TOPIC 6

Bituminous Materials

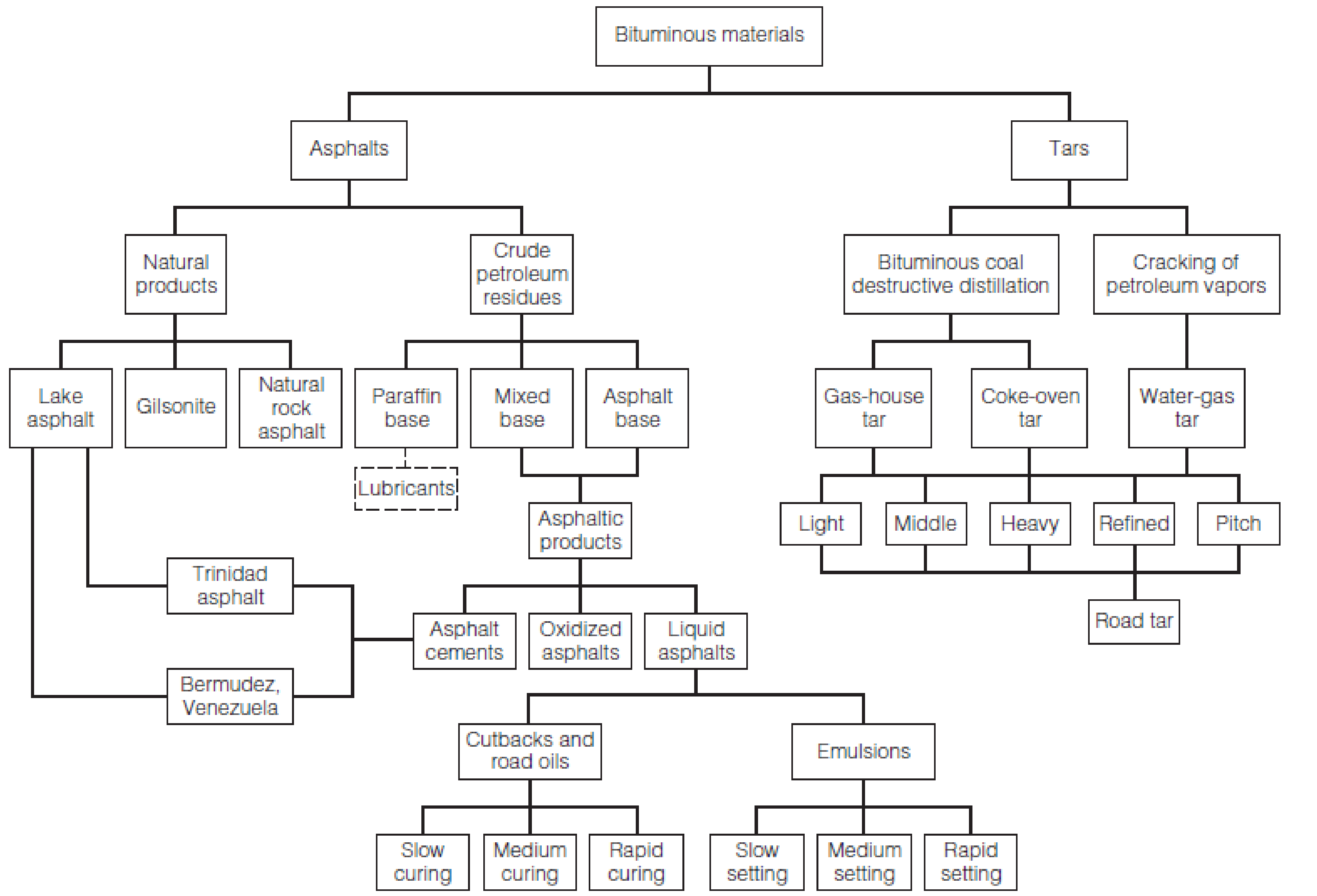
General Introduction

- Bituminous materials are classified as:
  - Asphalts and
  - Tars
- **Asphalt** is one of the oldest materials used in construction
- In the past, asphalt cement came from natural deposits and refineries
- Presently, practically all asphalt cement is from refined petroleum
- Asphalt is used mostly in pavement construction, but is also used as sealing and waterproofing agents
- **Tars** are produced by the destructive distillation of bituminous coal or by cracking petroleum vapors

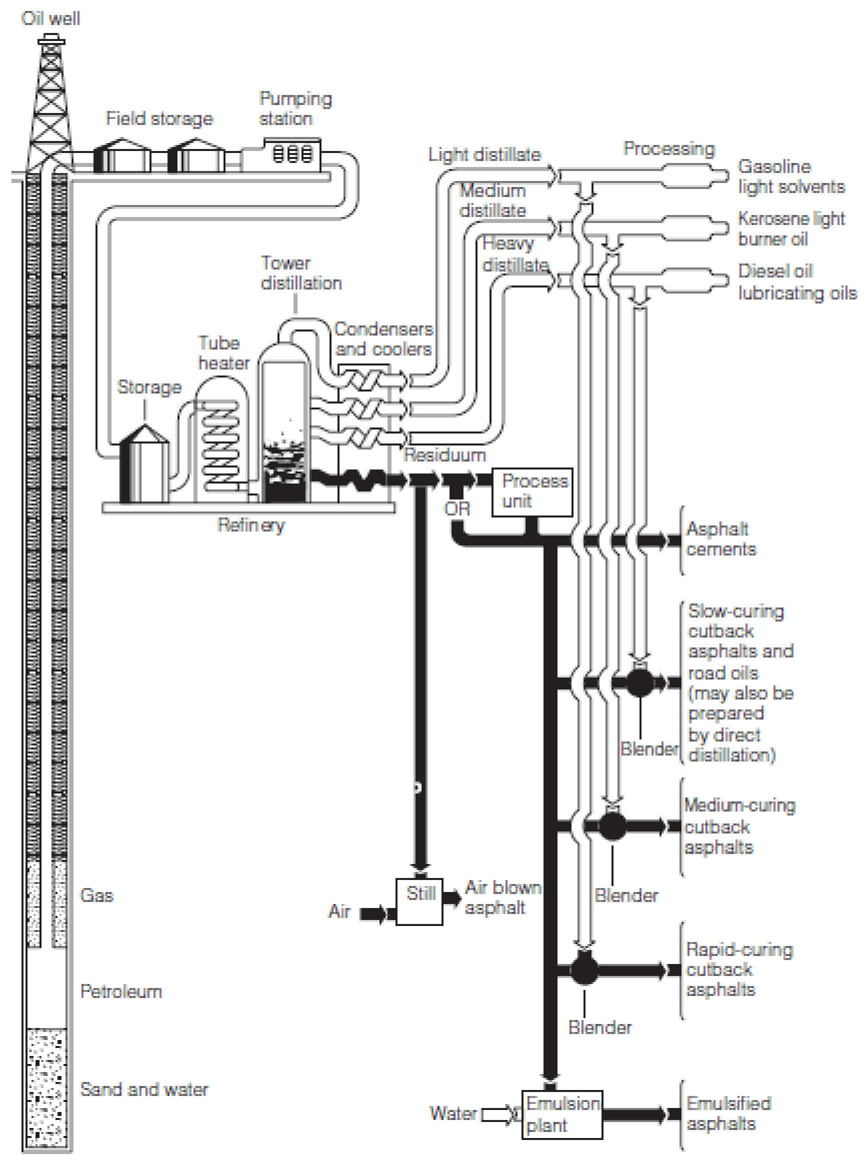
General Introduction

- Tar is used primarily for waterproofing membranes, such as roofs
- Tar may also be used for pavement treatments, particularly where fuel spills may dissolve asphalt cement, such as on parking lots and airport aprons (area at the airport where aircrafts are parked, refueled, loaded, etc.)
- In the fractional distillation process of crude petroleum, different products are separated at different temperatures
- The main products of fractional distillation include gasoline, kerosene, diesel oil, and asphalt residue (asphalt cement).
- Since asphalt is a lower-valued product than other components of crude oil, refineries are set up to produce the more valuable fuels at the expense of asphalt production

Classification of Bituminous Materials



Distillation of Crude Petroleum



Types of Asphalt Products

- Asphalt used in pavements is produced in three forms:
  1. Asphalt cement,
  2. Asphalt cutback, and
  3. Asphalt emulsion

Asphalt cement

- Asphalt cement is a blend of hydrocarbons of different molecular weights.
- At room temperatures, asphalt cement is a semisolid material that cannot be applied readily as a binder without being heated.
- Softest grade asphalts used for road construction have penetration value of 200-300, and the hardest has penetration values between 60 to 70
- Asphalt cement has excellent adhesive characteristics, which make it a superior binder for pavement applications but becomes hard and brittle when over-heated or aged and loses some ability to adhere to aggregates

Types of Asphalt Products

Emulsified Asphalts

- Emulsified Asphalts are liquid asphalt products at room temperature
- They have been developed to be used without heating
- **Emulsified asphalts** are a suspension solution of small asphalt globules (60-70%) in water (30-40%) which is assisted by a soap-like emulsifying agent (About 1%)
- Emulsifiers are think and brown liquids that reduce the viscosity (thickness) of asphalt.
- When the water evaporates, asphalt cement starts adhering to aggregates

Cutback Asphalts

- Similar to emulsified asphalts, cutbacks are liquid asphalt products at room temperature

