	21.0
Fine Agg.	(Hot Bin 5)	ناعمة	33.0
Total		المجموع	100.0

Bulk Specific Gravity of Combined Aggregate	(Gsb) =	2.723
Effective Specific Gravity of Combined Aggregate	(Gse) =	2.779
Absorbed Asphalt by Weight of Aggregate	(Pba) =	0.75%