नेपाल सरकार

भौतिक पूर्वाधार तथा यातायात मन्त्रालय

सडक विभाग

Marshall Mix Design

बिनोद प्रसाद सापकोटा
सि.डि.ई

Mix Design

- Introduction

-In different parts of the world, the term "asphalt" has different meanings.

-In Europe, asphalt is synonymous with what is called Hot Mix Asphalt (HMA) or Asphalt Concrete (AC) in the U.S.

-The term "bitumen" in Europe is synonymous with asphalt, asphalt cement or asphalt binder in the U.S.

-both the aggregate and the asphalt binder must be heated before mixing—hence the term "hot mix."

Introduction

Classification Mix

- **Dense Graded Mix**
  - a well-distributed aggregate gradation
  - Commonly used for Binding Layer and wearing Layer
  - Designed By Superpave, Marshall and Hveem Method
  - Generally up to 5 % air void

- **Open Graded Mix**
  - have a large volume of air voids
  - (typically 18 to 22 percent)
  - water will readily drain through the pavement layer
- **Gap Graded Mix (Stone Matrix Asphalt)**
  - a high-coarse aggregate content (typically 70 to 80 percent)
  - a high asphalt content (typically more than 6 percent)
  - a high-filler content (approximately 10 percent by weight)

Introduction

Mix Design

- **to determine the combination of asphalt cement and aggregate that will give long-lasting performance as part of the pavement structure.**
- **sufficient asphalt to ensure a durable pavement**
- **sufficient mix stability to satisfy the demands of traffic without distortion or displacement**
- **sufficient air voids in the total compacted mix to allow for a slight amount of additional compaction under traffic loading**
- **sufficient workability to permit efficient placement of the mix without segregation**
- **aggregate texture and hardness to provide sufficient skid resistance**

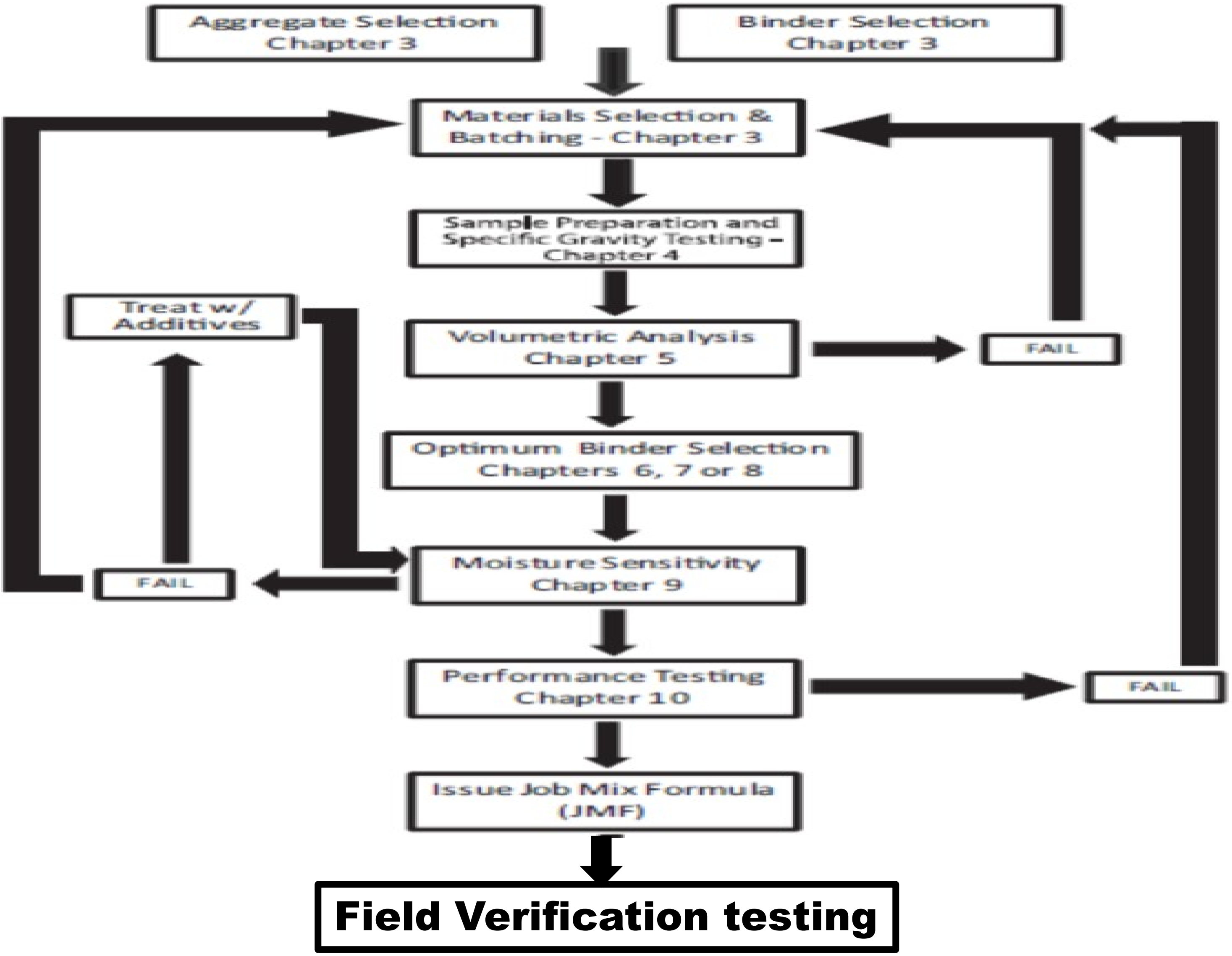
The final goal of mix design is to select a unique design binder content that will achieve a balance among all of the desired properties(durability, impermeability, strength, stability, stiffness, flexibility, fatigue resistance and workability) with specific properties as per site condition)

