Experiment #14

MARSHALL MIX DESIGN (Marshal flow and Marshal Stability Test)

INTRODUCTION

There are basically three mix design methods for asphalt namely as Marshall, Hveem and superpave methods, but the Marshall being relatively light, portable and relatively inexpensive instruments is the most widely used method. The results of Marshall Mix design method has also been found relatively close to the field.

Desirable properties

Following are the desirable properties that we want from our mix

1. Stability

   The ability to withstand traffic loads without distortion or deflection, especially at higher temperatures.
   To get good stability, use strong, rough, dense-graded, cubical aggregate with just enough binder to coat the aggregate particles. Excess bitumen lubricates the aggregate particles and lets them slide past each other more easily (which reduces stability).

2. Workability

   The ability to be placed and compacted with reasonable effort and without segregation of the coarse aggregate.
   Too much asphalt cement makes the mix tender. Too little bitumen makes it hard to compact. Too much natural sand can also make the mix tender because natural sand has smooth, round grains.

3. Skid Resistance

   Proper traction in wet and dry conditions.

   To get good skid resistance, use smaller aggregate so there are lots of contact points, use hard aggregate that doesn't polish and make sure you have enough air voids to prevent bleeding. Some states now use an open-graded friction course (OGFC) that allows water to drain to the sides of the pavement, eliminating hydroplaning. But OGFC is not very durable because of the open pores

4. Durability

   The ability to resist aggregate breakdown due to wetting and drying, freezing and thawing, or excessive inter-particle forces.

   To get good durability, use strong, tough, nonporous aggregate and enough bitumen to completely coat all of the aggregate particles (to keep them dry) and fill all of the voids between particles (to slow the oxidation of the asphalt cement). But this reduces stability.

5. Flexibility

When traffic load comes on to the pavement surface, the pavement should deform flexibly from top to bottom without any permanent deformation. The deformation should be elastic and not plastic.

6. Air voids

The pavement surface should possess adequate voids to avoid bleeding of bitumen.

The migration of bitumen to the surface of the pavement under wheel loads, especially at higher temperatures is known as bleeding.

Air voids incorporated in the pavement should not be too much, because greater percentage of voids decreases the stability. Practically 4% air voids are incorporated in the mix.

7. Economy

The design should be economical.

OBJECTIVE

To obtain optimum bitumen content for asphalt that will result in the desirable properties of the pavement.

STEPS FOR MIX DESIGN

1. AGGREGATE SELECTION

a) Determine aggregate physical properties

It includes the following

i. Toughness and abrasion
ii. **Durability and soundness**
iii. **Cleanliness and durability**
iv. **Particle shape and surface texture**
v. **Water absorption and specific gravity**

b) Create aggregate blend to meet the specification requirements

Sieve Size		Percent Passing		
		Subbase Course (Grading A)	Base Course (Grading B)	Surface Course (Grading F)
63 mm	2.5-inch	–	100	–
50 mm	2-inch	100	97 – 100	–
37.5 mm	1.5-inch	97 – 100	–	–
25.0 mm	1-inch	–	–	100
19.0 mm	0.75-inch	–	–	97 – 100
12.5 mm	0.5-inch	–	40 – 60 (8)	–
4.75 mm	No. 4	40 – 60 (8)	–	41 – 71 (7)
0.425 mm	No. 40	–	9 – 17 (4)	12 – 28 (5)
0.075 mm	No. 200	0 – 12 (4)	4 – 8 (3)	5 – 16 (4)

2. ASPHALT BINDER SELECTION

The asphalt binder selection should meet the specification requirement i-e

a) Flash and Fire point test
b) **Penetration test**
c) **Softening point test**
d) **Ductility test**

3. SAMPLE PREPARATION

- The Marshall method, like other mix design methods, uses several trial aggregate-asphalt binder blends (typically 5 blends with 3 samples each for a total of 15 specimens), each with a different asphalt binder content. The samples are typically prepared at 0.5% by weight of increments.

- The weight of the aggregate for the test is chosen to be 1200gms and is preheated at 160 to 175 ^{o}C.

- The trial percentage of asphalt binder is chosen starting from 3.5, 4, 4.5, 5….. Percentages of the total mix and heated at 130-145 ^{o}C.

