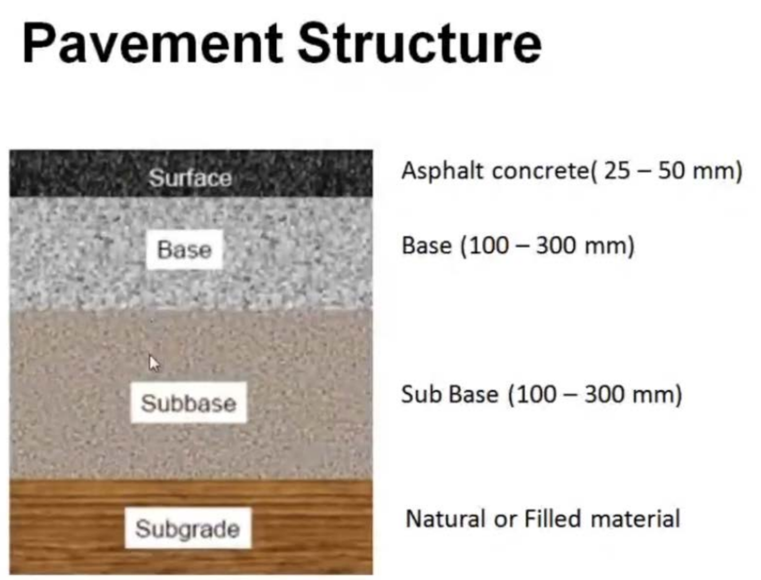
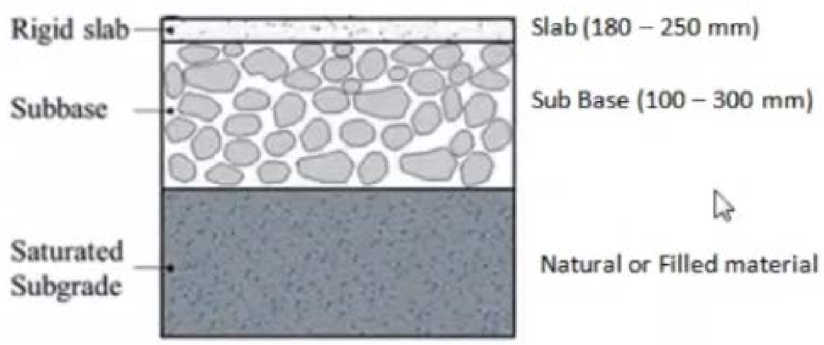
Chapter 6: Highway Materials

Pavement Structure





- **Subbase** is the layer of aggregate material laid on the **subgrade**, on which the **base course** layer is located. It may be omitted when there will be only foot traffic on the pavement, but it is necessary for surfaces used by vehicles.
- **Subbase** is often the main load-bearing layer of the pavement. Its role is to spread the load evenly over the subgrade.
- The **base course** or **basecourse** is located under the surface layer .

6.1 Introduction and Classification of Road Materials

- These are the materials which possess quality levels sufficient for their use as various pavement structural components including surfaces, bases, and/or sub bases.
- Three categories:
  - Mineral Materials
  - Binding Materials
  - Other Materials

Mineral Materials:

- These are either naturally occurring, semi-processed or fully-processed, used in pavement and structures.

- Sub-grade soil
  - Embankment Construction
- Coarse aggregates (stone chips, gravel/ crushed aggregates)
  - Pavement and other structures, filler materials
- Fine aggregate (sand/ stone dust, pit-run sand or river sand, screened materials)
  - Pavement and other structures
- Blast furnace slag, brick pebbles
  - Pavement and structures

Binding Materials

- The materials which are being used for bond different constituents of pavement
- They are:
  - cement, lime and other inorganic binding materials
    - Develop rigid and irreversible bonds
  - stone dust or cohesive soil
    - Develop semi rigid and semi flexible bond between materials
  - bitumen, tar and other organic binding materials
    - Develop flexible and reversible bond

Other Materials

- These materials are used to construct several structures such as retaining structures, drainage structures, etc.
  - Reinforcement bars
  - Timber
  - Stones, bricks, boulders, cobbles
  - Gabion wires
  - Geo-textiles, Geo-grids
  - Chemical additives
  - bio-engineering: trees, grass for slope protection
  - HDP pipes, hume pipes, precast units, etc