Introduction

Mix Design

- **The Marshall Mix Design procedure was developed in the 1930s by Bruce Marshall of the Mississippi Highway Department.**
- **Types**
  - **Marshall**
  - **Hveem**
  - **Superpave**

General Step of Mix Design



Understanding Before Design

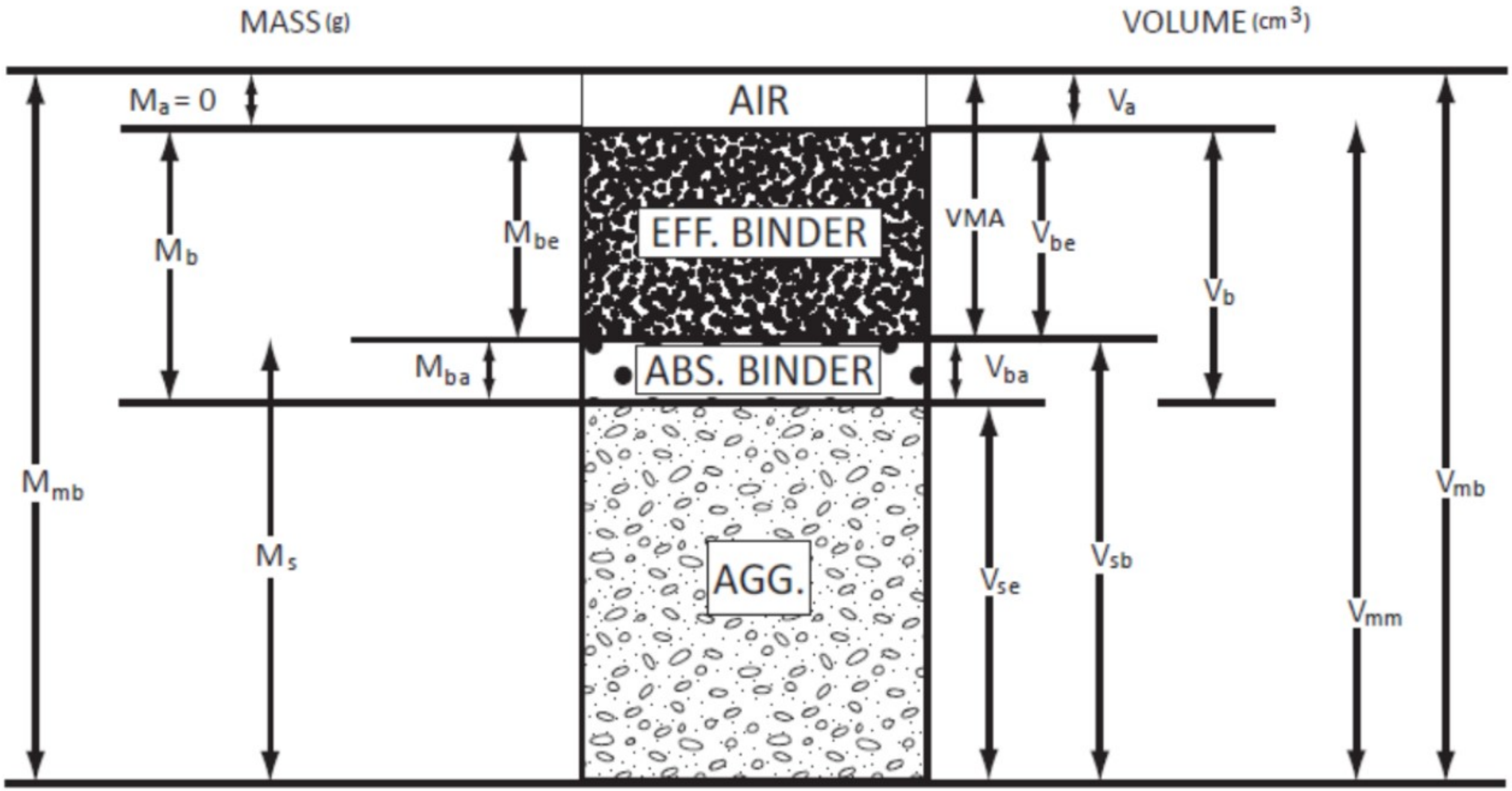


Fig. Phase Diagram

Understanding Before Design

V_a = Volume of Air
V_b = Volume of bitumen
V_{be} = effective Volume of bitumen
VMA= Void in Mineral Aggregate
V_{ba} = Volume of absorb bitumen
V_{sb} =Bulk Volume of Aggregate
V_{se} = Effective Volume of Aggregate
V_{mb} = Bulk Volume of Mix
V_{mm} = Volume of Aggregate and binder

Step wise design Procedure

1. Material Selection and General requirement

a.) Bitumen

- **Penetration Grade**
- **Viscosity Grade (See Table 1)**
- **Performance Grade (Superpave)**
- **Modified Bitumen**

b.) Aggregate (Fine + Course)

- **The coarse aggregates shall consist of crushed rock, crushed gravel or other hard material retained on 2.36 mm sieve.**
- **They shall be clean, hard, and durable, of cubical shape, free from dust and soft or friable matter, organic or other deleterious substances.**
- **Use of Anti-Striping agent (Striping Value test)**
- **See Table 2**

Material Requirement- Bitumen

Table 1 Specification for Paving Bitumen

S No.	Characteristics	Paving Grades				Method of Test
		VG10	VG20	VG30	VG40	Ref to
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	Penetration at 25°C, 100 g, 5 s, 0.1 mm, Min	80	60	45	35	NS: 221:2047 (Part III)/ IS: 1203
ii)	Absolute viscosity at 60°C, Poises	800-1200	1600-2400	2400-3600	3200-4800	NS: 237:2050 (Part VIII)/ IS: 1206 -2
iii)	Kinematic viscosity at 135°C, cSt, Min	250	300	350	400	NS: 237:2050 (Part VIII)/ IS :1206-3
iv)	Flash point (Cleveland open cup), °C, Min	220	220	220	220	NS: 237:2049 (Part VII)/ IS: 1448-69