- Both aggregate and bitumen are mixed in a mould and compacted on both sides by hammer.

- Dimensions of mould

  Diameter = 101.6mm

  Height of mould = 63.55 mm

  Note:-

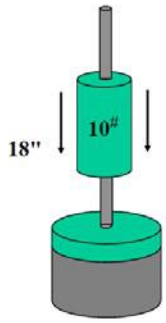
  The dimensions of the moulds are chosen such so that the stability factor is 1 which accounts for volume of mould.

- Hammer details

  Specified as a 457.2 mm (18 inches) free fall drop distance of a hammer assembly with a 4536 g (10 lb.) sliding weight.

- Number of blows

  Typically **35, 50 or 75** on each side depending upon anticipated traffic loading.



Make 3 specimens at each of 5 different asphalt contents

Traffic	Blows / Side
Light	35
Medium	50
Heavy	75

4. The Marshall Stability and Flow Test

The Marshall Stability and flow test provides the performance prediction measure for the Marshall Mix design method.

Stability is the maximum load that the specimen can carry at 60 $^{\circ}$C.
Flow is the deformation (plastic) in the sample during the application of the loading. The flow value for the sample is recorded against the stability value (max load) and is expressed in units of 0.25mm i-e

0.25mm deformation = 1unit
1mm deformation = 4units
1.5mm deformation = 6 units

The specimen is tested at 60 $^{\circ}$C because it is the maximum temperature of a pavement recorded in a year and the pavement is considered to be the weakest at this temperature.

Procedure

The specimen after compaction should be placed in **water bath** and temperature should be maintained at 60 $^{\circ}$C for 20 mins. For performing the test the specimen should be tested within 30 secs from the time it has been removed from the waterbath.

The stability portion of the test measures the maximum load supported by the test specimen at a loading rate of 50.8 mm/minute (2 inches/minute). Basically, the load is increased until it reaches a maximum then when the load just begins to decrease, the loading is stopped and the maximum load is recorded.
Flow is the deformation (plastic) in the sample during the application of the loading. During the loading, an attached dial gauge measures the specimen’s plastic flow as a

result of the loading (Figure 2).

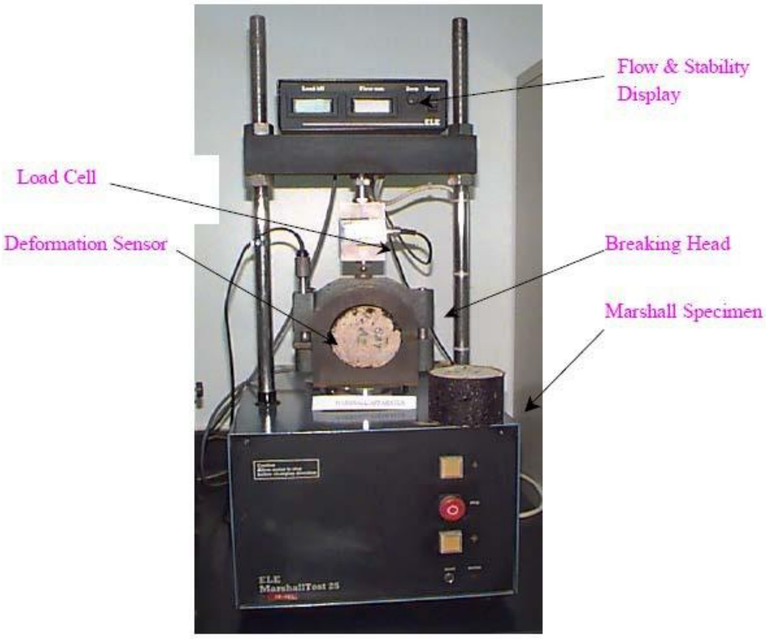


Figure 11.1 Marshall Stability & Flow Test Setup

Mix Criteria	Light Traffic (less than 104ESALs)		Medium Traffic (104 – 106ESALs)		Heavy Traffic (greater than 106ESALs)	
	Min.	Max.	Min.	Max.	Min.	Max.
Compaction (number of blows on each end of the sample)	35		50		75	
Stability (minimum)	2224 N (500 lbs.)		3336 N (750 lbs.)		6672 N (1500 lbs.)	
Flow (0.25 mm (0.01 inch))	8	20	8	18	8	16
Percent Air Voids	3	5	3	5	3	5

5. DENSITY AND VOIDS ANALYSIS

All mix design methods use density and voids to determine basic HMA physical characteristics.