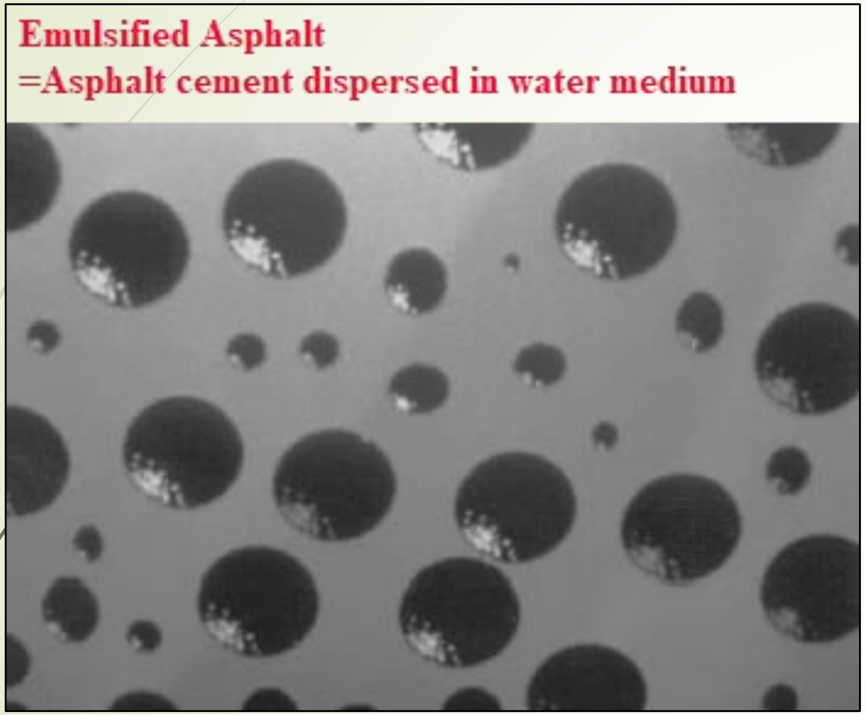
Types of Asphalt Products

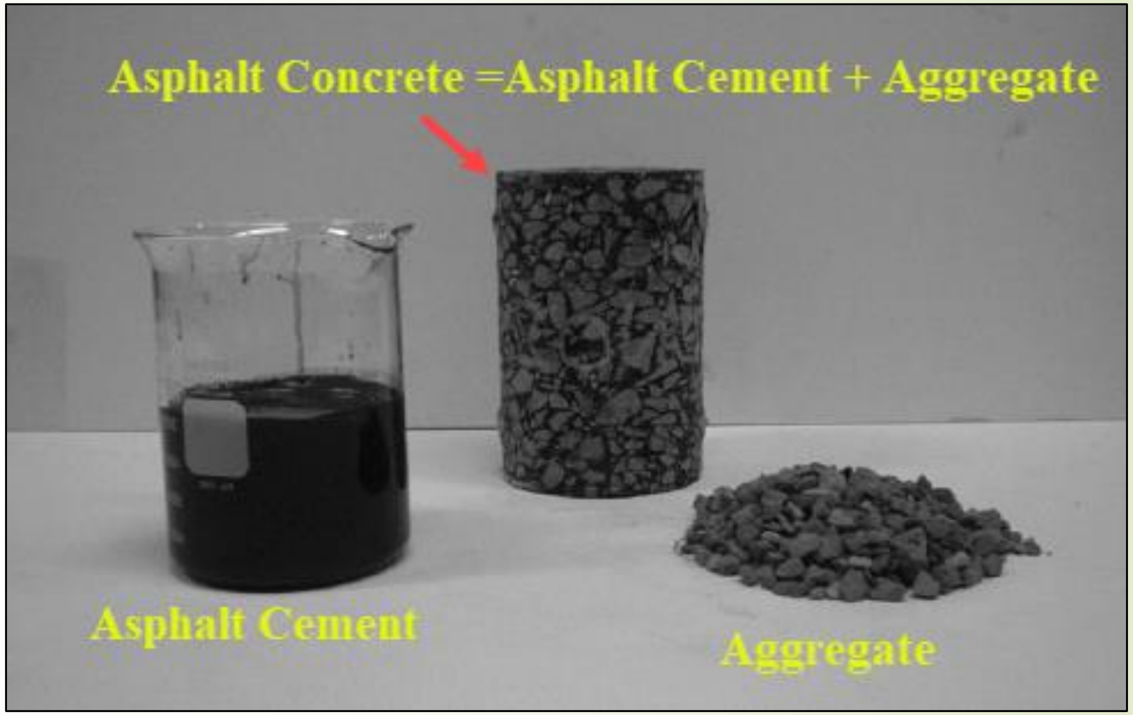
- In cutback asphalts, the asphalt cement is mixed with a diluent (thinning agent) that liquifies the asphalt making it ready for application
- After application, the diluent evaporates, leaving the asphalt cement to do its job
- Depending on the rate of curing, cutbacks can be classified as Slow-Curing (SC), Medium-Curing (MC), or Rapid-Curing (RC) Cutback Asphalts.
- These cutbacks are usually designated as SC-70, MC-30, or RC-70 where the number relates to the approximate Kinematic viscosity in centistockes at 60°C
- The fluidity of MC cutbacks depends on the amount of solvent in the material
- MC cutback asphalts can be used in the construction of pavement bases, surfaces, and surface treatments

Types of Asphalt Products

- Liquid asphalts are convenient. In the past, cutbacks were widely used for highway construction. They were effective and could be applied easily in the field.
- However, they cannot produce a quality of asphalt concrete comparable to what can be produced by heating neat asphalt cement and mixing it with carefully selected aggregates.
- Although emulsions and cutbacks can be used for the same applications, the use of emulsions is increasing because they do not include hazardous and costly solvents.
- The three main disadvantages of cutback asphalts include the following:
  - i. Petroleum costs have escalated, thus, the use of these expensive solvents as a carrying agent for the asphalt cement is no longer cost effective (Emulsified asphalts - dispensing asphalt in water are an alternative to dissolving asphalts in expensive solvents)
  - ii. Second, cutbacks are hazardous materials due to the volatility of the solvents.
  - iii. Finally, application of the cutback releases environmentally unacceptable hydrocarbons into the atmosphere.

Types of Asphalt Products





Properties of Asphalt Materials

- Properties of asphalt materials pertinent to pavement construction can be grouped into four:
  - Consistency
  - Aging and temperature sustainability
  - Rate of curing
  - Resistance to water action

Consistency

- Consistency properties refer to:
  - Variation of properties with temperature
  - Properties at a specified temperature
- The change in properties (consistency) of different asphalt materials differ considerably even at same temperature
- Temperature of asphalt materials is inversely proportional to the viscosity of the asphalt material
- When asphalt is mixed with aggregates, the mixture will perform properly only if the asphalt viscosity is within an optimum range

Properties of Asphalt Materials

- If the viscosity of asphalt is higher than the optimum range, the mixture will be too brittle and susceptible to low-temperature cracking
- If the viscosity is below the optimum range, the mixture will flow readily, resulting in permanent deformation in the wheel path (rutting)
- Due to temperature susceptibility, the grade of the asphalt cement should be selected according to the climate of the area.
- The viscosity of the asphalt should be mostly within the optimum range for the area's annual temperature range;
  - soft-grade asphalts are used for cold climates and
  - hard-grade asphalts for hot climates

Aging and temperature sustainability

- Aging is when asphalt loses its plasticity and becomes brittle due to chemical and physical reactions that take place when the material is exposed to environmental elements

Properties of Asphalt Materials

- Two common reactions are:
  - Oxidation when asphalt material is attacked by oxygen in the air
  - Volatilization which is the loss of lighter hydrocarbons from the asphalt material
- These two reactions cause loss of plastic characteristics of the asphalt material
- Temperature affects the rate of these reactions
- The higher the temperature, the higher the rate of oxidation and volatilization
- Asphalt gets hard and brittle at low temperatures and soft at high temperatures
- The viscosity of the asphalt decreases when the temperature increases.

Rate of Curing

- Curing is the process by which asphalt material increases its consistency as it loses solvent by evaporation. The smaller the quantity of solvent, the faster the curing rate

Properties of Asphalt Materials

Resistance to water action

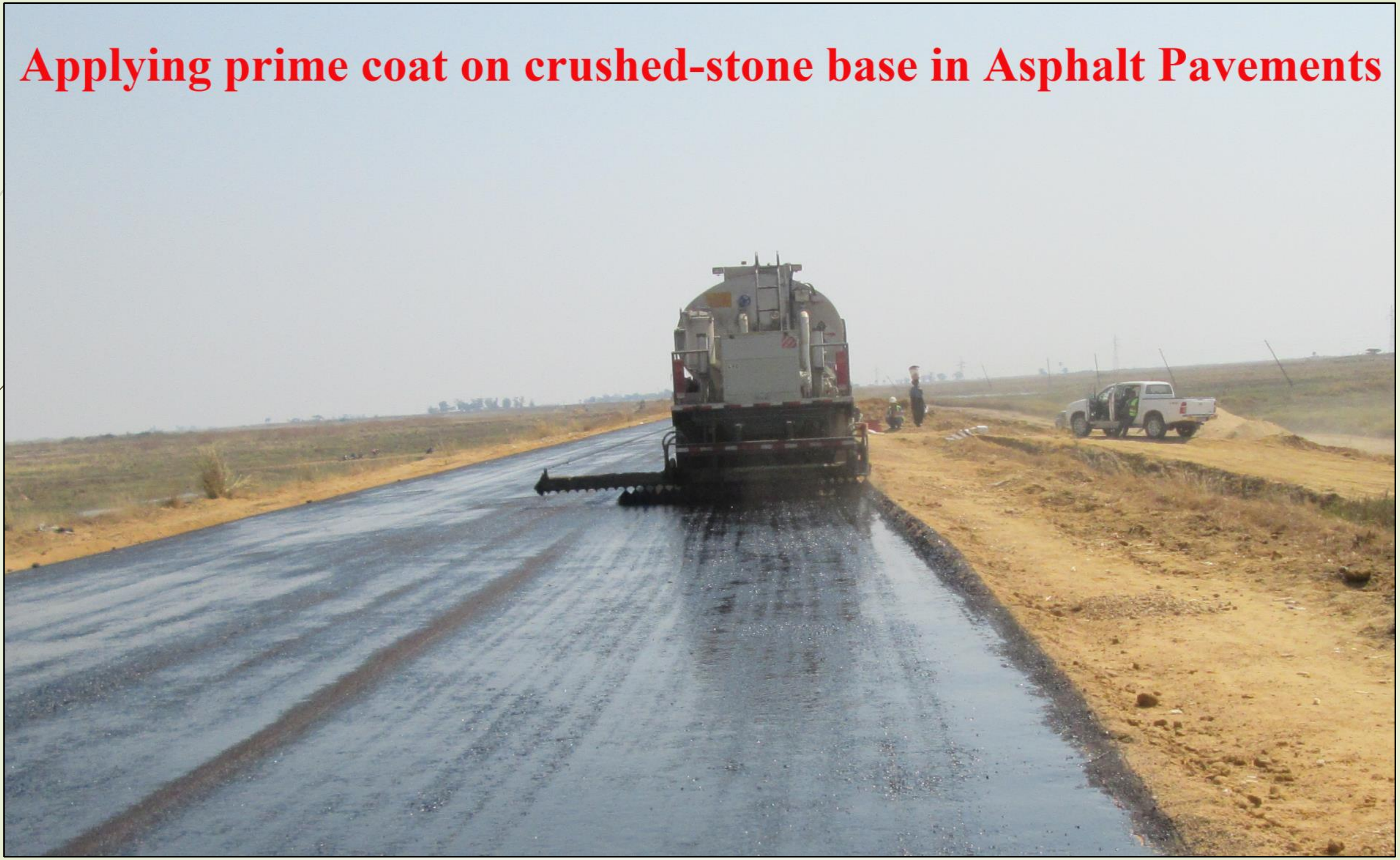
- When asphalt materials are used in pavement construction, it is important that the asphalt continues to adhere to the aggregates even with the presence of water
- If this bond between the asphalt and the aggregates is lost, the asphalt will strip from the aggregates, resulting in the deterioration of the pavement
- The asphalt therefore must sustain its ability to adhere to the aggregates even in the presence of water.
- In hot-mix, hot-laid asphalt concrete, where the aggregates are thoroughly dried before mixing, stripping does not normally occur and so no preventive action is usually taken.
- However, when water is added to a hot-mix, cold-laid asphalt concrete, commercial antistrip additives usually are added to improve the asphalt's ability to adhere to the aggregates.

