Marshal Mix Design

ASTM D1559 has standardized the Marshall Test procedures.

- Only applicable for hot-mix paving mixture
- Asphalt cement have to be used
- Maximum size of aggregate = 1” (25 mm) or less
- Standard test specimens are 2.5” (63.5 mm) high by 4” (101.6 mm) diameter
- Two principles feature of the method:
  - density - voids analysis
  - stability - flow test of the compacted test specimens
- The stability of the specimen is the maximum load resistance in pounds which the specimen can carry at 140 °F (60 °C)
- The flow value is the total movement or strain in units of 1/100 in. (0.25 mm) occurring in the specimen between no load and maximum load during the stability test
- In the Marshall method, each compacted test specimen is subjected to the following tests and analysis in the order listed:
  - Bulk Specific Gravity Determination
  - Stability - Flow Test
  - Density & Voids Analysis

- Marshall Design Criteria

Marshal mix criteria	Light traffic		Medium traffic		Heavy traffic	
	Min.	Max.	Min.	Max.	Min.	Max.
Compaction, number of blows on each end	35		50		75	
Stability, N (lb.)	3336 (750)	-	5338 (1200)	-	8006 (1800)	-
Flow, 0.25 mm	8	18	8	16	8	14
air voids	3	5	3	5	3	5
voids in mineral aggregate VMA	See table 19 – 7					
voids filled with asphalt VFA	70	80	65	78	65	75

TABLE 19-7 Minimum Percent Voids in the Mineral Aggregate (VMA) for the Marshall Method

Nominal Maximum Particle Size[1,2]		*Minimum VMA (percent)*		
		Design Air Voids (percent)[3]		
mm	*in.*	*3.0*	*4.0*	*5.0*
1.18	No. 16	21.5	22.5	23.5
2.36	No. 8	19.0	20.0	21.0
4.75	No. 4	16.0	17.0	18.0
9.5	⅜	14.0	15.0	16.0
12.5	½	13.0	14.0	15.0
19.0	¾	12.0	13.0	14.0
25.0	1.0	11.0	12.0	13.0
37.5	1.5	10.0	11.0	12.0
50	2.0	9.5	10.5	11.5
63	2.5	9.0	10.0	11.0

1 = Standard Specification for Wire Cloth Sieves for Testing Purposes, ASTM E11 (AASHTO M92)
2 = The nominal maximum particle size is one size larger than the first sieve to retain more than 10%
3 = Interpolate minimum VMA for design air void values between those listed.

Source: Modified from *Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types,* Manual Series No. 2, the Asphalt Institute.

1.

TABLE 18.2 Stability Correlation Ratios[A]

Volume of Specimen, cm^3	Approximate Thickness of Specimen, in.[B]	mm	Correlation Ratio
406 to 420	2	50.8	1.47
421 to 431	2 1/16	52.4	1.39
432 to 443	2 1/8	54.0	1.32
444 to 456	2 3/16	55.6	1.25
457 to 470	2 1/4	57.2	1.19
471 to 482	2 5/16	58.7	1.14
483 to 495	2 3/8	60.3	1.09
496 to 508	2 7/16	61.9	1.04
509 to 522	**2 ½**	**63.5**	**1**
523 to 535	2 9/16	65.1	0.96
536 to 546	2 5/8	66.7	0.93
547 to 559	2 11/16	68.3	0.89
560 to 573	2 3/4	69.8	0.86
574 to 585	2 13/16	71.4	0.83
586 to 598	2 7/8	73.0	0.81
599 to 610	2 15/16	74.6	0.78
611 to 625	3	76.2	0.76

[A]The measured stability of a specimen multiplied by the ratio for the thickness of the specimen equals the corrected stability for a 2 1/2 in. (63.5 mm) specimen.

[B]Volume-thickness relationship is based on a specimen diameter of 4 in. (101.6 mm).