Two different measures of densities are typically taken:

a. Bulk specific gravity (Gmb).
b. **Theoretical maximum specific gravity (TMD, Gmm).**

These densities are then used to calculate the volumetric parameters of the HMA. Measured void expressions are usually:

a. Air voids (Va), sometimes expressed as voids in the total mix (VTM)
b. **Voids in the mineral aggregate (VMA)**
c. **Voids filled with asphalt (VFA)**

DENSITIES

a) Bulk specific gravity (Gmb).

AASHTO T 166 - BULK SPECIFIC GRAVITY OF COMPACTED ASPHALT MIXTURES USING SATURATED SURFACE-DRY SPECIMENS

SCOPE

This test procedure determines the bulk specific gravity of specimens of compacted asphalt mixtures.

APPARATUS

- Balance, readable to 0.1% of the sample weight
- Suspension apparatus
- Water bath with overflow outlet
- Damp towel

PROCEDURE

- Record all weights to the nearest 0.1 g.
- Dry the specimens to constant weight.
- Samples saturated with water shall be initially dried overnight at 125 ± 5°F (52 ± 3°C) then weighed at two-hour intervals. Recently molded laboratory specimens which have not been exposed to moisture do not require drying.
- Cool the specimens to 77 ± 9°F (25 ± 5°C) and weigh each specimen. Record this mass as specimen in air.
- Immerse each specimen in water at 77 ± 1.8°F (25 ± 1°C) suspended beneath a balance for a period of 3 to 3½ minutes. Record this mass as specimen in water.
- Remove the specimen from the water and surface dry by blotting with a damp towel. Weigh the mass as quickly as possible and record as surface-dry specimen in air.

CALCULATIONS

$$Gmb = \qquad WWWW - WWWW$$

Where

Gmb = Bulk specific gravity of the compacted mix

W_a = Weight of the sample in air in SSD Condition

b) Theoretical maximum specific gravity (TMD, Gmm).

The ratio of the mass of a given volume of voidless (Va = 0) HMA at a stated temperature (usually 25 °C) to a mass of an equal volume of gas-free distilled water at the same temperature. It has practically zero air voids.

AASHTO T-209 - THEORETICAL MAXIMUM SPECIFIC GRAVITY AND DENSITY OF HOT MIX ASPHALT

SCOPE

This test determines the theoretical maximum specific gravity and density of uncompacted bituminous paving mixtures at 77°F (25°C).

APPARATUS

- Vacuum container
- Volumetric flasks,* two at 2000 mL each
- Vacuum gage, capable of measuring 30 mm Hg (4 kPa)
- Vacuum pump, capable of evacuating air from a flask to a pressure of
- 30 mm Hg (4 kPa)
- Thermometers
- Water bath
- Orbital shaker
- Pan
- Glass cover plate
- Balance

PROCEDURE

- Weigh and record all masses to the nearest tenth of a gram on SFN 7925.
- Cure laboratory prepared samples in an oven at 275 ± 9°F (135 ± 5°C) for a minimum of 2 hours or until constant mass is achieved.
- Paving mixtures that have not been prepared in a laboratory with oven-dried aggregates shall be dried to constant** mass at a temperature of 221 ± 9°F (105 ± 5°C).
- **Constant is defined as when mass repeats within 0.1%.
- Determine the weight of each flask full of distilled water, with a matching glass plate, at a temperature of 77 ± 1°F (25 ± 0.5°C).
- To obtain the weight, overfill the flask so the water is convexed above the brim. Then slide the cover plate over the brim of the flask. The flask should be free of any air bubbles. Dry the outside. Weigh and record.
- Spread in a large pan. Cool to room temperature. While this mixture is cooling, periodically, carefully separate the particles so that clumps of the fine aggregate portion are no larger than 1/4" (6.3 mm).
- Place the flask on a scale and tare the scale. Place half of the hot mix asphalt sample in the flask and weigh. After recording weight, add sufficient distilled water that is at approximately 77°F to cover the sample completely. Repeat this process with the remaining half of the material using the second flask.
- Remove entrapped air by subjecting the contents of both flasks to a partial

