6.3 Asphalt Mixtures and HMA Marshall mix design method

Asphalt Mixtures

- Pavement mixtures are either:
  - **Asphalt concrete mixtures**
  - **Portland cement concert mixtures**
- Asphalt mixtures are a uniformly mixed combination of asphalt cement, coarse aggregate, fine aggregate, and filler materials
- Types of asphalt mixtures are:

  A) Hot-mix, hot-laid

  B) Hot mix, cold-laid

  C) Cold-mix, cold-laid

Asphalt Mixtures

- Highway pavement mixtures must:
  - Resist deformation from imposed traffic loads
  - Be skid resistant even when wet
  - Not be affected easily by weathering forces
- The design of the mix used in producing the material for the asphalt mixture defines it characteristics.

A) Hot-Mix, Hot-Laid Asphalt Mixture

- Produced by properly blending asphalt cement, coarse aggregate, fine aggregate, and filler (dust)
  - at temperatures ranging from about **79-163C** (175-325F)
    - » depending on the type of asphalt cement used
- Suitable types of asphalt materials include:
  - AC-20, AC-10, and AR-8000
  - with penetration grades of 60-70, 85-100, 120-150, and 200-300
- **Objective of the mix design: determine an optimum blend of the different components that will satisfy the requirements of the given specifications.**

A) Hot-Mix, Hot-Laid Asphalt Mixture

- Hot-mix, hot-laid asphalt mixture normally prepared for high-type pavement construction
- The mixture can be described as:
  - Open graded (3⁄8 to 3⁄4 in) or Dense-graded (1⁄2 to 1 in)
  - Coarse-graded (1⁄2 to 3⁄4 in) or Fine-graded (1⁄2 to 3⁄4 in)
- Note that when designing a hot-mix mixture, a favorable balance must be found between a **highly stable product and a durable one**.

A) Hot-Mix, Hot-Laid Asphalt Mixture

- The mixture design process can be divided into:
  - **A) Aggregate Gradation**
  - **B) Asphalt Content**

A) Hot-Mix, Hot-Laid Asphalt Mixture

A) Aggregate Gradation

- The first phase in any mix design is the selection and combination of aggregates.
  - » Mechanical stabilization
- Aggregates usually are categorized as:
  - » **Crushed rock** (coarse aggregate retained on sieve No. 8)
  - » **Sand** (fine aggregate passing sieve No. 8)
  - » **Filler** (mineral dust that passes sieve No. 200)

Table 18.3 shows examples of asphalt paving Mixes-ASTM

Table 18.3

Table 18.3 Examples of Composition of Asphalt Paving Mixtures

	Dense Mixtures								
	Mix Designation and Nominal Size of Aggregate								
Sieve Size	*2 in. (50 mm)*	*1½ in. (37.5 mm)*	*1 in. (25 mm)*	*¾ in. (19 mm)*	*½ in. (12.5 mm)*	*⅜ in. (9.5 mm)*	*No. 4 (4.75 mm) (Sand Asphalt)*	*No. 8 (2.36 mm)*	*No. 16 (1.18 mm) (Sheet Asphalt)*
	Grading of Total Aggregate (Coarse Plus Fine, Plus Filler if Required) Amounts Finer Than Each Laboratory Sieve (Square Opening), Weight %								
2½ in. (63 mm)	100	...	...	...	...	...	...	...	...
2 in. (50 mm)	90 to 100	100	...	...	...	...	...	...	...
1½ in. (37.5 mm)	...	90 to 100	100	...	...	...	...	...	...
1 in. (25 mm)	60 to 80	...	90 to 100	...	...	...	...	...	...
¾ in. (19 mm)	...	56 to 80	...	90 to 100	100	...	...	...	...
½ in. (12.5 mm)	35 to 65	...	56 to 80	...	90 to 100	100	...	...	...
⅜ in. (9.5 mm)	...	...	...	56 to 80	...	90 to 100	100	...	...
No. 4 (4.75 mm)	17 to 47	23 to 53	29 to 59	35 to 65	44 to 74	55 to 85	80 to 100	...	100
No. 8 (2.36 mm)[A]	10 to 36	15 to 41	19 to 45	23 to 49	28 to 58	32 to 67	65 to 100	...	95 to 100
No. 16 (1.18 mm)	...	...	...	...	...	...	40 to 80	...	85 to 100
No. 30 (600 μm)	...	...	...	...	...	...	25 to 65	...	70 to 95
No. 50 (300 μm)	3 to 15	4 to 16	5 to 17	5 to 19	5 to 21	7 to 23	7 to 40	...	45 to 75
No. 100 (150 μm)	...	...	...	...	...	...	3 to 20	...	20 to 40
No. 200 (75 μm)[B]	0 to 5	0 to 6	1 to 7	2 to 8	2 to 10	2 to 10	2 to 10	...	9 to 20
	Open Mixtures								
	Mix Designation and Nominal Maximum Size of Aggregate								
Sieve Size	*2 in. (50 mm)*	*1½ in. (37.5 mm)*	*1 in. (25 mm)*	*¾ in. (19 mm)*	*½ in. (12.5 mm)*	*⅜ in. (9.5 mm)*	*No. 4 (4.75 mm) (Sand Asphalt)*	*No. 8 (2.36 mm)*	*No. 16 (1.18 mm) (Sheet Asphalt)*
	Base and Binder Courses						*Surface and Leveling Courses*		
2½ in. (63 mm)	100	...	...	...	...	...	...	...	...
2 in. (50 mm)	90 to 100	100	...	...	...	...	...	...	...