6.2 Sub-grade Soil

6.2.1 General

- Soil is a mineral material formed by the disintegration of rocks or decay of vegetation.
- For highway engineers, soil refers to all the unconsolidated mineral materials lying above the bed rock with which and upon which highways are constructed.
- Road construction requires soil in a massive scale.
- Soil contains air, water, organic matters and other chemicals all dispersed around the mineral particles.
- Sub grade soil is the supporting soil upon which pavement layers are laid.
- In cuts, sub-grade consists of parent soil. In filling sections, the sub-grade/ embankment consists of borrowed soil (treated or untreated) over the native ground.
- The design of pavement is very much dependent on the sub grade strength of soil. *(lower the sub-grade strength, thicker the pavement section)*

6.2.2 Characteristics of Sub-grade Soil

- Engineering properties of soil are largely dependent on the nature of parent rock.
- The properties and behaviour of soil is also generally influenced by the changes in moisture content, density and degree of compaction.
- The suitability of soil is to be judged based on their characteristics & the requirement.
- Useful characteristics for predicting behaviour are:
  - Grain size
  - Shape
  - Surface texture
  - Chemical composition
  - Moisture content
  - Dry density

Grain Size

- Coarse-grained soils or granular soil - the particle sizes greater than 0.075mm but less than 2.36mm size, such as sands and gravel
  - *Sieve analysis* to particle size distribution & gradation
- Fine-grained soils or cohesive soil - the particle size less than 0.075mm, such as silts (0.075mm to 0.002mm) and clays (<0.002mm)
  - *Hydrometer analysis* for particle size distribution & gradation analysis

Shape

- Important parameter for coarse soil
- Soil with high angularity number posses higher resistant to deformation *(interlocking)*
- Round particles are generally strong *(remaining after wearing & tearing)*
- Flat and flaky particles are usually weak *(easily breakdown)*

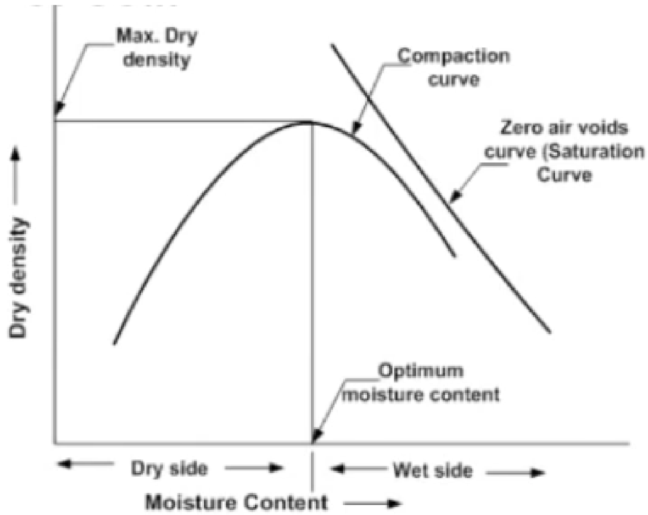
Soil Texture

- Soil texture indicates the relative content of particles of various sizes, such as sang, silt and clay in the soil.
- It determines the workability of soil and the water and air retention capacity of a soil sample.
- Fine textured soil - *silts and clays* (water retained)
- Coarse textured soil - *sands and gravel* (water easily drained out)

Soil Composition

- The basic components of soil are minerals, organic matter, water and air.
- The commonly found minerals in soil are Aluminosilicates, oxides, soil organic matter.

Moisture Content & Dry Density

- Dry density of a soil is the ratio of total dry mass of soil to the total volume of soil.
    - 

- Soil compacted to maximum dry density possesses increase in strength, decrease in voids and water movements, minimized settlement and less volume change due to variation in moisture content.

Soil Classification

Based on grain size

6.0mm	2.0	0.6	0.2	0.06	0.02	0.006	0.002	0.0006	0.0002
	Coarse	Medium	Fine	Coarse	Medium	Fine	Coarse	Medium	Fine
Gravel	Sand			Silt			Clay		

Textural Classification

- Also called Bureau of Public Roads Classification
- A triangular chart is the purpose of classifying soils in to mixes of sand, silt and clay.

