

STATE OF THE ART IN ASPHALT MIX DESIGN

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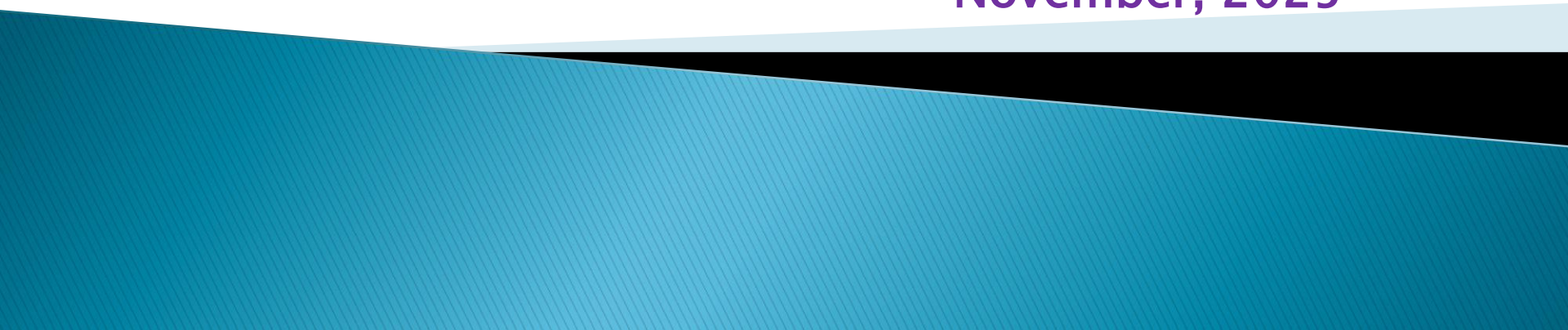
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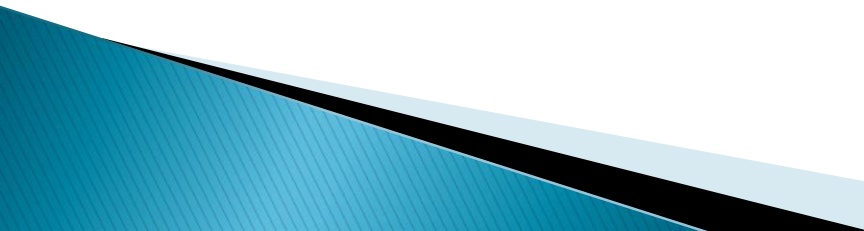
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Outline

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Introduction

- ❑ Asphalt mix design refers to the process of proportioning its components, generally aggregates and binder, so that the required properties are achieved (Zunamis et. al., 2018).

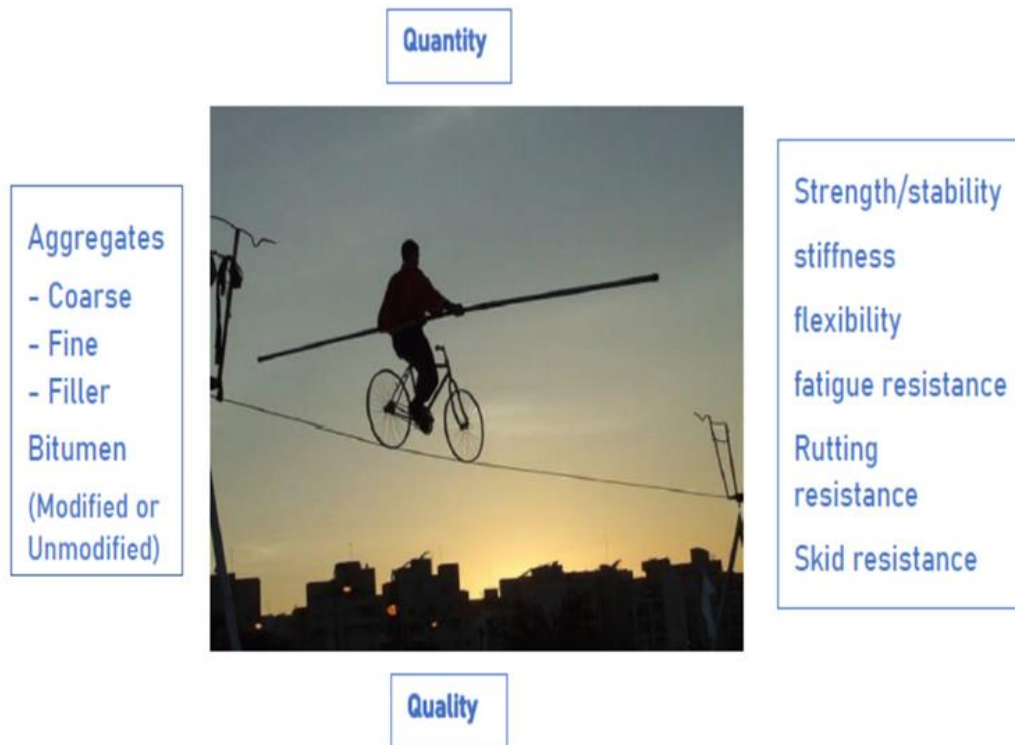
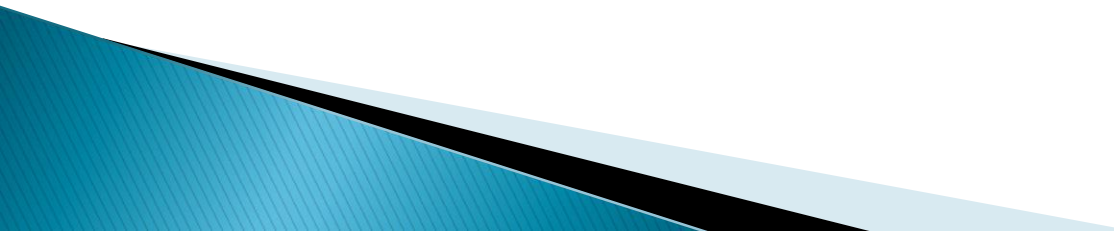


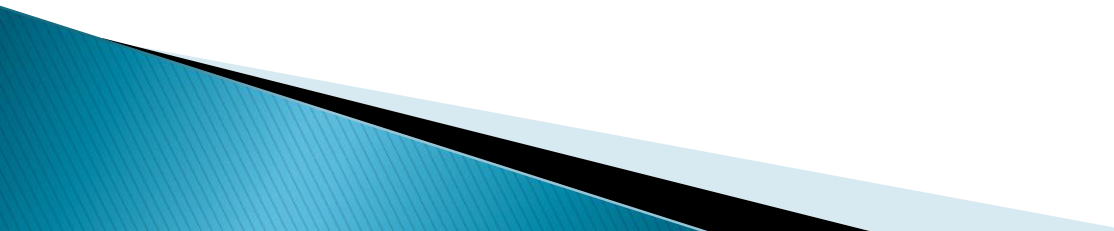
Plate 1: Balancing of asphalt mixtures materials

- ❑ It involves laboratory procedures to determine the properties and required proportions of the materials used in the asphalt mixture.

Introduction

- ❑ In many cases, the cause of poor performance of pavements has been attributed to:
 - ❖ a poor or inappropriate mix design; or
 - ❖ the production of a mixture different from what was designed in the laboratory.
 - ❑ The overall objective for the design of asphalt paving mixes is to determine the gradation of aggregates and the amount of binder content (optimum) that will result in a mix having:
 - ❖ sufficient bitumen to ensure a durable pavement;
 - ❖ sufficient mix stability to satisfy the demands of traffic without distortion or displacement;
- 

Introduction

- ❖ sufficient air voids in the total compacted mix to allow for a slight amount of additional compaction under traffic loading and a slight amount of thermal binder expansion without flushing, bleeding, and loss of stability;
 - ❖ a maximum void content to limit the permeability of harmful air and moisture into the mix;
 - ❖ sufficient workability to permit efficient placement of the mix without segregation and without sacrificing stability and performance; and
 - ❖ aggregate texture and hardness to provide adequate skid resistance in unfavourable weather conditions.
- 

Properties Considered in Mix Design

- ❑ The properties that are considered in asphalt mix design are:
 - ❖ resistance to permanent deformation;
 - ❖ resistance to fatigue;
 - ❖ resistance to low-temperature cracking;
 - ❖ moisture resistance;
 - ❖ durability and
 - ❖ workability.
- ❑ These properties determine the ability of the asphalt pavement to stand the test of time.

Properties Considered in Mix Design

Resistance to permanent deformation

- ❑ Permanent deformation results from the accumulation of small amounts of unrecoverable strain (small deformations) from repeated loads applied to the pavement.
- ❑ Wheel path rutting is the most common form of permanent deformation. Inadequate mix stability will lead to rutting (see Plate 2).



Plate 2: Rutting

Properties Considered in Mix Design

Resistance to Fatigue

- ❑ Fatigue resistance is the pavement's resistance to repeated bending under wheel loads (traffic). The result of a fatigue failure is fatigue cracking, often called alligator cracking (Plate 3).
- ❑ Producing an asphalt mix with good resistance to fatigue can be achieved by using pavement materials that are not easily weakened by moisture, so, attention must be paid to bitumen stiffness.



Plate 3: A typical pavement with fatigue cracking

Properties Considered in Mix Design

Low-temperature cracking

- ❑ This is not a problem in Nigeria but it is given serious attention in temperate climate.
- ❑ This is caused by temperature drops in pavement sufficiently to produce thermally induced stress in the HMA layer that exceeds the tensile strength of the asphalt mixture. The result is transverse cracks.
- ❑ In general, the solution to this problem is the proper choice of binder. The use of highly absorptive aggregates, or aggregates with high dust content, can aggravate low-temperature cracking.



Plate 4: Transverse crack (Low temperature cracking)

Properties Considered in Mix Design

Moisture resistance

- ❑ A major durability problem associated with moisture damage is commonly referred to as “stripping.”
- ❑ The best line of defense against stripping is having sufficient binder in the mix, which can be achieved by:
 - ❖ having a proper mix design and
 - ❖ constructing an impermeable mat by achieving a sufficient compaction.

Durability

- ❑ The ability to resist factors such as aging of the bitumen, disintegration of the aggregate, and stripping of the bitumen film from the aggregate.

Properties Considered in Mix Design

Durability (cont'd)

- ❑ Generally, the durability of a mixture can be enhanced by three methods:
 - ❖ designing the mix using a dense gradation of moisture-resistant and sound aggregate;
 - ❖ maximizing the bitumen film thickness on the aggregate; and
 - ❖ compacting the mixture to be impervious (which may be as low as 5 percent in-place air voids, depending on nominal maximum aggregate size and gradation).
- ❑ The use of 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 bitumen) are important to produce durable asphalt pavement

Properties Considered in Mix Design

Skid resistance

- ❑ The ability of an asphalt surface to minimize the skidding or slipping of vehicle tyres, particularly when the roadway surface is wet.
- ❑ A rough pavement surface with many little peaks and valleys will have greater skid resistance than a smooth textured surface.
- ❑ Also, the aggregates must resist polishing (smoothing) under traffic, and the mix must have enough air voids to prevent bleeding.