Table 18.3 (continued)

1½ in. (37.5 mm)	...	90 to 100	100	...	...	...	...	...	...
1 in. (25 mm)	40 to 70	...	90 to 100	100	...	...	...	...	...
¾ in. (19 mm)	...	40 to 70	...	90 to 100	100	...	...	...	...
½ in. (12.5 mm)	18 to 48	...	40 to 70	...	85 to 100	100	...	...	...
⅜ in. (9.5 mm)	...	18 to 48	...	40 to 70	60 to 90	85 to 100	...	...	...
No. 4 (4.75 mm)	5 to 25	6 to 29	10 to 34	15 to 39	20 to 50	40 to 70	...	100	...
No. 8 (2.36 mm)[A]	0 to12	0 to 14	1 to 17	2 to 18	5 to 25	10 to 35	...	75 to 100	...
No. 16 (1.18 mm)	...	...	...	...	3 to 19	5 to 25	...	50 to 75	...
No. 30 (600 μm)	0 to 8	0 to 8	0 to 10	0 to 10	...	...	...	28 to 53	...
No. 50 (300 μm)	...	...	...	...	0 to 10	0 to 12	...	8 to 30	...
No. 100 (150 μm)	...	...	...	...	...	...	...	0 to 12	...
No. 200 (75 μm)[B]	...	...	...	...	...	...	...	0 to 5	...
	Bitumen, Weight % of Total Mixture[C]								
	2 to 7	3 to 8	3 to 9	4 to 10	4 to 11	5 to 12	6 to 12	7 to 12	8 to 12

[A] In considering the total grading characteristics of a bituminous paving mixture, the amount passing the No. 8 (2.36 mm) sieve is a significant and convenient field control point between fine and coarse aggregate. Gradings approaching the maximum amount permitted to pass the No. 8 sieve will result in pavement surfaces having comparatively fine texture, while coarse gradings approaching the minimum amount passing the No. 8 sieve will result in surfaces with comparatively coarse texture.
[B] The material passing the No. 200 (75 μm) sieve may consist of fine particles of the aggregates or mineral filler, or both, but shall be free of organic matter and clay particles. The blend of aggregates and filler, when tested in accordance with Test Method D4318, shall have a plasticity index of not greater than 4, except that this plasticity requirement shall not apply when the filler material is hydrated lime or hydraulic cement.
[C] The quantity of bitumen is given in terms of weight % of the total mixture. The wide difference in the specific gravity of various aggregates, as well as a considerable difference in absorption, results in a comparatively wide range in the limiting amount of bitumen specified. The amount of bitumen required for a given mixture should be determined by appropriate laboratory testing, on the basis of past experience with similar mixtures, or by a combination of both.
SOURCE: *Annual Book of ASTM Standards, Section 4, Construction*, Vol. 04.03, Road and Paving Materials; Pavement Management Technologies, American Society for Testing and Materials, Philadelphia, PA, 2007.

Local (Palestinian) Specifications

SIEVE SIZE	PERCENT PASSING BY-WEIGHT GRADATION			
	Binder Course	Wearing Course	Thin Course*	Thin Course*
	(1”)	(3/4”)	(1/2”)	(3/8”)
1”	100	-	-	-
3/4”	70-100	100	100	-
1/2”	54-82	74-95	90-100	100
3/8”	44-74	60-86	-	90-100
No 4	32-54	40-65	45-70	60-80
No 8	-	-	25-55	35-65
No 10	-	25-45	-	-
No 20	14-30	16-30	-	-
No 40	8-23	10-22	-	-
No 50	-	-	5-20	6-25
No 80	4-15	6-15	-	-
No 200	2-8	3-8	2-9	2-10

A) Hot-Mix, Hot-Laid Asphalt Mixture

A) Aggregate Gradation

- The procedure used to select and combine aggregates is shown in the **following example**

Example 18.1 Determining Proportions of Different Aggregates to Obtain a Required Gradation

Table 18.4 gives the specifications for the aggregates and mix composition for highway pavement asphaltic concrete and Table 18.5 shows the results of a sieve analysis of samples from the materials available. We must determine the proportions of the separate aggregates that will give a gradation within the specified limits.

A) Hot-Mix, Hot-Laid Asphalt Mixture

A) Aggregate Gradation

Table 18.4 Required Limits for Mineral Aggregates Gradation and Mix Composition for an Asphalt Mixture for Example 18.1

Passive Sieve Designation	*Retained on Sieve Designation*	*Percent by Weight*
¾ in. (19 mm)	½ in.	0–5
½ in. (12.5 mm)	⅜ in.	8–42
⅜ in. (9.5 mm)	No. 4	8–48
No. 4 (4.75 mm)	No. 10	6–28
Total coarse aggregates	No. 10	48–65
No. 10 (2 mm)	No. 40	5–20
No. 40 (0.425 mm)	No. 80	9–30
No. 80 (0.180 mm)	No. 200	3–20
No. 200 (0.075 mm)	—	2–6
Total fine aggregate and filler	Passing No. 10	35–50
Total mineral aggregate in asphalt concrete		90–95
Asphalt cement in asphalt concrete		5–7
Total mix		100

A) Hot-Mix, Hot-Laid Asphalt Mixture

A) Aggregate Gradation

Table 18.5 Sieve Analysis of Available Materials for Example 18.1

Passing Sieve Designation	Retained on Sieve Designation	Percent by Weight: Coarse Aggregate	Fine Aggregate	Mineral Filler
¾ in. (19 mm)	½ in.	5	—	—
½ in. (12.5 mm)	⅜ in.	35	—	—
⅜ in. (9.5 mm)	No. 4	38	—	—
No. 4 (4.75 mm)	No. 10	17	8	—
No. 10 (2 mm)	No. 40	5	30	—
No. 40 (0.425 mm)	No. 80	—	35	5
No. 80 (0.180 mm)	No. 200	—	26	35
No. 200 (0.075 mm)	—	—	1	60
Total		100	100	100

A) Hot-Mix, Hot-Laid Asphalt Mixture

all three materials is required, since the coarse and fine aggregates do not together meet the requirement of 2 to 6 percent by weight of filler material. Therefore, a trial mix is selected arbitrarily within the prescribed limits. Let this mix be

Coarse aggregates = 55% (48–65% specified)
Fine aggregates = 39% (35–50% specified)
Filler = 6% (5–8% specified)

The selected proportions are then used to determine the combination of the different sizes as shown in Table 18.6. The calculation is based on the fundamental equation for the percentage of material P passing a given sieve for the aggregates 1, 2, 3 and is given as

$$P = aA_1 + bA_2 + cA_3 + \cdots \tag{18.3}$$

where

A_1, A_2, A_3 = the percentages of material passing a given sieve for aggregates 1, 2, 3
a, b, c = the proportions of aggregates 1, 2, 3 used in the combination
$a + b + c + \cdots = 100$

Note that this is true for any number of aggregates combined.