Uses of Asphalt

- The main use of asphalt is in pavement construction and maintenance.
- In addition, asphalt is used in sealing and waterproofing various structural components, such as roofs and underground foundations
- The selection of the type and grade of asphalt depends on the type of construction and the climate of the area.
- Asphalt cements, also called asphalt binders, are used typically to make hot-mix asphalt concrete for the surface layer of asphalt pavements
- Asphalt concrete is also used in patching and repairing both asphalt and portland cement concrete pavements.
- Liquid asphalts (emulsions and cutbacks) are used for pavement maintenance applications, such a fog seals, chip seals, slurry seals, and microsurfacing. Also to seal cracks in pavements
- Liquid asphalts are mixed with aggregates to produce cold mixes, as well.
- Cold mixtures are normally used for patching (when hot-mix asphalt concrete is not available), base and subbase stabilization, and surfacing of low-volume roads

Uses of Asphalt

Uses of Asphalt



Uses of Asphalt

Common Paving Applications for Asphalts

Term	Description	Application
Hot mix asphalt	Carefully designed mixture of asphalt cement and aggregates	Pavement surface, patching
Cold mix	Mixture of aggregates and liquid asphalt	Patching, low volume road surface, asphalt stabilized base
Fog seal	Spray of diluted asphalt emulsion on existing pavement surface	Seal existing pavement surface
Prime coat	Spray coat asphalt emulsion to bond aggregate base and asphalt concrete surface	Construction of flexible pavement
Tack coat	Spray coat asphalt emulsion between lifts of asphalt concrete	Construction of new pavements or between an existing pavement and an overlay
Chip seal	Spray coat of asphalt emulsion (or asphalt cement or cutback) followed with aggregate layer	Maintenance of existing pavement or low volume road surfaces
Slurry seal	Mixture of emulsion, well-graded fine aggregate and water	Resurface low volume roads
Microsurfacing	Mixture of polymer modified emulsion, well-graded crushed fine aggregate, mineral filler, water, and additives	Texturing, sealing, crack filling, rut filling, and minor leveling

Tests of Asphalt

- Several tests are conducted on asphalt materials to determine both their consistency and quality to ascertain whether materials used in highway construction meet the prescribed specifications.
- The common tests for asphalt;

i. **Viscosity** – This is a property used to describe asphalt materials in liquid state. Viscosity can be determined by the following methods

   1. Saybolt Furol Viscosity Test
   2. Kinematic Viscosity Test or
   3. Ring and Ball Softening Point (Not used often in highway specification)

ii. **Penetration Test**

   - The test gives an empirical measurement of the consistency of a material in terms of the distance a standard needle sinks into that material under a prescribed loading and time.

Tests of Asphalt

iii. **Ring-and-Ball Softening**

- Used to measure the susceptibility of blown asphalt to temperature changes by determining the temperature at which the material will be adequately softened to allow a standard ball to sink through it

iv. **Ductility Test**

- This test measures the property of asphalt binders to elongate under traffic load without getting cracked in road construction works. Ductility test on bitumen measures the distance in centimeters to which it elongates before breaking

v. **Thin-Film Oven Test (TFO)**

- One test used to evaluate the susceptibility characteristics of asphalt materials to changes in temperature and other atmospheric factors

vi. **Flash-Point Test**

- This is the temperature at which the asphalt material vapors will ignite instantaneously in the presence of an open flame

Classification of Asphalts

- Common methods of classifying asphalt binders (asphalt cements), asphalt cutbacks, and asphalt emulsions include;
  - Performance Grading method developed by Strategic Highway Research Program (SHRP)
  - The traditional viscosity, penetration, ductility, and softening point temperature approach
- The four methods typically used for classifying asphalt binders include:
  1. Performance grading
  2. Penetration grading
  3. Viscosity grading
  4. Viscosity of aged residue grading

Performance Grade Specifications and Selection

- Several grades of binder are available, based on their performance in the field. Names of grades start with PG (Performance Graded) followed by two numbers representing the maximum and minimum pavement design temperatures in Celsius

Classification of Asphalt

Performance Grade Specifications and Selection

- For example, an asphalt binder PG 52–28 would meet the specification for a design high pavement temperature up to 52°C and a design low temperature warmer than -28°C
- The high temperature is calculated 20 mm (0.75 in.) below the pavement surface, whereas the low temperature is calculated at the pavement surface
- One important difference between the Performance Grade specifications and the traditional specifications is in the way the specifications work.
- The physical properties (criteria) remain constant for all grades, but the temperatures at which these properties must be achieved vary, depending on the climate at which the binder is expected to be used
- The binder is selected to satisfy the maximum and minimum design pavement temperature requirements

Classification of Asphalt

Performance Grade Specifications and Selection

- The average seven-day maximum pavement temperature is used to determine the design maximum, whereas the design minimum pavement temperature is the lowest pavement temperature.
- Since the maximum and minimum pavement temperatures vary from one year to another, a reliability level is considered

Binder Grade Specifications

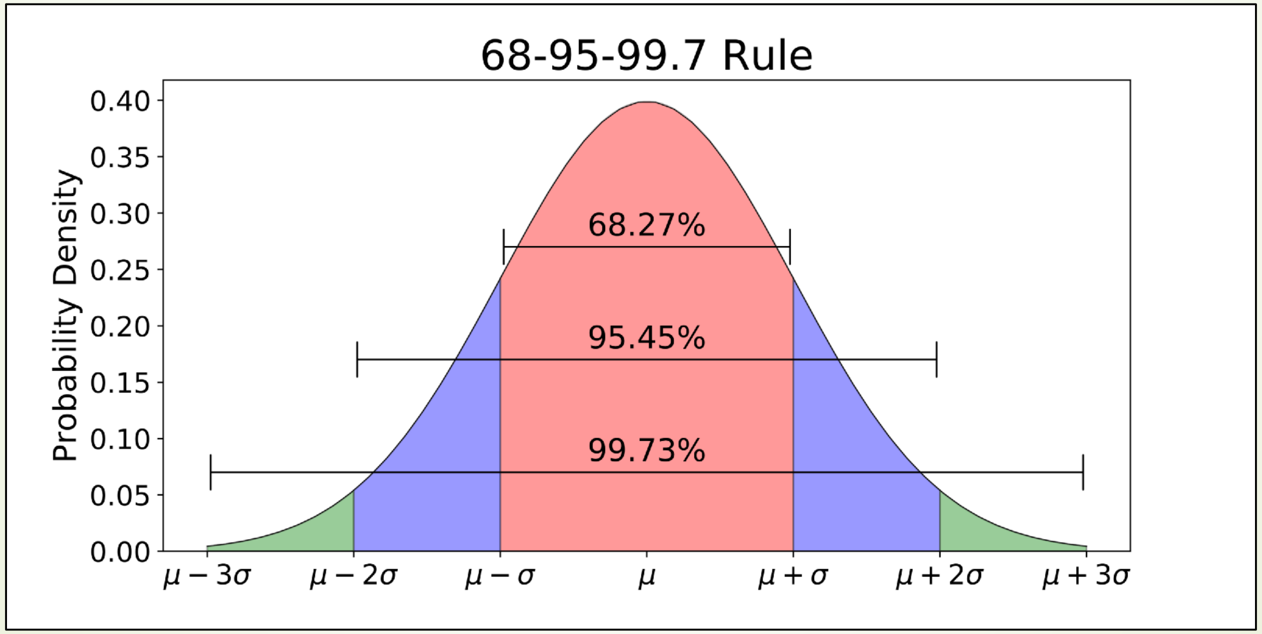
High Temperature Grades (°C)	Low Temperature Grades (°C)
PG 46	−34, −40, −46
PG 52	−10, −16, −22, −28, −34, −40, −46
PG 58	−16, −22, −28, −34, −40
PG 64	−10, −16, −22, −28, −34, −40
PG 70	−10, −16, −22, −28, −34, −40
PG 76	−10, −16, −22, −28, −34
PG 82	−10, −16, −22, −28, −34

Classification of Asphalt

Performance Grade Specifications and Selection – Example

What standard PG asphalt binder grade should be selected under the following conditions: The seven-day maximum pavement temperature has a mean of 57°C and a standard deviation of 2°C. The minimum pavement temperature has a mean -6°C of and a standard deviation of 3°C. Reliability is 98%.

Solution



At 98 % reliability: Min Temp/Max Temp = Mean$\mp$**2** $*$ ***Standard Deviation***

Classification of Asphalt

Performance Grade Specifications and Selection – Example

$$\Pr(\mu - 1\sigma \le X \le \mu + 1\sigma) \approx 0.6827$$
$$\Pr(\mu - 2\sigma \le X \le \mu + 2\sigma) \approx 0.9545$$
$$\Pr(\mu - 3\sigma \le X \le \mu + 3\sigma) \approx 0.9973$$

For an approximately normal data set;

i. The values within one standard deviation of the mean account for about 68% of the set;

ii. The values within two standard deviations account for about 95%; and

iii. The values within three standard deviations account for about 99.7%

At 98 % reliability: Min Temp/Max Temp = Mean$\mp 2 * \boldsymbol{Standard\ Deviation}$

$$T_{min/max}) = \bar{T}_{min/max} \mp 2\sigma$$

Classification of Asphalt

Performance Grade Specifications and Selection – Example

What standard PG asphalt binder grade should be selected under the following conditions: The seven-day maximum pavement temperature has a mean of 57°C and a standard deviation of 2°C. The minimum pavement temperature has a mean -6°C of and a standard deviation of 3°C. Reliability is 98%.

Solution

At 98 % reliability: Min Temp/Max Temp = Mean $\mp$**2** $*$ $\boldsymbol{Standard\ Deviation}$

High-temperature grade $\geq$ 57+ (2*2) $\geq$ 61°C

Low-temperature grade $\leq$ -6- (2*3) $\leq$ -12°C

Summary

Using table in previous slide, the closest standard PG asphalt binder grade that satisfies the two temperature grades is **PG 64–16.**

Classification of Asphalt

Performance Grade Specifications and Selection

- Several tests are used in the Performance Grade method to characterize the asphalt binder
- Four tests are performed on the neat or tank asphalt: flash point, solubility, rotational viscosity, and dynamic shear rheometer
- The flash point test is a safety test that measures the temperature at which the asphalt flashes; asphalt cement may be heated to a temperature below this without becoming a fire hazard
- Rotational Viscometer Test is carried out to establish the temperature susceptibility relationship used to determine the compaction and mixing temperatures required for the mix design process
- The dynamic shear rheometer is used to measure three specification requirements in the Performance Grading system: rutting, fatigue cracking, and thermal cracking
- To simulate the effect of aging on the properties of the binder, the rolling thin-film oven and pressure-aging vessel condition the binder for short-term and long-term effects.