Workability

- ❑ The ease with which asphalt mixtures can be placed and compacted.
- ❑ Harsh mixtures (containing a high percentage of coarse aggregate and/or low bitumen content) tend to segregate during handling and may be difficult to compact.
- ❑ Tender mixes (having a shortage or excess of mineral filler, excess bitumen, excessive medium-sized sand, and smooth and rounded aggregate particles) are too unstable to place and compact properly.
- ❑ High and low temperatures make a mix tender and unworkable.

Asphalt Mix Design Methods

The mix design methods include:

Hveem mix design

Marshall mix design

Superpave mix design

Balanced mix design

Hveem Mix Design

□ The Hveem mix design method consists of 6 basic steps:

- ❖ aggregate selection;
- ❖ asphalt binder selection;
- ❖ sample preparation (including compaction);
- ❖ stability determination using the Hveem stabilometer;
- ❖ density and voids calculations and
- ❖ optimum asphalt binder content selection.

Asphalt Mix Design Methods (Marshall)

Marshall Mix Design

The General Specification (Roads and bridges) specified the use of the Marshall mix design to establish the job mixes for asphalt mixtures.

The Marshall mix design involves:

- ❖ selection of the materials (aggregates and bitumen)
 - ❖ determination of the specific gravity of materials
 - ❖ the preparation of test specimens;
 - ❖ Determination of the bulk specific gravity and theoretical specific gravity of bituminous mix;
 - ❖ Determination of the stability (stability) and flow (flexibility) of the prepared samples
 - ❖ the density and voids analysis (volumetric characteristics) and
 - ❖ Establishing the job mix
- 

Asphalt Mix Design Methods (Marshall)

Selection and grading of the aggregates and bitumen

Appropriate aggregates (fine and coarse) and mineral filler (Table 1) required to ensure the blend of the aggregates falls within the specified envelope (Table 2) are selected based on their shape and size and the gradations are determined.

Three main types of aggregates used in bituminous mixtures are:

- Coarse aggregate (CA): A portion of the aggregate retained on the No. 5 mm opening sieve and shall be hard, clean, and durable crushed igneous rock. The crushed stone shall be free from dirt or other objectionable matter (FMPWH, 2016)
- Fine aggregate (FA): A portion of the aggregate passing the No. 5 mm opening sieve and shall be quarry fines produced from the crushing of igneous rock. They shall be composed of clean, tough, rough-surfaced, and angular particles, free from lumps, or balls of clay, loam, and other deleterious substances (FMPWH, 2016).
- Mineral filler. Finely ground particles of hydrated lime, Portland cement, or other non-plastic mineral matter approved by the Engineer. It shall be free from foreign or other objectionable materials and shall meet the requirements shown in Table 1 (FMPWH, 2016):

Asphalt Mix Design Methods (Marshall)

Selection and grading of the aggregates and bitumen (cont'd)

Table 1: Requirements for mineral filler

Sieve size	% by weight passing
300 μm	100
200 μm	95-100
75 μm	85-100

Asphalt Mix Design Methods (Marshall)

Selection and grading of the aggregates and bitumen (cont'd)

Table 2: Grading envelope for asphaltic concrete binder and wearing courses (FMPWH, 2016)

	% by Weight Passing	
Sieve Size	40 mm – 65 mm Binder Course	40 mm – 65 mm Wearing Course
31.8 mm	100	100
25 mm	90 - 100	100
19.0 mm	70 - 90	100
12.5 mm	55 - 80	85 - 100
9.5 mm	47 - 70	75 - 92
6.4 mm	40 - 60	65 - 82
2.8 mm	27 - 45	50 - 65
1.25 mm	20 - 34	36 - 51
600 µm	14 - 27	26 - 40
300 µm	8 - 20	18 - 30
150 µm	5 - 15	13 - 24
75 µm	2 - 7	7 - 14
Bitumen Content (% by weight of aggregate)	4.5 - 6.5	5 - 8.0

Asphalt Mix Design Methods (Marshall)

Selection and grading of the aggregates and bitumen (cont'd)

Two types of courses: wearing and binder courses are specified in the General Specifications (Roads and Bridges) (FMPWH, 2016) as shown in Table 2.

The pavement design will normally indicate whether only the wearing course or both are needed.

The proportioning of the aggregates is usually done by a trial-and-error method based on experience. Different percentages of the aggregates will be selected and checked to fall within the envelope.



Plate 5: Aggregates, Bitumen and Marshall samples

Asphalt Mix Design Methods (Marshall)

The specifications for the aggregates are shown in Tables 3

Table 3: Aggregate Specifications for Dense Bitumen Macadam and Asphaltic Concrete Wearing and Base

Pavement Course	Aggregate Crushing Value	Flakiness Index	Absorption Factor
Dense Bitumen Macadam Base	30	35	1.5
Dense Bitumen Macadam Wearing Course	30	35	0.5
Asphaltic Concrete Base	30	35	0.5
Asphaltic Concrete Wearing Course	30	35	0.5

Asphalt Mix Design Methods (Marshall)

Selection and grading of the aggregates and bitumen (cont'd)

The bitumen grades specified in the General Specifications (Roads and Bridges) are the 60/70 and 80/100 penetration grades (Table 4). Although, the 60/70 penetration grade is commonly used.

The bitumen will be selected and subjected to consistency tests like the penetration, softening point, and viscosity tests. It must meet the specifications.

Determination of the specific gravity of the aggregates and bitumen

Laboratory tests are conducted to determine the specific gravity of the aggregates and bitumen.

The values are required in calculating the volumetric characteristics of the mixture.



Asphalt Mix Design Methods (Marshall)

Table 4: Quality of Bitumen (FMPWH, 2016)

Property	Asphalt Cement (Bitumen)	
	80 – 100 Pen	60 – 70 Pen
Specific gravity at 25°C	1.00 – 1.05	1.01 – 1.06
Softening point at °C	45 - 52	48 - 56
Penetration at 25°C ...0.1 mm	80 -100	60 – 7-
Density at 25 °C cm minimum	100	100
Minimum loss on heating for 5 hours at 163°C by weight max	0.5	0.2
Solubility in CS ₂ % by weight ... min	99	99
Drop in penetration after heting % original ... max	20	20
Flash point (open cut) at °C min	225	250
Ash % by weight ... max	0.5	0.5

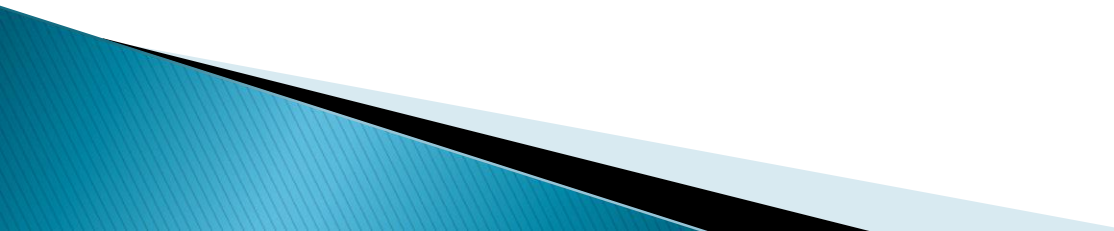
Asphalt Mix Design Methods (Marshall)

Preparation of the specimens

The samples for the stability and flow test are prepared after establishing the aggregate gradations and achieving the right proportioning of the aggregates such that the curve falls within the envelope and selecting the appropriate bitumen.

This involves mixing the heated aggregates (120 to 149°C) and asphalt binder (135 to 163°C) in precise proportions and compacting the mixture into cylindrical specimens using a specialized Marshall compactor. The samples are given 35, 50 or 75 blows at the top and bottom for light, medium or heavy trafficked road, respectively.

Marshall test specimens (Plate 5) are typically cylindrical samples with a diameter of 101.6 mm (4 inches) and a height of 63.5 mm (2.5 inches).



Asphalt Mix Design Methods (Marshall)

The automatic compactor and the specimen extractor are shown in Plates 6 and 7, respectively.



Plate 6: Automatic compactor



Plate 7: Specimen Extractor

Asphalt Mix Design Methods (Marshall)

Determination of the bulk specific gravity and theoretical specific gravity of bituminous mix:

The bulk specific gravity or the actual specific gravity of the mix G_m is calculated as shown in equation 1:

$$G_m = \frac{W_m}{W_m - W_w} \quad (1)$$

where, W_m is the weight of the mix in air

W_w is the weight of the mix in water.

Note that $W_m - W_w$ gives the volume of the mix.

Sometimes to get accurate bulk specific gravity, the specimen is coated with thin film of paraffin wax, when weight is taken in the water. However, this requires considering the weight and volume of wax in the calculations.

Asphalt Mix Design Methods (Marshall)

Determination of the bulk specific gravity and theoretical specific gravity of asphalt mix:

The theoretical specific gravity G_t is calculated as shown in Equation 2

$$G_t = \frac{W_1 + W_2 + W_3 + W_b}{\frac{W_1}{G_1} + \frac{W_2}{G_2} + \frac{W_3}{G_3} + \frac{W_b}{G_b}} \quad (2)$$

where W_1 is the weight of coarse aggregate in the total mix, W_2 is the weight of fine aggregate in the total mix, W_3 is the weight of filler in the total mix, W_b is the weight of bitumen in the total mix, G_1 is the apparent specific gravity of coarse aggregate, G_2 is the apparent specific gravity of fine aggregate, G_3 is the apparent specific gravity of the filler and G_b is the apparent specific gravity of the bitumen.

Asphalt Mix Design Methods (Marshall)

Determination of the stability and flow

The Marshall stability and flow test is conducted on the specimens.

Marshall stability measures the maximum load the asphalt concrete specimen can withstand before failure at 60°C.

It indicates the mixture's resistance to deformation and the ability to support traffic loads.

The Marshall flow test measures the deformation the asphalt concrete specimen undergoes under the maximum load and gives insight into the mixture's flexibility

The values are adjusted using the correction factor.

The Marshall stability and flow testing machine is shown in Plate 8.

Asphalt Mix Design Methods (Marshall)



Plate 8: Marshall stability and flow testing machine

Asphalt Mix Design Methods (Marshall)

Volumetric characteristics of asphalt mixtures

The phase diagram of the asphalt mix expressing the volumetric features is shown in Figure 1.