v)	Solubility in trichloroethylene, percent, Min	99	99	99	99	NS: 221:2047 (Part IV)/IS: 1216
vi)	Softening point (R&B), °C, Min	40	45	47	50	NS / IS: 1205.
vii)	Tests on residue from rolling thin film oven test:					
a)	Viscosity ratio at 60°C, Max	4	4	4	4	NS: 221:2046 (Part II)/ IS: 1206-2
b)	Ductility at 25°C, cm, Min	75	50	40	25	NS: 221:2046 (Part I)/ IS: 1208

Table 2 Physical Requirements for Coarse Aggregate for Dense Bituminous Macadam

Property	Test	Specification	Method of Test
Cleanliness (dust)	Grain size analysis	Max 5% passing 0.075 mm sieve	IS:2386 Part I
Particle shape	Combined Flakiness and Elongation Indices*	Max 35%	IS:2386 Part I
Strength	Los Angeles Abrasion Value or Aggregate Impact Value	Max 35% Max 27%	IS:2386 Part IV
Durability	Soundness either: Sodium Sulphate or Magnesium Sulphate	Max 12% Max 18%	IS:2386 Part V
Water Absorption	Water Absorption	Max2%	IS:2386 Part Ill
Stripping	Coating and Stripping of Bitumen Aggregate Mix	Minimum retained coating 95%	IS:6241
Water Sensitivity	Retained Tensile Strength**	Min. 80%	AASHTO 283

Coarse Aggregate Requirement

Property	Test	Specification	Method of Test
Deleterious materials: **Cleanliness (dust)**	Grain size analysis	Max 5% passing 0.075 mm sieve	IS:2386 Part I
Toughness/Strength	Los Angeles Abrasion Value or Aggregate Impact Value	DBM : Max 35% BC : Max. 30% DBM: Max 27% BC : Max. 24%	IS:2386 Part IV
Durability	Soundness either: Sodium Sulphate or Magnesium Sulphate	Max 12% Max 18%	IS:2386 Part V
Polishing	Polished Stone Value	Min 55	BS:812-114
Water Sensitivity	Retained Tensile Strength*	Min 80%	AASHTO 283
Water Absorption	Water Absorption	Max 2%	IS:2386.Part III
Stripping	Coating and Stripping of Bitumen Aggregate Mix	Minimum retained coating 95%	IS: 6241