- Vacuum of 30 mm Hg (4 kPa). Maintain the partial vacuum and agitate the
- Containers and contents with an orbital shaker that is set at 225 to 250 rpm with a 3/4" throw for 15 minutes ± 30 seconds.
- Note: Problems have been encountered with some mixes clumping and forming a mass instead of freely moving particles during the 15-minute agitation period. If this happens, it is probable that all the entrapped air will not be removed. (This is more likely to happen when the sample is not adequately cooled before putting it in the flasks). The mix will have to be broken up before agitation continues. This can be done by:

  • Shutting off the vacuum to the flask while keeping the vacuum pump running.
  • Maintain all those connections.
  • Vigorously hand shake the flask until the sample is free moving.
  • Take care so vacuum is not lost to the flask.
  • Return the flask to the shaker and turn on the vacuum to the flask.
  • Do not stop the timer through this procedure.

- After removing from orbital shaker, release the vacuum by increasing the
- Pressure at a rate not to exceed 60 mm Hg (8 kPa) per second. Remove
- Flasks from shaker. Fill flasks (slightly overfill) with distilled water that is at a temperature of 77 ± 1°F (25 ± 0.5°C). Place in a water bath at a temperature of 77 ± 2°F (25 ± 1°C) for 10 minutes ± 30 seconds.
- Remove from water bath, slide the glass cover plate over the flask, and remove from the bath. Dry the outside. Weigh and record.
- Flask Calibration
- Determine the weight of each flask full of distilled water, with a matching glass plate, at a temperature of 77±1°F (25±0.5°C).
- To obtain the weight, overfill the flask so the water is convexed above the brim. Then slide the cover plate over the brim of the flask. The flask should be free of any air bubbles. Dry the outside. Weigh and record

CALCULATIONS

The theoretical maximum specific gravity weight in air is calculated as follows:

Theoretical Maximum Specific Gravity = $\frac{}{(A+D-E)}$

A = mass of oven-dry sample in air

D = mass of container filled with water at 77°F (25°C)

E = mass of container filled with sample and water at 77°F (25°C)

Note:

The difference in maximum specific gravity results of two properly conducted tests on the same sample shall not exceed 0.011. Use the average of the results from the two flasks of the passing test for the final maximum specific gravity.

If the difference exceeds 0.011, rerun the test.

VOIDS

a) Volume of voids in mineral aggregates (VMA)

The percent voids in mineral aggregate (VMA) is 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

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

VMA = percent voids in compacted mineral aggregates (percent of bulk volume)

Gmb = bulk specific gravity of compacted mixture

Gsb = bulk specific gravity of aggregate

Ps = aggregate percent by weight of total paving mixture

Use Eq. 18.5 to calculate G_{sb}.

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

Pca, Pfa, Pmf = percent by weight of coarse aggregate, fine aggregate, and mineral filler in paving mixture.

Gbca, Gbfa, Gbmf = bulk specific gravities of coarse aggregate, fine aggregate, and mineral filler, respectively.

b) Percent Air Voids in Compacted Mixture.

This is 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. It can be obtained from

$$P_a = 100\frac{G_{mm} - G_{mb}}{G_{mm}} \qquad (18.12)$$

where

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

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

Table 2. Typical Marshall Minimum VMA (from Asphalt Institute, 1979[5])

Nominal Maximum Particle Size		Minimum VMA (percent)
(mm)	(U.S.)	
63	2.5 inch	11
50	2.0 inch	11.5
37.5	1.5 inch	12
25.0	1.0 inch	13
19.0	0.75 inch	14
12.5	0.5 inch	15
9.5	0.375 inch	16
4.75	No. 4 sieve	18
2.36	No. 8 sieve	21
1.18	No. 16 sieve	23.5

6. OPTIMUM BINDER CONTENT

There are two procedures for finding the optimum bitumen content:

1. ASPHALT INSTITUTE METHOD

The optimum binder content according to Asphalt institute method is the average of:-

a) Bitumen content with maximum bulk specific gravity.
b) Bitumen content corresponding to maximum stability.
c) Bitumen content corresponding to 4% air voids.