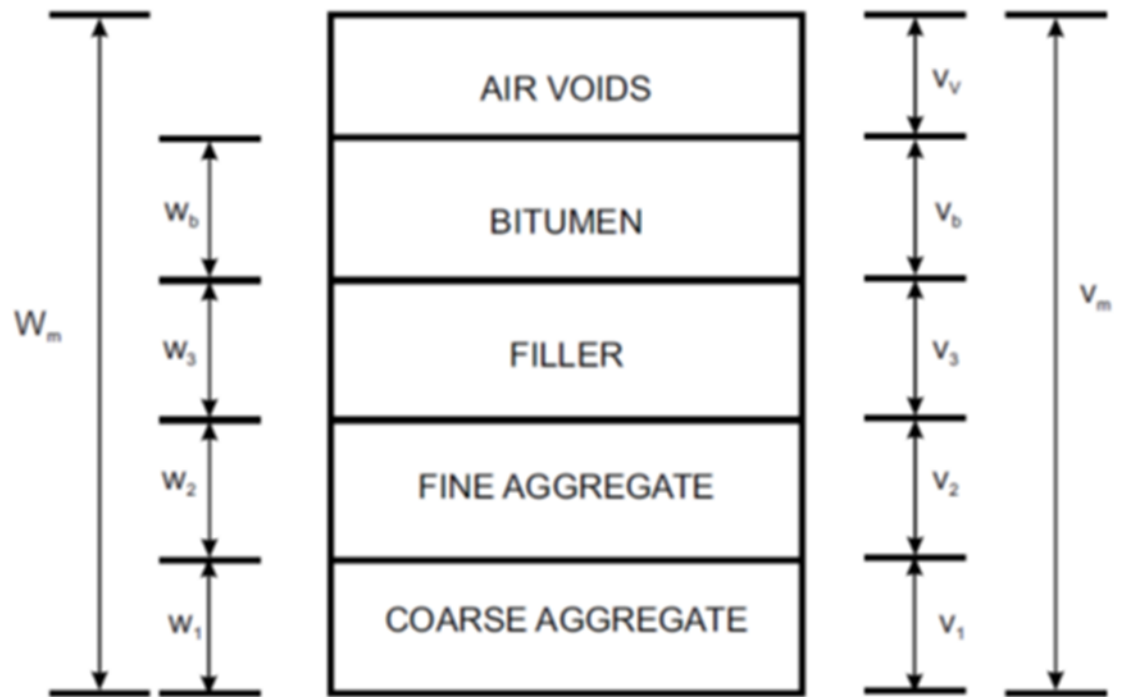


Figure 1: Phase diagram of asphalt mix

Asphalt Mix Design Methods (Marshall)

Volumetric characteristics of asphalt mixtures

Air voids

The air voids in a paving mixture (see Figure 1) are small pockets of air between the bitumen-coated aggregate particles.

A certain percentage of air voids is necessary for the finished hot mix asphalt (HMA) to allow for additional compaction under traffic and a slight amount of asphalt expansion because of temperature increases.

The durability of an asphalt pavement is a function of the air void content.

The values of 3%-8% and 3%-5% are specified for binder and wearing courses, respectively (FMPWH, 2016).

Air voids V_v is the percent of air voids by volume in the specimen is calculated as shown in Equation 3:

$$V_v = \left(\frac{G_t - G_m}{G_t} \right) \times 100 \quad (3)$$

where G_t is the theoretical specific gravity of the mix and G_m is the bulk or actual specific gravity of the mix.

Asphalt Mix Design Methods (Marshall)

Volumetric characteristics of asphalt mixtures

Voids in the mineral aggregate:

Space between aggregate particles occupied by air and asphalt binder. This is critical for ensuring sufficient binder coverage and adequate durability.

Voids in the mineral aggregate (VMA) must remain high enough to achieve an adequate bitumen film thickness, which results in durable asphalt pavement.

VMA is calculated as the sum of the percent air voids and percent bitumen content in the mixes as shown in Equation 4.

$$VMA = V_v + V_b \quad (4)$$

where V_v is the percent air voids in the mix and V_b is the percent bitumen content in the mix.

Asphalt Mix Design Methods (Marshall)

Volumetric characteristics of asphalt mixtures

Voids filled with bitumen:

Percentage of intergranular void space between the aggregate particles (VMA) that contains or is filled with an effective binder (see Figure 1).

VFB is used to ensure proper bitumen film thickness in the mix.

If it is too low, the mix will have poor durability, or if it is too high, the mix can be unstable.

The VFB values specified for asphalt concrete binder and wearing courses are 65 – 72% and 75 -82%, respectively. The VFB is calculated as shown in Equation 5.

$$VFB = \frac{V_b}{VMA} \times 100 \quad (5)$$

where V_b is the percent bitumen content in the mix and VMA is the percent voids in the mineral aggregate.

Asphalt Mix Design Methods (Marshall)

Volumetric characteristics of asphalt mixtures

Bitumen content:

The total bitumen content is the amount of bitumen that must be added to the mixture to produce the desired mix qualities.

Aggregate absorption is critical in determining optimum bitumen content.

The volume of bitumen V_b is calculated as shown in Equation 6.

$$V_b = \left(\frac{\frac{W_b}{G_b}}{\frac{W_1 + W_2 + W_3 + W_b}{G_m}} \right) \times 100 \quad (6)$$

where W_1 is the weight of coarse aggregate in the total mix,

W_2 is the weight of fine aggregate in the total mix

W_3 is the weight of filler in the total mix,

W_b is the weight of bitumen in the total mix,

G_b is the apparent specific gravity of bitumen, and

G_m is the bulk specific gravity of mix

Asphalt Mix Design Methods (Marshall)

Establishing the Job Mix

Once the stability and flow values have been determined and the volumetric characteristics calculated, the asphalt mixture is checked to determine if it meets the specifications (Table 5) at the optimum bitumen content using the graphs shown in Figure 2.

- i. Stability versus bitumen content
- ii. Flow versus bitumen content
- iii. Air voids versus bitumen content
- iv. Voids filled with bitumen versus bitumen content
- v. Bulk specific gravity/Unit weight/ Density versus the bitumen content

The optimum bitumen content is determined as the average bitumen content corresponding to the bitumen contents at maximum stability, maximum bulk specific gravity, and 4 percent air voids.

$$OBC = \frac{BC \text{ at maximum stability} + BC \text{ at Maximum } G_m + BC \text{ at } 4\% V_V}{3} \quad (7)$$

Asphalt Mix Design Methods (Marshall)

Table 5: Specifications for the Asphalt Mixture

Property	Base course	Wearing course
Optimum binder content	4.5% - 6.5%	5.0% - 8.0%
Stability. Not less than	3.5 kN	3.5 kN
Flow	2 mm - 6 mm	2 mm - 4 mm
Voids in total mixture	3% - 8%	3% - 5%
Voids filled with bitumen	65% - 72%	75% - 82%

Asphalt Mix Design Methods (Marshall)

Establishing the Job Mix

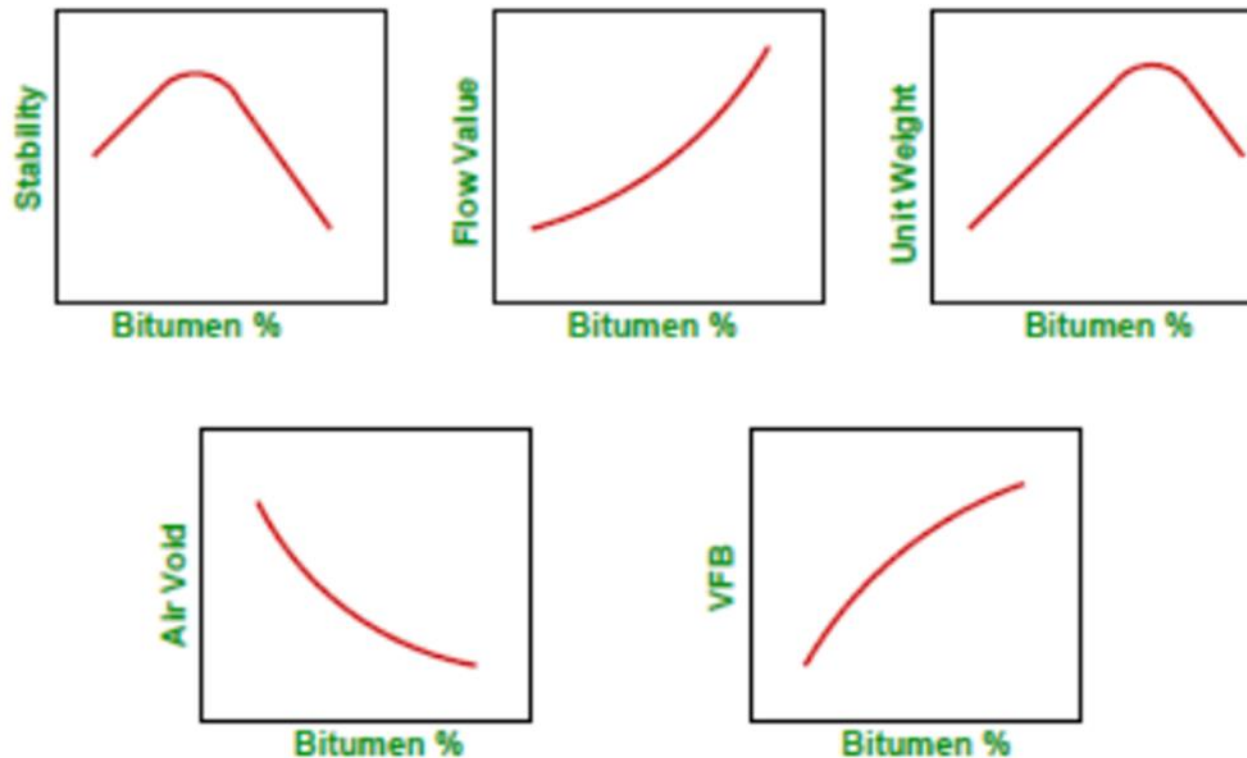


Figure 2: Graphs of Marshall parameters versus bitumen content

Asphalt Mix Design Methods (Marshall)

Extraction test

- ❑ The extraction test is essential for quality control. It involves the determination of the bitumen content in the prepared asphalt mixture.
- ❑ This ensures the asphalt mix has the required bitumen (OBC) for stable, durable, and safe pavement with good resistance to rutting and fatigue cracking.
- ❑ The test is carried out following British Standards (BS EN 12697-1, 2012)

$$\text{bitumen content (g)} = \frac{(W_1 - (W_2 + W_3))}{W_1} \quad (8)$$

W_1 = Weight of the sample in grams

W_2 = weight of the extracted aggregates in grams

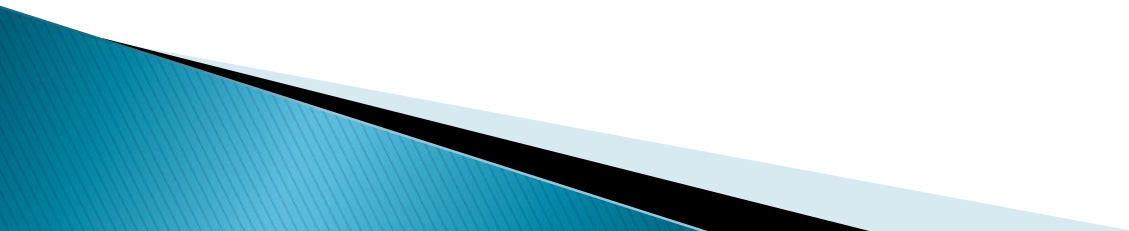
W_3 = weight of the fine aggregate fragments in grams

Asphalt Mix Design Methods (Marshall)

Case Study

The gradations, weights, and specific gravity of materials and the stability and flow results of the Marshall test conducted on asphalt concrete mix are shown in Tables 6, 7, and 8.

Carry out the volumetric analysis and determine the optimum bitumen content.