Standard Method of Test For
THEORETICAL MAXIMUM SPECIFIC GRAVITY AND DENSITY OF BITUMINOUS PAVING MIXTURES
(ASTM D 2041-91)

Theoretical Maximum Specific Gravity, $G_{mm} = A / (A + D - E)$

Where:

A = mass of oven dry sample in air, g

D = mass of container filled with water at 25 °C

E = mass of container filled with sample and water at 25 °C

Test No.	Mass of Oven Dry Sample in Air, g A	Mass of Container filled with water at 25 °C D	Mass of Container filled with sample and water at 25 °C E	Theoretical Maximum Specific Gravity A / (A+D-E)
1				
2				
3				
Average Theoretical Maximum Specific Gravity				

ANALYSIS OF COMPACTED PAVING MIXTURES

General: The analytical procedures described herein apply either to paving mixtures that have been compacted in the laboratory, or to undisturbed samples that have been cut from a pavement in the field. When a paving mixture is compacted in the laboratory, the compactive effort should provide a density equal to the density the mixture will ultimately attain under traffic following compaction by rolling during construction.

By analyzing a compacted paving mixture (V_a), voids in the mineral aggregate (VMA), and effective asphalt content (P_{be}), some indication of the probable service performance of the pavement is provided. The efficacy of compaction, either during construction or after years of service can be determined by comparing the specific gravity of an undisturbed sample cut from a pavement with the laboratory compacted specific gravity of the paving mixture.

Definition:

Bulk Specific Gravity (G_{sb}): The ratio of the weight in air of a unit volume of a permeable material (including both permeable and impermeable voids normal to the material) at a stated temperature to the weight in air of equal volume of gas free distilled water at a stated temperature.

Apparent Specific Gravity (G_{sa}): The ratio of the weight in air of a ;unit volume of an impermeable material at a stated temperature to the weight in air of equal density of an equal volume of gas free distilled water at a stated temperature.

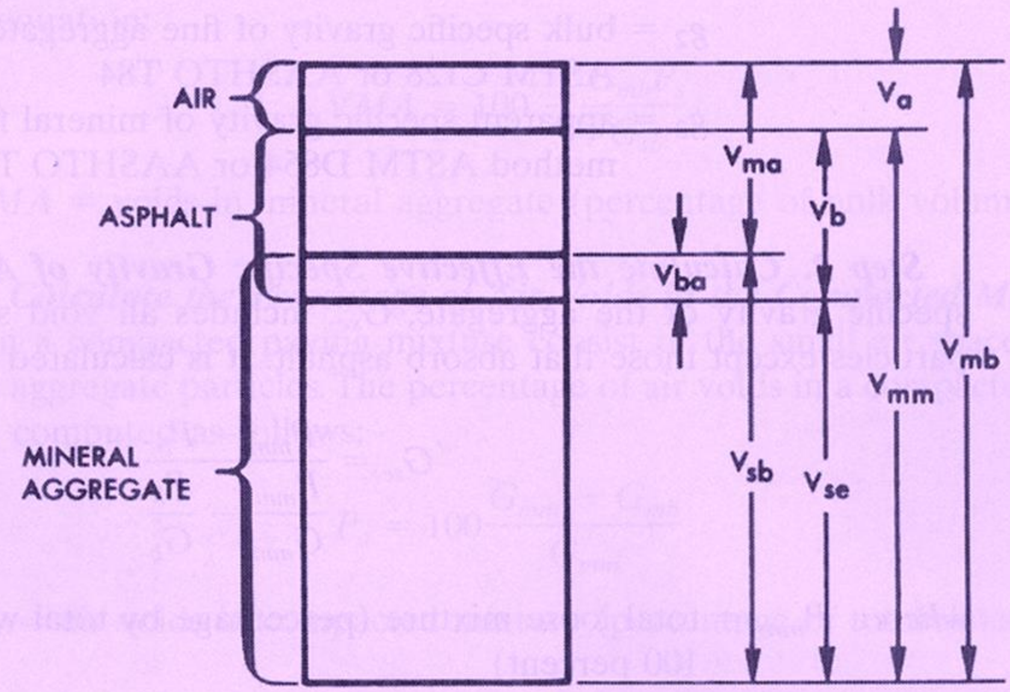
Effective Specific Gravity (G_{se}): The ratio of the weight in air of a unit volume of a permeable material (excluding voids permeable to asphalt) at a stated temperature to the weight in air of equal density of an equal volume of gas free distilled water at a stated temperature.