It can be seen that the combination obtained, as shown in the last column of Table 18.6, meets the specified limits as shown in the last column of Table 18.4. The trial combination is therefore acceptable. Note, however, that the first trial may not always meet the specified limits. In such cases, other combinations must be tried until a satisfactory one is obtained.

A) Hot-Mix, Hot-Laid Asphalt Mixture

Table 18.6 Computation of Percentages of Different Aggregate Sizes for Example 18.1

Passing Sieve Size	*Retained on Sieve Size*	*Percent by Weight* Coarse Aggregate	Fine Aggregate	Mineral Filler	Total Aggregate
19 mm	12.5 mm	$0.55 \times 5 = 2.75$	—	—	2.75
12.5 mm	9.5 mm	$0.55 \times 35 = 19.25$	—	—	19.25
9.5 mm	No. 4	$0.55 \times 38 = 20.90$	—	—	20.90
No. 4	No. 10	$0.55 \times 17 = 9.35$	$0.39 \times 8 = 3.12$	—	12.47
No. 10	No. 40	$0.55 \times 5 = 2.75$	$0.39 \times 30 = 11.70$	—	14.45
No. 40	No. 80	—	$0.39 \times 35 = 13.65$	$0.06 \times 5 = 0.3$	13.95
No. 80	No. 200	—	$0.39 \times 26 = 10.14$	$0.06 \times 35 = 2.10$	12.24
No. 200	—	—	$0.39 \times 1 = 0.39$	$0.06 \times 60 = 3.60$	3.99
Total		55.0	39.0	6.0	100.00

A) Hot-Mix, Hot-Laid Asphalt Mixture

B) Asphalt Contents

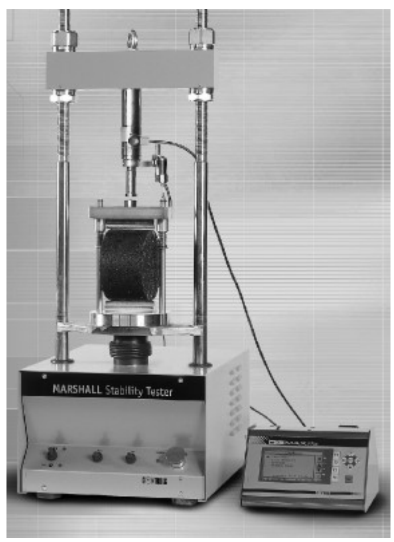
- This part aims to determine the **optimum percentage of asphalt**.
  - » This percentage should be within the prescribed limits
- The gradation of the aggregates and the optimum amount of asphalt cement usually are referred to as the job-mix formula (**JMF**).
- Two commonly used methods to determine the optimum asphalt content:
  - » **Marshall method,**
  - » **Hveem method**

Marshall Method

- The original concepts of this method were developed by Bruce Marshall.
  - Test specimens of 4 in diameter and 2 ½ in height.
  - They are prepared by a specified procedure of heating, mixing, and compacting the mixture of asphalt and aggregates which is subjected to:
    - » Stability flow test
    - » Density-voids analysis

Marshall Method

- **Stability:** **is the maximum load resistance *N* in pounds that the specimen will achieve at 140F under specified conditions**.
- **Flow:** **is the total movement of the specimen in units of 0.01'' during the stability test as the load is increased from zero to the maximum**.



Marshall Stability Equipment

Marshall Method / Test procedure

- Test specimens for the Marshall method are prepared for a range of asphalt contents within the prescribed limits **(usually every 0.5%)**
- At least **three specimens** are provided for each asphalt content,
  - to facilitate the provision of adequate data
- The amount of aggregates required for each specimen is about **1.2 kg**
- The aggregates is dried at a temperature between **105C (221F)** and **110C (230F)** until a constant weight is obtained.

Marshall Method / Test procedure

- **The mixing temperature** for this procedure is set as the temperature that will produce a kinematic viscosity of 170±20 centistokes, or a Saybolt Furol viscosity of 85±10 seconds, in the asphalt.
- **The compacting temperature** is that which will produce a kinematic viscosity of 280±30 centistokes, or a Saybolt Furol viscosity of 160±15 seconds.
- The compactive effort used is either **35, 50, or 75** blows of the hammer falling a distance of 18 in., depending on the design traffic category
  - Both sides compaction

Marshall Method / Optimum AC

- **The optimum asphalt content can be estimated according to the following steps:**

① Calculate the average bulk density for each level of asphalt mixture for the 3 specimens.

$$G_{mb} = \frac{W_a}{W_a - W_w}$$

W_a = weight of sample in air (g)
W_w = weight of sample in water (g)

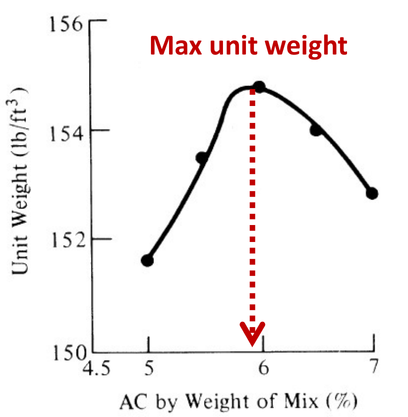
– The average unit weight of each mixture is then obtained by:

$$\text{Average unit weight} = G_{mb} \times \gamma_w$$

$$\text{where the desnsity of the water} = 62.4 Ib / ft^3$$

Marshall Method / Optimum AC

① Plot the unit weight with the asphalt content by weight %



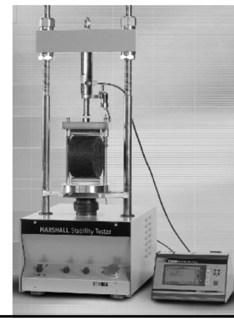
(a) Unit of weight versus asphalt content

Marshall Method / Optimum AC

② Calculate the average Marshall stability (Ib) and the flow value (0.01 in) at each asphalt AC %

– **Marshall Stability Test**

- the specimen is immersed in a bath of water at a temperature of **60±1 C** (**140±1.8F**) for a period of **30 to 40 minutes**.
- The specimen is loaded at a constant rate of deformation of **0.2 in. (5 mm)** per minute until failure occurs.