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6.2.3 Desirable Properties of Sub-grade Soil

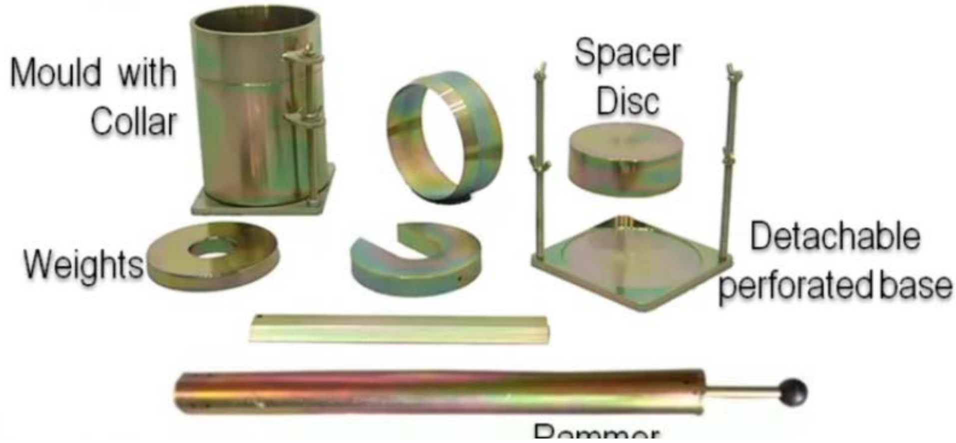
- Stability:
    - Resistance to permanent deformation under loads, resistance to weathering, ability to retain desired sub grade support.
- Incompressibility: *(Clay) [bumping of roads -up & down]*
    - Resistant to change in volume upon the application of pressure
    - Soil used in sub grade and embankment construction and foundation should be incompressible.
- Permanency in strength:
    - Permanency in strength is the property of soil, which allows sub grade to support pavement with the same degree of strength under varied condition of moisture and weather. *(rainy vs. winter seasons)*
- Minimum change in volume and stability under adverse conditions of weather and ground water:
    - It is required to ensure minimum variation in expansion.
- Good drainage:
    - Good drainage characteristics are essential to avoid excessive moisture and frost action.
- Ease in compaction:
    - It is the property of soil, which ensures higher dry density with minimum compaction effort for increasing strength characteristics and permanency in strength.

Test on Soil - CBR Test

- California Bearing Ratio (CBR) test is developed by the California Division of Highway, USA.
- It is a method to measure the **relative strength** of the material. (with relative to that of *cross aggregate* [standard material])
- CBR is defined as the ratio of force per unit area required to penetrate a soil mass with standard circular piston at the rate of 1.25mm/min to that required for the corresponding penetration of a standard material *(crushed aggregate)*.
    - $CBR = \frac{TestLoad}{StandardLoad} \times 100\%$

Laboratory CBR Test

Apparatus

- Cylindrical mould of 150mm diameter and 175mm height provided with a collar of about 50mm length and detachable perforated base 10mm thick.
- Compaction rammer, surcharge weight-annular weights each of 2.5kg and 147mm diameter with central hole of 53mm diameter
- Loading machine with the cylindrical plunger and dial gauges to measure penetration and load
- IS sieve 19.6mm OR 20mm, coarse filter paper, balance, etc.
- 

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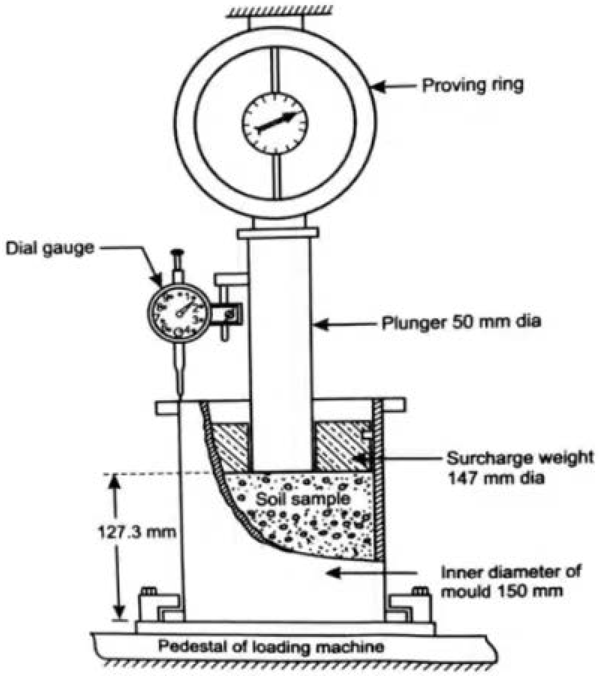
Preparation of specimen

- Undisturbed sample
  - obtained by pushing the mould with steel cutting edge of 150mm into the ground till the mould is sufficiently full and trim the top and bottom
- Remolded specimen
  - soil sample shall pass a 19mm IS Sieve and retained on 4.75mm IS Sieve and mixed with either field moisture OR OMC and compacted *statically* or *dynamically*
  - *statically*: gradually applied load till the required height of soil is achieved
  - *dynamically*: PROCTER TEST; soil compacted in different layers