Voids in the Mineral Aggregate (VMA): The volume of intergranular void space between the aggregate particles of a compacted paving mixture that includes the voids and the effective asphalt content, expressed as a percent of the total volume of the sample.

Effective Asphalt Content (P_{be}): The total asphalt content of a paving mixture minus the portion of asphalt that is lost by absorption into the aggregate particles.

Air Voids (V_a): The total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as percent of the bulk volume of the compacted paving mixture.

Volume Relationships in a Compacted Mix: Figure 19-1 depicts the volume relationships between aggregate, air voids in mineral aggregate, total asphalt content, asphalt lost by absorption into the aggregate particles, and effective asphalt content.



V_{ma} = Volume of voids in mineral aggregate
V_{mb} = Bulk volume of compacted mix
V_{mm} = Voidless volume of paving mix
V_a = Volume of air voids
V_b = Volume of asphalt
V_{ba} = Volume of absorbed asphalt
V_{sb} = Volume of mineral aggregate (by bulk specific gravity)
V_{se} = Volume of mineral aggregate (by effective specific gravity)

FIGURE 19-1 Representation of volumes in a compacted asphalt specimen.

OUTLINING PROCEDURE FOR ANALYZING A COMPACTED PAVING MIXTURE:

1. Measure the bulk specific gravities of the coarse aggregate and of the fine aggregate.
2. Measure the specific gravity of the asphalt cement and the mineral filler.
3. Calculate the bulk specific gravities of the aggregate combination in the paving mixture.
4. Measure the maximum specific gravity of the loose paving mixture. (ASTM D 2041)
5. Measure the bulk specific gravity of the compacted paving mixture.
6. Calculate the effective specific gravity of aggregate.
7. Calculate asphalt absorptions of aggregate.
8. Calculate the effective asphalt content of the paving mixture.
9. Calculate the percent voids in the mineral aggregate in the compacted paving mixture.
10. Calculate the percent air voids in the compacted paving mixture.

EQUATIONS FOR SAMPLE CALCULATIONS:

- Bulk Specific Gravities of Aggregate: When the total aggregate consists of separate fractions of coarse aggregate, fine aggregate, and mineral filler, all having different specific gravities

$$G_{sb} = \frac{P_1 + P_2 + \cdots + P_n}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + \cdots + \frac{P_n}{G_n}}$$

Where:
G_{sb} = bulk specific gravity for the total aggregate
P_1 , P_2 , P_n = percentages by weight of aggregates 1, 2, ... n; and,
G_1 ,G_2 , G_n = bulk specific gravities of aggregate 1, 2, ... n

- Effective Specific Gravity of Aggregate: When based on the maximum specific of a paving mixture, G_{mm}, the effective specific gravity of G_{se}, of the aggregate includes all void spaces in the aggregate particles except those that absorb asphalt. It is determined as follows:

$$G_{se} = \frac{P_{mm} - P_b}{\frac{P_{mm}}{G_{mm}} - \frac{P_b}{G_b}}$$

Where:
G_{se} = effective specific gravity of aggregate;
P_{mm} = total loose mixture, percent by total weight of mixture = 100 percent,
P_b = asphalt, percent by total weight of mixture,
G_{mm} = maximum specific gravity of paving mixture (no air voids),
G_b = specific gravity of asphalt.

Maximum Specific Gravities of Mixtures with Different Asphalt Contents: In designing a paving mixture with a given aggregate, the maximum specific gravities, G_{mm}, at different asphalt contents are needed to calculate the percentage of air voids for each asphalt content. After getting the results from these tests and calculating the effective specific gravity of the aggregate, the maximum specific gravity for any other asphalt can be obtained as shown below. For all practical purposes, the effective specific gravity of the aggregate is constant because asphalt absorption does not vary appreciably with variation in asphalt content.