Gradation Requirement

Composition for	BC		DBM	
Nominal Maximum aggregate size(NMAS)	13.2 mm	19 mm	26.5 mm	35.5 mm
Gradation Type	(Ref. Table1.1)			
IS Sieve (mm)	Cumulative % by weight of total aggregate passing			
45				100
37.5			100	95-100
26.5		100	90-100	63-93
19	100	90-100	71-95	-
13.2	90-100	59-79	56-80	55-75
9.5	70-88	52-72	-	-
4.75	53-71	35-55	38-54	38-54
2.36	42-58	28-44	28-42	28-42
1.18	34-48	20-34	-	-
0.6	26-38	15-27	-	-
0.3	18-28	10-20	7-21	7-21
0.15	12-20	5-13	-	-
0.075	4-10	2-8	2-8	2-8

Filler Material Requirement

- **Filler should consist of finely divided mineral matter such as rock dust, hydrated lime or cement.**
- **The filler should be free from organic impurities and have a plasticity Index not greater than 4 (For Dust)**
- **Where the mix fail to meet the requirements of the water sensitivity test (80% as min. retained tensile strength, AASHTO T283) , then 2 percent by total weight of aggregate, of hydrated lime should be used and percentage of fine aggregate reduced accordingly.**

Grading Requirements for Mineral Filler	
IS sieve (mm)	Cumulative Percent Passing by Weight of Total Aggregate
0.6	100
0.3	98-100
0.075	85.-100

Real Case of Filler Material (Stone Dust)

Sieve Size mm	% Passing				
	19 down	10 down	**Dust**		Sand
19.0	100	100	**100**		100
12.5	28.4	100	**100**		100
10.0	2.7	94.7	**100**		99.6
4.75	0.2	2.6	**99.6**		87.1
2.00	0.2	1.5	**77.2**		77.6
0.425	0.2	1.4	**30.5**		29.4
0.180	0.1	1.4	**18.4**		9.4
0.075	0.1	0.7	**11.4**		4.6

Provided dust is not a dust it is a crushed fine aggregate

Marshall Mix Design

Step 1

- **Selection of Materials**
    - **40 down, 26 down, 20 down, 10 down, 4.75 down , dust , bitumen (Types)**
- **Test the requirement as above**
- **Specific Gravity test of Aggregate, fine aggregate, bitumen, filler**
- **Sieve Analysis of aggregate , fine aggregate, filler**

Marshall Mix Design

Step 2 Aggregate Blending / Job mix

- **Use hit and trail method (Spread Sheet)**
- **Bailey Method**
- **Programing based method**

Sive size(mm)	26 down Agg	10 down Agg	Crushed fine agg	Total	Specification Limit
	30 (%)	25 (%)	45(%)		
37.5	30.0	25.0	45.0	100.0	100
26.5	26.4	25.0	45.0	96.40	90-100
19.0	8.5	25.0	45.0	78.53	71-95
13.20	1.3	24.7	45.0	70.96	56-80
4.75	0.6	4.3	36.4	41.31	38-54
2.36	0.0	3.1	30.9	33.94	28-42
0.3	0.0	1.8	11.6	13.39	7-21
0.075	0.0	0.3	3.1	3.36	2-8

Marshall Mix Design- Step 2 Continue…

Step 2 Aggregate Blending / Job mix

Excel Sheet

Marshall Mix Design- Step 2 Continue…

After Job Mix

-Take around 1200 Gram of Pre heated Mix Aggregate and take pre heated bitumen of different percentage by weight of Mix Aggregate .

- **Different percentage range form 4% to 6.5% each increment of .5 % (binder content)**
- **Mix the mixture by Mixture Equipment or Manually .**
- **Mixing Temperature should be equal to the temperature at which binder has a viscosity of 170 ± 20 mm^2/s (.17± .02 Pa.s) Generally 160 to 165 ◦ C . Heating should not be greater than 177 ◦ C .**
- **Now prepare pre heated mould (90 to 143 ◦ C) and fill up mould with mix and compact immediately in compaction apparatus. The compaction temperature should be equal to the temperature at which binder has viscosity of 280 ± 30 mm^2 /s(.28± .03 Pa.s) Generally 145 to 150 ◦ C**
- **1 cSt = 1 $mm^2 \cdot s^{-1}$ (Kinematic Viscosity)**
- **Compaction should carried out with 50 or 75 blows on each side as per specification. And cool it to the room temperature around 4 to 5 hrs.**

Marshall Mix Design- Step 2 Continue…

Mixture machine

Marshall Mix Design- Step 2 Continue…

Compaction machine

Marshall Mix Design- Step 2 Continue…

Mould and Sample

Step 3. Volumetric Analayis

Marshall Method Criteria[1]	As per MS-2						As per DOR Specification	
	Light Traffic[2] Surface & Base		Medium Traffic[2] Surface & Base		Heavy Traffic[2] Surface & Base		Viscosity Grade Paving Bitumen	
	Min	Max	Min	Max	Min	Max	Min	Max
Compaction, number of blows each end of specimen	35		50		75		75	
Stability, N	3336	-	5338	-	8006	-	9000	-
Flow[3,4], 0.25 mm (0.01 in.)	8	18	8	16	8	14	8	16
Percent Air Voids[6]	3	5	3	5	3	5	3	5
Percent Voids in Mineral Aggregate (VMA)[5]	NMAS, mm		Minimum VMA, percent					
			3.0		4.0		5.0	
	13.2		13		14		15	
	19		12		13		14	
	26.5		11		12		13	
	37.5		10		11		12	
Percent Voids Filled With Asphalt (VFA)	70	80	65	78	65	75	65	75

Step 3 Volumetric Analysis Continue..