Compaction Method	Nos. of Blow	Rammer weight (kg)	Drop Height (mm)	Nos. of layer of soil
Light	56	2.6	310	3
Heavy	56	4.89	450	5

Test Setup

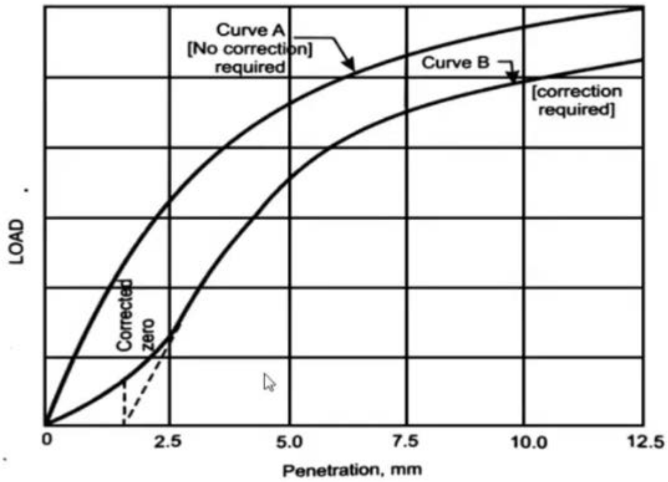
- 

Test Procedure

- The specimen is may be soaked or unsoaked.
- Load is applied by the loading frame through a cylinder plunger of 50mm diameter and penetration is measured.
- Rate of penetration is maintained at 1.25mm/min.
- Record the load readings at penetrations of 0.5, 1.0, 1.5, 2.0, 3.0, 4.0, 5.0, 7.5, 10 and 12.5mm.

Calculation

- Plot a load penetration curve (Figure)



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- CBR Value is:
    - $CBR = 100\frac{x}{y}$
        - x = material resistance or the unit load on the piston (pressure) for 2.5mm or 5mm of penetration
        - y = standard unit load (pressure) for well graded crushed stone
            - for 2.5 mm of penetration = 1370kg
            - for 5.0mm of penetration = 2055kg

CBR values of some materials

Description of Material	CBR
Well-graded crushed aggregates	100
Well-graded natural gravels	80
Silty gravel or silty, sandy gravel	40-80
Well-graded sands, gravelly sands	20-50
Clayey gravel or sandy, clayey gravel	20-40
Silty or clayey sands	10-40
Fine clean sands	10-20
Lean (low-plasticity) clays, sandy clays	5-15
Silts, sandy silts	5-15
Organic silts, lean organic clays	4-8
High plasticity clays	3-5

6.3 Road Aggregate

6.3.1 Definition and Classification of Road Aggregates

- It is a material such as crushed stone, slag, gravel, sand or other materials of mineral origin, used in combination with a binding material to form bituminous mixes and cement concrete, macadam, mortar, mastic, plaster etc. or alone as in filter beds *(filling side of retaining walls; for drainage)* and various sub-surface drainage system.
- macadam: *[semi rigid; stone dust in coarse aggregates; application with water and compacted;* ***water-bound macadam****]*
- mastic: *[alphalt/bitumen (in liquid form) + aggregate; also known as* ***asphalt concrete****]*

Classification

Based on Source

1. Natural Aggregate:
    - Stone aggregates collected from nature
    - These are processed mechanically involving crushing, screening, washing, sieving etc. but do not undergo chemical processing.
    - Examples: stones, boulder, sand, gravel, crushed stone chips, river shingles
2. Artificial Aggregate:
    - They are obtained as the by product of steel manufacturing plants and brick kilns.
    - Example: blast furnace slag and broken brick ballast

Based on Size

- Coarse aggregate
    - Either uncrushed natural or crushed stone or combination of natural gravel and crushed stones, most os which retained on 4.75mm IS sieve.
- Fine aggregate
    - Either natural sand or crushed stone and most of which passes 4.75mm IS sieve and retained on 75 μm

Note:

- for surface dressing & otta seal: max size of aggregate used = 14-20mm
- for base & sub-base layers: max size of aggregate used = 50-63mm

Based on Geology of Origin

1. Igneous rocks
    - formed by cooling of the molten magma
    - e.g.: basalts, granites, etc.
2. Sedimentary rocks
    - formed at the surface of the earth by the process of weathering, transportation, and deposition by wind, water, snow, or biological processes

    - e.g.: sandstone, siltstone, shale limestone, dolomite, etc.

