Asphalt binders & asphalt mixtures

Chapter 13

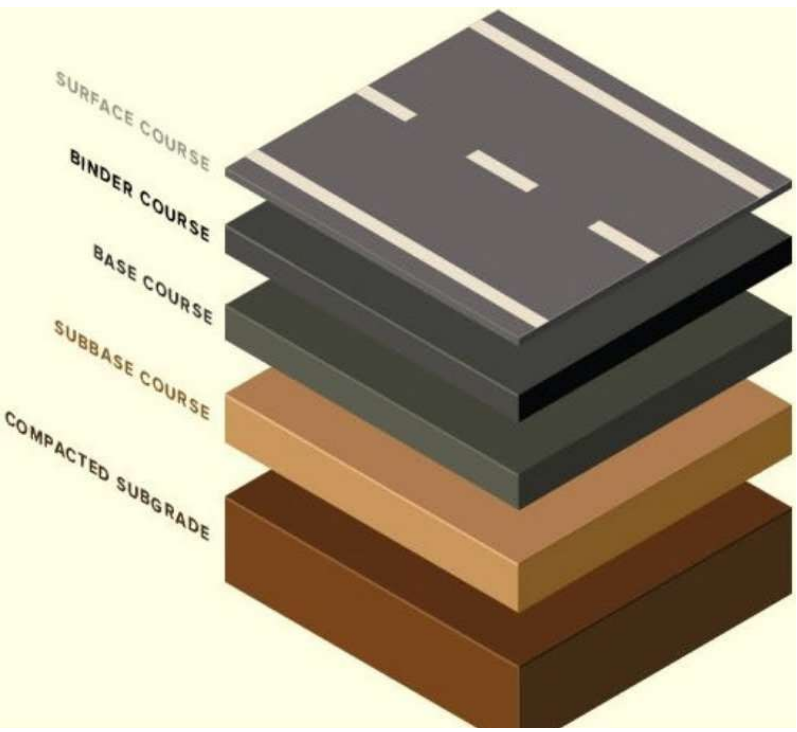
Bituminous Materials

- **Definition:** Bituminous materials are one of the oldest materials used in construction (Asphalt binders were used in 3000 B.C.). It is a solid, semisolid, or viscous cementitious material, natural or manufactured, and composed of "hydrocarbons".

- The most common bituminous materials are
  - Asphalts : available as natural deposits or are produced from petroleum processing.
  - Tars : obtained through the destructive distillation of materials such as wood, and coal.

Engineering use of bituminous materials

- Asphalt is used mostly in pavement construction, but is also used as sealing and waterproofing agents.
- Tar is used primarily for waterproofing membranes. Tar may also be used for pavement treatments.



Sources of Asphalt

Based on its source, Asphalt can be categorized as:

- Natural Rock asphalts: obtained from rock deposits containing bituminous materials.
- Native asphalts: obtained from asphalt lakes in Trinidad and other Caribbean areas.
- Petroleum asphalts: products of the distillation of crude oil. These asphalts are used as the most common bituminous paving materials.

Asphalt advantages

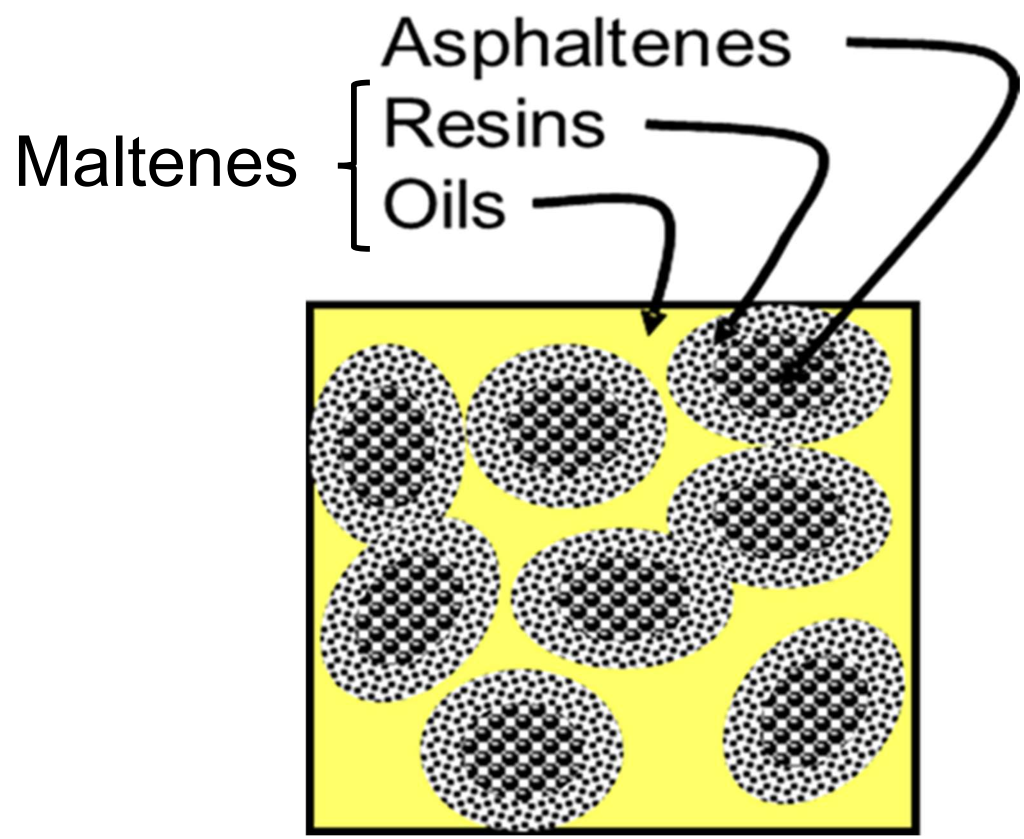
The main advantages of asphalt are:

- Asphalt is strong and durable cementing material with excellent adhesive and waterproofing characteristics.
- Cost-Effective. Widely available material; fast to construct; and provides for smooth roads increasing traffic safety and reducing wear and tear on vehicles which brings down vehicle operating costs.
- Environmentally friendly. Asphalt is 100% recyclable and the most recycled product in America.
- Highly resistant to the action of most acids, alkalis and salts.

Chemical Composition of Asphalt

- Asphalt is a mixture of a wide variety of hydrocarbons of different molecular weights primarily consisting of hydrogen and carbon, with minor components such as sulfur, nitrogen, and oxygen and trace metals.

- In the compounds level asphalt consists of two major compounds:
  - Asphaltenes and
  - Maltenes (petrolenes) which consist of resins and oils.



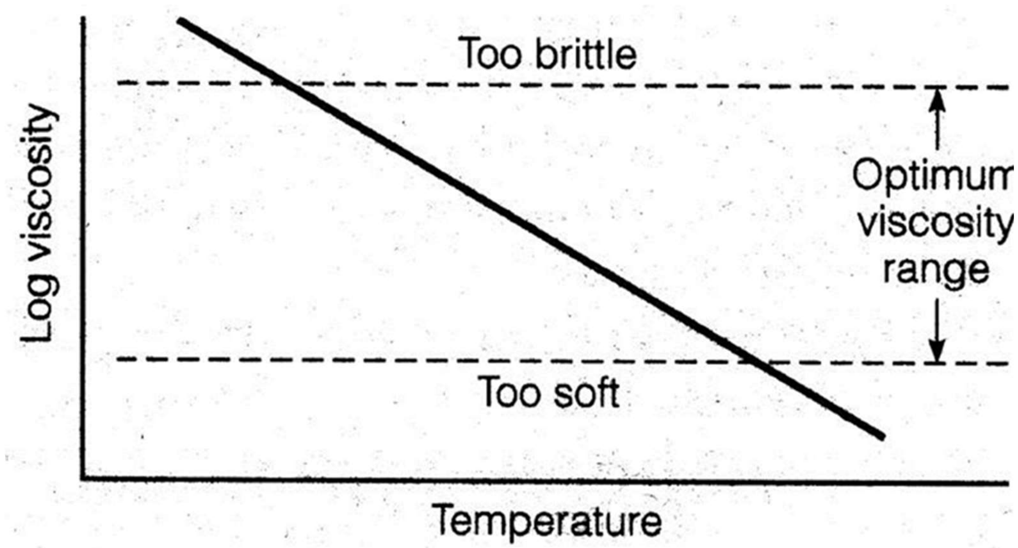
Chemical Composition of Asphalt

- **The asphaltenes** are dark brown, friable solids responsible for the viscosity and the adhesive property of the asphalt. If the asphaltene content is less than 10%, the asphalt concrete will be difficult to compact to the proper construction density.
- **The maltenes (petrolenes)** consist of resins and oils.
  - Resins are dark and semisolid or solid, with a viscosity that is largely affected by temperature. The resins act as agents to disperse asphaltenes in the oils.
  - Oils are clear or white liquids.
- The physical and aging properties of asphalt depend on its chemical composition and molecular structure. As asphalt includes heavier molecules it becomes harder and more viscous. Additionally, asphalt sensitivity to temperature is also dependent on its chemical composition.