Find out the Percentage Air Voids

$$P_a = 100\ x\ \frac{V_a}{V_{mb}}$$

Where Pa= % Air Voids
Va= Volume of Air Voids
Vmb= Bulk Volume of Sample

Another Formula For Lab

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

Where ,

Gmb=Bulk Specific Gravity of the sample
Gmm=maximum specific gravity of paving mixture

Step 3 Volumetric Analysis Continue.. Air Void

Determination of G mb (Bulk Specific Gravity) in Laboratory

$$G_{mb} = \frac{A}{(B - C)}$$

where:

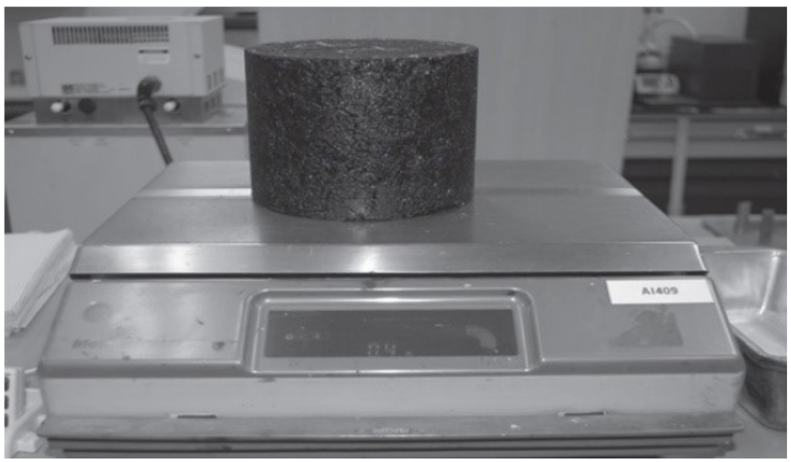
A = dry mass of the specimen in air

B = saturated surface-dry (SSD) mass of the specimen in air

C = mass of the specimen in water at 25°C

Step 3 Volumetric Analysis Continue.. Air Void

Determination of G mb (Bulk Specific Gravity) in Laboratory



Step 3 Volumetric Analysis Continue.. Air Void

Determination of G mm (maximum specific gravity of paving mixture) in Laboratory (ASTM D 2041)

$$G_{mm} = \frac{A}{A - (C - B)}$$

where: Gmm = maximum specific gravity of the mixture,
A = mass of dry sample in air, g,
B = mass of bowl under water, g,
And
C* = mass of bowl and sample under water, g

- **The sample should be free from air voids by Specific Gravity meter equipment**
- **Average of More than Two Sample**


HP:+15922636002(Ren Pan)
GOLD
8YR
Gold Supplier
Trade Assurance
hyoilpurifier.en.alibaba.com
GD-0711A Maximal Theoretic Special Gravity Tester

Step 3 Volumetric Analysis Continue.. Air Void

Now Calculate the effective specific gravity (G_{se})

$$G_{se} = \frac{P_s}{\left(\frac{100}{G_{mm}}\right) - \left(\frac{P_b}{G_b}\right)}$$

Where,

P_s **= % of Aggregate by total mix Weight**

P_b **=% of Binder Content by total mix Weight**

G_{mm} **= Maximum Specific Gravity of Paving mixture**

G_b **= Specific Gravity of Binder**

Step 3 Volumetric Analysis Continue.. Air Void

Calculation of the Maximum specific gravity (G_{mm})of paving mixture of different binder Contents

$$G_{mm} = \frac{100}{\left(\frac{Ps}{Gse}\right) + \left(\frac{P_b}{G_b}\right)}$$

Where,

P_s = % of Aggregate by total mix Weight

P_b =% of Binder Content by total mix Weight

G_{se} = Effective Specific Gravity of Paving mixture

G_{b} = Specific Gravity of Binder

* **AS binder Content increase G_{mm} Always decreases..Why??**

Step 3 Volumetric Analysis Continue.. Air Void

Calculation of the Maximum specific gravity (G_{mm})of paving mixture of different binder Contents

$$G_{mm} = \frac{100}{\left(\frac{Ps}{Gse}\right) + \left(\frac{P_b}{G_b}\right)}$$