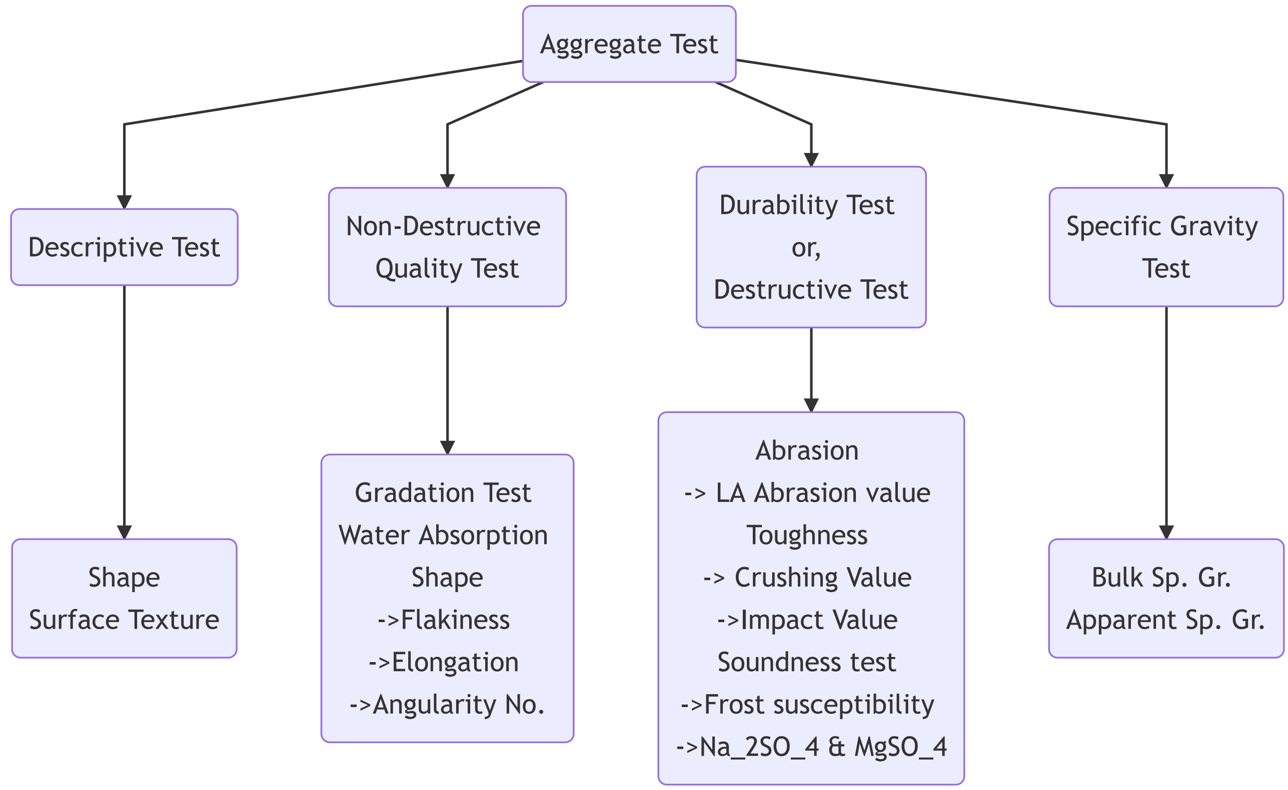
3. Metamorphic rocks
    - the rocks which have undergone significant changes after their formation due to pressure and temperature
    - e.g.: slate, phyllite, schist, gneiss, quartzite, marble, etc.

- **In Nepal**, igneous rocks are not found much, sedimentary and metamorphic rocks are found.

6.3.2 Desirable Properties of Road Aggregates

1. Strength
    - the resistance of aggregates to crushing under heavy traffic load
    - Aggregate Crushing Value (ACV) Test
2. Hardness
    - the resistance of aggregate to abrasion (wear and tear) under the wheel of the traffic
    - Los Angeles Abrasion (LAA) Test, Deval Abrasion Test, Polished Stone Test, etc.
3. Toughness
    - the resistance of aggregate to impact due to moving wheel loads.
    - e.g.: impact due to bump/jump of vehicles
    - Aggregate Impact Value (AIV) Test
4. Durability
    - the resistance to weathering action or ability to remain strong over long period
    - Soundness Test
5. Proper Shape
    - it determines interlocking and crushing properties
    - the use of proper shape of aggregate ensures the strength of the pavement
    - flakiness index, elongation index, angularity number, etc
6. Proper Gradation
    - An aggregate contains all standard fractions of aggregate in required proportion
    - sieve analysis
7. Good adhesion
    - the aggregates should have less affinity with water than bituminous materials
    - the hydrophobic aggregate (limestone) is preferred over hydrophilic aggregate (quartz, sandstone) in bituminous mix.
8. Cementation
    - it is the binding action of the surface layer of aggregate and binder (cement, sand dust)