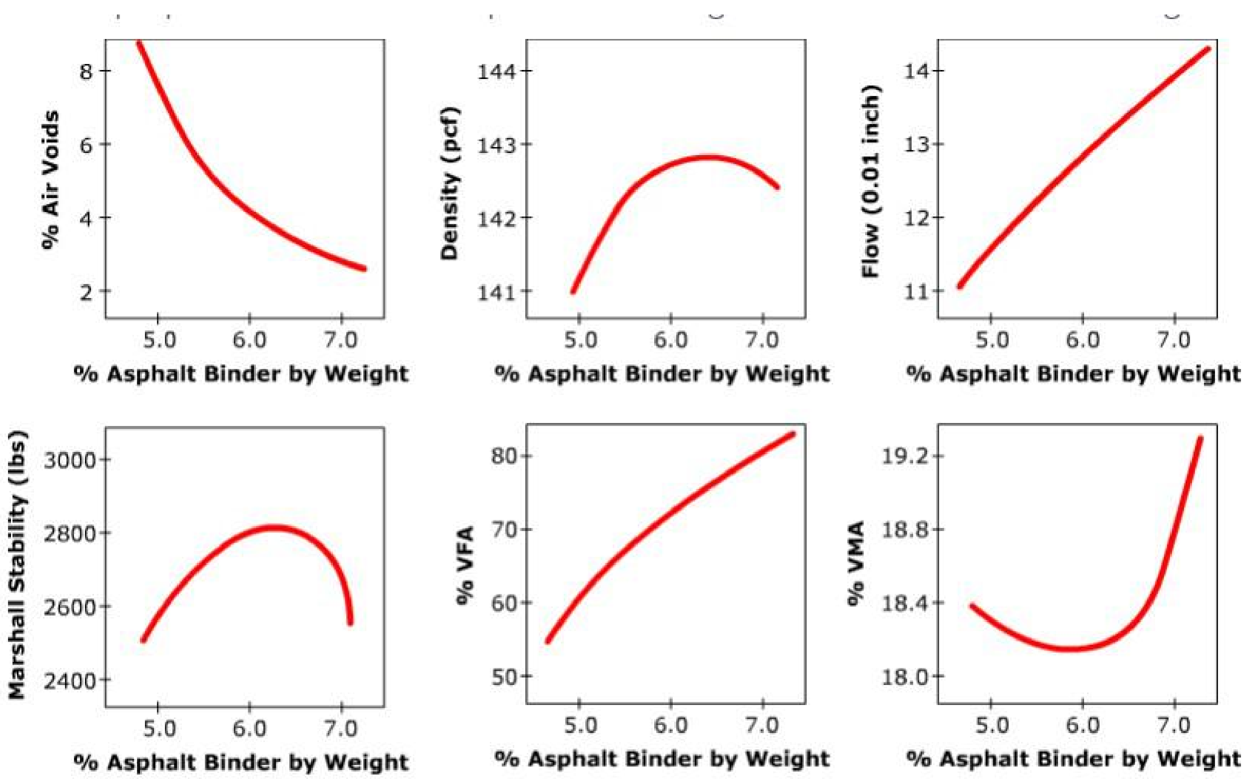
(The Asphalt Institute Procedure)

Maximum Density, Maximum Stability, 4% Air Voids

$$AC = \frac{5.1 + 4.7 + 4.3}{3} = 4.7\%$$

2. TEXAS DEPARTMENT OF TRANSPORTATION METHOD (TDOT)

- Determine the asphalt binder content that corresponds to the specifications median air void content (typically this is 4 percent). This is the optimum asphalt binder content.
- Determine properties at this optimum asphalt binder content by referring to the plots. Compare each of these values against specification values and if all are within specification, then the preceding optimum asphalt binder content is satisfactory. Otherwise, if any of these properties is outside the specification range the mixture should be redesigned.


% Air Voids
Density (pcf)
Flow (0.01 inch)
Marshall Stability (lbs)
% VFA
% VMA
% Asphalt Binder by Weight
5.0
6.0
7.0