Where,

P_s = % of Aggregate by total mix Weight

P_b =% of Binder Content by total mix Weight

G_{se} = Effective Specific Gravity of Paving mixture

G_b = Specific Gravity of Binder

* **AS binder Content increase G_{mm} Always decreases..Why??**

Step 3 Volumetric Analysis Continue.. Air Void

Calculation of the % Air Voids of sample (P_a)

$$P_a = \frac{G_{mm} - G_{mb}}{G_{mm}} X100$$

Where,

G_{mm} = Maximum Specific Gravity of Sample

G_{mb} = Bulk Specific Gravity of Binder

* **AS binder Content increase G_{mm} Always decreases..Why??**

Step 3 Volumetric Analysis Continue.. Air Void

Calculation of the Voids in Mineral Aggregate (VMA) of sample

$$VMA = \frac{G_{sb} - Ps * G_{mb}}{G_{sb}} X100$$

Where,

G_{sb} = combine Specific Gravity of Aggregate

G_{mb} = Bulk Specific Gravity of Binder

*** Analysis ??**

Step 3 Volumetric Analysis Continue.. Air Void

Calculation of the Voids fill with Asphalt (VFA) of sample

$$\textbf{VFA} = \frac{\text{VMA} - Pa}{VMA} \textbf{X100}$$

Where,

P_a = Percentage Air Voids %

G_{mb} = Bulk Specific Gravity of Binder

* **Analysis ??**

Step 4 Stability and Flow Value

-Marshall testing machine conforming to ASTM D6927

- Specimens dia 101.6 mm , height -63.5 mm
- For modified dia 152.4 mm, height 95.2 mm

-After determination of bulk specific gravity,

- Measure the height of sample (required for correction)
- Immerse specimen in water bath 60^{o} C ± 1^{o} C for 30 to 40 minutes
- Use automatic recording device
- Testing head maintained temperature at 21.1 to 37.8 C
- Zero reading and Apply load at the rate of 51 mm deflection per minutes
- Records the maximum stability value and flow value
- Complete all action with in 30 seconds
- Stability correction as per height different then 63.5 mm

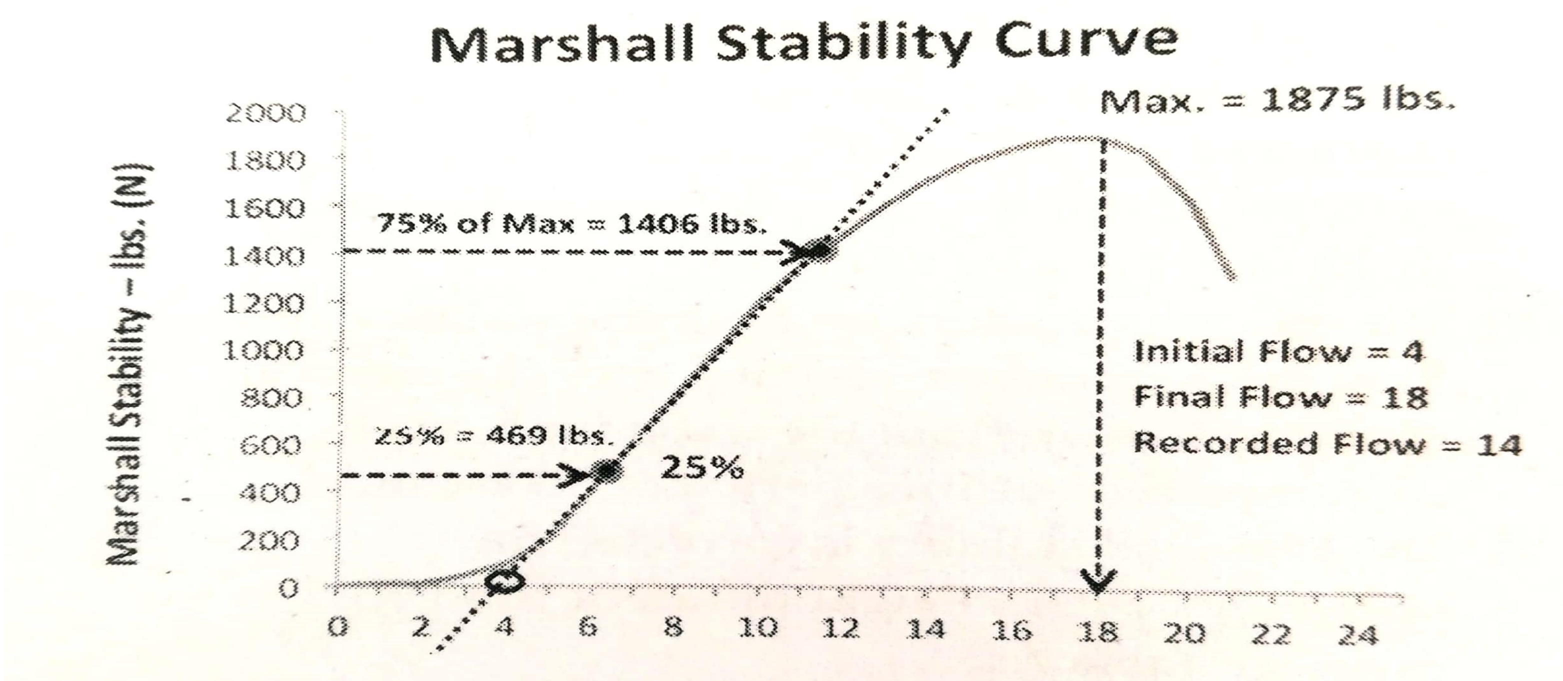
Step 4 Stability and Flow Value Continued