Temperature Susceptibility of Asphalt

- At room temperature Asphalt is a semi solid material. The consistency of asphalt is greatly affected by temperature. Asphalt gets hard and brittle at low temperatures and soft at high temperatures.

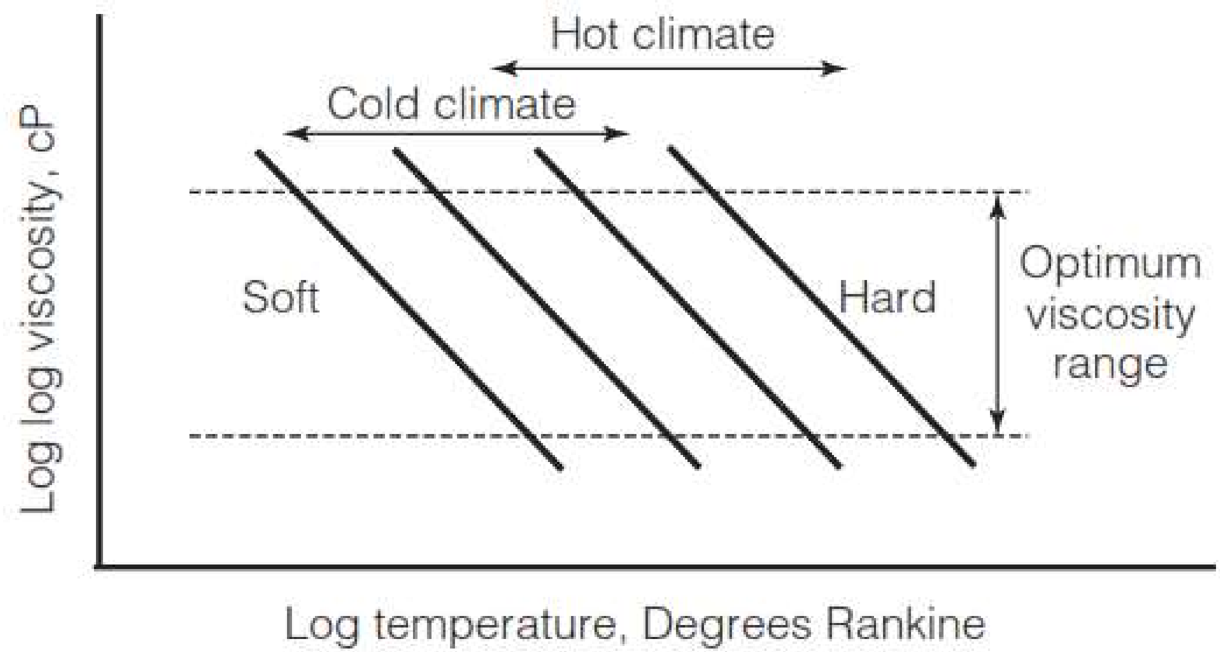
- Asphalt's temperature sensitivity can be represented by the slope of the line shown in the Figure; the steeper the slope the higher the temperature susceptibility (sensitivity) of the asphalt.



Typical relation between asphalt viscosity and temperature.

Temperature Susceptibility of Asphalt

- 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

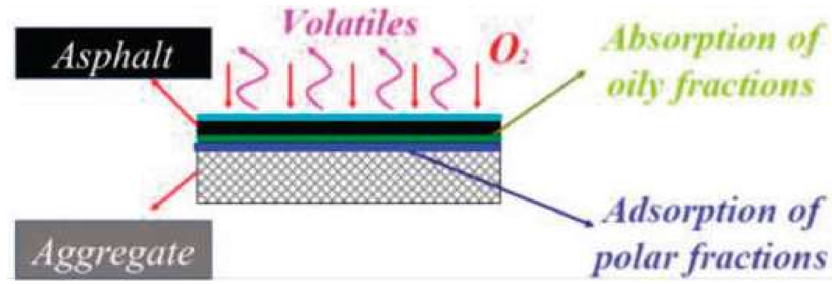


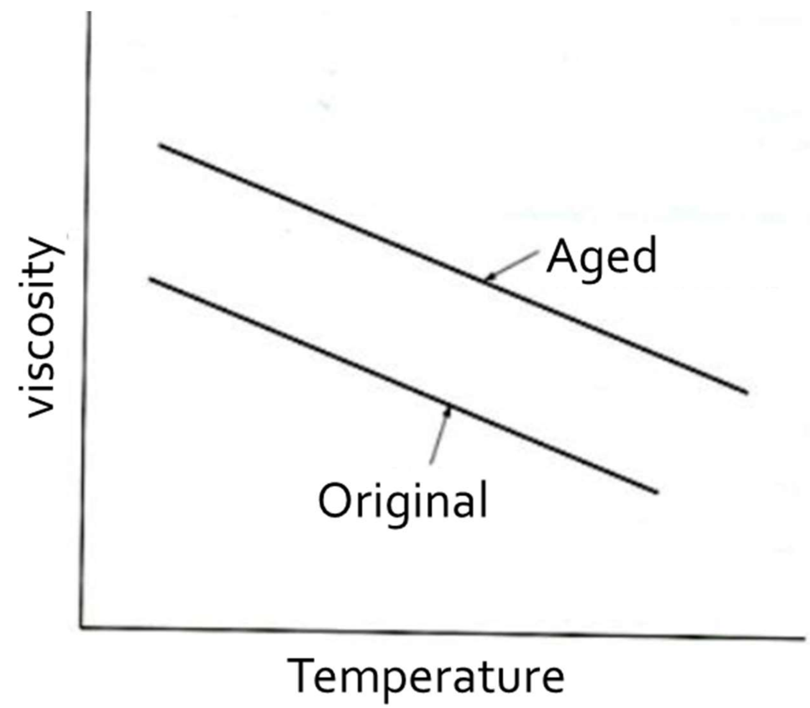
Selecting the proper grade of asphalt binder to match the climate.