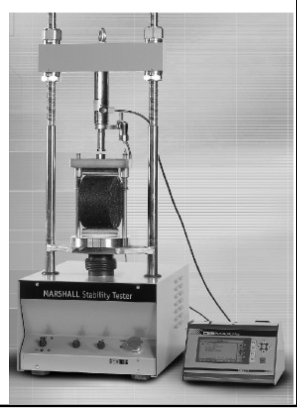


Marshall Method / Optimum AC

– **Marshall Stability Test**

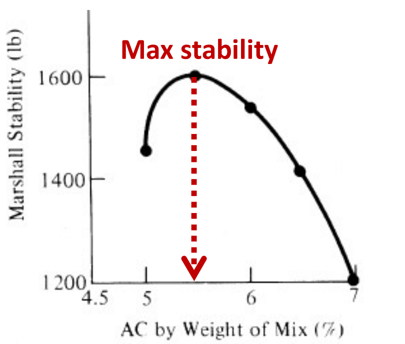
- **Marshall stability value:** The total load N in pounds that causes failure of the specimen at 60C (140F).
- **Flow value:** The total amount of deformation in units of 0.01 in. that occurs up to the point the load starts decreasing (failure point)

The total time between removing the specimen from the bath and completion of the test **should not exceed 30 seconds.**

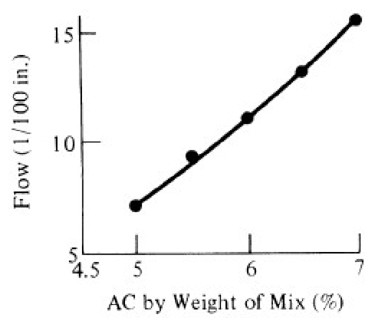


Marshall Method / Optimum AC

② Plot the stability and flow with the asphalt content by weight %.



(b) Marshall stability versus asphalt content



(c) Flow versus asphalt content

Marshall Method / Optimum AC

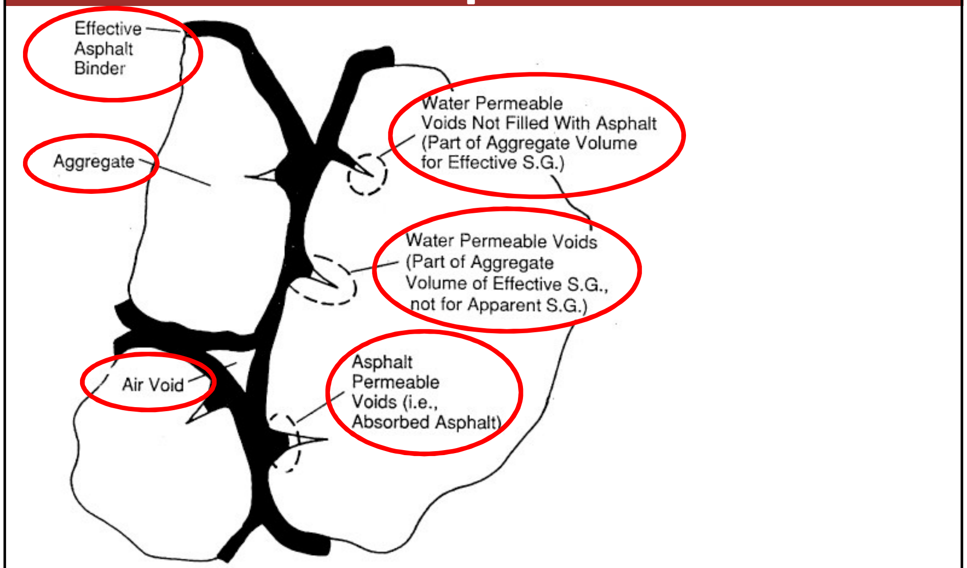
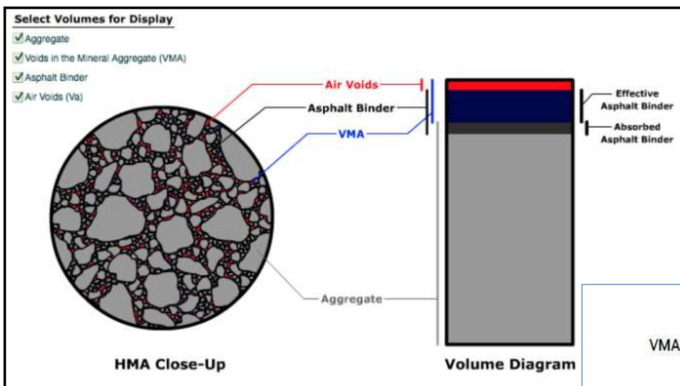


Figure 18.14 Bulk, Effective, and Apparent Specific Gravities; Air Voids; and Effective Asphalt Content in Compacted Asphalt Paving Mixture



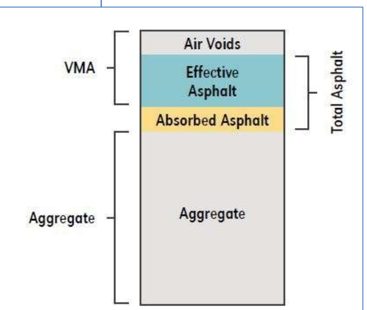


Figure 2: Simplified representation of asphalt, aggregate, and air in a compacted asphalt mix specimen

interchange

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Aggregates and HMA Mix Tests & Calculations