Classification of Asphalt

Other (Traditional) methods of classifying asphalts

Viscosity Grading System of Asphalt Cement

Grade	Absolute Viscosity (poises)
AC-2.5	250 ± 50
AC-5	500 ± 100
AC-10	1000 ± 200
AC-20	2000 ± 400
AC-30	3000 ± 600
AC-40	4000 ± 800

Penetration Grading System of Asphalt Cement

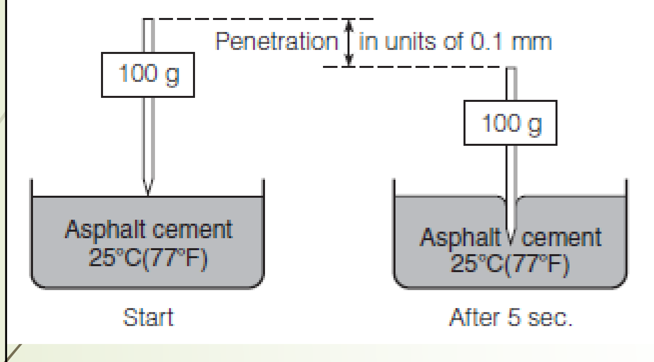
	Penetration	
Grade	min.	max.
40–50	40	50
60–70	60	70
85–100	85	100
120–150	120	150
200–300	200	300

Aged-Residue Grading System of Asphalt Cement

Grades	Absolute Viscosity (poises)
AR-1000	1000 ± 250
AR-2000	2000 ± 500
AR-4000	4000 ± 1000
AR-8000	8000 ± 2000
AR-16000	16000 ± 4000

Classification of Asphalt

Other (Traditional) methods of classifying asphalts



Penetration Test

Absolute Viscosity Aparatus

Asphalt Concrete

- Asphalt concrete, also known as hot-mix asphalt (HMA), consists of **asphalt binder** and **aggregates** mixed together at a high temperature and placed and compacted on the road while still hot
- The performance of asphalt (flexible) pavements is largely a function of the asphalt concrete surface material
- The objective of the asphalt concrete mix design process is to provide the following properties:
  - Stability or resistance to permanent deformation under the action of traffic loads, especially at high temperatures
  - Fatigue resistance to prevent fatigue cracking under repeated loadings
  - Resistance to thermal cracking that might occur due to contraction at low temperatures
  - Resistance to hardening or aging during production in the mixing plant and in service

Asphalt Concrete

  - Resistance to moisture-induced damage that might result in stripping of asphalt from aggregate particles
  - Skid resistance, by providing enough texture at the pavement surface
  - Workability, to reduce the effort needed during mixing, placing and compaction

- Regardless of the set of criteria used to state the objectives of the mix design process, the design of asphalt concrete mixes requires compromises
- Moreover, the produced mix must be practical and economical.
- If appropriate design asphalt content is not used, the pavement will lack durability or stability, resulting in premature pavement failure
- Typical design asphalt contents range from 4% to 7% by weight of total mix

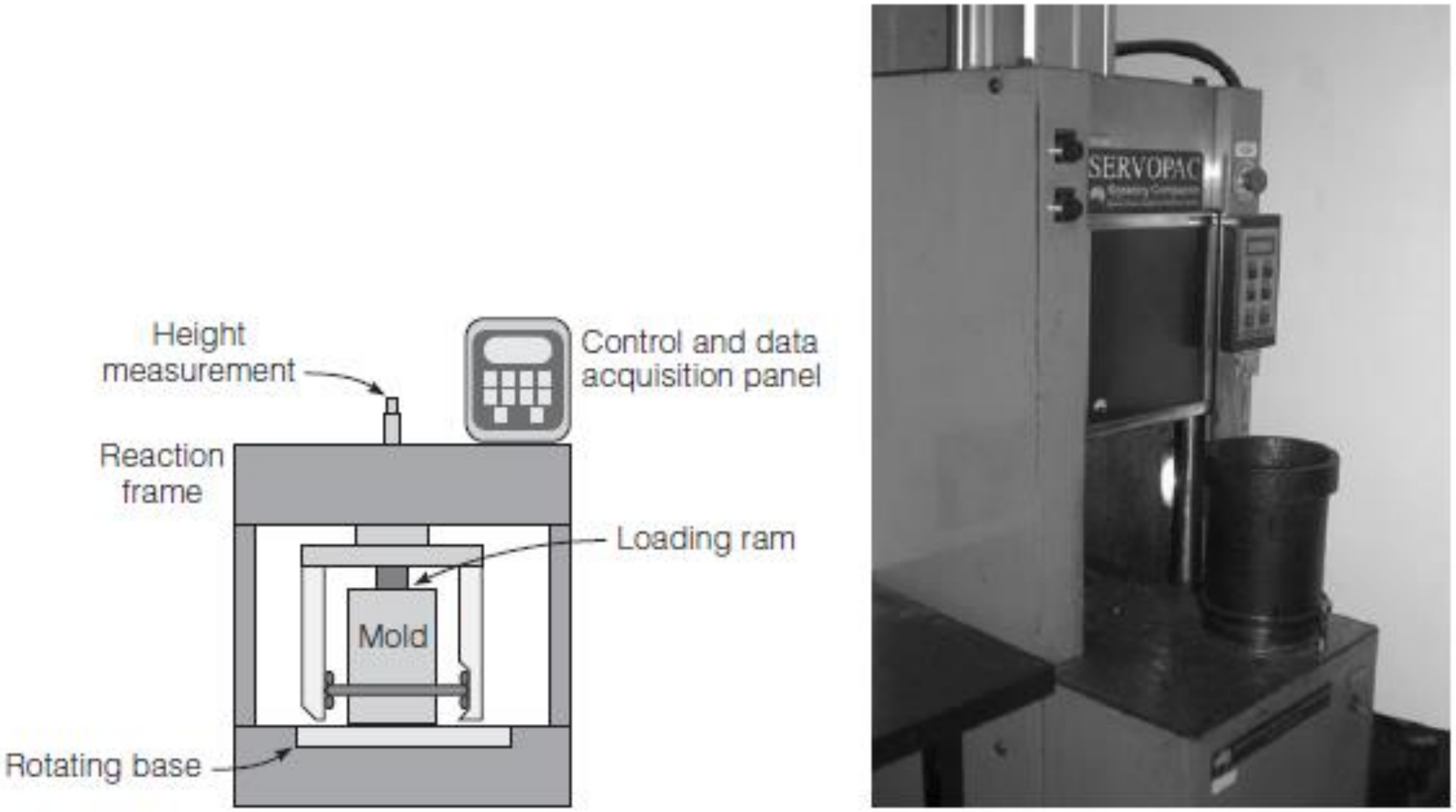
Asphalt Concrete Mix Design

- Three methods used to design asphalt concrete are:
  1. Superpave Mix design – Superior Performing Asphalt Pavements (Uses Superpave gyratory compactor)
  2. Marshall (ASTM D1559) – was commonly used (before superpave mix design method was developed) for its simplicity and ability to use field control (Uses Marshall hammer)
  3. Hveem (ASTM D1560)
- Both Marshall and Hveem methods are empirical - they are based on previous observations
- The major difference between Marshall and Hveem methods is in the methods of determining the optimum asphalt content
- Due to their empirical nature they are not readily adaptable to new conditions, such as modified binders, large-sized aggregates, and heavier traffic loads
- The Superpave design system is performance based and is more realistic than the Marshall and Hveem methods.

Asphalt Concrete Mix Design

- Regardless of the compaction method, the procedure for preparing specimens basically follows the same four steps:
  1. Heat and mix the aggregate and asphalt cement
  2. Place the material into a heated mold
  3. Apply compaction force
  4. Allow the specimen to cool and extrude from the mold
- The greatest difference among the compaction procedures is the manner in which the compaction effort is applied.
- For the gyratory compaction, the mixture in the mold is placed in the compaction machine at an angle to the applied force. As the force is applied the mold is gyrated, creating a shearing action in the mixture.
- Superpave mix design method (FHWA, 1995) uses a gyratory compactor (SGC)
- In the Marshall procedure, a slide hammer weighing is dropped from a height of 0.46 m

Asphalt Concrete Mix Design



Superpave gyratory compactor

Asphalt Concrete Mix Design

Marshall Compactor

Asphalt Concrete Mix Design

Density and Void Analysis

- Regardless of the mix design method used, it is important to understand the density and voids analysis of compacted asphalt mixtures for both mix design and construction control
- Since volumes are difficult and not practical to measure, weights are used instead; the specific gravity is used to convert from weight to volume
- Asphalt concrete mixture consists of aggregates, asphalt binder, and air voids
- Portion of the asphalt is absorbed by aggregate particles
- Three important parameters commonly used are:
  - **Voids in Total Mix) (VTM)** - % of air voids between the coated aggregates after compaction. Usually between 2-4%. Affects durability of asphalt pavement. The lower the air voids, the less permeable. Too much air voids provide passageways through the mix for entrance of damaging water and air. Too low air voids can lead to flashing or bleeding, a condition where excess binder squeezes out to the surface

Asphalt Concrete Mix Design

- **Voids Filled with Asphalt** (VFA)
- **Voids in the Mineral Aggregate** (VMA)

❖ Regardless of the compaction method, the samples are first used to determine the bulk specific gravity of the mix

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

Where:

G_{mb} = Bulk Specific Gravity of the Mix

A = Dry Weight of Sample

B = Saturated Surface Dry Weight of Sample

C = Submerged Weight

Asphalt Concrete Mix Design

- The theoretical maximum specific gravity of the sample at one asphalt content can be calculated as follows:

$$G_{mm} = \frac{A}{A + D + E}$$

Where:

G_{mm} = Theoretical maximum specific gravity of the asphalt concrete

A = dry weight of loose material

D= calibration weight of the submerged vacuum bowl

E= submerged weight of the vacuum bowl with the sample

- Once G_{mm} for sample at one asphalt content is determined, it can be used to estimate G_{mm} at other asphalt contents by first computing the effective specific gravity

Asphalt Concrete Mix Design

- Maximum theoretical specific gravity of uncompacted Samples:

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

Where:

G_{mm} = Theoretical maximum specific gravity of the asphalt concrete

P_s = % weight of aggregate

P_b = % weight of the asphalt cement

G_{se} = effective specific gravity of the aggregate coated with asphalt (determined for only one asphalt content, it is constant for all asphalt contents)

- The Marshal method uses this method for determining G_{mm} at each of the asphalt contents.
- The Superpave method requires directly measuring G_{mm} at each asphalt content evaluated during the mix design process