Aging or Hardening of Asphalt

Aging or hardening is the process under which asphalt becomes harder and brittle due to increase in the viscosity of asphalt caused by:

1. The evaporation and oxidation of the lighter, oily constituents during mixing at high temperatures, called "volatilization" (short-term aging or hardening).
2. The oxidation of the oils to resins and resins to asphaltenes when used over a period of years (long-term or in-service aging or hardening)

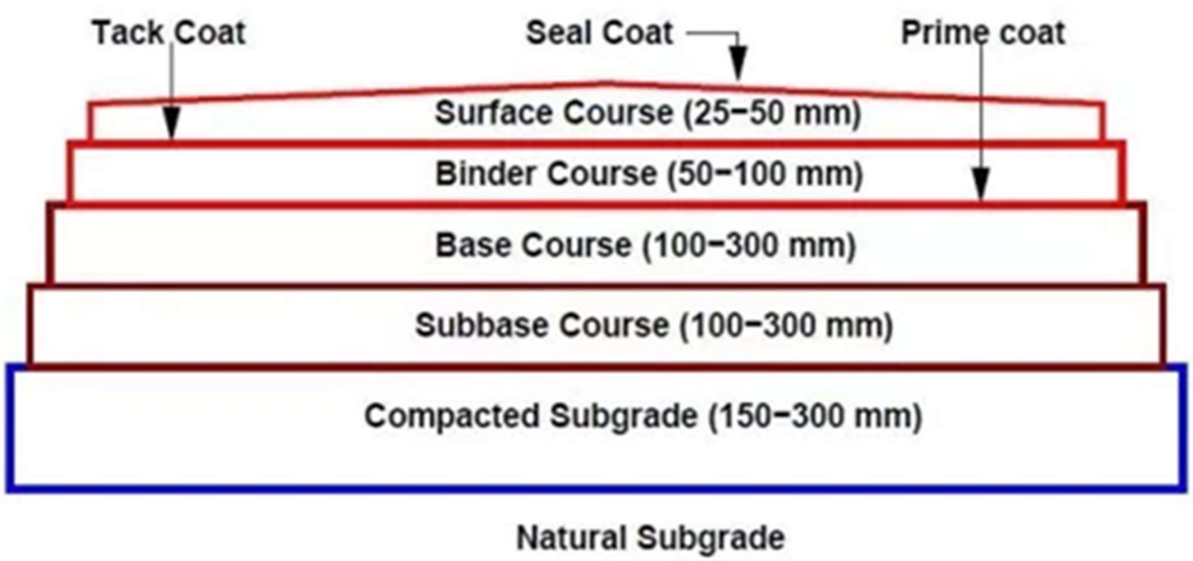




Types of Asphalt Products

Asphalt used in pavements is produced in three forms:

- Asphalt cement
- Asphalt cutback, and
- Asphalt emulsion.



Typical cross section of a flexible pavement

<u>Asphalt product used in Pavement</u>

- Surface course
- Binder
- Tack Coat
- Prime Coat
- Seal Coat

Cutback Asphalt

A cutback is produced by dissolving asphalt cement in a lighter hydrocarbon solvent. When the cutback is sprayed on a pavement or mixed with aggregates, the solvent evaporates, leaving the asphalt residue as the binder.

- **<u>Types and grades of Cutbacks</u>**

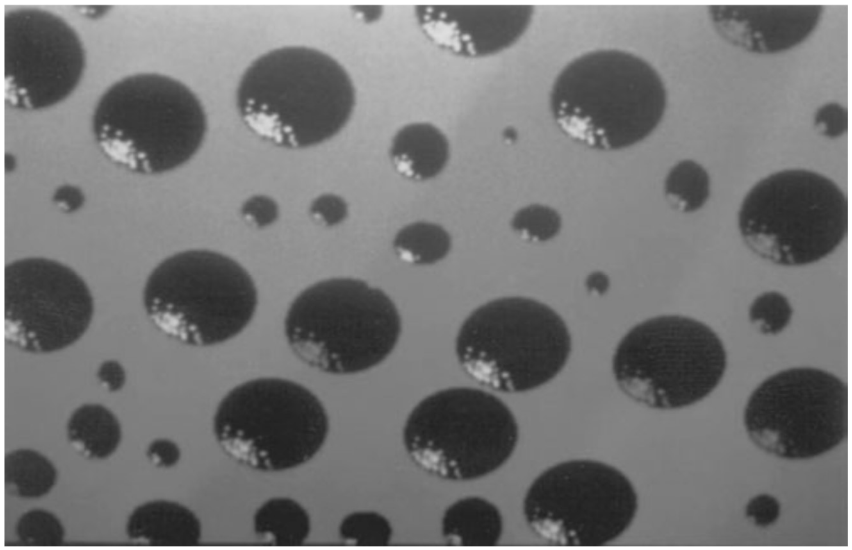
- ***Rapid-Curing (RC).*** Produced by adding a light diluent of high volatility (generally gasoline or naphtha) to asphalt cement. These are used primarily for tack coat and surface treatments.
- ***Medium-Curing (MC).*** Produced by adding a medium diluent of intermediate volatility (generally kerosene) to asphalt cement. These are generally used for prime coat.
- ***Slow-Curing (SC).*** Produced by adding oils of low volatility (generally diesel or other gas oils) to asphalt cement. They are generally used for prime coat, and as dust palliatives.

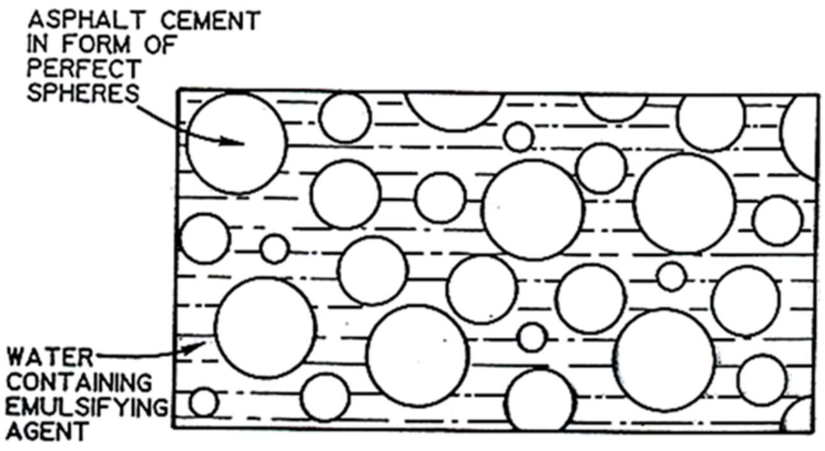
Cutback Asphalt

Applying cutback – Prime coat

Emulsified Asphalt

- Emulsified Asphalt is produced by dispersing the asphalt in water as emulsion as shown in the Figure. In this process the asphalt cement is physically broken down into micron-sized globules that are mixed into water containing an emulsifying agent.
- Emulsified asphalts typically consist of about 60% to 70% asphalt cement, 30% to 40% water, and a fraction of a percent of emulsifying agent (basically a soap material).





Emulsified Asphalt

Emulsified Asphalt

Types of Emulsified Asphalt

The emulsifying molecule has two distinct components, the head portion, which has an electrostatic charge, and the tail portion, which has a high affinity for asphalt. The charge can be either positive to produce a cationic emulsion or negative to produce an anionic emulsion.

- Anionic emulsions adhere better to aggregate particles with positive surface charges (e.g., limestone)
- Cationic emulsions adhere better to aggregate particles with negative surface charges (e.g., sandstone, quartz, siliceous gravel). Cationic emulsions also work better with wet aggregates and in colder weather

Emulsified Asphalt

Advantages of emulsified asphalt compared with Cutbacks

Emulsified asphalts are increasingly being used in lieu of cutback asphalts for the following reasons:

- Environmental regulations: Emulsions are relatively pollution free
- Lower application temperature.
- Safety and economy: Emulsions are safe to use more economic.
- Emulsions can also be applied effectively to a damp pavement, whereas dry conditions are required for cutback asphalts

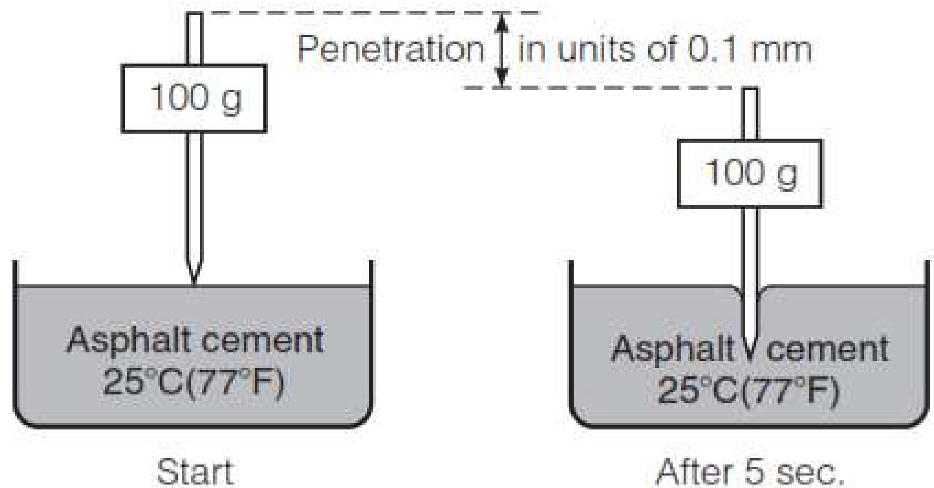
Asphalt cement (binder)

Binder Characterization

- Many tests are available to characterize asphalt cement.
- Since the properties of the asphalt are highly sensitive to temperature, all asphalt tests must be conducted at a specified temperature within very tight tolerances.
- Traditionally the asphalt cement specifications typically were based on measurements of
  - viscosity,
  - penetration,
  - ductility, and
  - softening point temperature.