6.3.3 Tests on Road Aggregates and their Significance



Descriptive Tests

- These tests are the visual examination of an aggregate.
- These tests describe aggregate in terms of both the shape and the surface texture of the particles.
- Subjective descriptions of characteristics of these mineral aggregate

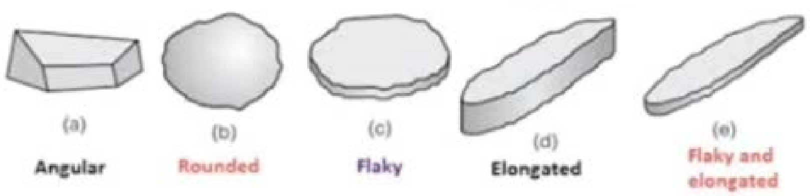
Shape

1. Angular
    - they possess well defined edges
    - good interlocking and strength
2. Rounded
    - without well defined plane
    - minimum voids
    - good workability but poor interlocking behaviour
3. Flaky
    - it has small thickness (<60%) compared to width or length; less strength and durability
4. Elongated
    - has large dimension (1.8 times) compared to other two dimensions; less strength and durability
5. Flaky and elongated
    - length is larger than width and width is larger than thickness
    - BOTH: smallest dimension < 60% & largest 1.8 times
6. Irregular

  - does not have definite shape and well defined plane
  - less workability
  - higher interlocking behaviour than rounded aggregate and lesser than angular aggregate

Note:

- rounded aggregate are suitable for cement-concrete due to higher workability
- in flexible pavement (bituminous concrete), the most important property: interlocking property
- since rounded aggregate deforms when loaded, not suitable here



Surface Texture

Surface texture is a measure of smoothness or roughness of the aggregate

- Glassy: an aggregate looks like a block of glass
- Granular: consists of aggregation of mineral grains of approximately equal size
- Rough: they provide more surface area to bond with binding material resulting higher bond strength
- Smooth: free from irregularities; not suitable for bonding
- Crystalline: they have crystallized minerals
- Honeycombed: the aggregate with the hollow spaces and cavities
- Porous: consists of small pores, good adhesion, need more binder

Non-Destructive Quality Test

- Evaluate the properties of aggregate without significant damage to teh original aggregate
- Used to determine its suitability for a specific use
- The results are compared with specification to determine its suitability
  - Standard and Specification of Road & Bridge
- They are:
  1. Gradation Test
  2. Water Absorption Test
  3. Shape Test

Gradation Test

- Also called sieve analysis, screen analysis, or mechanical analysis
- Used to determine the aggregate particle size distribution
- A sample of dry aggregate of known weight is separated through a series of sieves with progressively smaller openings.
- The retained sample is expressed EITHER as the total percentage passing or retained on each sieve OR as the percentages retained between successive sieves.
- Apparatus: IS Sieves of sizes - 80mm, 63mm, 50mm, 40mm, 31.5mm, 25mm, 20mm, 16mm, 12.5mm, 10mm, 6.3mm, 4.75mm, 3.35mm, 2.36mm, 1.18mm, 600μm, 300μm, 150μm, and 75μm.

- Balance ($\pm$ 0.1%)

Procedure

1. Take sample dried at 110 $\pm$ 5oC and weighed.
2. Select the sieves sizes suitable to the specification.
3. Sieve by using a set of IS Sieves for 15 minutes.
4. Weigh the material retained on each sieve.