- **Aggregates:**
  - Percentages by weight (**P_s**) of Aggregate Mix (and ca, fa, mf)
  - Bulk Specific Gravity (**G_{sb}**) of Aggregate Mix (and ca, fa, mf)
  - Apparent Specific Gravity (**G_{asb}**) of Aggregate Mix (and ca, fa, mf)
- **Bitumen**
  - Percentages by weight of bitumen **(P_b)**
  - Bulk Specific Gravity of bitumen **(G_b)**
- **Asphalt Mix**
  - Percent Voids in compacted Mineral Aggregate **(VMA)**
  - Bulk Specific Gravity of compacted mix **(G_{mb})**
  - % air voids **(P_a)**
  - Maximum specific gravity of paving mix **(G_{mm})**
  - Effective Specific Gravity of Aggregate **(G_{se})**
  - Asphalt absorption **(P_{ba})**
  - Effective Asphalt Content **(P_{be})**

interchange

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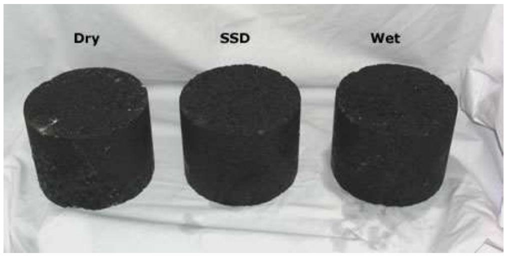
Specific Gravity test of the mix



interchange

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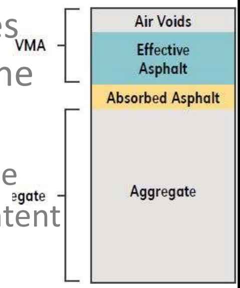
Marshall Method / Optimum AC

③ Calculate the percent Voids in compacted Mineral Aggregate **VMA**.

- **VMA:** the percentage of void spaces between the granular particles in the compacted paving mixture,
  - including the air voids and the volume occupied by the effective asphalt content



$$VMA = 100 - \frac{G_{mb} P_s}{G_{sb}}$$

VMA = percent voids in compacted mineral aggregates (percent of bulk volume)
G_{mb} = bulk specific gravity of compacted mixture
G_{sb} = bulk specific gravity of aggregate
P_s = aggregate percent by weight of total paving mixture

Marshall Method / Optimum AC

$$VMA = 100 - \frac{G_{mb} P_s}{G_{sb}}$$

- P_s**:** aggregate percent by weight of total paving mixture is calculated by:

$$P_s = 1 - P_b$$

P_b = percent by weight of asphalt in paving mixture

Marshall Method / Optimum AC

– **Bulk Specific Gravity of Aggregate G_{sb}:**

$$G_{sb} = \frac{\text{the weight in air of a unit volume (including all normal voids) of a permeable material at a selected temperature}}{\text{the weight in air of the same volume of gas-free distilled water at the same selected temperature}}$$

– Since the aggregate mixture consists of different fractions aggregate with different specific gravities,

- the bulk specific gravity of the total aggregate in the paving mixture is given as:

Marshall Method / Optimum AC

$$G_{sb} = \frac{P_{ca} + P_{fa} + P_{mf}}{\frac{P_{ca}}{G_{bca}} + \frac{P_{fa}}{G_{bfa}} + \frac{P_{mf}}{G_{bmf}}}$$

G_{sb} = bulk specific gravity of aggregates in the paving mixture

P_{ca}, P_{fa}, P_{mf} = percent by weight of coarse aggregate, fine aggregate, and mineral filler, respectively, in the paving mixture. (Note that P_{ca}, P_{fa}, and P_{mf} could be found either as a percentage of the paving mixture or as a percentage of only the total aggregates. The same results will be obtained for G_{sb})

$G_{bca}, G_{bfa}, G_{bmf}$ = bulk specific gravities of coarse aggregate, fine aggregate, and mineral filler, respectively

- **It is not easy to accurately determine the bulk specific gravity of the mineral filler.**
  – **The apparent specific gravity may therefore be used with very little error**

Marshall Method / Optimum AC

– **Apparent Specific Gravity of Aggregates G_{asb}:**

$$G_{asb} = \frac{\text{the weight in air of a unit volume (including all normal voids) of an impermeable material at a selected temperature}}{\text{the weight of an equal volume of distilled water at the same temperature}}$$

$$G_{asb} = \frac{P_{ca} + P_{fa} + P_{mf}}{\frac{P_{ca}}{G_{aca}} + \frac{P_{fa}}{G_{afa}} + \frac{P_{mf}}{G_{amf}}}$$

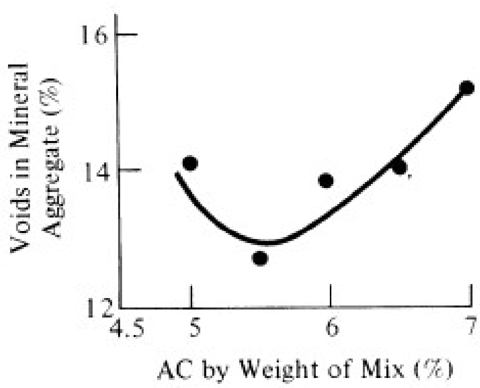
G_{asb} = *apparent* specific gravity of the aggregate mixture

P_{ca}, P_{fa}, P_{mf} = percent by weight of coarse aggregate, fine aggregate, and mineral filler, respectively, in the mixture

$G_{aca}, G_{afa}, G_{amf}$ = apparent specific gravities of coarse aggregate, fine aggregate, and mineral filler, respectively

Marshall Method / Optimum AC

③ Plot the VMA with the asphalt content by weight %.



(d) VMA versus asphalt content

Marshall Method / Optimum AC

④ Calculate the percent air voids in compacted mixture P_a.