Penetration and penetration Test

- Asphalt binder consistency or ability to flow can be measured by the value of penetration of a specific device into the binder at a specific temperature. A large penetration value indicates a soft binder and a small penetration value indicates a hard binder.
- **Penetration test (ASTM D5).** An asphalt sample is prepared and brought to 25°C. A standard needle with a total mass of 100 g is placed on the asphalt surface.

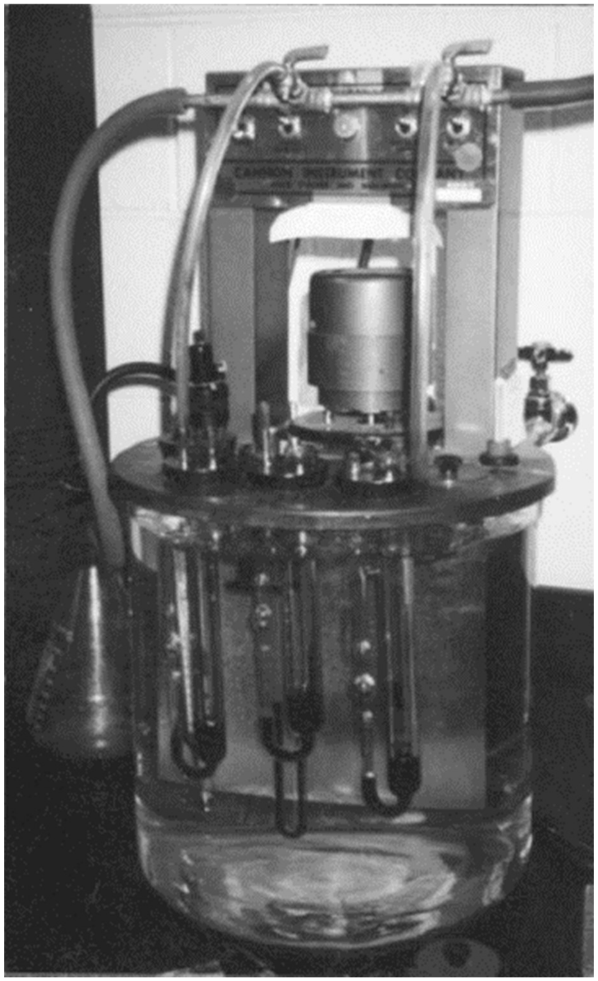


The needle is released and allowed to penetrate the asphalt for 5 seconds, as shown in the Figure. The depth of penetration, in units of 0.1 mm, is recorded and reported as the penetration value.

Absolute and Kinematic Viscosity

- Similar to the penetration, the viscosity measure is used to measure asphalt consistency. Two types of viscosity are commonly measured: absolute and kinematic.

Absolute Viscosity Test



- The absolute viscosity procedure (ASTM D2171) requires heating the asphalt cement and pouring it into a viscometer placed in a water or oil bath at a temperature of 60°C (see Figure).
- The time during which the asphalt flows under pressure between two timing marks on the viscometer is measured using a stopwatch. Then the flow time is used to obtain the absolute viscosity in units of poises.

Absolute and Kinematic Viscosity

Kinematic Viscosity Test

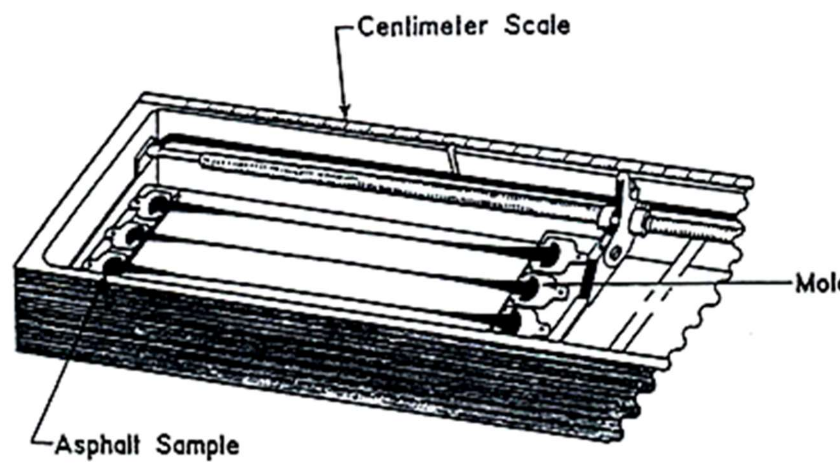
- The kinematic viscosity test procedure (ASTM D2170) is similar to that of the absolute viscosity test, except that the test temperature is 135°C. Since the viscosity of the asphalt at 135°C is fairly low, vacuum is not used.
- The time it takes the asphalt to flow between the two timing marks is multiplied by the calibration factor to obtain the kinematic viscosity in units of cenistokes (cSt), (1 stoke = 100 centistokes = 1 cm^2/s)

Asphalt Ductility

- The ductility of asphalt is defined as the distance in centimeters, to which it will elongate before breaking
- Ductility is sometimes used as an indirect gage of adhesion and cohesion of asphalt, where *Adhesion is the ability to stick* to aggregate particles in the asphalt concrete, while Cohesion is the ability to hold the aggregate particles firmly in place

Ductility Test

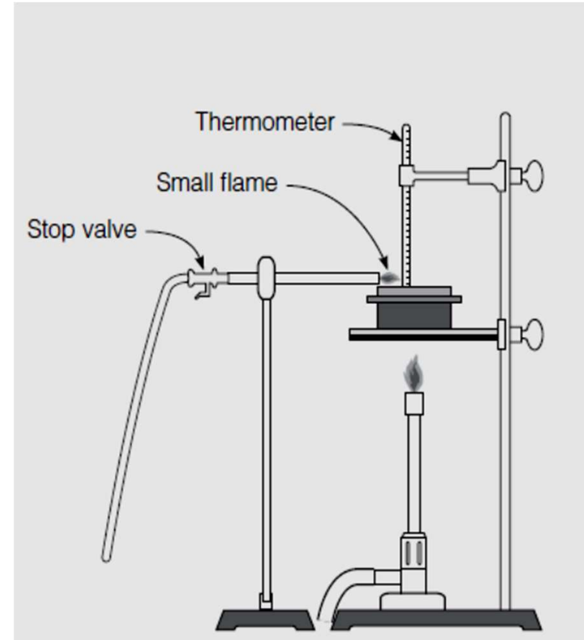
Ductility test measures the distance in centimeters that a standard briquette of asphalt cement will stretch (@ 5 cm/min at 25 °C) before breaking, as shown in the following figure. It is performed on the asphalt cement samples in accordance with ASTM D113.



Ductility Test

Flash Point Test

- The flash point test is a safety test that measures the temperature at which the asphalt flashes.
- The test is done using the Cleveland open cup method (ASTM D92) requires partially filling a standard brass cup with asphalt cement. The asphalt is then heated at a specified rate and a small flame is periodically passed over the surface of the cup, as shown in the Figure.