Step 4 Stability and Flow Value Continued

Step 4 Stability and Flow Value Continued

-Use Stability correction Chart as per thickness of sample(page No.86 of MS 2)

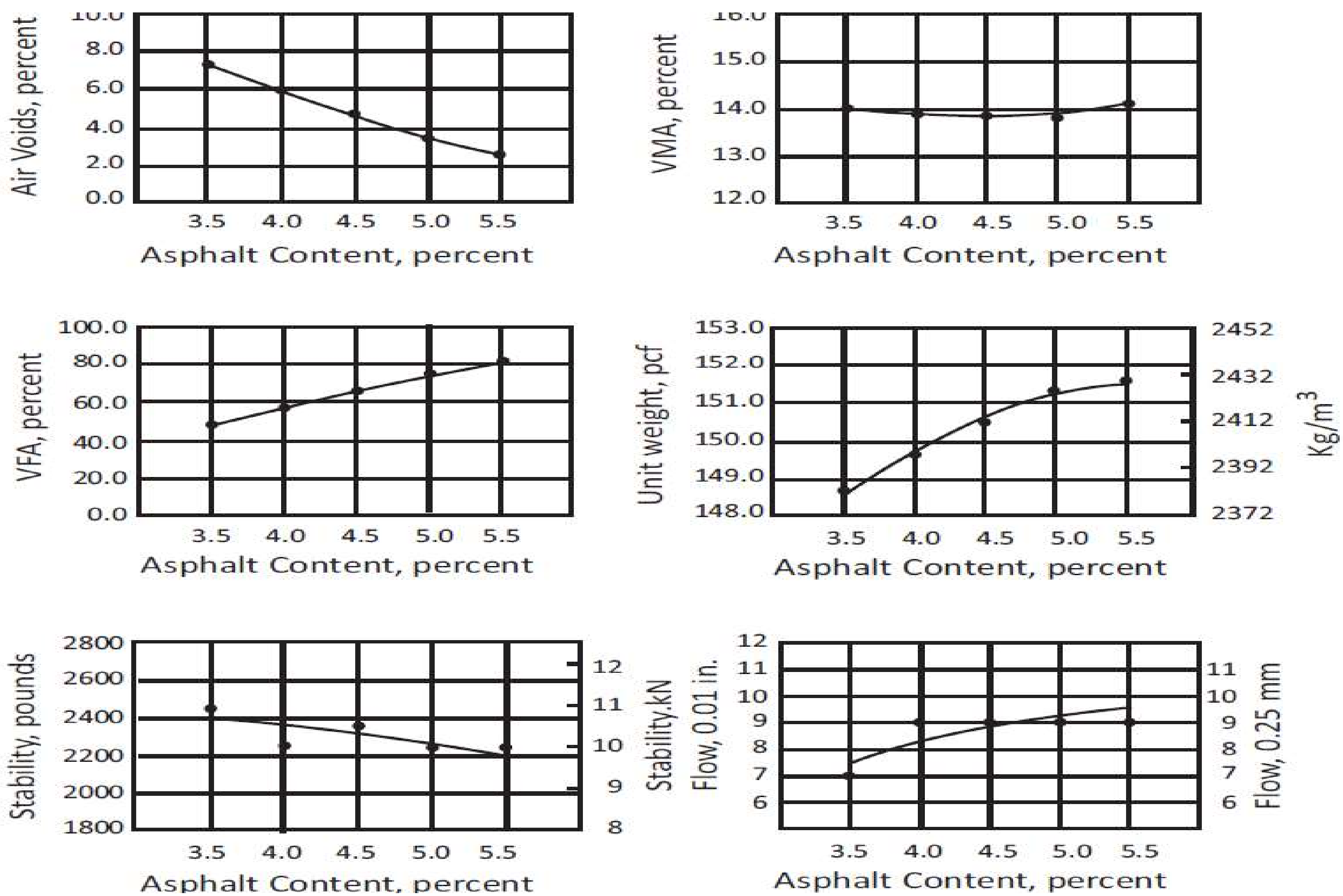
-Use correction in flow value in case of automatic reading devices (For analog system correction is not required depending up on experience)



Step 5 Analysis on different parameters with respect to binder Contents

- **Bulk Density(G mb) increase with increase in Binder Content (Pb) – Voids fill with binder –slightly reduces the volume- increase in mass pag e44**
- **For filled void the volume increases thus slightly reduce in Bulk density (G mb)**