– **Percent Air Voids in Compacted Mixture P_a** : the ratio (expressed as a percentage) between the volume of the small air voids between the coated particles and the total volume of the mixture.

$$P_a = 100\frac{G_{mm} - G_{mb}}{G_{mm}}$$

P_a = percent air voids in compacted paving mixture
G_{mm} = maximum specific gravity of the compacted paving mixture
G_{mb} = bulk specific gravity of the compacted paving mixture

Marshall Method / Optimum AC

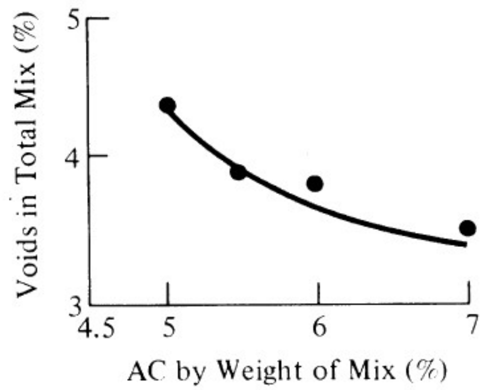
- **Maximum Specific Gravity of Paving Mixture G_{mm}**
  – It assumes no air voids in the asphalt concrete.
  – Best accuracy is attained at mixtures near the **optimum asphalt content**.
  – A special test is conducted to determine the maximum specific gravity for all the samples with different asphalt cement content.

$$G_{mm} = \frac{100}{(P_s/G_{se}) + (P_b/G_b)}$$

G_{mm} = maximum specific gravity of paving mixture (no air voids)
P_s = percent by weight of aggregates in paving mixture
P_b = percent by weight of asphalt in paving mixture
G_{se} = effective specific gravity of the aggregates (assumed to be constant for different asphalt cement contents)
G_b = specific gravity of asphalt

Marshall Method / Optimum AC

④ Plot the percent air voids in compacted mixture P_a with the asphalt content by weight %.



(e) Voids in total mix versus asphalt content

Marshall Method / Optimum AC

⑤ The previous plots are used to select the asphalt contents for:

- ✓ **maximum stability**
- ✓ **maximum unit weight**
- ✓ **percent voids in the total mix within the limits specified (usually the median of the limits)**

- **The average of the asphalt contents is the optimum asphalt content.**
- Then stability and flow for this optimum content is obtained from the appropriate graphs and compared with **the required criteria (Table 18.7)**

Marshall Method / Optimum AC

Table 18.7 Suggested Test Limits

(a) Maximum and Minimum Values

Marshall Method Mix Criteria	*Light Traffic ESAL < 10^4 (see Chapter 19)*	*Medium Traffic 10^4 < ESAL < 10^6 (see Chapter 19)*	*Heavy Traffic ESAL > 10^6 (see Chapter 19)*
Compaction (No. of blows each end of Specimen)	35	50	75
Stability *N* (lb)	3336 (750)	5338 (1200)	8006 (1800)
Flow, 0.25 mm (0.1 in.)	8 to 18	8 to 16	8 to 14
Air Voids (%)	3 to 5	3 to 5	3 to 5

(b) Mineral Percent Voids in Mineral Aggregates

Standard Sieve Designation	*Percent*
No. 16	23.5
No. 4	21
No. 8	18
⅜ in.	16
½ in.	15
¾ in.	14
1 in.	13
1½ in.	12
2 in.	11.5
2½ in.	11

SOURCE: Federal Highway Administration, U.S. Department of Transportation.

Marshall Method / Optimum AC

- **Other important parameters to be calculated:**
  1. Effective Specific Gravity of Aggregate G_{se}
  2. Asphalt absorption P_{ba}
  3. Effective Asphalt Content P_{be}

Marshall Method / Optimum AC

i. **Effective Specific Gravity of Aggregate G_{se} .**

– It is the specific gravity of the aggregates when all void spaces in the aggregate particles are included, **except those that are filled with asphalt**.

$$G_{se} = \frac{100 - P_b}{(100/G_{mm}) - (P_b/G_b)}$$

G_{se} = effective specific gravity of the aggregates
G_{mm} = maximum specific gravity of paving mixture (no air voids)
P_b = asphalt percent by total weight of paving mixture (thus 100 – P_b is the percent by weight of the base mixture that is not asphalt)
G_b = specific gravity of the asphalt

Marshall Method / Optimum AC

ii. **Asphalt absorption P_{ba}.**

– It is the percent by weight of the asphalt that is absorbed by the aggregates based on the total weight of the aggregates

$$P_{ba} = 100 \frac{G_{se} - G_{sb}}{G_{sb} G_{se}} G_b$$

P_{ba} = amount of asphalt absorbed as a percentage of the total weight of aggregates
G_{se} = effective specific gravity of the aggregates
G_{sb} = bulk specific gravity of the aggregates
G_b = specific gravity of asphalt

Marshall Method / Optimum AC

ii. **Effective Asphalt Content P_{be}.**

- It is the difference between the total amount of asphalt in the mixture and that absorbed into the aggregate particles
- The effective asphalt content is that which coats the outside of the aggregate particles and influences the pavement performance

$$P_{be} = P_b - \frac{P_{ba}}{100} P_s$$

P_{be} = effective asphalt content in paving mixture (percent by weight)
P_b = percent by weight of asphalt in paving mixture
P_s = aggregate percent by weight of paving mixture
P_{ba} = amount of asphalt absorbed as a percentage of the total weight of aggregates