Asphalt Mix Design Methods (Marshall)

Table 6: Gradations of the aggregates

Size (mm)	¾	19%	½	11%	3/8	17%	Quarry Dust	38%	River sand	15%	Blend	Envelope
19.0	44.4	8.4	100	11	100	17	100	38	100	15	89.4	70-90
12.5	2.1	0.40	41.03	4.51	100	17	100	38	100	15	74.9	55- 80
9.6	1.42	0.27	1.93	0.21	13.4	2.28	100	38	100	15	55.8	47-70
6.3			1.2	0.13	1.79	0.30	97.7	37.1	100	15	52.5	40-60
2.36					1.67	0.28	71.1	27.0	96.9	14.5	41.8	27-45
1.18							53.9	20.5	88.3	13.2	33.7	20-34
0.600							40.0	15.2	65.1	9.8	25.0	14-27
0.300							28.2	10.7	24.0	3.6	14.3	8-20
0.150							14.8	5.6	6.2	0.9	6.5	5-15
0.075							7.6	2.9	1.9	0.3	3.2	2 -7

Asphalt Mix Design Methods (Marshall)

Table 7: Weight and Specific Gravity of Materials

Bitumen Content (%)	Weight of Coarse Aggregate	Weight of Fine Aggregate	Weight of Filler	Weight of Bitumen	Weight of mix (air)	Weight of mix (Water)
4.5	642	324	180	54	1222	659
5	642	324	180	60	1246	678
5.5	642	324	180	66	1209	673
6	642	324	180	72	1241	698
6.5	642	324	180	78	1210	673
7	642	324	180	84	1232	677
Specific Gravity						
Coarse Aggregate	Fine Aggregate	Filler	Bitumen			
2.80	2.60	1.90	0.98			

Table 8: Stability and flow results

Bitumen Content (%)	Uncorrected Stability (kN)	CF	Corrected Stability (kN)	Flow (mm)	Corrected Flow (mm)
4.5	12.552	1.000	12.552	24	6.0
5	13.2	1.000	13.200	23	5.8
5.5	15.064	1.000	15.064	22	5.5
6	17.656	1.000	17.656	20	5.0
6.5	14.712	1.000	14.712	19	4.8
7	11.225	1.000	11.225	17	4.3

Asphalt Mix Design Methods (Marshall)

Table 9: Summary of the Calculations of volumetric characteristics

% BC	GT	GM	V_v (%)	V_b (%)	VMA (%)	VFB (%)
4.5	2.382	2.171	8.858	9.969	18.827	52.951
5	2.365	2.195	7.188	11.143	18.331	60.788
5.5	2.349	2.256	3.959	12.536	16.495	75.999
6	2.333	2.285	2.057	13.783	15.840	87.014
6.5	2.317	2.253	2.762	14.650	17.412	84.137
7	2.302	2.220	3.562	15.470	19.032	81.284

Asphalt Mix Design Methods (Marshall)

Apparent specific gravity, G_t

$$G_t = \frac{W_1 + W_2 + W_3 + W_b}{\frac{W_1}{G_1} + \frac{W_2}{G_2} + \frac{W_3}{G_3} + \frac{W_b}{G_b}}$$

$$G_t = \frac{642 + 324 + 180 + 54}{\frac{642}{2.80} + \frac{324}{2.60} + \frac{180}{1.90} + \frac{54}{0.98}}$$

$$G_t = \frac{1200}{229.29 + 124.62 + 94.73 + 55.10}$$

$$G_t = \frac{1200}{503.74}$$

$$G_t = 2.382$$

Asphalt Mix Design Methods (Marshall)

Bulk specific gravity, G_m

$$G_m = \frac{W_m}{W_m - W_w}$$

$$G_m = \frac{1222}{1222 - 659}$$

$$G_m = 2.171$$

Air voids (V_v)

$$V_v = \left(\frac{G_t - G_m}{G_t} \right) \times 100$$

$$V_v = \left(\frac{2.382 - 2.171}{2.382} \right) \times 100$$

$$V_v = 8.858$$

Asphalt Mix Design Methods (Marshall)

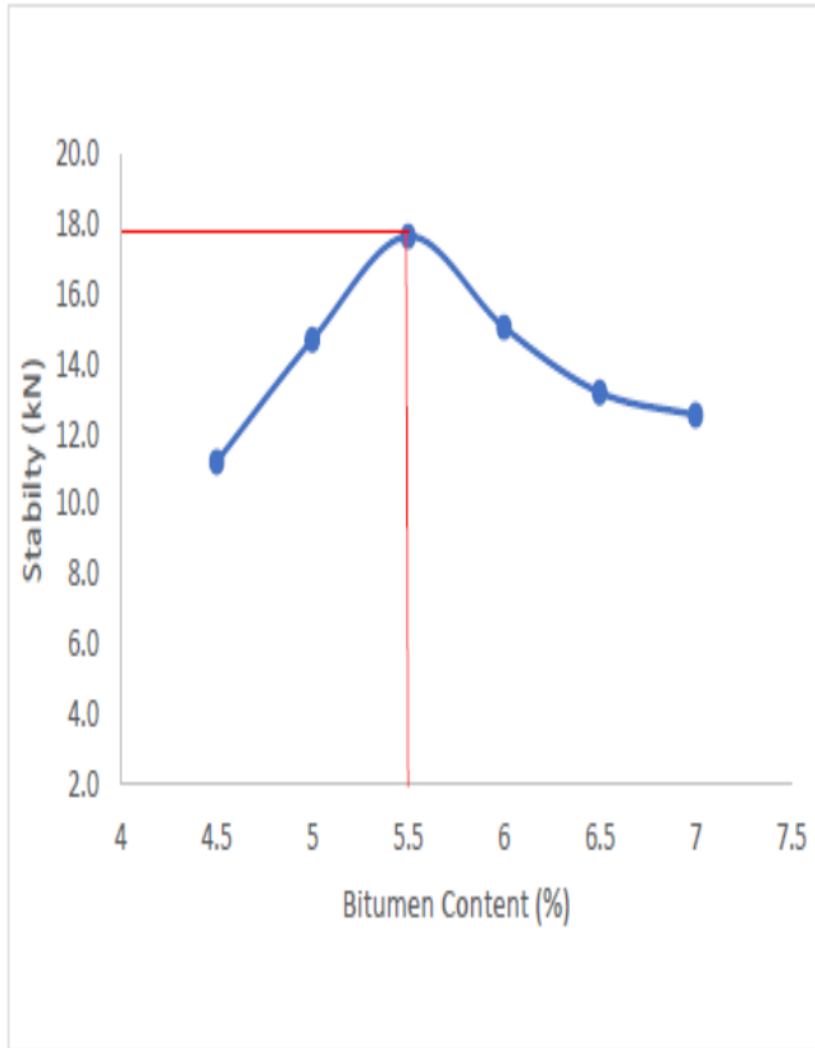


Figure 3: Stability versus the bitumen content

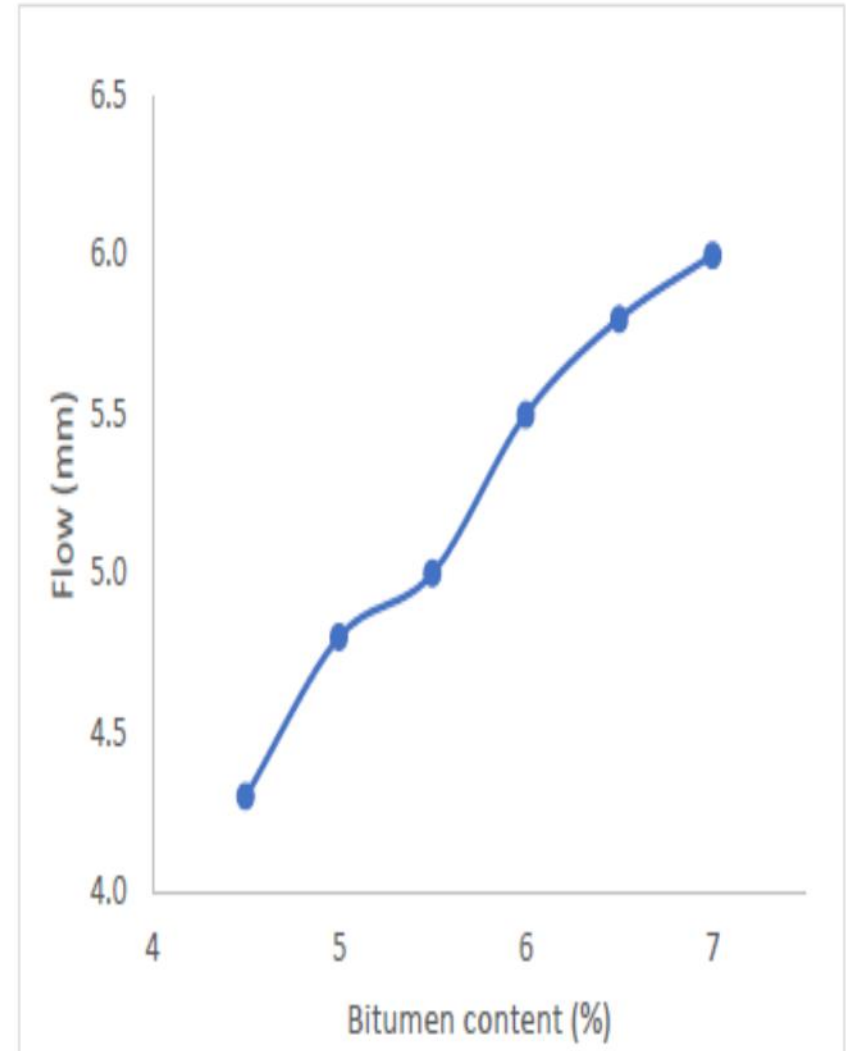


Figure 4: Flow versus the bitumen content

Asphalt Mix Design Methods (Marshall)