Asphalt Concrete Mix Design

Density and Void Analysis

1. ***Voids in Total Mix***

$$VTM = \frac{V_v}{V_m} * 100 = 100(1 - \frac{G_{mb}}{G_{mm}})$$

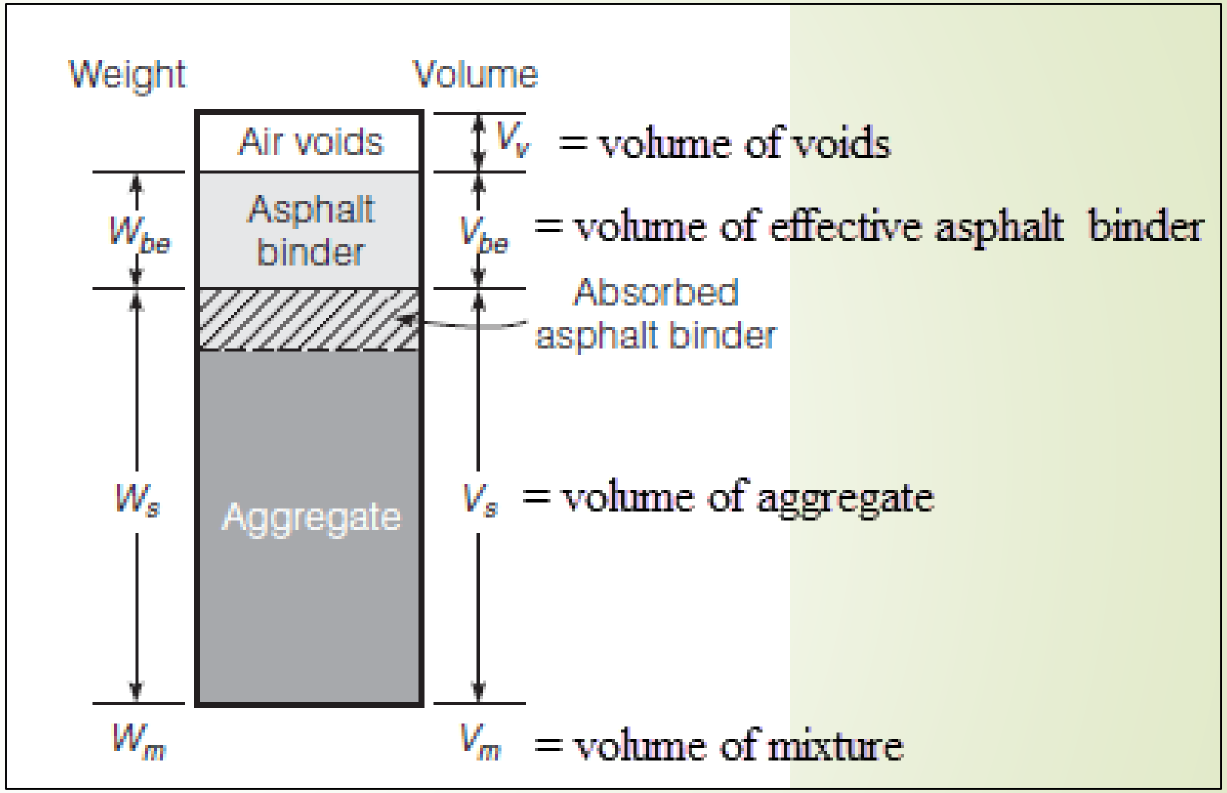
3. ***Voids Filled with Asphalt***

$$VFA = \frac{V_{be}}{V_{be}+V_v} * 100100 = 100(\frac{VMA-VTM}{VMA})$$

2. ***Voids in Mineral Aggregate***

$$VMA = \frac{V_v + V_{be}}{V_m} * 100 = (100 - G_{mb}\frac{P_s}{G_{sb}})$$

G_{sb} = Specific gravity of the aggregate



❖ The effective asphalt is the total asphalt minus the absorbed asphalt

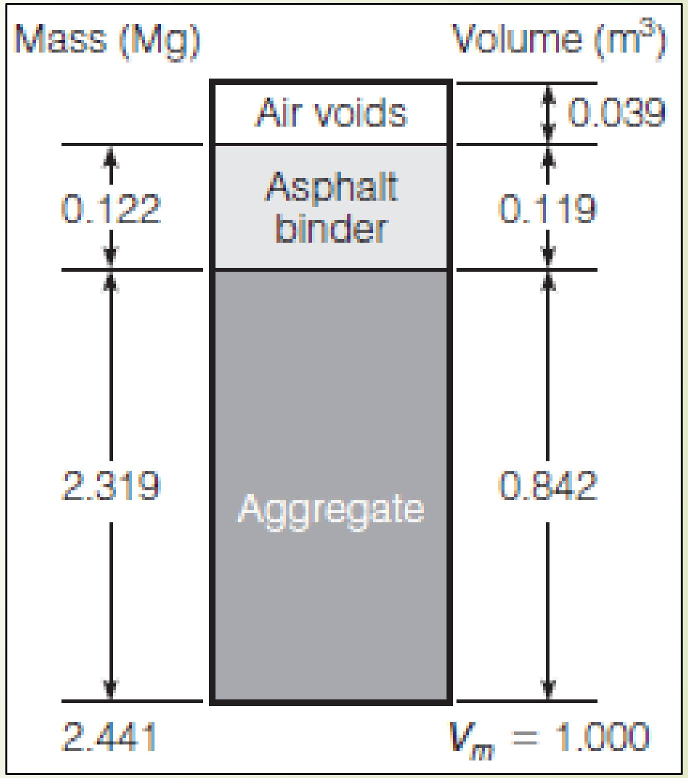
Asphalt Concrete Mix Design

Density and Void Analysis – Example 1

A compacted asphalt concrete specimen contains 5% asphalt binder (Sp. Gr. 1.023) by weight of total mix, and aggregate with a specific gravity of 2.755. The bulk density of the specimen is 2.441 $Mg/\ m^3$. Ignoring absorption, compute VTM, VMA, and VFA.

Solution

Referring to the figure:



Assume V_m=1 m^3

Determine mass of mix and components:

Total mass = 1 * 2.441 = 2.441 Mg

Mass of asphalt binder = 0.05 * 2.441 = 0.122 Mg

Mass of aggregate = 0.95 * 2.441 = 2.319 Mg

Asphalt Concrete Mix Design

Density and Void Analysis – Example 1

Determine volume of components:

$$V_b = \frac{0.122}{1.023} = 0.119m^3$$

Since the problem statement specified no absorption, $V_{be} = V_b$

Determine V_s = Volume of Stone (Aggregate)

$$V_s = \frac{2.319}{2.755} = 0.842\ m^3$$

Determine V_v = Volume of Voids

$$V_v = V_m - V_s - V_b$$

$$V_v = 1 - 0.842 - 0.199 = 0.039\ m^3$$

Asphalt Concrete Mix Design

Density and Void Analysis – Example 1

Volumetric calculations:

$$VTM = \frac{V_v}{V_m} * 100 = \frac{0.039}{1.00} * 100 = 3.9\%$$

$$VMA = \frac{V_v + V_{be}}{V_m} * 100 = \frac{0.039 + 0.119}{1.00} * 100 = 15.8\%$$

$$VFA = \frac{V_{be}}{V_{be} + V_v} * 100 = \frac{0.119}{0.119 + 0.039} * 100 = 75\%$$

Asphalt Concrete Mix Design

Volumetric Relationships used for asphalt mix design analysis – Example 2

An asphalt concrete specimen has the following properties:

1. Asphalt content = 5.9% by total weight of mix
2. Bulk specific gravity of the mix , G_{mb} = 2.457
3. Theoretical maximum specific gravity, G_{mm} = 2.598
4. Bulk specific gravity of aggregate, G_{sb} = 2.692

Calculate the percents VTM, VMA, and VFA.

Solution

$$VTM = 100\left(1 - \frac{G_{mb}}{G_{mm}}\right) = 100\left(1 - \frac{2.457}{2.598}\right) = 5.4\%$$

$$VMA = \left(100 - G_{mb}\frac{P_s}{G_{sb}}\right) = \left(100 - 2.457\frac{100 - 5.9}{2.692}\right) = 14.1\%$$

$$VFA = 100\left(\frac{VMA - VTM}{VMA}\right) = 100\left(\frac{14.1 - 5.9}{14.1}\right) = 61.7\%$$

Marshall Mix Design

- The basic steps required for performing Marshall mix design can be summarized into two:
  - i. Selection of Aggregates and
  - ii. Determination of Optimum Asphalt Content
- Asphalt Institute breaks down these steps into 6:
  1. Aggregate evaluation
  2. Asphalt cement evaluation
  3. Specimen preparation
  4. Marshall stability and flow measurement
  5. Density and voids analysis
  6. Design asphalt content determination

1. Aggregate Evaluation

- The aggregate characteristics that must be evaluated before it can be used for an asphalt concrete mix include the durability, soundness, presence of deleterious substances, polishing, shape, and texture.
- Agency specifications define the allowable ranges for aggregate gradation

Marshall Mix Design

- The standard Marshall method is applicable to densely graded aggregates with a maximum size of not more than 25 mm (AASHTO T245).
- A modified Marshall method is available using larger molds and a different compaction hammer for mixes with a nominal maximum aggregate size up to 50 mm (ASTM D5581).

2. Asphalt cement evaluation

- The grade of asphalt cement is selected based on the expected temperature range and traffic conditions.
- Most highway agencies have specifications that prescribe the grade of asphalt for the design conditions

3. Specimen preparation

- The full Marshall mix-design procedure requires 18 specimens 101.6 mm in diameter and 63.5 mm high.
- The stability and flow are measured for 15 specimens. In addition, 3 specimens are used to determine the theoretical maximum specific gravity G_{mm}

Marshall Mix Design

- The specimens for the theoretical maximum specific gravity determination are prepared at the estimated design asphalt content. Samples are also required for each of five different asphalt contents; the expected design asphalt content, ∓ 0.50 and ∓ 0.10
- Engineers use experience and judgment to estimate the design asphalt content
- Specimen preparation for the Marshall method uses the Marshall compactor
- The Marshall method requires mixing of the asphalt and aggregates at a temperature where the kinematic viscosity of the asphalt cement is 170 ∓ 0.50 cSt and compacting temperature
- corresponds to a viscosity of 280 ∓ 0.50 cSt.
- The Asphalt Institute permits three different levels of energy to be used for the preparation of the specimens: 35, 50, and 75 blows on each side of the sample
- Most mix designs for heavy-duty pavements use 75 blows, since this better simulates the required density for pavement construction.

Marshall Mix Design

4. Marshall Stability and Flow Measurement

- The Marshall stability of the asphalt concrete is the maximum load the material can carry when tested in the Marshall Apparatus
- The test is performed at a deformation rate of 51 mm/min and a temperature of 60°C
- The Marshall flow is the deformation of the specimen when the load starts to decrease
- Stability is reported in newtons and flow is reported in units of 0.25 mm of deformation

5. Density and Voids Analysis

- Involves determination of VTM, VMA, and VFA

6. Design Asphalt Content Determination

- Traditionally, test results and calculations are tabulated and graphed to help determine the factors that must be used in choosing the optimum asphalt content

Marshall Mix Design

Asphalt Institute Criteria for Marshall Mix Design (The Asphalt Institute, 2001)

	Traffic Level					
	Light		Medium		Heavy	
Compaction (Blows)	35		50		75	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Stability, kN (lb)	3.34 (750)	—	5.34 (1,200)	—	8.01 (1,800)	—
Flow, 0.25 mm (0.01 in.)	8	18	8	16	8	14
Air Voids, %	3	5	3	5	3	5
VMA, %	Use Criteria in Table for minimum percent of VMA					
VFA, %	70	80	65	78	65	75

Marshall Mix Design

Minimum Percent Voids in Mineral Aggregate (VMA) (The Asphalt Institute, 2001)

Nominal Maximum Particle Size[1]	Minimum VMA, Percent — Design Air Voids 3.0	4.0	5.0
2.36 mm (No. 8)	19.0	20.0	21.0
4.75 mm (No. 4)	16.0	17.0	18.0
9.5 mm (3/8 in.)	14.0	15.0	16.0
12.5 mm (1/2 in.)	13.0	14.0	15.0
19.0 mm (3/4 in.)	12.0	13.0	14.0
25.0 mm (1.0 in.)	11.0	12.0	13.0

Marshall Mix Design – Example

The Marshall method was used to design an asphalt concrete mixture. A PG 64-22 asphalt cement with a specific gravity G_b of 1.031 was used. The mixture contains a 9.5 mm nominal maximum particle size aggregate with a bulk specific gravity G_{sb} of 2.696. The theoretical maximum specific gravity G_{mm} of the mix at asphalt content of 5.0% is 2.470. Trial mixes were made with average results as shown in the following table:

Asphalt Content (P_b) (% by Weight of Mix)	Bulk Specific Gravity (G_{mb})	Corrected Stability (kN)	Flow (0.25 mm)
4.0	2.360	6.3	9
4.5	2.378	6.7	10
5.0	2.395	5.4	12
5.5	2.405	5.1	15
6.0	2.415	4.7	22

Determine the design asphalt content using the Asphalt Institute design criteria for medium traffic. Assume a design air void content of 4%.