Cleveland open cup flash point test apparatus.

- The flash point is the temperature of the asphalt when the volatile fumes coming off the sample will sustain a flame for a short period of time. The minimum temperature at which the volatile fumes are sufficient to sustain a flame for an extended period of time is the fire point.

Classification of Asphalt Binder

Asphalt binder is produced in several grades or classes. There are several methods for classifying asphalt binders such as:

- Penetration grading
- Viscosity grading
- Performance grading

Penetration Grading

- Penetration grading's basic assumption is that the less viscous the asphalt, the deeper the needle will penetrate.
- Asphalt binders with high penetration numbers (called "soft") are used for cold climates while asphalt binders with low penetration numbers (called "hard") are used for warm climates.
- Penetration grades are listed as a range of penetration units (one penetration unit = 0.1 mm) such as 60-70.

Penetration grading system

	Grade	Penetration min.	Penetration max.
Hardest grade →	40–50	40	50
Typical grades used in Palestine →	60–70	60	70
	85–100	85	100
	120–150	120	150
Softest grade. Used for cold climates →	200–300	200	300

Viscosity Grading

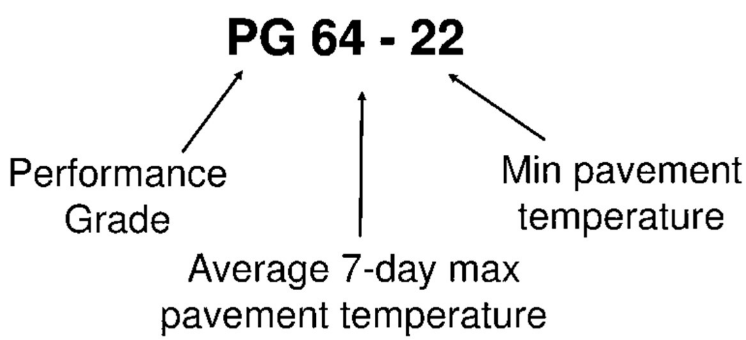
- Based on asphalt binder's viscosity. Viscosity is measured in poise . The lower the number of poises, the lower the viscosity and thus the more easily a substance flows. Thus, AC-5 (viscosity is 500 ± 100 poise at 60° C) is less viscous than AC-40 (viscosity is 4000 ± 800 poise at 60° C).
- Typical asphalt binders used in Palestine are AC-30 and AC-40.
- Viscosity grading is better than penetration grading system.

Viscosity grading system

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

Performance Grading (PG system)

- The PG system is based on the idea that an asphalt binder's properties should be related to the conditions under which it is used. This involves expected climatic conditions as well as aging considerations.
- Superpave performance grading is reported using two numbers, the first being the average seven-day maximum pavement temperature (in °C) and the second being the minimum pavement design temperature likely to be experienced (in °C).



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

Asphalt Concrete mix Design

Asphalt Concrete [Hot Mix Asphalt (HMA)]

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.

<u>Constituents of the mix</u>

- Aggregates
  - Coarse aggregates
  - Fine aggregates
  - Filler
- Binder
- Air voids

Asphalt concrete mix design

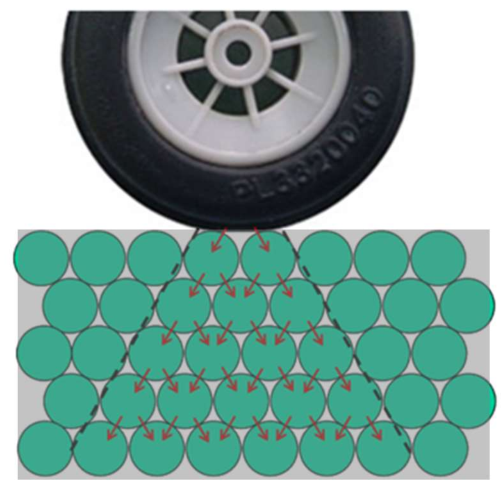
- The purpose of asphalt concrete mix design is to determine the asphalt content (%As) using the available asphalt and aggregates. The design asphalt content varies for different material types, material properties, loading levels, and environmental conditions.
- There are three principal bituminous mix design methods in general use. They are Marshall Method, Hveem Method and Superpave Method.

Aggregates for HMA

The desirable qualities of HMA are dependent to a considerable degree on the nature and grading of the aggregates used.

Coarse aggregates

Offer compressive and shear strength, contribute to the stability of a bituminous paving mixture largely due to interlocking and frictional resistance of adjacent particles. It usually consists of crushed stone, crushed gravel, or crushed slag.



Fine aggregates

Fills the voids in the coarse aggregate and stiffens the binder, it contributes to stability by interlocking & frictional resistance. consists of Crushed materials and sand.

Aggregates for HMA

Mineral filler. Materials that Pass # 200 sieve; Fills the voids, stiffens the binder. consists usually of Limestone dust, Portland cement, Slag, Dolomite dust; Required to be dry & free from lumps and shall be Hydrophobic in nature

- Selection of aggregates requires running various tests to determine properties such as: Toughness and abrasion; Durability and soundness; Cleanliness and deleterious materials; Particle shape and surface texture; Gradation and size; and Specific gravity and absorption.

IN GENERAL The Right Type of Aggregate shall be:

1. Strong and Durable
2. No Deleterious Substances
3. Cubical (Angular and Equidimensional)
4.
5. Low porosity
6. Clean, Rough, and Hydrophobic
7. Hard, and Dense-Graded

The criteria of asphalt mix design

The objective of the asphalt concrete mix design process is to provide the following properties :

1. Stability or resistance to permanent deformation under the action of traffic loads, especially at high temperatures.
2. Fatigue resistance to prevent fatigue cracking under repeated loadings.
3. Resistance to thermal cracking that might occur due to contraction at low temperatures.
4. Skid resistance, by providing enough texture at the pavement surface
5. Durability resistance to moisture-induced damage that might result in stripping of asphalt from aggregate particles.
6. Workability, to reduce the effort needed during mixing, placing and compaction

Marshall Method

- Is a very popular method because of its relative simplicity, economical equipment and proven record. The method were originally developed by Bruce Marshall of the Mississippi Highway Department around 1939 and then refined by the U.S. Army.
- The Marshall method seeks to select the asphalt binder content at a desired density that satisfies minimum stability and range of flow values.
- Typically, the Marshall mix design method consists of three basic steps:
    - Aggregate selection.
    - Asphalt binder (Cement) selection.
    - Optimum asphalt binder content determination.

Optimum asphalt binder content determination

Asphalt content is determined experimentally through the following steps.

A. Specimens preparation

B. Marshall stability and flow measurement

C. Density and voids analysis

D. Selection of the optimum asphalt binder content

Specimens preparation

- Procedure for preparing specimens basically follows the same four steps:
  - Heat and mix the aggregate and asphalt cement
  - Place the material into a heated mold
  - Apply compaction force
  - Allow the specimen to cool and extrude from the mold

- The sample. Each sample is about 100mm in diameter by approximately 70 mm thick, made of approximately 1200gm of aggregates and filler heated to a temperature of 175 – 190°C and mixed with binder heated to a temperature of 121 – 125°C.

Specimens preparation

- Several trial aggregate-asphalt binder blends (typically 5 blends with 3 samples each for a total of 15 specimens), each with a different asphalt binder content shall be prepared. Then, by evaluating each trial blend's performance, an optimum asphalt binder content can be selected.
- Typical in Palestine the reference asphalt content to start with is assumed to be 4.5-5%, the trial blends must contain a range of asphalt contents both above and below the reference asphalt content. samples are typically prepared at 0.5 percent by weight of mix increments, with at least two samples above the estimated reference binder content and two below.
- Additionally, three loose mixture specimens near optimum asphalt content to measure Rice or Maximum theoretical specific gravity.