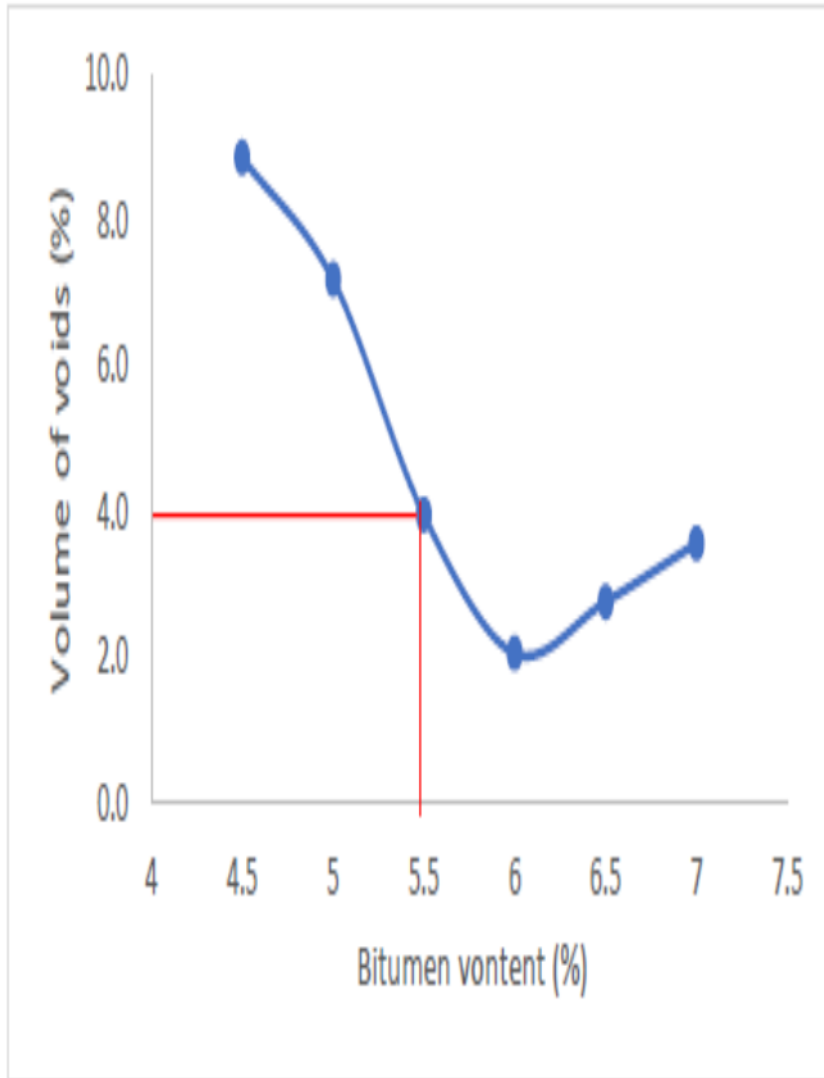


Figure 5: Volume of voids versus the bitumen content

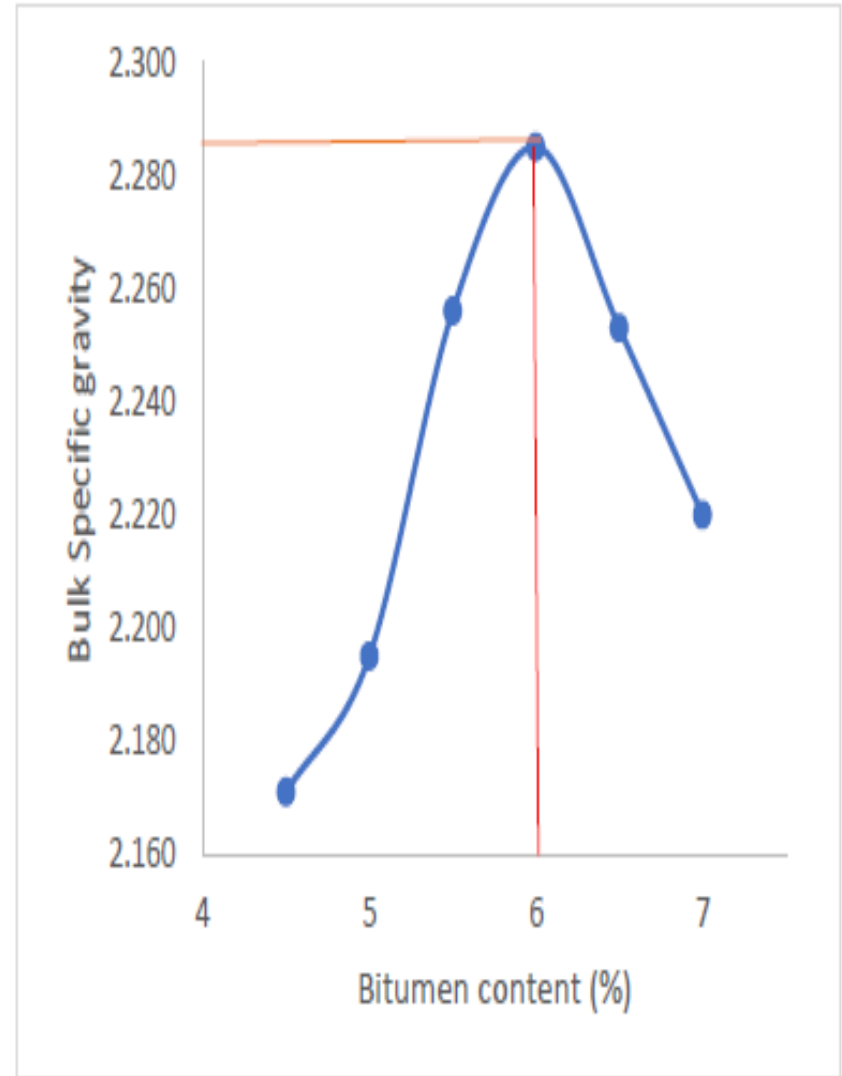
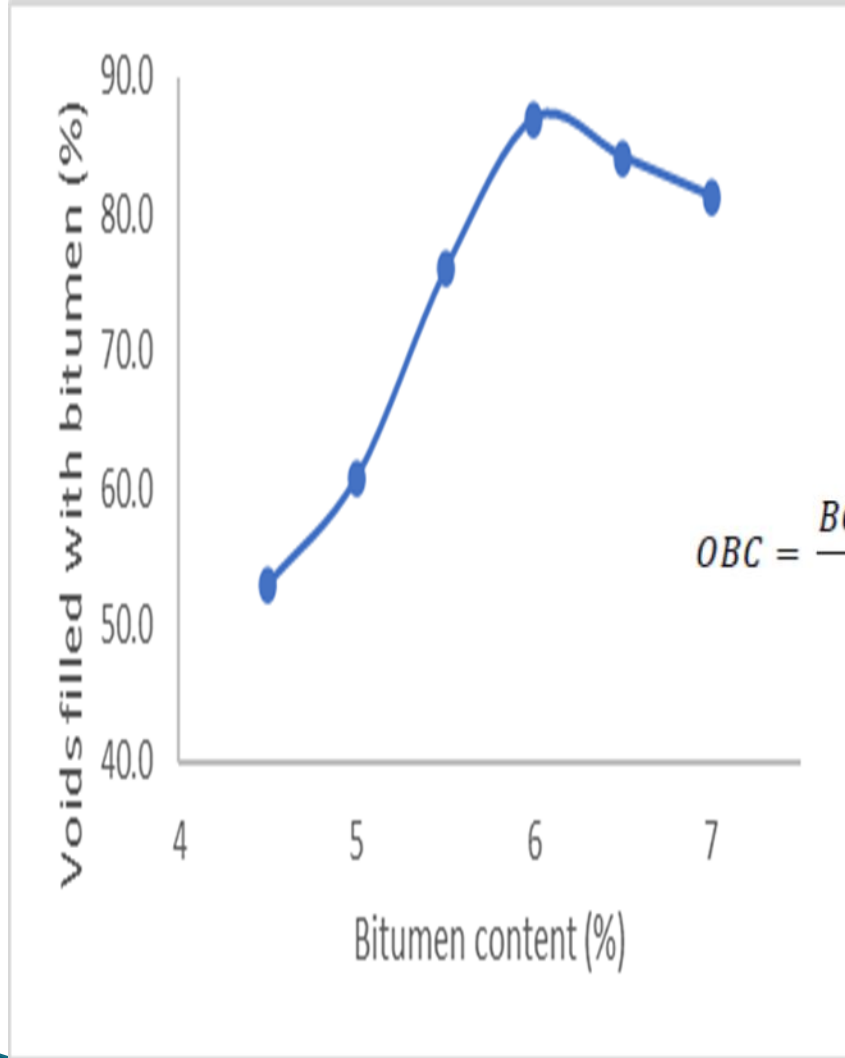


Figure 6: Bulk-specific gravity versus the bitumen content

Asphalt Mix Design Methods (Marshall)



Bitumen content at maximum stability = 5.5 %

Bitumen content at maximum bulk specific gravity = 6%

Bitumen content at 4% air voids = 5.5 %

$$OBC = \frac{BC \text{ at maximum stability} + BC \text{ at Maximum } G_m + BC \text{ at } 4\% V_v}{3}$$

$$\begin{aligned} OBC &= \frac{5.5 + 6.0 + 5.5}{3} \\ &= 5.7\% \end{aligned}$$

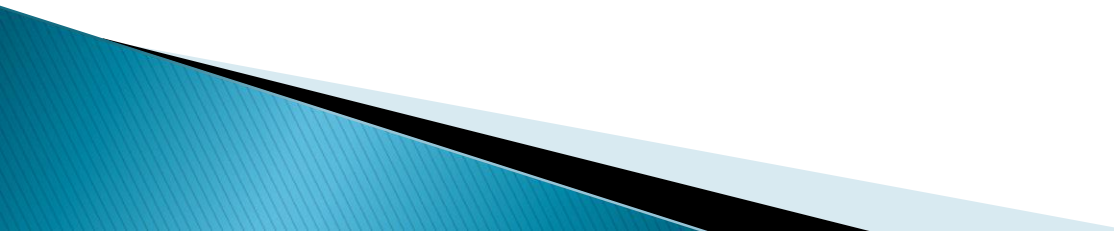
Figure 7: Voids filled with bitumen gravity versus the bitumen content

Asphalt Mix Design Methods

Superpave Mix Design

- It is a comprehensive method of designing paving mixes tailored to the unique performance requirements dictated by the traffic, environment (climate), and structural section at a particular pavement site.
 - It facilitates selecting and combining asphalt binder, aggregate, and any necessary modifier to achieve the required level of pavement performance.
 - It addresses the reduction and control of permanent deformation, fatigue cracking, and low-temperature cracking directly, through materials selection and mix design.
 - It also explicitly considers the effects of aging and moisture sensitivity in promoting or arresting the development of these three distresses.
- 

Asphalt Mix Design Methods (Superpave)

- ❑ The objective of the Superpave mix design system is to define an economical blend of asphalt binder and aggregate that yields a paving mix having:
 - ❖ sufficient asphalt binder;
 - ❖ sufficient voids in the mineral aggregate (VMA) and air voids;
 - ❖ sufficient workability; and
 - ❖ satisfactory performance characteristics over the service life of the pavement.
- 

Asphalt Mix Design Methods (Superpave)

- ❑ The four basic steps of Superpave asphalt mix design (Figure 8) are:
 - ❖ materials selection;
 - ❖ selection of the design aggregate structure;
 - ❖ selection of the design asphalt binder content; and
 - ❖ evaluation of the mixture's moisture sensitivity.

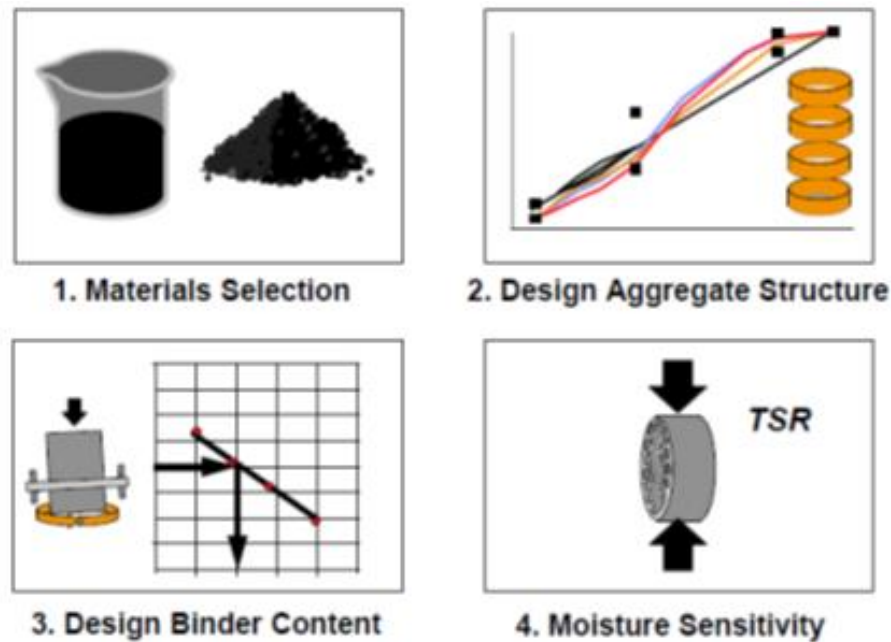


Figure 8: Steps of Superpave mix design

Asphalt Mix Design Methods (Superpave)

Materials selection

The properties of the materials are evaluated to select the right materials.