The percentage retained is calculated as:

$$\%Retained = \frac{W_{sieve}}{W_{total}} \times 100\%$$

- W_{sieve} = weight retained on given sieve size
- W_{sieve} = total weight of sample

Significance

- a variation in the aggregate grading affect the amount of binder required
    - more fine content -> more surface area -> more binder usage
- proper aggregate grading contributes to properties such as:
    - strength: well graded aggregate preferred
    - stability: well graded aggregate preferred
    - workability: more fine content -> less workability
    - permeability: more coarse content -> more permeability
    - skid resistance: more coarse content -> more skid resistance

Note: The values obtained are compared with standard specification

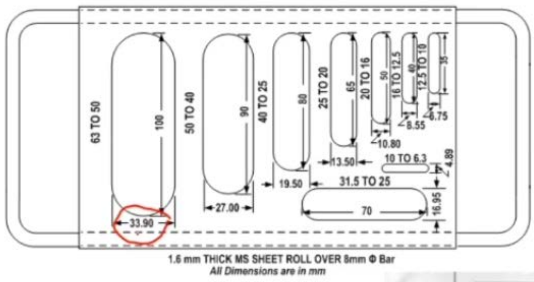
Shape Test

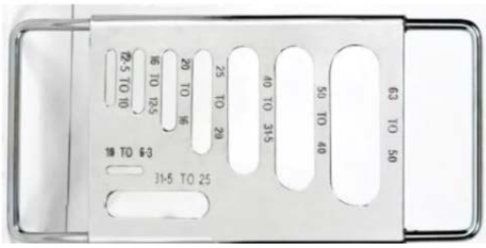
- Shape test is determined by finding percentage of flaky and elongated particles
- Three measures of particle shape are:
    1. Flakiness Index (FI)
    2. Elongation Index (EI)
    3. Angularity Number (AN)

Flakiness Index (FI)

- The FI of an aggregate is the percentage by weight of particles, whose least thickness is less than three-fifths (60%) of the mean dimension.
- The mean dimension is the average of two adjacent sieve apertures (sizes) between which the particle is retained.
- Presence of flaky particles results the weak pavement due to the possibilities of breaking down under heavy loads.

Thickness Gauge for Flakiness Measurement



- 

Dimension of Thickness (for FI) and Length Gauges (for EI)

Size of Aggregate		Thickness Gauge	Length Gauge
Passing through IS sieve, mm	Retained on IS Sieve, mm	(0.6 times the mean sieve), mm	(1.8 times the mean sieve), mm
63.0	50	33.90	-
50.0	40.0	27.00	81.0
40.0	31.5	19.50	58.5
31.5	25.0	16.95	-
25.0	20.0	13.50	40.5
20.0	16.0	10.80	32.4
16.0	12.5	8.55	25.6
12.5	10.0	6.75	20.2
10.0	6.3	4.89	14.7