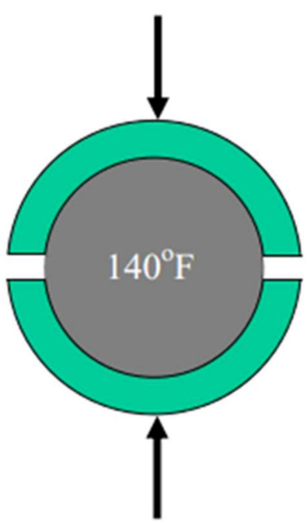
Specimens preparation

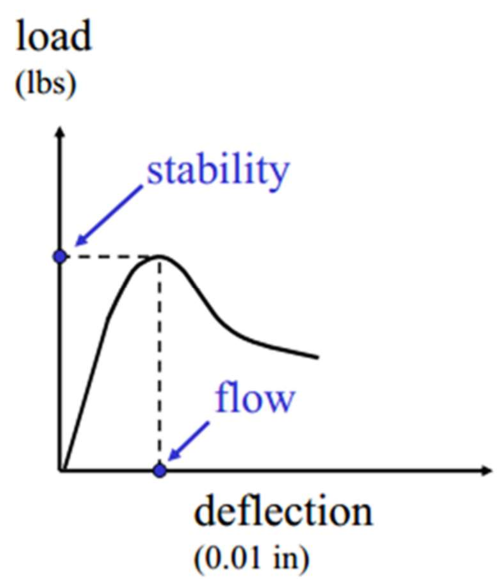
- **Specimen compaction**. The mix sample is placed in a preheated mold and compacted by a hummer with specific number of blows as shown in the table bellow on each side.

Light Traffic	Medium Traffic	Heavy Traffic
ESAL < 10^4	10^4 < ESAL< 10^6	ESAL > 10^6
15 blow	50 blow	75 blow

Marshall stability and flow measurement

- Marshall stability of a test specimen is the maximum load required to produce failure when the specimen is preheated to a prescribed temperature (60C) placed in a special test head and the load is applied at a constant strain (5 cm per minute).
- While the stability test is in progress dial gauge is used to measure the vertical deformation of the specimen. The deformation at the failure point expressed in units of 0.25 mm is called the Marshall flow value of the specimen.





Density and voids analysis

- **<u>Theoretical Maximum Specific Gravity of the mix (G_{mm}) (Rice gravity).</u>** Is the density of the mix when it is fully compacted (zero voids)

- Can be determine by testing by taking a sample of loose HMA (i.e., not compacted), weighing it in air then placing it in a vacuum bowl and cover it with water. A vacuum is applied to remove all air from the sample. After weighting the bowl containing the sample submerged the volume of the sample can be calculated and so its G_{mm}.

$$G_{mm} = \frac{W_{air}}{volume\ (mix - air\ voids)}$$

Density and voids analysis

- G_{mm} can also be calculated using the mix components weights and the corresponding apparent specific gravity such as

$$G_{mm} = \frac{W_1 + W_2 + W_3}{\frac{W_1}{G_1} + \frac{W_2}{G_2} + \frac{W_3}{G_3}}$$

- Or

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

- Solving the upper equation for G_{se} produces

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

where

G_{mm} = theoretical maximum specific gravity of the asphalt concrete
P_s = percent weight of the aggregate
P_b = percent weight of the asphalt cement
G_{se} = effective specific gravity of aggregate coated with asphalt
G_b = specific gravity of the asphalt binder

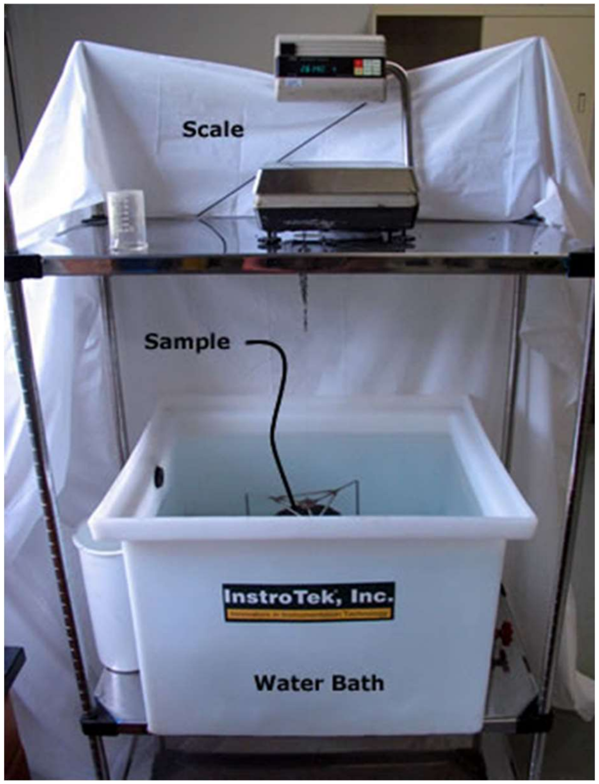
Density and voids analysis

- **<u>Bulk specific gravity of the mix G_{mb}</u>.** is the specific gravity considering air voids. It can be determined experimentally using the submerge method as

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

where

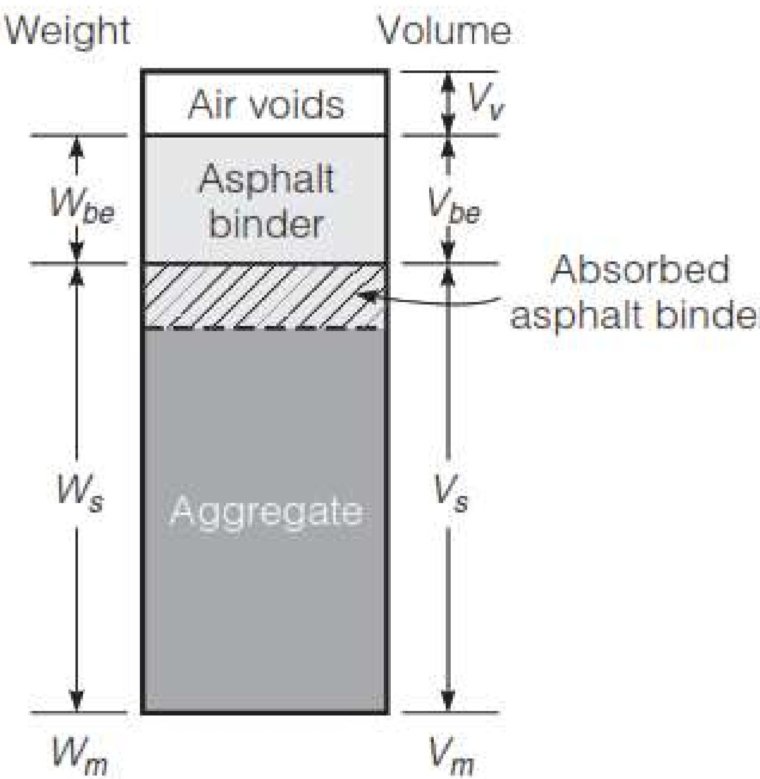
- A = dry weight of sample
- B = saturated surface dry weight
- C = submerged weight



- Note that specific gravity especially the **Theoretical maximum specific gravity** is a critical HMA characteristic because it is used to calculate percent air voids in compacted HMA.

Density and voids analysis

- **Voids.** Three important parameters commonly used are percent of air voids (voids in total mix) (VTM), voids in the mineral aggregate (VMA), and voids filled with asphalt (VFA). These are defined as



Components of compacted asphalt mixture.

$$VTM = \frac{V_V}{V_m}100$$

$$VMA = \frac{V_V + V_{be}}{V_m}100$$

$$VFA = \frac{V_{be}}{V_{be} + V_V}100$$

where

Vv = volume of air voids

Vbe = volume of effective asphalt binder

Vm = total volume of the mixture

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

Density and voids analysis

- **Volumetric relationships**. The following Equations demonstrate the volumetric relationships used for asphalt mix design analysis.