Measurement of the binder's properties

- ❑ The new Superpave binder tests measure physical properties that can be related directly to field performance by engineering principles.
- ❑ The three most critical stages are:
 - ❖ during transport, storage, and handling (unaged binder);
 - ❖ during mix production and construction (Rolling Thin Film Oven test); and
 - ❖ after long periods in a pavement (Pressure Aging Vessel).
- ❑ The tests are shown in Table 10 and Figure 9.

Asphalt Mix Design Methods (Superpave)

Table 10: Superpave binder tests

Superpave binder test	Purpose
Dynamic shear rheometer (DSR)	Measure properties at high and intermediate temperatures
Rotational viscometer (RV)	Measure properties at high temperature
Bending beam rheometer (BBR) Direct tension test	Measure properties at low temperature
Rolling thin film oven test (RTFO)	Simulate aging during mix production and construction
Pressure aging vessel (PAV)	Simulate aging a long period of service

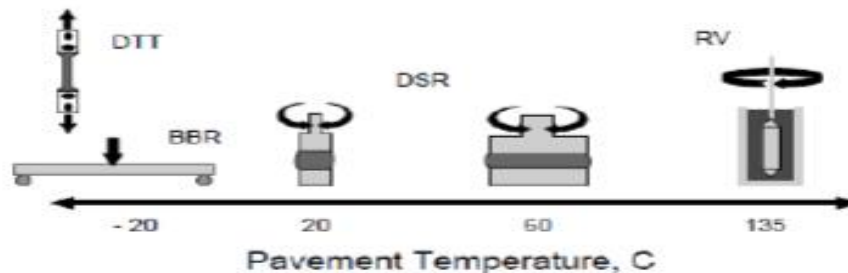
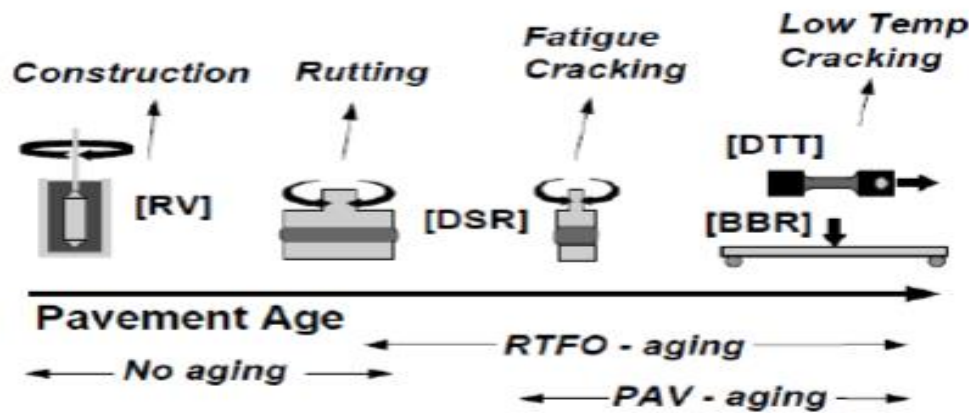


Figure 9: Superpave binder tests

Asphalt Mix Design Methods (Superpave)

Materials selection (cont'd)

Measurement of the aggregate properties

- ❑ Two categories of aggregate properties were established in the Superpave system: **consensus** and **source** properties.

Consensus Properties

- ❑ These characteristics were called “consensus properties” because there was wide agreement in their use and specified values.
- ❑ The properties are:
 - ❖ coarse aggregate angularity;
 - ❖ fine aggregate angularity;
 - ❖ flat, elongated particles, and
 - ❖ clay content.

Asphalt Mix Design Methods (Superpave)

Materials Selection (cont'd)

Measurement of the aggregate properties

Source Properties

- ❑ Pavement experts believed that certain other aggregate characteristics were critical. However, critical values of these properties could not be reached by consensus because the needed values were source-specific.
- ❑ Consequently, a set of “source properties” was recommended.
- ❑ The properties are:
 - ❖ toughness;
 - ❖ soundness, and
 - ❖ deleterious materials.

Asphalt Mix Design Methods (Superpave)

Gradation and Design Aggregate Structure

Superpave uses the 0.45 power gradation chart to define a permissible gradation.

Maximum size: One sieve size larger than the nominal maximum size.

Nominal maximum size: One sieve size larger than the first sieve to retain more than 10 percent.

The maximum density gradation: This represents a gradation in which the aggregate particles fit together in their densest possible arrangement.

This must be avoided because there would be very little aggregate space within which to develop sufficiently thick bitumen films for a durable mixture.

To specify aggregate gradation, two additional features are added to the 0.45 power chart: control points and a restricted zone. Control points function as master ranges through which gradations must pass.

Asphalt Mix Design Methods (Superpave)

Gradation and Design Aggregate Structure (cont'd)

The 0.45 power gradation chart with a maximum density gradation for a 19 mm maximum aggregate size and 12.5 mm nominal maximum size is shown in Figure 10.

The control points and restricted zone for a 12.5 mm Superpave mixture are illustrated in Figure 11.

The term used to describe the cumulative frequency distribution of aggregate particle sizes is the design aggregate structure.

A design aggregate structure that lies between the control points and avoids the restricted zone meets the requirements of Superpave for gradation (Figure 12).

Superpave defines five mixture types with their nominal maximum aggregate size as shown in Table 11

Asphalt Mix Design Methods (Superpave)

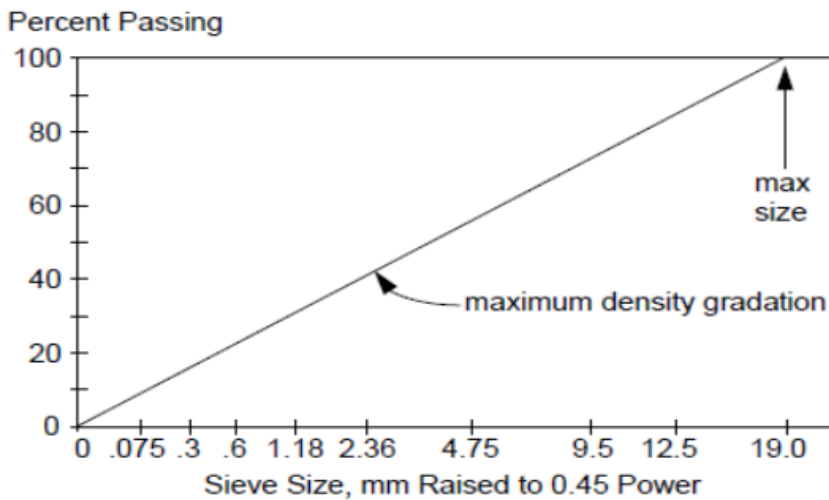


Figure 10: 0.45 Power gradation chart

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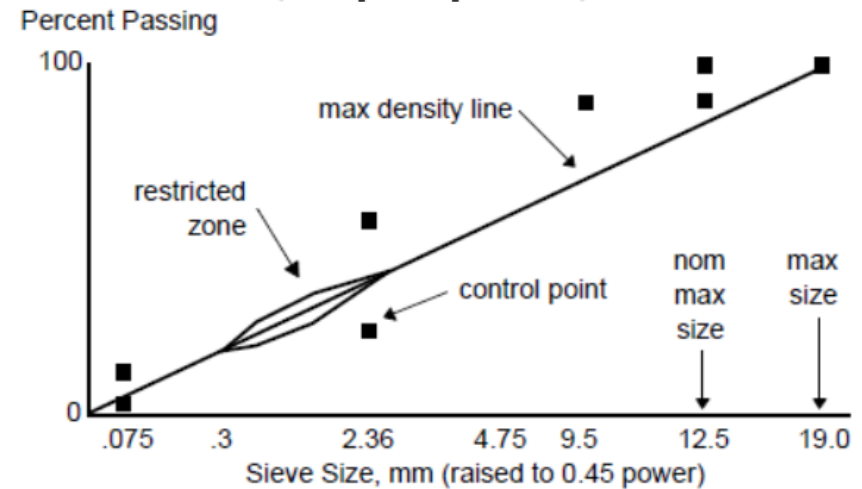


Figure 11: The control points and restricted zone for a 12.5 mm Superpave mixture

Table 11: Superpave Mixtures

Superpave mixture designation	Nominal maximum size (mm)	Maximum size (mm)
37.5 mm	37.5	50
25 mm	25	37.5
19 mm	19	25
12.5 mm	12.5	19
9.5 mm	9.5	12.5

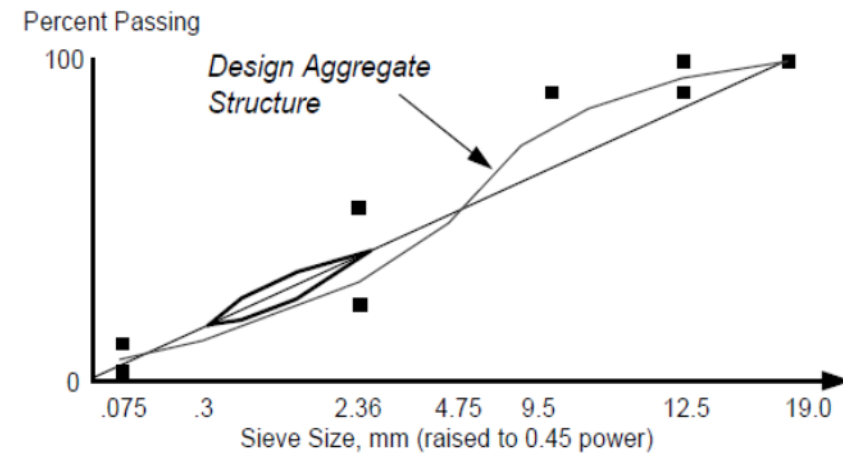


Figure 12: Design aggregate structure

Asphalt Mix Design Methods (Superpave)

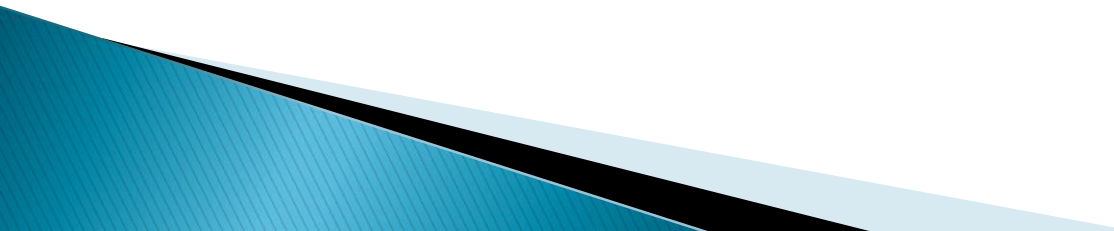
Selection of design binder content

The next step is to evaluate the trial blends by compacting specimens and determining the volumetric properties of each trial blend.