Marshall Mix Design – Example

Step 1: Compute G_{se} at 5% asphalt binder content and $G_{mm} = 2.470$

$$G_{se} = \frac{P_s}{(\frac{100}{G_{mm}} - \frac{P_b}{G_b})} = \frac{100-5}{(\frac{100}{2.470} - \frac{5}{1.031})} = 2.666$$

Step 2: Use G_{se} at 5% asphalt binder to calculate G_{mm} for the other asphalt contents

At 4.0 % asphalt binder:

$$G_{mm} = \frac{100}{(\frac{P_s}{G_{se}} + \frac{P_b}{G_b})} = \frac{100}{(\frac{100-4.0}{2.666} + \frac{4.0}{1.031})} = 2.51$$

Step 3: Compute VTM

At 4.0 % asphalt binder:

$$VTM = 100\left(1 - \frac{G_{mb}}{G_{mm}}\right) = 100\left(1 - \frac{2.360}{2.51}\right) = 5.86\%$$

Marshall Mix Design – Example

Step 4: Compute VMA

At 4.0 % asphalt binder:

$$VMA = \left(100 - G_{mb}\frac{P_s}{G_{sb}}\right) = \left(100 - 2.360\frac{100-4}{2.696}\right) = 16\ \%$$

Step 5: Compute VFA

At 4.0 % asphalt binder:

$$VFA = 100\left(\frac{VMA - VTM}{VMA}\right) = 100\left(\frac{16.0 - 5.86}{16.0}\right) = 63.3\%$$

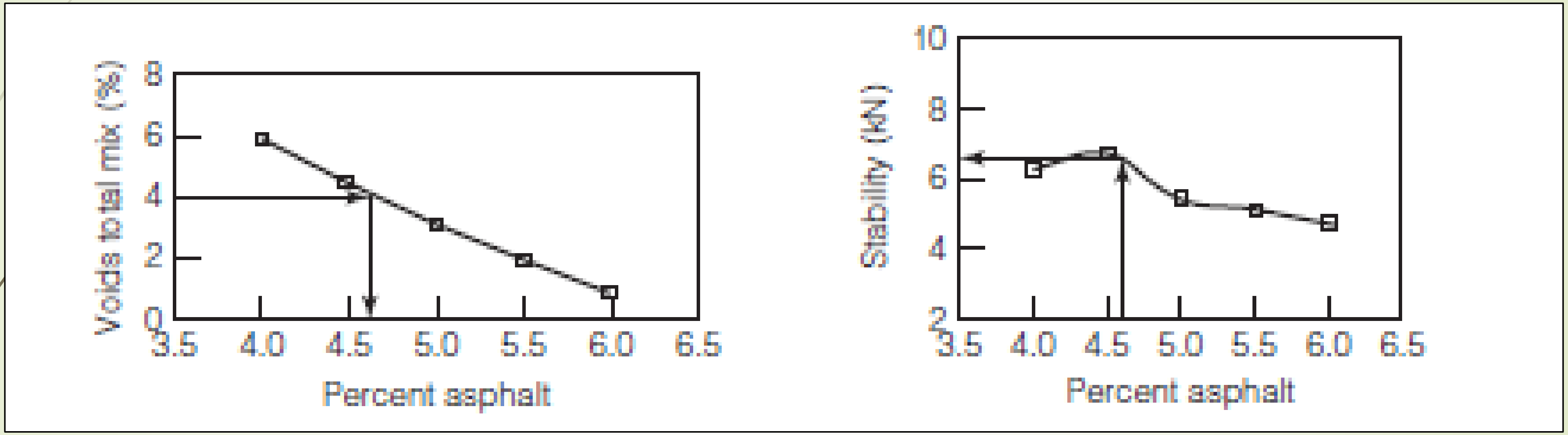
Marshall Mix Design – Example

Summary of Calculations

P_b (%)	G_{mb}	Corrected Stability (kN)	Flow, (0.25 mm)	G_{mm}	G_{se}	VTM (%)	VMA (%)	VFA (%)
4.0	2.360	6.3	9	2.507		5.9	16.0	63.3
4.5	2.378	6.7	10	2.488		4.4	15.8	71.9
5.0	2.395	5.4	12	2.470	2.666	3.0	15.6	80.5
5.5	2.405	5.1	15	2.452		1.9	15.7	87.8
6.0	2.415	4.7	22	2.434		0.8	15.8	95.0

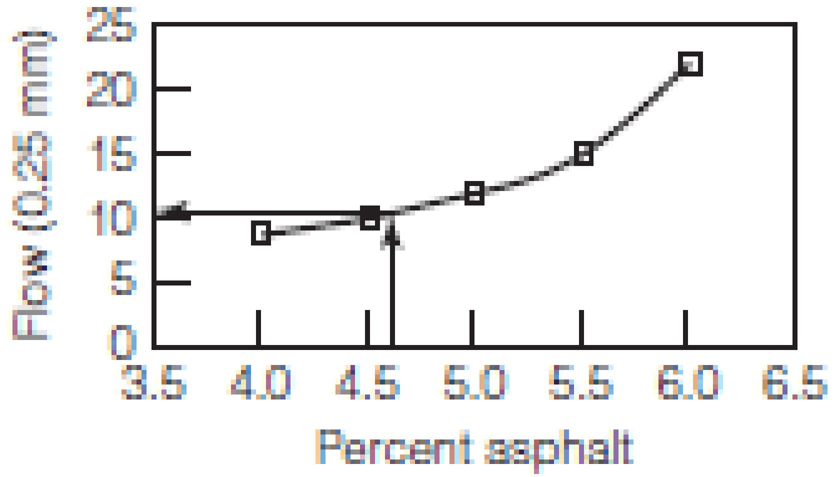
Marshall Mix Design – Example

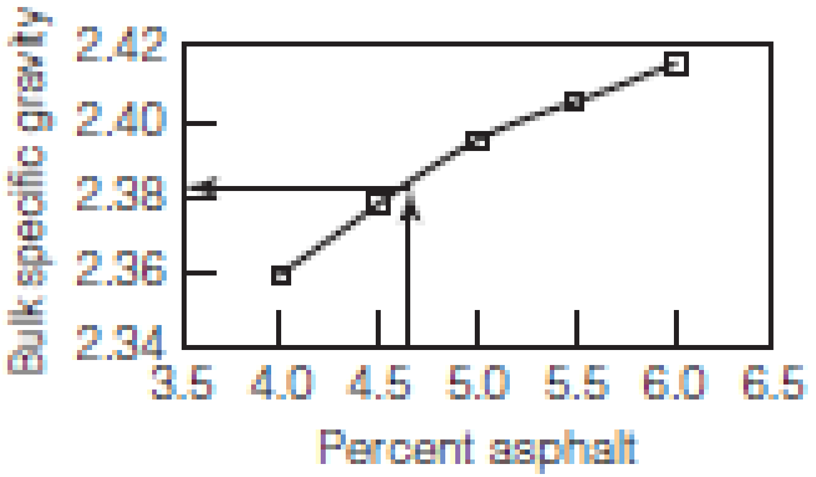
Step 6: Plot stability, flow and volumetric parameters versus asphalt content



Marshall Mix Design – Example

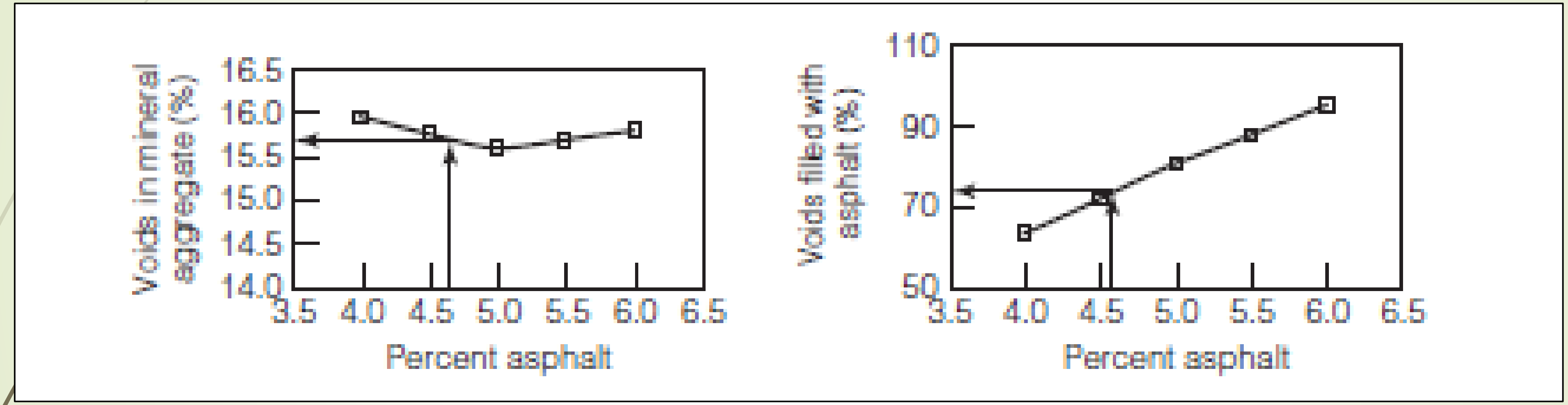
Step 6: Plot stability, flow and volumetric parameters versus asphalt content





Marshall Mix Design – Example

Step 6: Plot stability, flow and volumetric parameters versus asphalt content



Marshall Mix Design – Example

Step 7: Determine the asphalt content at VTM=4% and the corresponding parameters.

Compare with criteria:

At VTM = 4%, Find Corresponding Parameters from Graphs		
Parameter	From Graph	Criteria
% of Asphalt binder at VTM = 4%	4.6	
Stability in N at 4.6 % Binder	6600	5400 (min)
Flow (0.25 mm) at 4.6 % Binder	10.5	8 to 16
VMA (%) at % 4.6 % Binder	15.7	15.0 (min)
VFA at 4.6 % Binder	75	65 to 78

Since all parameters are within acceptance criteria, Optimum Asphalt Content = 4.6 %

Superpave Mix Design

- The Superpave mix-design process consists of:
  - i. **Selection of Materials**
    1. Binder and
    2. Aggregates
  - ii. **Volumetric Trial Mix Design**
    3. Determination of design aggregate structure
    4. Determining trial percentage of asphalt binder for each trial aggregate blend
    5. Evaluating trial mix designs
    6. Obtaining design asphalt binder content
  - iii. **Selection of Final Mix Design**

Superpave Mix Design

1. Binder Selection

- The binder is selected based on the maximum and minimum pavement temperatures, as discussed earlier

Maximum Pavement Design Temperature (defined at a depth of 20 mm below the pavement surface)

$$T_{20mm} = (T_{air} - 0.00618Lat^2 + 0.2289Lat + 42.2)(0.9545) - 17.78$$

T_{20mm} = high-pavement design temperature at a depth of 20 mm

T_{air} = seven-day average high air temperature (°C)

Lat = the geographical latitude of the project location (degrees)

Superpave Mix Design

Minimum Pavement Design Temperature (average of the minimum one-day air temperature for the year at the surface of the pavement)

$$T_{\text{pav}} = 1.56 + 0.72T_{\text{air}} - 0.004Lat^2 + 6.26\log_{10}(H + 25) - Z(4.4 + 0.52\sigma_{\text{air}}^2)^{1/2}$$