$$G_{mm} = \frac{P_{mm}}{\frac{P_s}{G_{se}} + \frac{P_b}{G_b}}$$

Where:
G_{mm} = maximum specific gravity of paving mixture (no air voids)
P_{mm} = total loose mixture, percent by total weight of mixture = 100 percent
P_s = aggregate, percent by total weight of mixture
P_b = asphalt percent by total weight of mixture
G_{se} = effective specific gravity of aggregate, and
G_b = specific gravity of asphalt

Asphalt Absorption: Absorption is expressed as a percentage by weight of aggregate rather than as a percentage by total weight of mixture. Asphalt, P_{ba} absorption is determined as follows:

$$P_{ba} = \left(\frac{G_{se} - G_{sb}}{G_{sb} G_{se}}\right) G_b \times 100$$

Where:
P_{ba} = absorbed asphalt, percent by weight of aggregate,
G_{se} = effective specific gravity of aggregate,
G_{sb} = bulk specific gravity of aggregate, and
G_b = specific gravity of asphalt

Effective Asphalt Content of a Mixture: The effective asphalt content, P_{be} of a paving mixture is the total asphalt content minus the quantity of asphalt lost by absorption into the aggregate particles. It is the portion of the total asphalt content that remains as a coating on the outside of the aggregate particles, and is the asphalt content on which service performance of an asphalt paving mixture depends. The formula is:

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

Where:
P_{be} = effective asphalt content, percent by total weight of mixture,
P_b = asphalt, percent by total weight of mixture,
P_{ba} = absorbed asphalt, percent by weight of aggregate, and,
P_s = aggregate, percent by total weight of mixture.

Percent VMA in Compacted Paving Mixture: The voids in the mineral aggregate, VMA, are defined as the intergranular void space between the aggregate particles in a compacted paving mixture that includes the air voids and the effective asphalt content, expressed as a percent of the total volume. The VMA is calculated on the basis of the bulk specific gravity of the aggregate and is expressed as a percentage of the bulk volume of the compacted paving mixture.

$$VMA = 100 - \left[\frac{(G_{mb} P_s)}{G_{sb}}\right]$$

Where:
VMA = voids in mineral aggregate (percent of bulk volume),
G_{sb} = bulk specific gravity of aggregate,
G_{mb} = bulk specific gravity of compacted mixture, and,
P_s = aggregate, percent by total weight of mixture.

Calculating Percent Air Voids in Compacted Mixture: The air voids V_a, in a compacted paving mixture consist of the smaller air spaces between the coated aggregate particles. The percentage of air voids in a compacted mixture can be determined by the following equation:

$$V_a = \left(1 - \frac{G_{mb}}{G_{mm}}\right) \times 100$$

Where:
V_a = air voids in a compacted mixture, percent of total volume,
G_{mm} = maximum specific gravity of paving mixture (as determined above) or as determined directly for a paving mixture by ASTM D 2041,
G_{mb} = bulk specific gravity of compacted mixture.

Voids Filled with Asphalt: The voids in the aggregate filled with asphalt, VFA, are defined as, the amount of voids in the aggregate of a compacted bituminous mixture is equal to the apparent volume of the mixture minus the true volume of the mineral aggregate. The percentage of the voids in the aggregate are calculated as follows:

$$VFA = \left(\frac{P_{be} \times G_{mb}}{G_b + VMA}\right) \times 100$$

$$VFA = \frac{VMA - P_a}{VMA} \times 100$$

Where:
VFA = voids in the aggregate filled with asphalt,
P_{be} = effective asphalt content, percent by total weight of mixture,
G_{mb} = bulk specific gravity of compacted mixture,
VMA = voids in mineral aggregate (percent of bulk volume), and,
G_b = specific gravity of asphalt.
P_a = air voids in compacted mixture, percent of total volume,

Trends and Relations of Test Data: The test property curves, plotted as described in Figure 19-4, should follow the pattern as described in the figure in a consistent form. Trends generally noted are outlined as follows:

1. The stability value increases with increasing asphalt content up to a maximum after which the stability decreases.
2. The follow value increases with increasing asphalt content.
3. The curve for unit weight of total mix is similar to the stability curve, except that the maximum unit weight normally (but not always) occurs at a slightly higher asphalt content than the maximum stability.
4. The percent of air voids decreases with increasing asphalt content, ultimately approaching a minimum void content.
5. The percent voids in the mineral aggregate generally decrease to a minimum value then increase with increasing asphalt contents.
6. The percent voids in the aggregate filled with asphalt rises rapidly at low binder contents and tends to level off at high binder contents.