For each blend, a minimum of two specimens are compacted using the Superpave Gyrotory Compactor (SGC) (Figure 13).

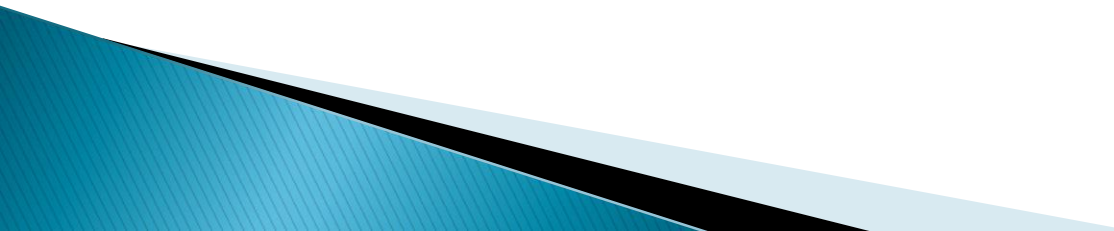
The trial asphalt binder content can be estimated based on experience with similar materials. If there is no experience, the trial binder content can be determined for each trial blend by estimating the effective specific gravity of the blend and

The mix design engineer can also gain insight into the compactibility of HMA during compaction from the data generated.



Asphalt Mix Design Methods (Superpave)

Selection of design binder content

- ❑ Two new sophisticated testing devices were developed:
 - ❖ the Superpave Shear Tester (SST) and
 - ❖ Indirect Tensile Tester (IDT).
 - ❑ The test output from these devices can provide direct indications of behaviour of the mix, or will eventually generate input to performance prediction models.
 - ❑ Using the mechanical properties of the HMA and these performance prediction models, mix design engineers will be able to estimate the combined effect of asphalt binders, aggregates, and mixture proportions.
 - ❑ Table 12 shows the compaction parameters for the Superpave gyratory compactor.
- 

Asphalt Mix Design Methods (Superpave)

Selection of design binder content

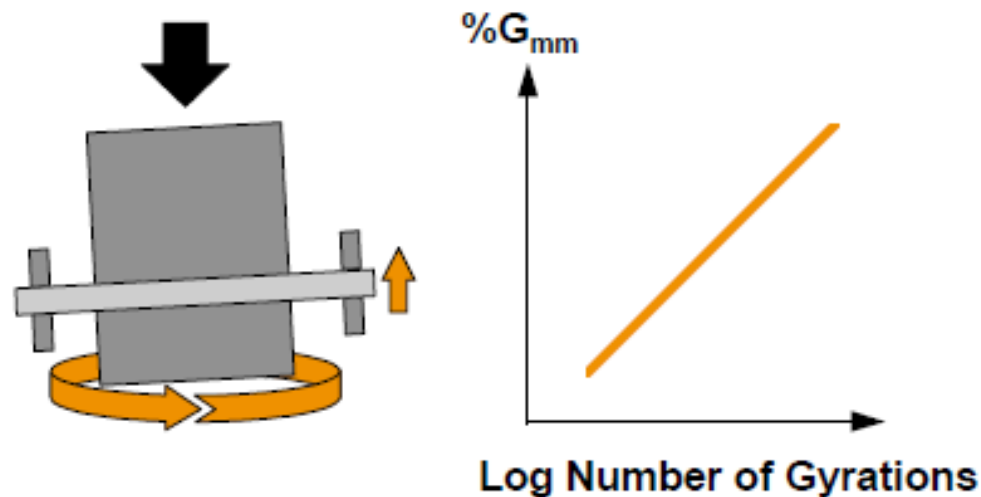


Figure 13: Superpave gyratory compactor (SGC) system

Table 12: Compaction parameters for the Superpave gyratory compactor

Superpave design gyratory compactive effort			
Design ESALS (millions)	Compactive parameters		
	$N_{initial}$	N_{design}	$N_{maximum}$
< 0.3	6	50	75
0.3 to < 3	7	75	115
3 to < 10	8	100	160
≥ 30	9	125	205

Asphalt Mix Design Methods (Superpave)

Selection of design binder content (cont'd)

- ❑ Mixture volumetric requirements consist of air voids, voids in the mineral aggregate, voids filled with bitumen, and the mixture density during compaction at N_{ini} and N_{max} .
- ❑ The design air void content is 4% in Superpave.

Moisture Susceptibility

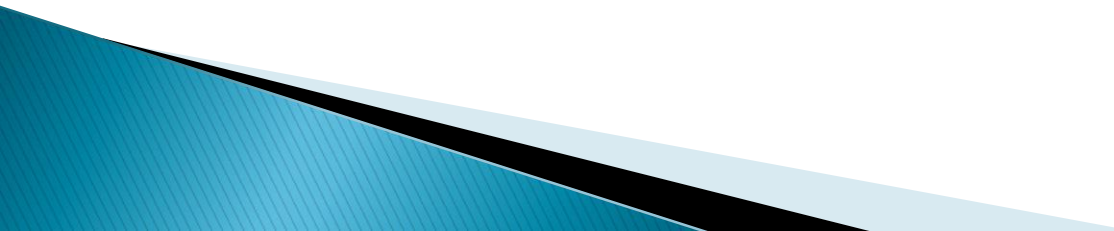
- ❑ The moisture susceptibility test used to evaluate HMA for stripping is AASHTO T 283, “Resistance of Compacted Bituminous Mixtures to Moisture Induced Damage.”
- ❑ In the test, two subsets of test specimens are produced, conditioned, and tested for indirect tensile strength.
- ❑ The test result is reported as the ratio of the tensile strength of the conditioned subset to that of the unconditioned subset. This ratio is called the “tensile strength ratio” or TSR.
- ❑ Superpave requires a minimum TSR of 80 percent. Lower values are indicative of mixtures that may exhibit stripping problems after construction.

Asphalt Mix Design Methods (BMD)

Balanced Mix Design

- ❑ Balanced mix design (BMD) is asphalt mix design using performance tests on appropriately conditioned specimens that address multiple modes of distress considering mix aging, traffic, climate, and location within the pavement structure.
- ❑ The complexity of the Superpave tests and increasing concerns about the durability and cracking issues of asphalt pavements along with the growing awareness of the shortcomings of volumetric mix design systems made state highway agencies (SHAs) and the asphalt pavement industry explore the use of BMD.

Balanced mix design approaches

- ❑ Four alternate approaches to Balanced Mix Design described in AASHTO PP 105 are as follows:
- 

Asphalt Mix Design Methods (BMD)

Approach A:

- ❑ This requires full compliance with the existing volumetric requirements and additional performance requirements (Figure 14).
- ❑ It is the most conservative approach and has the lowest innovation potential.

Approach B

- ❑ This requires full compliance with the existing volumetric requirements at the preliminary OBC (Figure 14).
 - ❑ It allows moderate changes in asphalt binder content for performance optimization based on mixture performance test results.
 - ❑ Although it is slightly more flexible than Approach A, it is still considered a conservative approach with limited innovation potential
- 

Asphalt Mix Design Methods (BMD)

Approach C

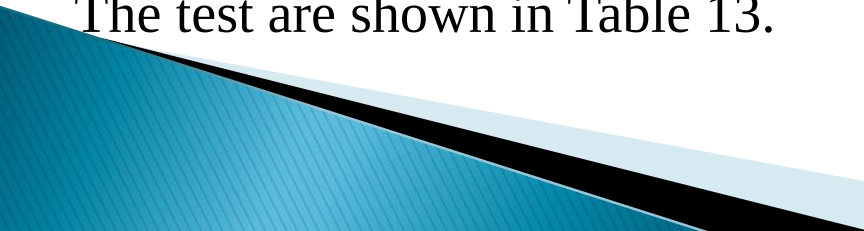
- ❑ This allows some of the volumetric requirements to be relaxed or eliminated as long as the performance criteria are satisfied.
- ❑ The mix design modifications that can be used in performance optimization are not limited to changes in asphalt binder content.
- ❑ Therefore, it is less conservative than Approach A and Approach B and provides a medium degree of innovation potential (Figure 15).

Approach D

- ❑ This has no requirement on volumetric properties.
- ❑ It relies solely on mixture performance test results for mix design optimization.
- ❑ It is considered the least conservative approach with the highest degree of innovation potential (Figure 15).

The guide for the selection and evaluation of materials and the options for performance tests are described in AASHTO Standard Practice MP 46.

The test are shown in Table 13.



Asphalt Mix Design Methods (BMD)

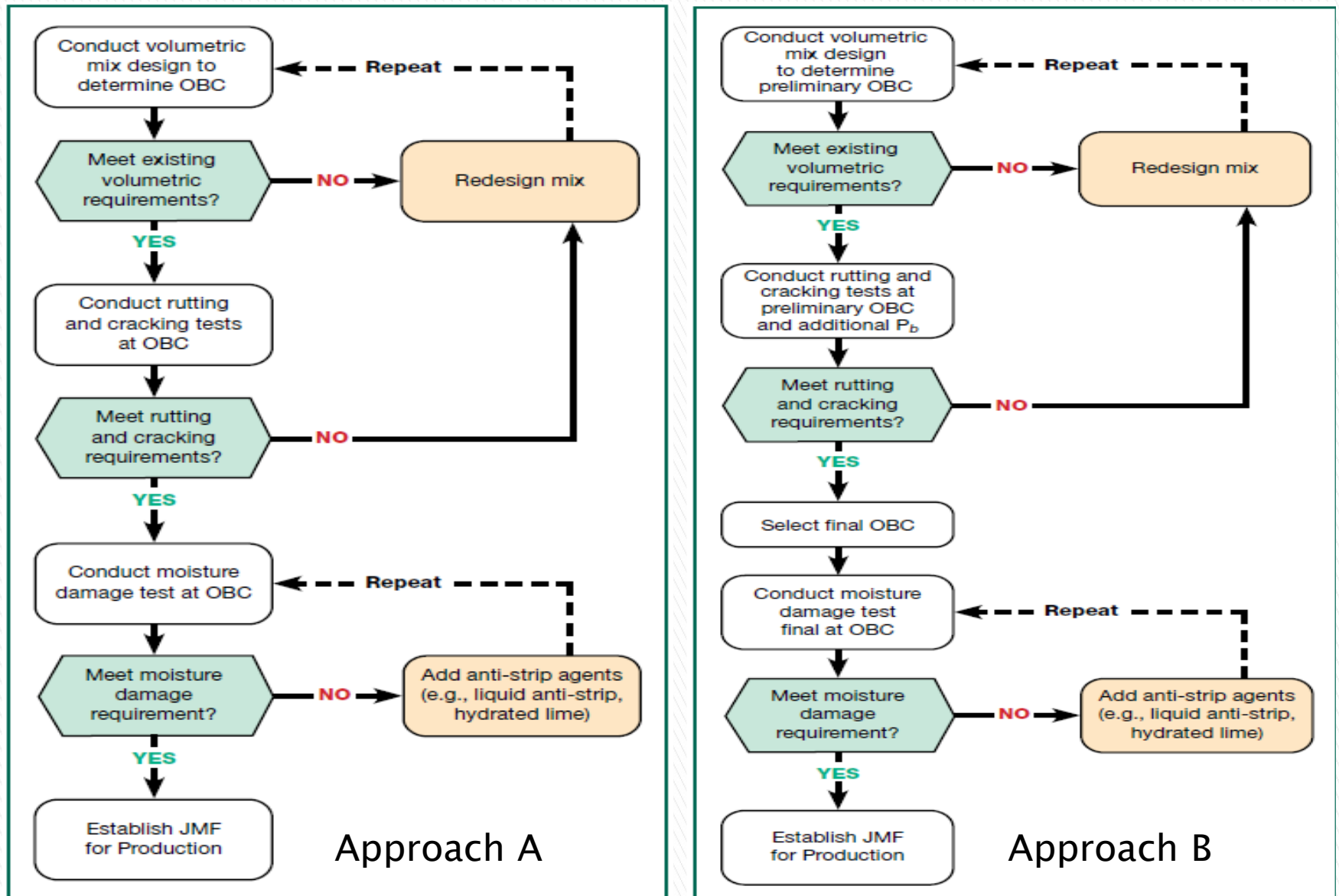


Figure 14: Approaches A and B for BMD

Asphalt Mix Design Methods (BMD)