Marshall Method / Optimum AC

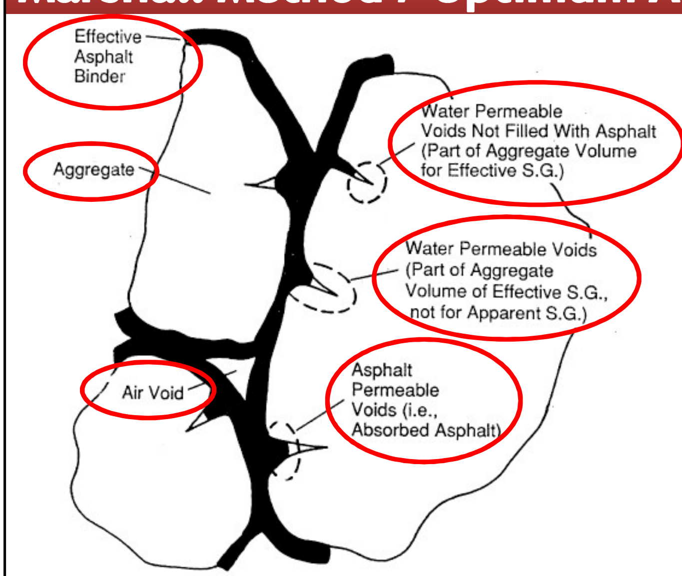


Figure 18.14 Bulk, Effective, and Apparent Specific Gravities; Air Voids; and Effective Asphalt Content in Compacted Asphalt Paving Mixture

Marshall Method / Optimum AC

Example 18.2

Example 18.2 Designing an Asphalt Concrete Mixture

In designing an asphalt concrete mixture for a highway pavement to support medium traffic, data in Table 18.8 showing the aggregate characteristics and Table 18.9 (page 984) showing data obtained using the Marshall method were used. Determine the optimum asphalt content for this mix for the specified limits given in Table 18.7.

Table 18.8 Aggregate Characteristics for Example 18.2

Aggregate Type	*Percent by Weight of Total Paving Mixture*	*Bulk Specific Gravity*
Coarse	52.3	2.65
Fine	39.6	2.75
Filler	8.1	2.70

Note: The nominal maximum particle size in the aggregate mixture is 1 in.

Example 18.2, continued

Example 18.2

Table 18.9 Marshall Test Data for Example 18.2

Asphalt % by Weight of Total Mix	*Weight of Specimen (g)* in Air 1	in Air 2	in Air 3	in Water 1	in Water 2	in Water 3	*Stability (lb)* 1	Stability 2	Stability 3	*Flow (0.01 in.)* 1	Flow 2	Flow 3	*Maximum Specific Gravity of Paving Mixture*
5.0	1325.6	1325.4	1325.0	780.1	780.3	779.8	1460	1450	1465	7	7.5	7.	2.54
5.5	1331.3	1330.9	1331.8	789.6	789.3	790.0	1600	1610	1595	10	9.	9.5	2.56
6.0	1338.2	1338.5	1338.1	798.6	798.3	797.3	1560	1540	1550	11	11.5	11.	2.58
6.5	1343.8	1344.0	1343.9	799.8	797.3	799.9	1400	1420	1415	13	13.	13.5	2.56
7.0	1349.0	1349.3	1349.8	798.4	799.0	800.1	1200	1190	1210	16	15.	16.	2.54

Example 18.2, continued

For 5% asphalt content, the average bulk specific gravity is given as

$$G_{mb} = \frac{1}{3}\left(\frac{1325.6}{1325.6 - 780.1} + \frac{1325.4}{1325.4 - 780.3} + \frac{1325.0}{1325.0 - 779.8}\right)$$
$$= \frac{1}{3}(2.43 + 2.43 + 2.43)$$
$$= 2.43$$

Therefore, the bulk density is $2.43 \times 62.4 = 151.6\ \text{lb/ft}^3$.

interchange

Example 18.2, continued

$$VMA = 100 - \frac{G_{mb}P_s}{G_{sb}}$$

For 5% asphalt content,

$$G_{mb} = 2.43$$
$$P_{ta} = 95.0 \text{ (total aggregate percent)}$$

Use Eq. 18.5 to calculate G_{sb}.

$$G_{sb} = \frac{P_{ca} + P_{fa} + P_{mf}}{(P_{ca}/G_{bca}) + (P_{fa}/G_{bfa}) + (P_{mf}/G_{bmf})}$$

Determine P_{ca}, P_{fa}, and P_{mf} in terms of total aggregates.

$$P_{ca} = 0.523 \times 95.0 = 49.7$$
$$P_{fa} = 0.396 \times 95.0 = 37.6$$
$$P_{mf} = 0.081 \times 95.0 = 7.7$$

interchange

Example 18.2, continued

$$G_{sb} = \frac{49.7 + 37.6 + 7.7}{(49.7/2.65) + (37.6/2.75) + (7.7/2.70)} = 2.69$$

$$P_{ta} = (100 - 5) = 95$$

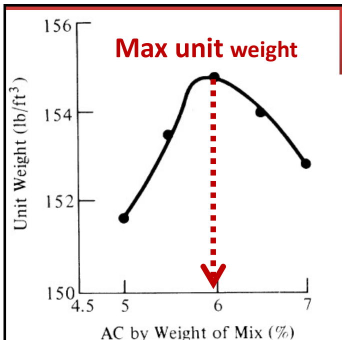
and

$$VMA = 100 - \frac{2.43 \times 95}{2.69} = 14.18$$

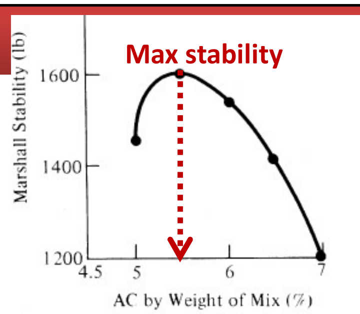
$$P_a = 100\,\frac{G_{mm} - G_{mb}}{G_{mm}}$$

For 5% asphalt content,

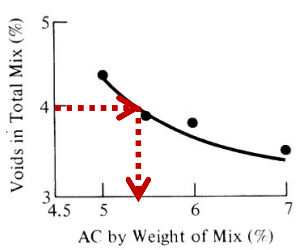
$$P_a = 100\,\frac{2.54 - 2.43}{2.54} = 4.33$$



(a) Unit of weight versus asphalt content



(b) Marshall stability versus asphalt content



(e) Voids in total mix versus asphalt content

$\%AC_{opt}$ = (6.0 + 5.5 + 5.4) / 3 = 5.6%

The mix meets all requirements in Table 18.7 for stability, flow, AV, & VMA.