- T_{pav} = low AC-pavement temperature below surface (°C)
- T_{air} = low air temperature (°C)
- Lat =latitude of the project location (degrees)
- H = depth of pavement surface mm
- $\boldsymbol{\sigma}_{air}$ = standard deviation of the mean low air temperature (°C)
- Z is from the standard normal distribution table: At 98 % Confidence Interval, Z =2.055

Superpave Mix Design

Adjustments to Binder Selected

1. When the design loads are moving slowly, the selected asphalt binder based on the procedure described earlier should be shifted higher one high-temperature grade.
2. When design load is stationary, the binder selected from the procedure should be shifted higher two high-temperature grades
3. For equivalent single axle loads (ESAL) of 10,000,000 to 30,000,000, the engineer should CONSIDER shifting the binder selected based on the procedure by one high-temperature binder grade
4. For ESALs exceeding 30,000,000, a shift of one high-temperature grade is REQUIRED

Superpave Mix Design

2. Selection of Aggregate

- Aggregate for Superpave mixes must pass both:
  - **Source properties** - (defined by the owner) may include Los Angeles abrasion, soundness, and deleterious materials
  - **Consensus requirements** - part of the national Superpave specification and are on the blend of aggregates. These properties include Coarse aggregate angularity, fine aggregate angularity, sand equivalency (clay content), flat and elongated particles, etc.
- Specification limits for these properties depend on the traffic level and how deep under the pavement surface the materials will be used

Superpave Mix Design

Coarse Aggregate Angularity Criteria

Traffic, Million ESALs	*Depth from Surface*	
	< 100 mm	*> 100 mm*
< 0.3	55/–	–/–
< 1	65/–	–/–
< 3	75/–	50/–
< 10	85/80	60/–
< 30	95/90	80/75
< 100	100/100	95/90
> 100	100/100	100/100

Superpave Mix Design

Fine Aggregate Angularity Criteria

Traffic, Million ESALs	*Percent Air Voids in Loosely Compacted Fine Aggregates Smaller than 2.36 mm* — *Depth from Surface* < *100 mm*	> *100 mm*
< 0.3	—	—
< 1	40	—
< 3	40	40
< 10	45	40
< 30	45	40
< 100	45	45
≥ 100	45	45

Superpave Mix Design

Thin and Elongated Particles Criteria

Traffic, Million ESALs	*Maximum, Percent*
< 0.3	—
< 1	—
< 3	10
< 10	10
< 30	10
< 100	10
≥ 100	10

Superpave Mix Design

Clay Content Criteria

Traffic, Million ESALs	*Sand Equivalent Minimum, Percent*
< 0.3	40
< 1	40
< 3	40
< 10	45
< 30	45
< 100	50
≥ 100	50

Superpave Mix Design

Superpave Mixture Gradations

Superpave Designation	*Nominal Maximum Size, mm*	*Maximum Size, mm*
37.5 mm	37.5	50.0
25.0 mm	25.0	37.5
19.0 mm	19.0	25.0
12.5 mm	12.5	19.0
9.5 mm	9.5	12.5

Superpave Mix Design

3. Determination of Design Aggregate Structure

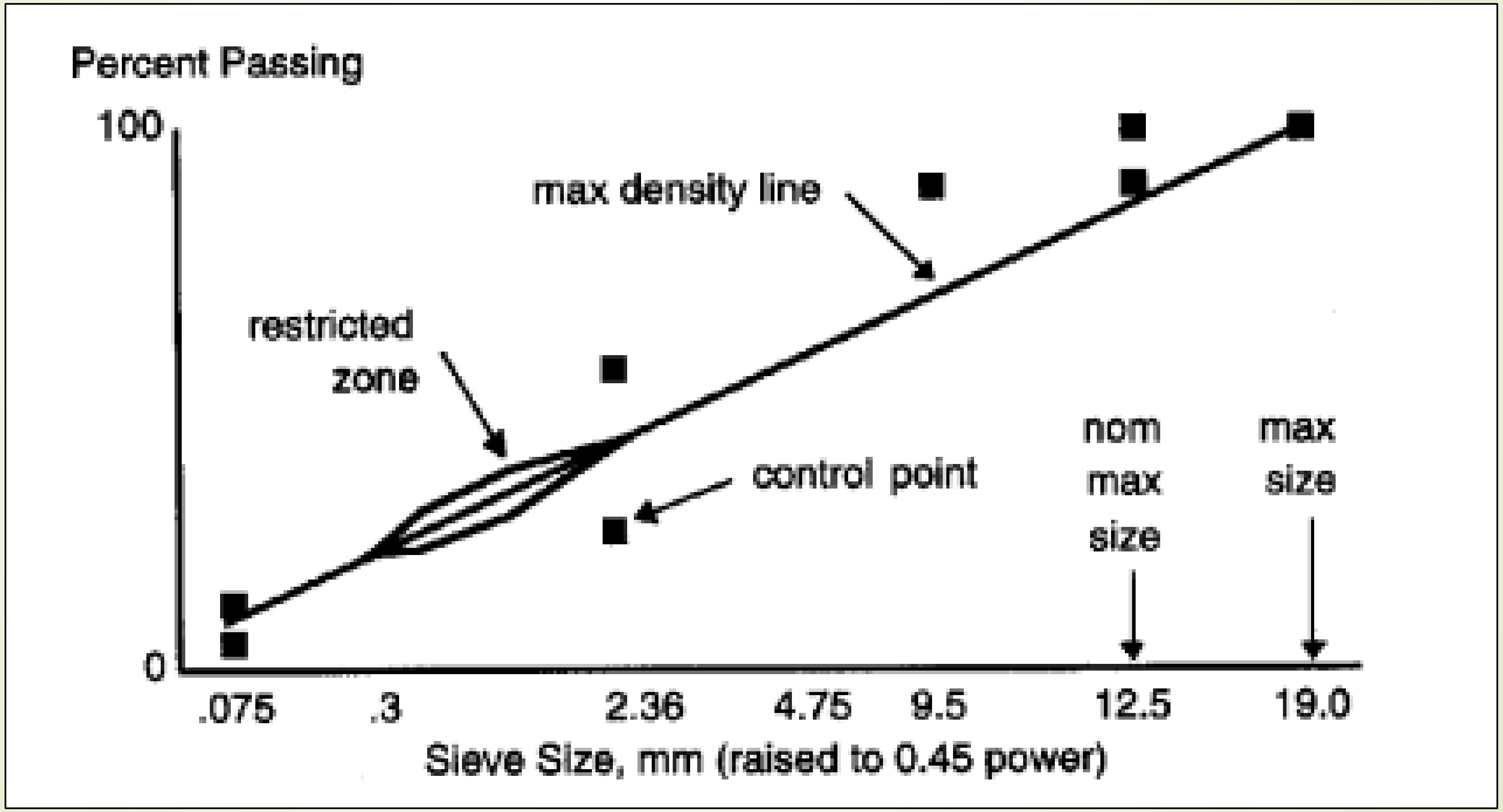
- In selecting the design aggregate structure, the materials engineer must first ensure that the individual aggregate and asphalt materials meet the criteria discussed
- Aggregate used in asphalt concrete must be well graded. The 0.45 power chart is recommended for Superpave mix designs. The gradation curve must go between control points
- Trial blends (Usually three are recommended) should then be prepared by varying the percentages from the different available stockpiles
- The bulk specific gravity and other combined properties of the selected aggregate blend may be obtained from the equation below:

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

$P_1, P_2, \ldots P_n$ are individual %s by mass and $G_1, G_2, \ldots G_n$ are individual bulk spec. gr. of aggregates

Superpave Mix Design

- The figure shows the gradation requirements for the 12.5 mm nominal-sized Superpave mix



Superpave Mix Design

4. Determining Trial Percentage of Asphalt Binder for each Trial Aggregate Blend

- This selection is based on certain volumetric characteristics of the mixture which are dependent on the accumulated traffic load.
- The Superpave volumetric mix design is proposed for three levels of traffic load
  - Level 1: Accumulated traffic < 10^6 ESAL
  - Level 2: 10^6 <Accumulated traffic<10^7 ESAL
  - Level 3: Accumulated traffic >10^7 ESAL
- The Level 1 design procedure primarily is based on the volumetric analysis of the mix while Levels 2 and 3 mix design procedures incorporate performance tests that are used to measure fundamental properties and predict pavement performance.
- The difference between Levels 2 and 3 is that a more complete set of performance-based mixture properties are obtained and a more comprehensive set of models set is used to determine fatigue and permanent deformation

Superpave Mix Design

- A brief discussion of the Level 1 procedure is given here.
- The basic assumption made in the Level 1 mix design process is that properties of the mix (such as air voids and voids in mineral aggregate) are suitable surrogates for mixture performance.
- Volumetric properties determined for the trial mixtures are :
  1. VTM
  2. VMA
  3. VFA
  4. Asphalt Content (P_b)
  5. Absorbed Asphalt Volume (P_{ba})
  6. Effective Asphalt Content (P_{be})
- Although no specific number of trial blends is recommended, it is generally accepted that three trial blends that have a range of gradation will be adequate.

Superpave Mix Design

- Compute an initial trial asphalt content for a trial aggregate gradation that will meet VMA requirements shown below:

Voids in Mineral Aggregate Criteria

Nominal Maximum Size (mm)	*Minimum Voids in Mineral Aggregate (%)*
9.5	15.0
12.5	14.0
19.0	13.0
25.0	12.0
37.5	11.0
50.0	10.5

Superpave Mix Design

- The following steps to compute an initial trial asphalt content;

Step 1: Compute the bulk and apparent specific gravities of the total aggregates in the trial aggregate mix

$$\text{Bulk Specific Gravity, } G_{sb} = \frac{P_1 + P_2 + \cdots + P_n}{\frac{P_1}{G_{sb1}} + \frac{P_2}{G_{sb2}} + \cdots + \frac{P_n}{G_{sbn}}}$$

$$\text{Apparent Specific Gravity, } G_{asb} = \frac{P_1 + P_2 + \cdots + P_n}{\frac{P_1}{G_{asb1}} + \frac{P_2}{G_{asb2}} + \cdots + \frac{P_n}{G_{asbn}}}$$

P_1, $P_2, \ldots P_n$ are individual %s by mass and G_{sb1}, $G_{sb2}, \ldots G_{sbn}$ and G_{asb1}, $G_{asb2}, \ldots G_{asbn}$ are individual bulk and apparent specific gravities of aggregates respectively

Superpave Mix Design

Step 2: Compute the effective specific gravity of the total aggregate in the trial gradation

$$\text{Effective Specific Gravities, } G_{se} = G_{sb} + 0.8(G_{asb} - G_{sb})$$

- The designer may decide to change the implicit multiplication factor of 0.8, particularly when absorptive aggregates are used, as values close to 0.6 or 0.5 are more appropriate for these aggregates.