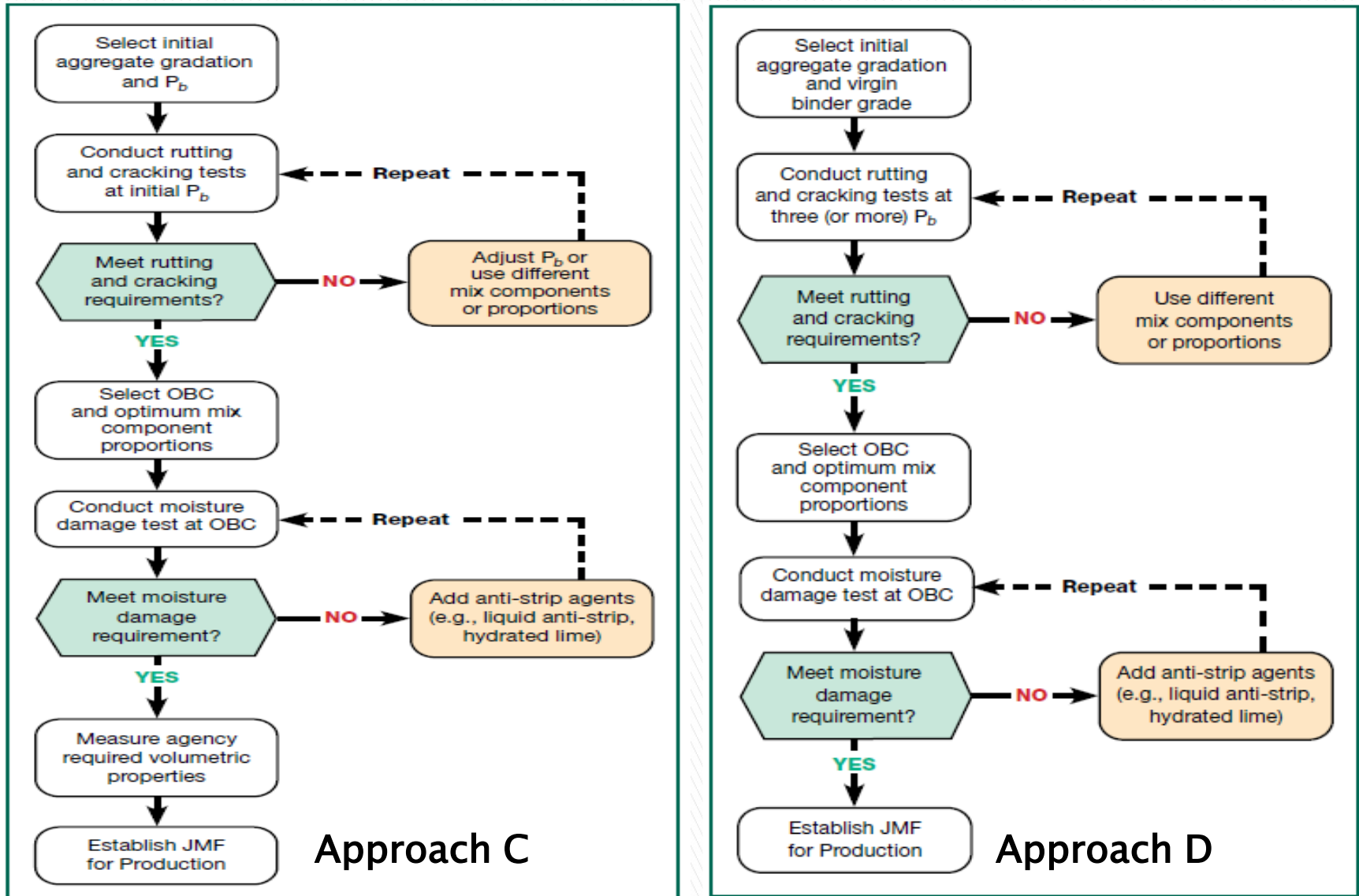


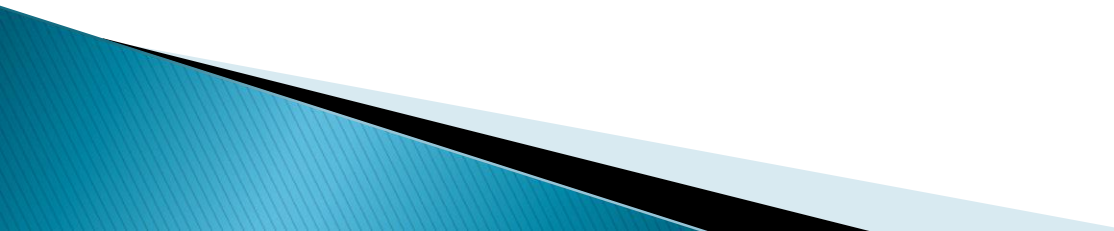
Figure 15: Approaches C and D for BMD

Asphalt Mix Design Methods (BMD)

Table 13: Performance tests for BMD

Distress mode	Performance Tests	Test Method
Cracking	Disk-Shaped Compact Tension Test (DCT)	ASTM D7313
	Illinois Flexibility Index Test (I-FIT)	AASHTO T 393
	Low-Temperature Semi-Circular Bend Test (SCB)	AASHTO T 394
	IDT Creep Compliance and Strength Test	AASHTO T 322
	Texas Overlay Test (OT)	TXDOT Tex-248-F
	Direct Tension Cyclic Fatigue Test	AASHTO TP 107 AASHTO TP 133
	N flex Factor	AASHTO TP 141
	Flexural Bending Beam Fatigue Test	AASHTO T 321
	Semi-Circular Bend Test (Louisiana method)	LADOTD TR 330 ASTM D8044
	Indirect Tensile Asphalt Cracking Test (IDEAL-CT)	ASTM D8225
Rutting	Hamburg Wheel Tracking Tester (HWTT)	AASHTO T 324
	Asphalt Pavement Analyzer (APA)	AASHTO T 340
	High-Temperature Indirect Tension (HT-IDT)	ALDOT-458 ASTM D6931
	Rapid Shear Rutting Test (IDEAL-RT)	ASTM Work Item (WK 71466)
	Flow Number Test (FN)	AASHTO T 378
	Stress Sweep Rutting (SSR)	AASHTO TP 134
Moisture Damage	Tensile Strength Ratio (TSR)	AASHTO T 283
Abrasion loss	Cantabro Abrasion Loss Test	AASHTO TP 108

Comparison of the Mix Design Methods

- ❑ The different mix design methods have strengths and weaknesses.
 - ❑ The attempt to rectify the weakness in a particular method resulted in another method.
 - ❑ The strengths and the weaknesses are highlighted in Table 6.
 - ❑ However, the balanced mixed design addresses the shortcomings in these methods.
 - ❑ BMD gives room for more flexibility in the design approaches.
 - ❑ It hands the initiative to the agencies to determine the best approach to adopt in a particular situation.
- 

Comparison of the Mix Design Methods

Table 14: Strengths and weaknesses of mix design methods

Marshall mix design	Hveem mix design	Superpave mix design
It is most common, simple to implement and not expensive	It is easy to implement, However, it is expensive and not portable	It more complex and more expensive
The impact compaction used with the Marshall method does not simulate mixture densification as it occurs in a real pavement	The kneading method of laboratory compaction is thought to better simulate the densification characteristics of HMA in a real pavement.	It is able to compact trial mix specimens to densities achieved under actual pavement climate and loading conditions.
Marshall stability does not adequately estimate the shear strength of HMA.	Hveem stability is a direct measurement of the internal friction component of shear strength. It measures the ability of a test specimen to resist lateral displacement from application of a vertical load.	The Superpave Shear Tester (SST) and Indirect Tensile Tester (IDT) provide direct indications of mix behaviour.
This does not take into consideration aging of the binder during storage, mixing, compaction and when the pavement is in service	This does not take into consideration aging of the binder during storage, mixing, compaction and when the pavement is in service	It takes into consideration aging of the binder during storage, mixing, compaction and when the pavement is in service
It pays attention to density and voids properties of asphalt materials.	The Hveem method also entails a density-voids analysis	Also, It involves the density and voids analysis.
Moisture sensitivity test is not considered.	The mixture's resistance to swell in the presence of water is also determined.	Moisture sensitivity test is carried out.

The Way Forward

- ❑ As mentioned earlier, the Marshall mix design method is used in Nigeria for the design of asphalt mixtures.
 - ❑ It is believed that the Marshall mix design method has many drawbacks.
 - ❑ The Superpave mix design, although complex, can be simplified and adopted for asphalt mix design in the country.
 - ❑ The right binder for different regions of the country can be established through nationwide research and included in the General Specifications for roads.
 - ❑ Also, this will save practitioners the problem of having to undertake a series of tests to select the right binder.
 - ❑ The balanced mix design is still being experimented with and will require that a nationwide study be conducted and guidelines prepared for its adoption, and the approach to be used in a particular situation must be established.
- 

Conclusion

- ❑ The asphalt mix design methods have evolved over the years
- ❑ Work is still being done to improve and simplify the processes to ensure that the mix design guarantees the production of asphalt mixtures that are durable, stable, flexible impermeable, workable, and have good resistance to fatigue and permanent deformation.

A stack of four sticky notes in yellow, orange, pink, and green is placed on a light blue background. A magnifying glass with a black handle and frame is positioned over the top left corner of the sticky notes. A black pen with a silver tip lies diagonally across the bottom right corner of the yellow sticky note. The text "Thank you For your Attention" is written in a black, cursive script on the yellow sticky note.

*Thank you
For your
Attention*