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

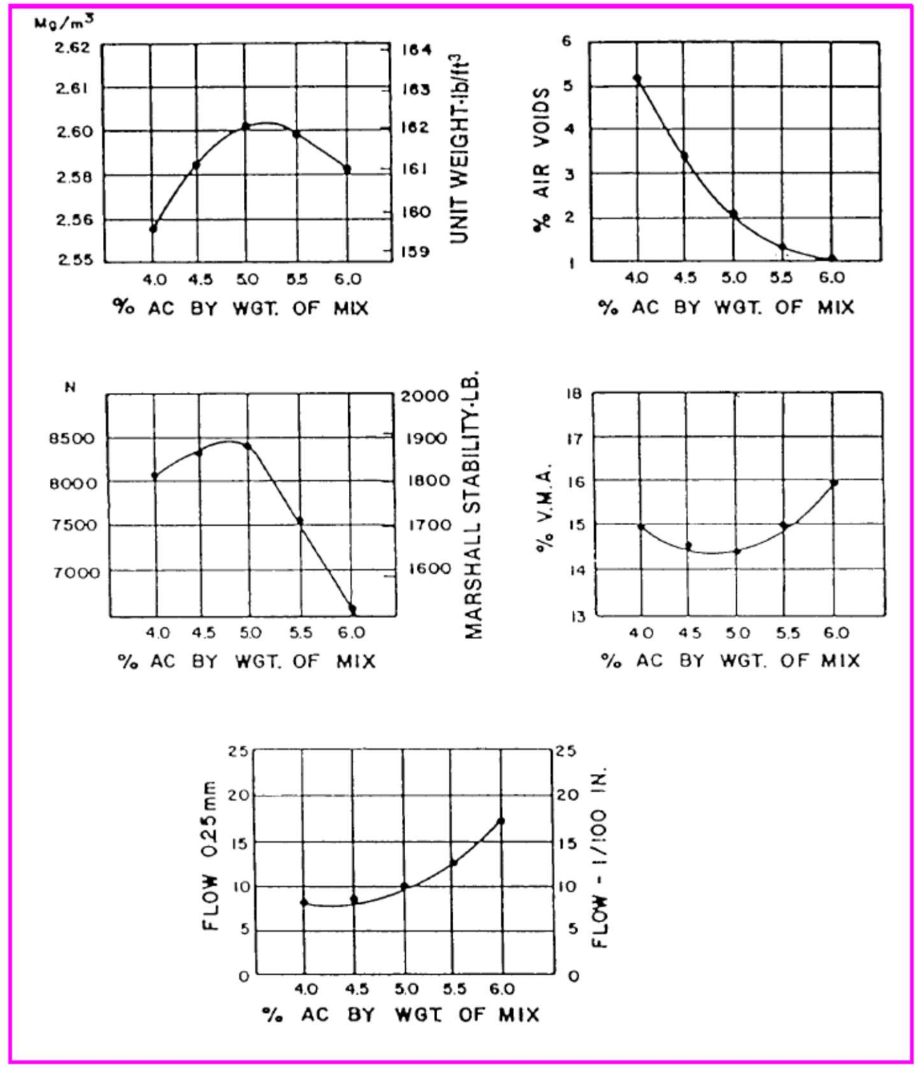
$$VMA = \left(100 - G_{mb}\frac{P_s}{G_{sb}}\right)$$

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

Selection of the optimum asphalt binder content

The average value of the previous properties are determined for each mix with different bitumen content and the following graphical plots are prepared:

1. Binder content versus Marshall stability
2. Binder content versus VMA
3. Binder content versus percentage of void (VTM) in the total mix
4. Binder content versus flow.
5. Binder content versus unit weight or bulk specific gravity (G_{mb})



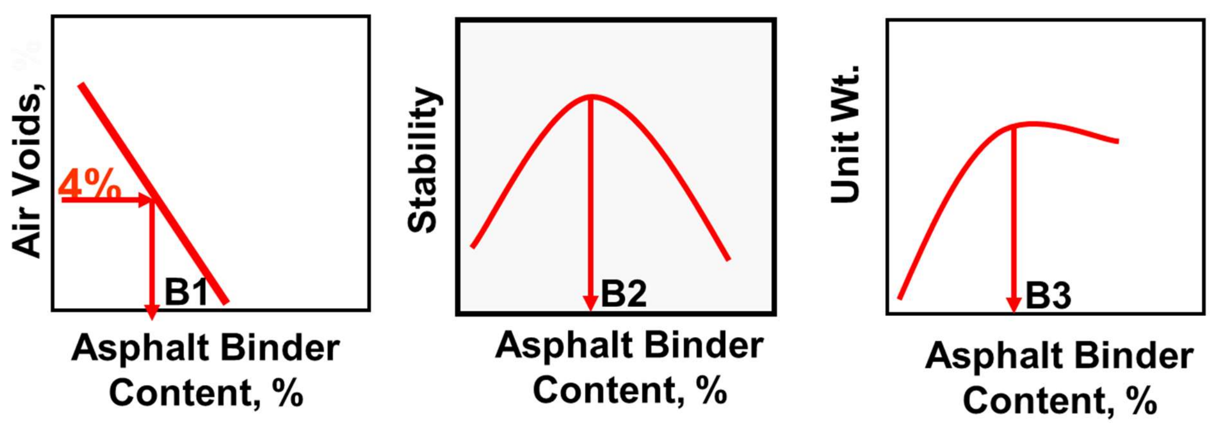
Selection of the optimum asphalt binder content

The optimum binder content for the mix design can be determined by taking average value of the following three bitumen contents found form the graphs obtained in the previous step. (The Asphalt Institute Procedure)

1. Binder content corresponding to maximum stability
2. Binder content corresponding to maximum bulk specific gravity (G_{mb})
3. Binder content corresponding to the median of designed limits of percent air voids (VTM) in the total mix (i.e. 4%)

Optimum binder content

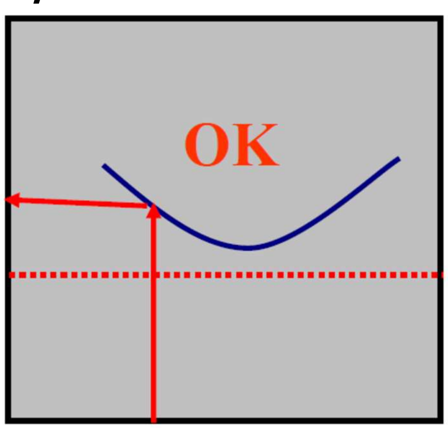
$$B0 = \frac{B1 + B2 + B3}{3}$$



Selection of the optimum asphalt binder content

- Use target optimum binder (Asphalt) content **B_o** to check if ALL Mix criteria as shown in the following slide are met. If not adjust slightly to meet all criteria if possible; else change gradation and repeat analysis.

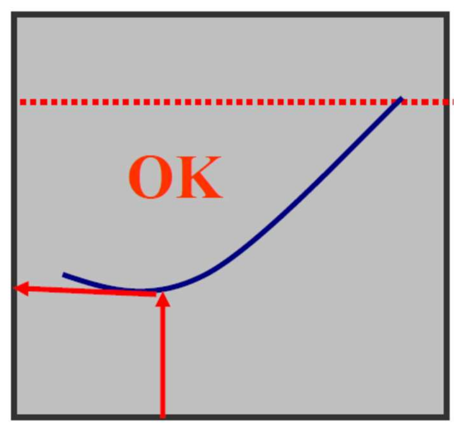
VMA, %



Minimum

Asphalt Content, %

Flow



Upper limit

Lower Limit

Asphalt Content, %

Typical Marshall Design Criteria

	Light Traffic ESAL < 10^4	**Medium Traffic 10^4 < ESAL< 10^6**	**Heavy Traffic ESAL> 10^6**
Compaction	35	50	75
Stability N (lb.)	3336 (750)	5338 (1200)	8006 (1800)
Flow, 0.25 mm (0.1 in)	8 to 18	8 to 16	8 to 14
Air Voids, %	3 to 5	3 to 5	3 to 5
Voids in Mineral Agg. (VMA)	Varies with aggregate size		

Minimum values for VMA depend upon nominal maximum aggregate size; for a 9.5-mm mix, the minimum VMA is 14% for an air void content of 3%, 15% for an air void content of 4%, and 16% for an air void content of 5%. For a 12.5-mm mix, minimum VMA values are 1% lower; for a 19-mm mix, minimum VMA values are 2% lower. As aggregate size increases, minimum VMA decreases.