Graphical Charts:

Prepare a graphical plot for the following values from the data obtained:

1. Stability verses asphalt content
2. Flow verses asphalt content
3. Specific gravity of total mix verses
4. Percent Air voids verses asphalt content
5. Percent Voids in Mineral Aggregate (VMA) versus asphalt content
6. Voids Filled with Asphalt (VFA) versus asphalt content

Specification Limits:

Class A	Limit
Total Mineral Aggregate	96 - 93
Asphaltic Binder	4 - 7
Stability (kgs)	820 min
Voids in total mix	3.0 - 5.0
Flow, 0.25 mm	8.0 - 14.0
Voids Filled with Asphalt (VFA), %	65 - 75
VMA, %	See table 19 – 7

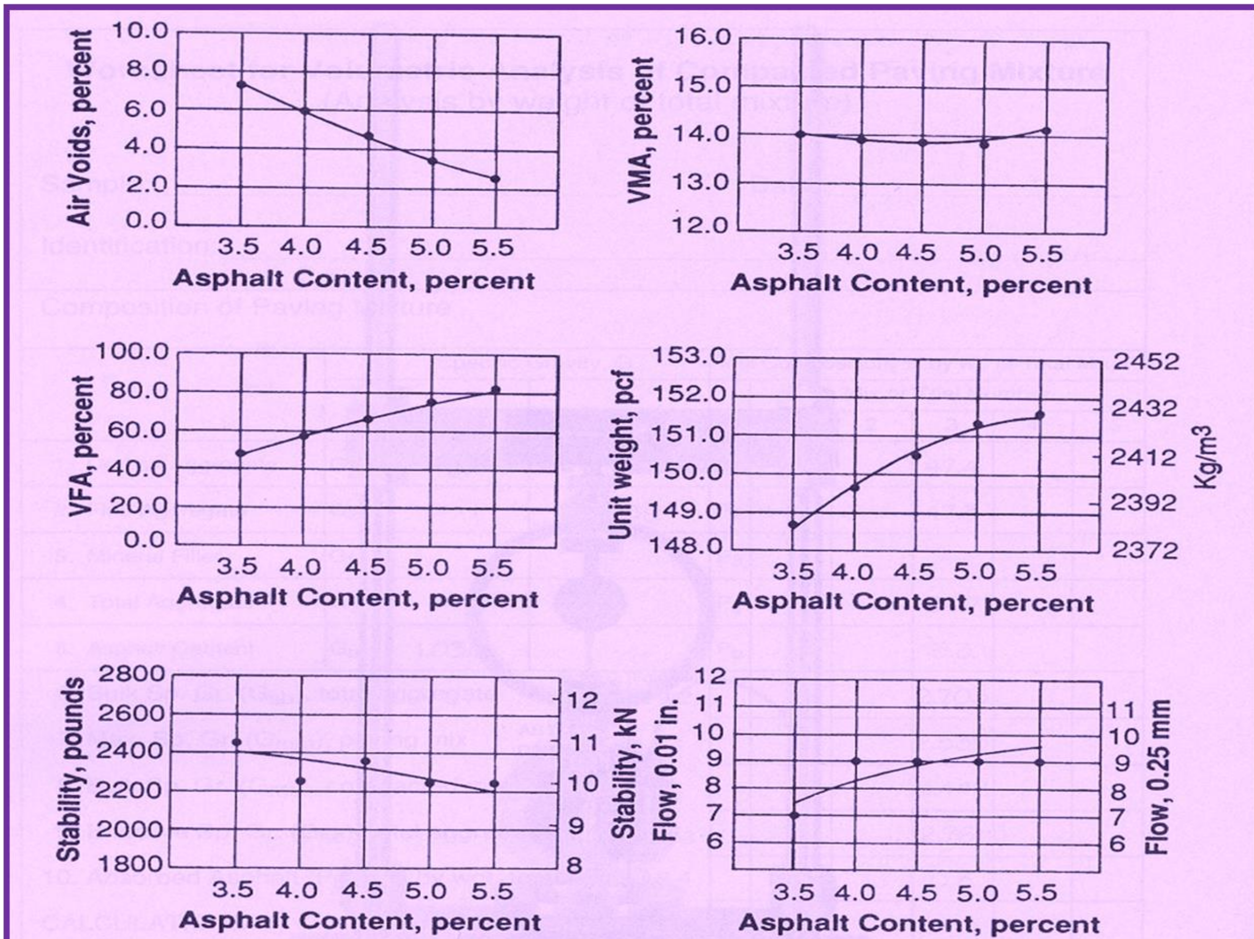


FIGURE 19-4 Test property curves for hot-mix design data by the Marshall method. (Courtesy the Asphalt Institute.)

Determination of Optimum Asphalt Content: The optimum asphalt content of the asphalt paving mix is determined from the test curves to be used for the medium traffic category.

- **Original and Modified method:**

1. Asphalt content at maximum specific gravity =
2. Asphalt content at maximum stability =
3. Asphalt content at 4 % Air Voids =

Optimum asphalt content, average =

- **Asphalt Institute method:**

Optimum asphalt content is the Asphalt content at 4 % Air Voids

Marshal Mix Design Cheat Sheet

General Workflow

1- Prepare three pills.
2- Prepare a loose specimen.
3- Using the compacted pills, determine the specific gravity for each of the compacted pills and calculate the average (G_{mb}).
4- Using the loose specimen, determine the theoretical maximum density (G_{mm}).
5- Carry out the Stability and Flow test for each pill and calculate the average.
6- Prepare a table containing the data obtained by your group and pass it to the laboratory supervisor. A complete table (results for all binder contents) will be established and provided to all groups.
7- As soon as receiving the complete table, student shall carryout the Marshall analysis and provide a complete report.

Lab. Work Steps