Step 3: Estimate amount of asphalt binder (cm^3/cm^3) absorbed by the aggregates

$$\text{Volume of absorbed binder, } P_{ba} = \frac{P_s(1-VTM)}{\frac{P_b}{G_b}+\frac{P_s}{G_{se}}}\left[\frac{1}{G_b} - \frac{1}{G_{se}}\right]$$

P_b = percent of binder (assumed 0.05)
P_s = percent of aggregate (assumed 0.95)
G_b = specific gravity of binder (assumed 1.02)
VTM = volume of air voids (assumed 0.04 cm^3/cm^3 of mix)

Superpave Mix Design

Step 4: Estimate the percent of effective asphalt binder

$$\text{Effective Asphalt Binder}, V_{be} = 0.176 - (0.0675)\log(S_n)$$

S_n = the nominal maximum sieve size of the total aggregate in the trial aggregate gradation (mm)

Step 5: Determine percentage of trial asphalt binder

amount of asphalt binder (cm^3/cm^3) absorbed by the aggregates

$$\%\ \text{by mass of trial binder in mix}\ i, P_{bi} = \frac{G_b(V_{be} - V_{ba})}{\left(G_b(V_{be} - V_{ba})\right) + W_s} * 100$$

$$W_s = mass\ of\ aggregate\ in\ grams = \frac{P_s(1 - VTM)}{\frac{P_b}{G_b} + \frac{P_s}{G_{se}}}$$

Superpave Mix Design

4. Evaluation of Trial Mix Designs

i. Preparation and Compaction of Trial Mixes

- After selecting the appropriate aggregate structure and binder, trial specimens are prepared with three different aggregate gradations and asphalt contents
- Two specimens are prepared for each trial asphalt mixes
- Specimens are compacted using the Superpave Gyratory Compactor (SGC) with a gyration angle of 1.16 degrees (internal mold measurement) and a constant vertical pressure of 600 kPa
- The number of gyrations used for compaction is determined based on the traffic level

Superpave Mix Design

- Superpave method recognizes three critical stages of compaction, initial, design, and maximum.
- The **design compaction level** corresponds to the compaction that is anticipated at the completion of the construction process.
- The **maximum compaction level** corresponds to the ultimate density level that will occur after the pavement has been subjected to traffic for a number of years
- The **initial compaction level** was implemented to assist with identifying “tender” mixes. A tender mix lacks stability during construction, and hence will displace under the rollers rather than densifying.

Superpave Mix Design

- The level of compaction in the Superpave system is given with respect to a **design number of gyrations N_{des}**
- The design number of gyrations N_{des} depends on the average design high air temperature and the design ESAL
- The two other levels of gyrations (maximum and initial) are important.
  - The maximum number of gyrations, N_{max}, is used to compact the test specimens;
  - The initial number of gyrations, N_{ini}, is used to estimate the compactibility of the mixture
- N_{max} and N_{ini} are obtained from N_{des} as shown.

$$Log\ N_{max} = 1.10 Log N_{des}$$

$$Log\ N_{ini} = 0.45 Log N_{des}$$

Superpave Mix Design

The table below shows the values of N_{des} for different ESALs and average design air temperatures.

Number of Initial (N_{ini}), Design (N_{des}) and Maximum (N_{max}) Ggyrations Required for Various Traffic Levels and Maximum Temperature Environments

Design ESALs (millions)	Average Design High Air Temperature											
	< 39°C			39 to 40°C			41 to 42°C			43 to 45°C		
	N_{ini}	N_{des}	N_{max}	N_{ini}	N_{des}	N_{max}	N_{ini}	N_{des}	N_{max}	N_{ini}	N_{des}	N_{max}
< 0.3	7	68	104	7	74	114	7	78	121	7	82	127
0.3–1.0	7	76	117	7	83	129	7	88	138	8	93	146
1.0–3.0	7	86	134	8	95	150	8	100	158	8	105	167
3.0–10.0	8	96	152	8	106	169	8	113	181	9	119	192
10.0–30.0	8	109	174	9	121	195	9	128	208	9	135	220
30.0–100.0	9	126	204	9	139	228	9	146	240	10	153	253
> 100	9	143	235	10	158	262	10	165	275	10	172	288

Superpave Mix Design

4. Evaluation of Trial Mix Designs

ii. **Determination of critical parameters for each Trial Mix**

- The theoretical maximum specific gravity (G_{mm}) of the pavement mix is determined using the equation below:

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

- Each trial aggregate gradation then is evaluated with respect to its VMA at N_{des} gyrations and the densities are evaluated at $N_{initial}$ and N_{max}
- This involves determining the volumetric properties at the N_{des} gyration level of each paving mix and estimating the VMA at 4 percent air voids
- The air voids content is not usually at the required 4 percent. Thus, there is change in asphalt content to achieve a 4 percent air void content. This is obtained through a procedure that involves shifting the densification curves to determine the change in VMA that will occur as a result of this shift

Superpave Mix Design

- The design parameters are estimated from the shifted curve and compared with the Level 1 criteria
- The VMA criteria are given in the table below:

Voids in Mineral Aggregate Criteria

Nominal Maximum Size (mm)	*Minimum Voids in Mineral Aggregate (%)*
9.5	15.0
12.5	14.0
19.0	13.0
25.0	12.0
37.5	11.0
50.0	10.5

- The criteria for densities are that $C_{initial}$ should be less than 89 percent and C_{max} should be less than 98 percent - where C is a correction factor

Superpave Mix Design

- The following physical properties of the compacted specimens are determined:
  - Estimated bulk specific gravity, G_{mbe}
  - Corrected bulk specific gravity, G_{mbc}
  - Corrected percent of maximum theoretical specific gravity

Estimated bulk specific gravity, G_{mbe}

$$G_{mbe} = \frac{\frac{W_m}{V_{mx}}}{\gamma_w}$$

where

W_m = mass of specimen (grams)
γ_w = density of water = 1g/cm
V_{mx} = volume of compaction mold (cm^3)

$$V_{mx} = \frac{\pi d^2 h_x}{4} \times 0.01 \text{ cm}^3/\text{mm}^3$$

where

d = diameter of mold (150 mm)
h_x = height of specimen in mold during compaction (mm)

Superpave Mix Design

- Since the cylinder in which the mold is compacted is not smooth and the equation for calculating volume is based on this assumption, the actual volume of the compacted mixture will be less than that obtained from the equation.
- The estimated bulk specific gravity therefore is corrected using the corrected factor obtained as the ratio of the measured bulk specific gravity to the estimated bulk specific gravity

$$C = \frac{G_{mbm}}{G_{mbe}}$$

where

C = correction factor
G_{mbm} (measured) = measured bulk specific after N_{max}
G_{mbe} (estimated) = estimated bulk specific after N_{max}

Corrected bulk specific gravity, G_{mbc}

- The Corrected bulk specific gravity, $\boldsymbol{G_{mbc}}$ at any other gyration level can then be obtained using the equation below:

$$\boxed{G_{mbc}\,(\text{corrected}) = C \times G_{mbe}\,(\text{estimated})}$$

Superpave Mix Design

Corrected percent of maximum theoretical specific gravity

- The percentage maximum theoretical specific gravity G_{mm} for each desired gyration is then computed as the ratio of G_{mbc} (corrected) to G_{mm} (measured).
- The average G_{mm} value for each gyration level is obtained using the G_{mm} values for the samples compacted at that level.

VTM, VMA, VFA, and % variation of VMA from 4 % at N_{des}

- The values for the volumetric properties at N_{design}

$$\text{VTM} = 100\left(\frac{G_{mm} - G_{mb}}{G_{mm}}\right)$$

$$VFA = 100\left(\frac{VMA - \text{VTM}}{VMA}\right)$$

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

Superpave Mix Design

- If the percent of air voids is 4 %, then the values obtained for the volumetric criteria are compared with the corresponding criteria values
- If these criteria are met, then the blend is acceptable.
- When the VMA is not 4 percent, it is necessary to determine an estimated design asphalt content with a VMA of 4 percent using below:

$$P_{b,estimated} = P_{bi} - [0.4 * (4 - VTM)]$$

- The VMA and VFA at $\boldsymbol{N_{des}}$, $\boldsymbol{G_{mm}}$ at $\boldsymbol{N_{max}}$, and $\boldsymbol{N_{ini}}$ then are estimated for the design asphalt content obtained using the following equations

$$VMA_{estimated} = VMA_{ini} + C_1 * (4 - VTM)]$$

This value obtained is compared with the corresponding values in the table given earlier

where

VMA_{initial} = VMA from trial asphalt binder content
C_1 = constant = 0.1:VTM less than 4.0 percent
= 0.2:VTM is greater than 4.0 percent

Superpave Mix Design

$$VFA_{\text{estimated}} = 100\,\frac{VMA_{\text{estimated}} - 4.0}{VMA_{\text{estimated}}}$$

- This value obtained in above equation is compared with the range of acceptable values given

VFA Criteria **for Gmm at Nmax**

Traffic, Million ESALs	*Design VFA, Percent*
< 0.3	70–80
< 1	65–78
< 3	65–78
< 10	65–75
< 30	65–75
< 100	65–75

Superpave Mix Design

$$G_{\text{mm,estimated}} \text{ at } N_{\max} = G_{\text{mm,trial}} \text{ at } N_{\max} - (4 - \mathbf{VTM})$$
$$G_{\text{mm,trial}} = G_{\text{mm}} \text{ for the trial mix}$$

$$P_{\text{be}} = -(P_{\text{b}} \times G_{\text{b}}) \times \left(\frac{G_{\text{se}} - G_{\text{sb}}}{G_{\text{se}} - G_{\text{sb}}}\right) + P_{\text{b,estimated}}$$

Superpave Mix Design

Obtaining Dust Percentage

- The proportion of the percentage by mass of the material passing the 0.075-mm sieve to the effective binder content by mass of the mix in percent

$$DP = \frac{P_{0.75}}{P_{be}}$$

where

DP = dust percentage
$P_{0.75}$ = aggregate content passing the 0.075-mm sieve, percent by mass of aggregate
P_{be} = effective asphalt content, percent by total mass of mixture

- The range of acceptable dust proportion is from 0.6 to 1.2.
- Based on these results, the designer will accept one or more of the trial blends that meet the desired criteria

Superpave Mix Design

Obtaining Design Asphalt Binder Content

- After the selection of the design aggregate structure from the trial blends, the selected trial blend becomes the design aggregate structure.
- Batch, mix, and compact more samples (minimum of two specimens) with this gradation with four asphalt contents (+0.5 and -0.5 percent of the estimated asphalt content and at least two with an asphalt content of +1.0 percent are compacted)
- Determine volumetric properties
- Select P_b at 4.0% air voids and check other volumetric properties

Moisture Sensitivity

- Measured on proposed aggregate blend and asphalt content

Hot Mix Asphalt Concrete Production and Construction

- The production and construction of asphalt concrete highways can be described as a three-step process:
  i. production of raw materials – production of asphalt cement at petroleum refineries
  ii. manufacturing asphalt concrete – batch plants or drum (single drum is used for both drying the aggregates and mixing in the asphalt cement)
  iii. field operations - The HMA is transported from the plant to the paving location where it is placed using an asphalt paver
    - Asphalt pavers are designed to produce a smooth surface when operated properly.
    - The keys to proper operation are a constant flow of material through the paver and maintaining constant paver speed
    - The final step in the construction process is compaction of the pavement mat

Hot Mix Asphalt Concrete Production and Construction

Asphalt Additives

- Many types of additives (modifiers) are used to improve the properties of asphalt or to add special properties to the asphalt concrete mixtures
- A relatively recent development in asphalt paving is warm mix, which uses modifiers, or a modified process, to produce asphalt concrete at lower temperatures than conventional hot mix

Recycling of Asphalt Concrete

- In an effort to efficiently use available resources, there was a need to recycle or reuse old pavement materials
- Recycling became more important in the mid-1970s due to the increase in asphalt prices.

Thank You!!!