Example 18.2, continued

The properties of the paving mixture containing the optimum asphalt content now can be determined from Figure 18.13 and compared with the suggested criteria given in Table 18.8. The values for this mixture are

Unit weight = 153.8 lb/ft^3
Stability = 1600 lb
Flow = 9.5 units of 0.01 in.
Percent void total mix = 3.9
Percent voids in mineral aggregates = 13

This mixture meets all the requirements given in Table 18.7 for stability, flow, and percent voids in total mix.

The mix meets all requirements in Table 18.7 for stability, flow, AV, & VMA.

interchange

Mix Specifications

Table 18.7 Suggested Test Limits

(a) Maximum and Minimum Values

Marshall Method Mix Criteria	*Light Traffic ESAL < 10^4 (see Chapter 19)*	*Medium Traffic 10^4 < ESAL < 10^6 (see Chapter 19)*	*Heavy Traffic ESAL > 10^6 (see Chapter 19)*
Compaction (No. of blows each end of Specimen)	35	50	75
Stability N (lb)	3336 (750)	5338 (1200)	8006 (1800)
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(b) Mineral Percent Voids in Mineral Aggregates

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1½ in.	12
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2½ in.	11

SOURCE: Federal Highway Administration, U.S. Department of Transportation.

A) Hot-Mix, Hot-Laid Asphalt Mixture

- **In general, the produced asphalt cement mixture should have:**
  - **Adequate amount of asphalt** to ensure a durable pavement
  - **Adequate mix stability** to prevent unacceptable distortion and displacement when traffic load is applied
  - **Adequate voids** to permit a small amount of compaction when traffic load is applied without loss of stability, blushing, and bleeding,
    - » Without causing harmful penetration of air and moisture into the compacted mixture.
  - **Adequate workability** to facilitate placement of the mix without segregation.

A) Hot-Mix, Hot-Laid Asphalt Mixture

- **When the mix design does not satisfy all of the requirements, it is necessary to adjust the original blend of aggregates.**
- Guidelines:
  - **Low Voids and Low Stability**
    - » Add coarse aggregate or reduce asphalt content
  - **Low Voids and Satisfactory Stability**
  - **High Voids and Satisfactory Stability**
    - » Add mineral dust filler in the mix
  - **Satisfactory Voids and Low Stability**
    - » The quality of the aggregate should be improved
  - **High Voids and Low Stability**

B) Hot-Mix, Cold-Laid Asphalt Mixture

- Asphalt mixtures here are **manufactured hot** and then shipped and laid immediately or stockpiled for future use.
- They are suitable for **small jobs**.
- They are also a suitable material for **patching high-type pavements**.
- The Marshall method of mix design can be used, with high-penetration asphalt
- The manufactured product should be discharged at a temperature of 170F ±10.

B) Hot-Mix, Cold-Laid Asphalt Mixture

- **In the production process:**
  - About 0.75 percent by weight of a **medium-curing cutback asphalt** MC-30 (after adding a wetting agent) is mixed with the aggregates for another 10 seconds.
  - Then high-penetration asphalt cement and water then are added simultaneously to the mixture
    - » Water is necessary to ensure that the material remains workable after cooling down to normal temperatures.
  - **Amount of water depends** on when the mixture is to be used.

C) Cold-Mix, Cold-Laid Asphalt Mixture

- **Emulsified asphalts and low-viscosity cutback asphalts are used.**
- **The production process is similar to that of the hot-mix asphalts, except that:**
  - Mixing is done at normal temperatures
  - It is not always necessary to dry the aggregates.
    - » However, saturated aggregates and aggregates with surface moisture should be dried before mixing.

C) Cold-Mix, Cold-Laid Asphalt Mixture

- **Types of Cold-Mix, Cold-Laid Asphalt Mixture:**
  1. **Seal Coats**
     - » **Fog Seal: a thin application of slow-curing emulsified asphalt, usually with no aggregate.**
       - Reduce the infiltration of air and water into the pavement
       - Prevent the progressive separation of aggregate particles from the surface downward or from the edges inward (raveling) in a pavement
       - Bring the surface of the pavement to its original state

C) Cold-Mix, Cold-Laid Asphalt Mixture

» **Slurry Seal**: **uniformly mix of a slow-setting asphalt emulsion, fine aggregate, mineral filler, and water.**

- Slurry seal is used as a low-cost maintenance material for pavements carrying light traffic.

» **Aggregate Seals**: **obtained by spraying asphalt, immediately covering it with aggregates, and then rolling the aggregates into the asphalt.**

C) Cold-Mix, Cold-Laid Asphalt Mixture

2. Prime Coats

» **It is obtained by spraying asphalt binder materials onto non-asphalt base courses.**

» **Used to** :

- **Provide a waterproof surface** on the base
- Fill capillary voids in the base
- Facilitate the bonding of loose mineral particles
- Facilitate the adhesion of the surface treatment to the base

C) Cold-Mix, Cold-Laid Asphalt Mixture

3. Take Coats

- » A thin layer of asphalt sprayed over an old pavement to facilitate the bonding of the old pavement and a new course which is to be placed over the old pavement.
- » Slow-setting emulsified asphalts or Rapid-curing cutback asphalts.

4. Surface Treatments

- » Obtained by applying asphalt material and suitable aggregates on a flexible base course to provide a suitable wearing surface for traffic.
- » It is used to protect the base course and to eliminate the problem of dust on the wearing surface

Superpave Systems

- New system for specifying the asphalt materials.
- Superpave → Superior Performing Asphalt Pavements.
- The disadvantages of prior methods:
  - It was difficult to relate the results obtained from laboratory analysis in the existing systems to the performance of the pavement without field experience (effect of Temperature).
  - Performed tests are empirical, and field experience is required to determine whether the results obtained have meaningful information

Superpave Systems

- **Advantages of Superpave Mix Design Method:**
  - Uses performance-based and performance-related characteristics as the selection criteria for the mix design.
  - It is unique in that it is performance-based and engineering principles can be used to relate the results obtained from its tests and analyses to field performance.