1- Collect aggregate of different sizes. 1200 gm.
2- Find the weight percentage and specific gravity of each size.
3- Find the bulk specific gravity of aggregate mixture (G_{sb}).
4- Heat the aggregate to 160 °C for 3 to 4 h.
5- Find the weight of the asphalt based on the designated asphalt content percentage.
6- Find the specific gravity of asphalt G_b.
7- Heat the asphalt cement to 155 °C for not more than one hour to prevent overheating.
8- Mix all four specimens at temperature not less (145 °C).
9- Use 75 blows on each side of the specimen to compact three specimens for heavy traffic.
10- Do not mix the fourth specimen.
11- Leave the specimens to cool.
12- Find the mix bulk specific gravity (G_{mb}) using the three bills.
13- Find the theoretical maximum density (G_{mm}) using the loose specimen.
14- Cary out the Stability and Flow test and make stability correction.
15- Tabulate the results and hand it to the lab. supervisor.

Marshal Analysis Steps

P_b	4			4.5			…
Specimen	1	2	3	1	2	3	…
Weight in air							…
Weight in water							…
Weight in SSD							…
Volume							…
G_{mb}							…
Average G_{mb}							…
Measured stability							…
Correlation factor							…
Corrected stability							…
Average stability							…
Flow							…
Average flow							…

	Asphalt Content					
	4.0	4.5	5.0	5.5	6.0	6.5
Stability						
Flow						
G_{mb}						
G_{mm}						

1- Find effective specific gravity of aggregate G_{se} using G_{mm} obtained from lab.
2- Find calculated G_{mm}.
3- Find absorbed asphalt percentage P_{ba}.
4- Find effective asphalt content of a mixture P_{be}.
5- Find percentage of void in mineral aggregate VMA.
6- Find percentage of air voids in compacted mixture V_a.
7- Find percentage of voids filled with asphalt VFA.
8- Plot trends and relations of test data.
9- Find optimum asphalt content OAC.

P_b	G_{mm} Measured	G_{se}	G_{mm} calculated	P_{ba}	P_{be}	G_{mb}	VMA	V_a	VFA	Stability	Flow
4											
4.5											
5											
5.5											
6											