- **As binder content increase Theoretical Maximum Gravity(Gmm) always decrease because of higher specific Gravity of aggregate rather than binder**
- **Air Voids (Pa) always decrease with increase in binder content**
- **Percentege void in mineral aggregate (VMA) initially drecrease and than increase as increase in binder contents (page no 85)**
- **% Void filled with asphalt (VFA) is always increase with increase in binder content**
- **Stability Value increase up to maximum and then decrease with increase in binder contents**
- **Flow Value continuously increase with increase in binder content**



Air Voids, percent
10.0
8.0
6.0
4.0
2.0
0.0
3.5 4.0 4.5 5.0 5.5
Asphalt Content, percent
VMA, percent
16.0
15.0
14.0
13.0
12.0
3.5 4.0 4.5 5.0 5.5
Asphalt Content, percent
VFA, percent
100.0
80.0
60.0
40.0
20.0
0.0
3.5 4.0 4.5 5.0 5.5
Asphalt Content, percent
Unit weight, pcf
153.0
152.0
151.0
150.0
149.0
148.0
2452
2432
2412
2392
2372
Kg/m3
3.5 4.0 4.5 5.0 5.5
Asphalt Content, percent
Stability, pounds
2800
2600
2400
2200
2000
1800
12
11
10
9
8
Stability,kN
3.5 4.0 4.5 5.0 5.5
Asphalt Content, percent
Flow, 0.01 in.
12
11
10
9
8
7
6
11
10
9
8
7
6
Flow, 0.25 mm
3.5 4.0 4.5 5.0 5.5
Asphalt Content, percent

Step 6 Optimum Binder Selection

- **From graph between binder content and air void find the optimum binder content for 4% air voids**
- **After finding Binder content than find other parameters**
- **Parameters (density, stability, VFA, VMA, Flow) as per specification limit**
- **If not meet repeat the test**
- **Repetition and experience –leads accurate design**

Modified Marshall method

-Generally aggregate size more than 25mm up to 38 mm

- Less deviation in data
- Hammer weight 10.2 kg (4.5 Kg non modified)
- Specimen dia 152.4 mm (101.6 mm non modified)
- Height 92.5 mm (63.5 mm)
- No of blows (1.5 times than non modified)i.e 75 or 112 each side
- Minimum stability 2.25 times , Flow value 1.5 times
- Stability correction factor as per thickness is different

Design Criteria as per MS 2

Marshall Method Criteria[1]	Light Traffic[3] Surface & Base		Medium Traffic[3] Surface & Base		Heavy Traffic[3] Surface & Base	
	Min	Max	Min	Max	Min	Max
Compaction, number of blows each end of specimen	35		50		75	
Stability[2], N (lb.)	3336 (750)	–	5338 (1200)	–	8006 (1800)	–
Flow[2,4,5], 0.25 mm (0.01 in.)	8	18	8	16	8	14
Percent Air Voids[7]	3	5	3	5	3	5
Percent Voids in Mineral Aggregate (VMA)[6]	See Table 7.3					
Percent Voids Filled With Asphalt (VFA)	70	80	65	78	65	75

NOTES:
1. All criteria, not just stability value alone, must be considered in designing an asphalt paving mix.
2. Hot mix asphalt bases that do not meet these criteria when tested at 60°C (140°F) are satisfactory if they meet the criteria when tested at 38°C (100°F) and are placed 100 mm (4 inches) or more below the surface. This recommendation applies only to regions having a range of climatic conditions similar to those prevailing throughout most of the United States. A different lower test temperature may be considered in regions having more extreme climatic conditions.
3. Traffic classifications
   - Light Traffic conditions resulting in a 20-year Design ESAL $< 10^4$
   - Medium Traffic conditions resulting in a 20-year Design ESAL between 10^4 and 10^6
   - Heavy Traffic conditions resulting in a 20-year Design ESAL $> 10^6$
4. The flow value refers to the point where the load begins to decrease. When an automatic recording device is used, the flow should be corrected as shown in section 7.3.3.3.
5. The flow criteria were established for neat asphalts. The flow criteria are often exceeded when polymer-modified or rubber-modified binders are used. Therefore, the upper limit of the flow criteria should be waived when polymer-modified or rubber-modified binders are used.
6. Percent voids in the mineral aggregate are to be calculated on the basis of the ASTM bulk specific gravity for the aggregate, as discussed in chapter 5.
7. Percent air voids should be targeted at 4 percent. This may be slightly adjusted if needed to meet the other Marshall criteria.

Excel Sheet Exercise

Water Sensitivity- % air void more than 8%-stripping effect-adhesion failure between binder and aggregate
Tensile Strength Ratio more than 80%

Treatment hydrated lime or cement 2%-3%


THANK
YOU