Example 1

The specific gravities and weight proportions for aggregate and bitumen are as below for the preparation of Marshall mix design. The volume and weight of one Marshall specimen was found to be 475 cc and 1100 gm. Assuming absorption of bitumen in aggregate is zero, find VMT, V_b, VMA and VFA.

A_* : aggregate; B: Asphalt binder

Item	A_1	A_2	A_3	A_4	B
Wt (gm)	825	1200	325	150	100
Sp. Gr	2.63	2.51	2.46	2.43	1.05

Example 1

- G_{mm} not given from test but can be calculated from components $G_{mm} = \frac{825+1200+325+150+100}{\frac{825}{2.63}+\frac{1200}{2.51}+\frac{325}{2.46}+\frac{150}{2.43}+\frac{100}{1.05}} = 2.406$

- $G_{mb} = \frac{1100}{475} = 2.316$

- $VTM = 100\left(1 - \frac{2.316}{2.406}\right) = 3.741$

- $V_b = \frac{\frac{100}{1.05}}{475} 100 = 20.052$

- $VMA = VTM + V_b = 3.741 + 20.05 = 23.793\%$

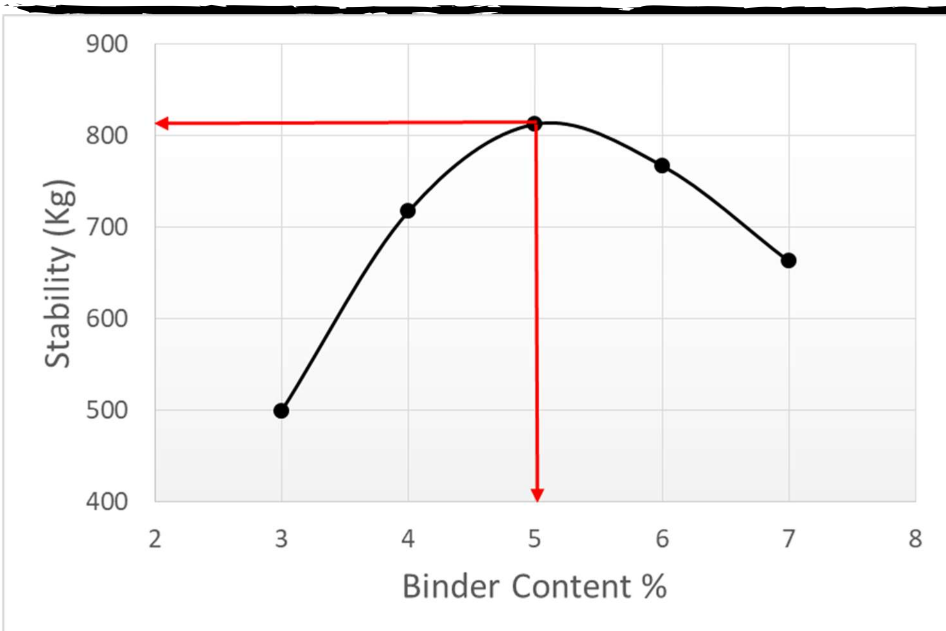
- $VFA = 100 \frac{20.052}{23.793} = 84.277\%$

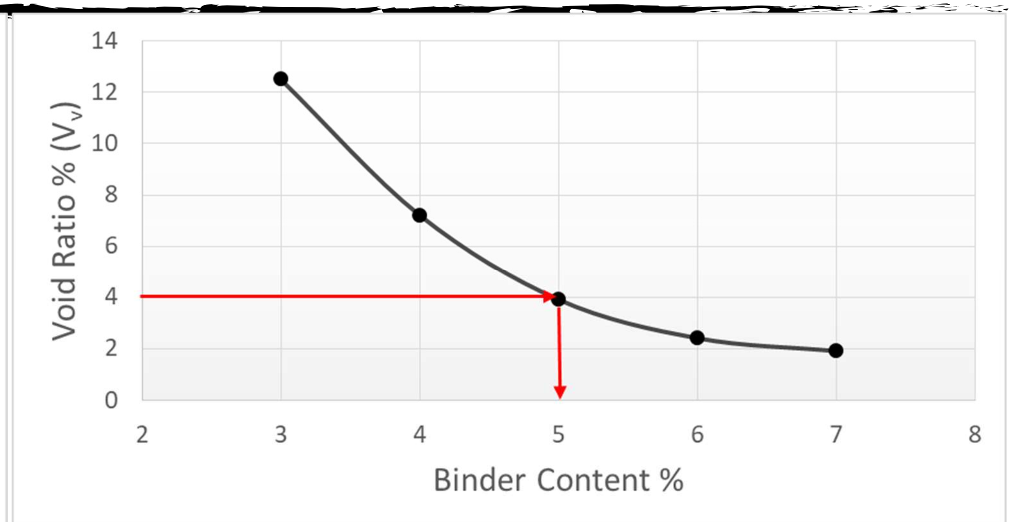
Example 2

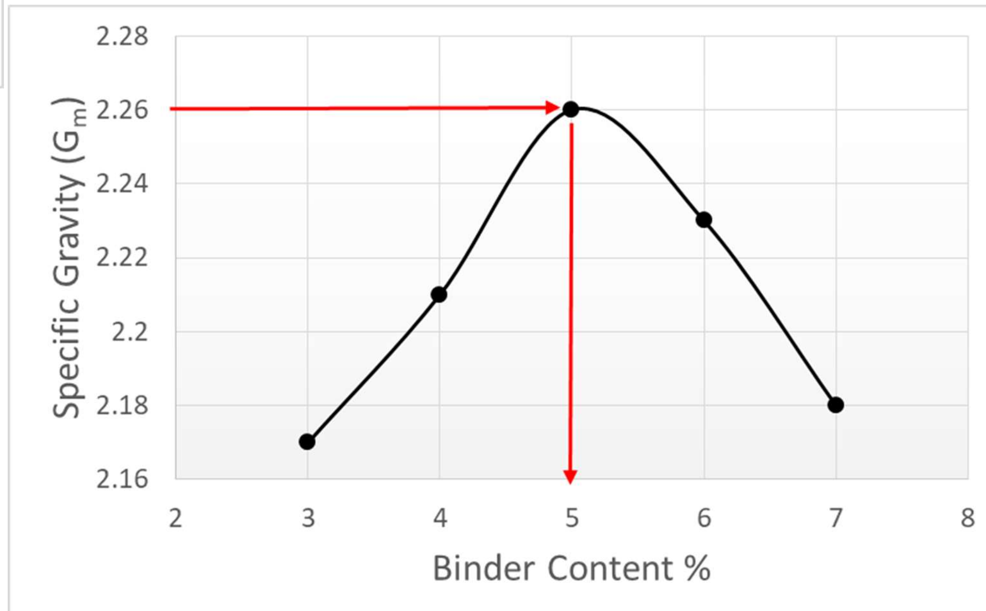
The results of Marshall test for five specimen is given below. Find the optimum binder content of the mix.

Binder content	Stability (Kg)	Flow (Units)	V_v (%)	VFB (%)	G_m
3	499.4	9	12.5	34	2.17
4	717.3	9.6	7.2	65	2.21
5	812.7	12	3.9	84	2.26
6	767.3	14.8	2.4	91	2.23
7	662.8	19.5	1.9	93	2.18

Example 2







1. Max stability = 5 percent binder content
2. Max Gm = 5 percent bitumen content.
3. 4% percent air void = 5 percent bitumen content.
4. The optimum bitumen extent is the average of above = 5 percent.