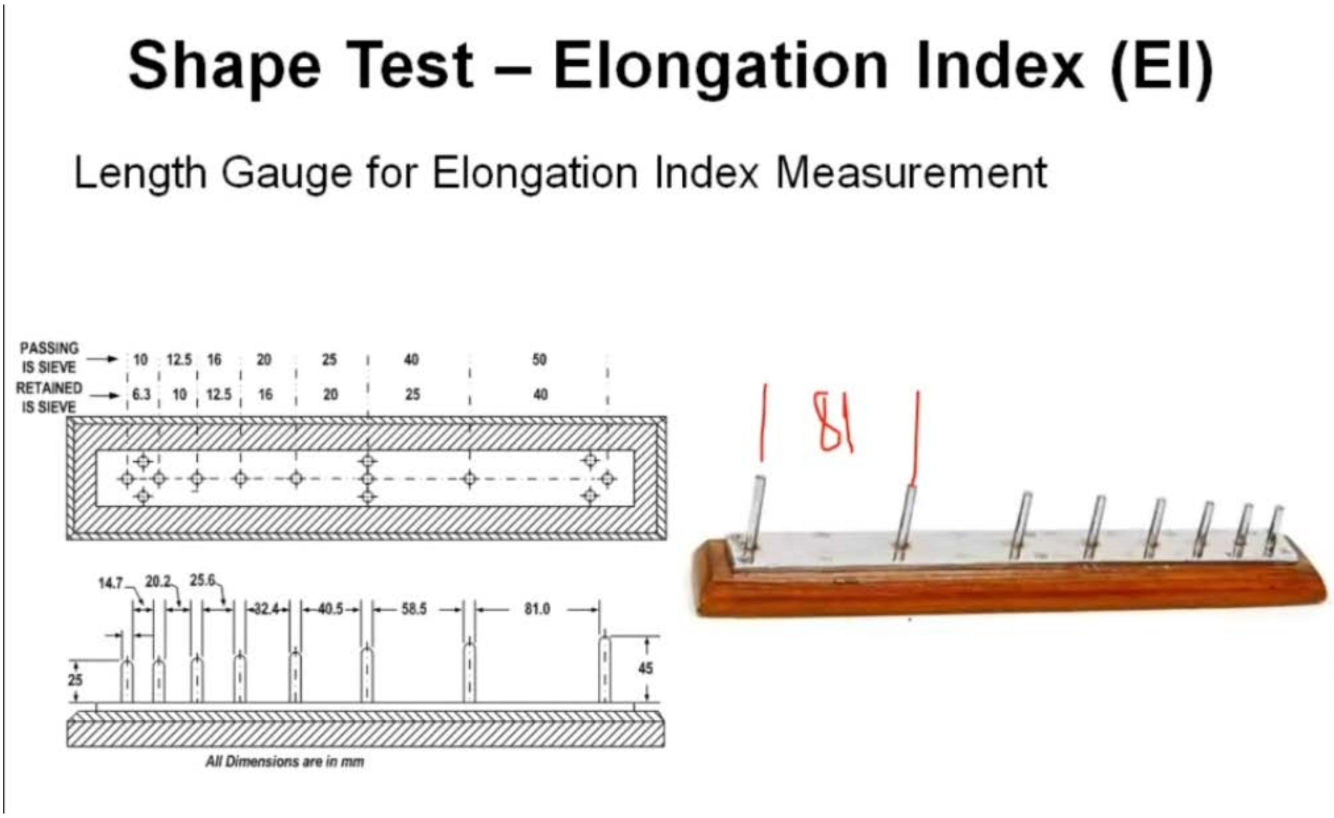
Test Procedure

- Sieve the sample through the IS sieves.
- Take a minimum of 200 pieces of retained on each sieve size.
- Pass each aggregate from slots whose widths are 0.6 times the individual mean dimensions.
- Weigh material passing the gauge $(X_1, X_2, ...)$.
    - Flakiness index $= \dfrac{X_1 + X_2 + ...}{W_1 + W_2 + ...} \times 100$
- Recommended values are:
    - Base/ Sub-base: < 35%
    - Bituminous carpet: < 30%
    - Bituminous concrete, penetration macadam, surface dressing etc.: <25%

- Bituminous macadam, WBM: <15%

- Penetration macadam: Firstly aggregate spread, then liquid bitumen sprayed, and small aggregate over it, then rolled
- Surface macadam: *opposite of penetration macadam*; firstly bitumen, then aggregate
- Bituminous macadam: bitumen and large size aggregate mixed, spread, rolled
- Bituminous carpet & bitumen concrete: mixed before laying, but different size of aggregate

Elongation Index (EI)

- The Elongation index of an aggregate is the percentage by weight of particles, whose greatest length is greater than 1.8 times their mean dimension.
- The mean dimension is the average of two adjacent sieve apertures between which the particle is retained.
- Presence of longer particles results the weak pavement due to the possibilities of breaking down under heavy loads.
- 

Test Procedure

- Same as flakiness index
- Elongation index $= \dfrac{Y_1 + Y_2 + ...}{W_1 + W_2 + ...} \times 100$
- Recommended values:
  - Base/ Sub-base: <30%
  - Surface course: <15%

Angularity Number (AN)

- Angularity number is the amount, to the nearest whole number, by which the percentage of voids exceeds 33 when an aggregate is compacted in a specified manner in a standardized metal cylinder.
- AN measures the voids in excess of round aggregates and value ranges from 0 to 11 sizes.

- Higher AN value, more angular and less workable. Bituminous pavement higher AN value is preferred as high stability due to interlocking of aggregates; preferred value: 7-10

Test Procedure

- 
  15.64 dia x 15.64 height
- Sample is placed in the cylinder and tamped 100 times by the rod.
- Second and third layers are placed and tamped.
- The excess aggregate is struck-off.
- Take weight of cylinder and aggregate, and find weight of aggregate (W), sp. Gr. of aggregate (G_s).
- Take weight of water to fill the cylinder (W_w).

Then,
AN
= Void % - 33%
= (1-solid fraction) * 100% - 33%
$= \left(1 - \frac{1}{W_w} \times \frac{W_w}{G_s}\right) 100\% - 33\%$
$= 67 - \frac{100W}{W_w G_s}$

Specific Gravity Test

- Specific gravity is defined as the ratio of weight of aggregate to the weight of equal volume of water.
- The specific gravity of an aggregate is considered to be a measure of strength or quality of the material.
- Aggregates having low specific gravity are generally weaker than those with higher specific gravity values.
- The specific gravity of road aggregates varies from about **2.5 to 3.0** with an average of about **2.68**.
- SSD: Saturated Surface Dried

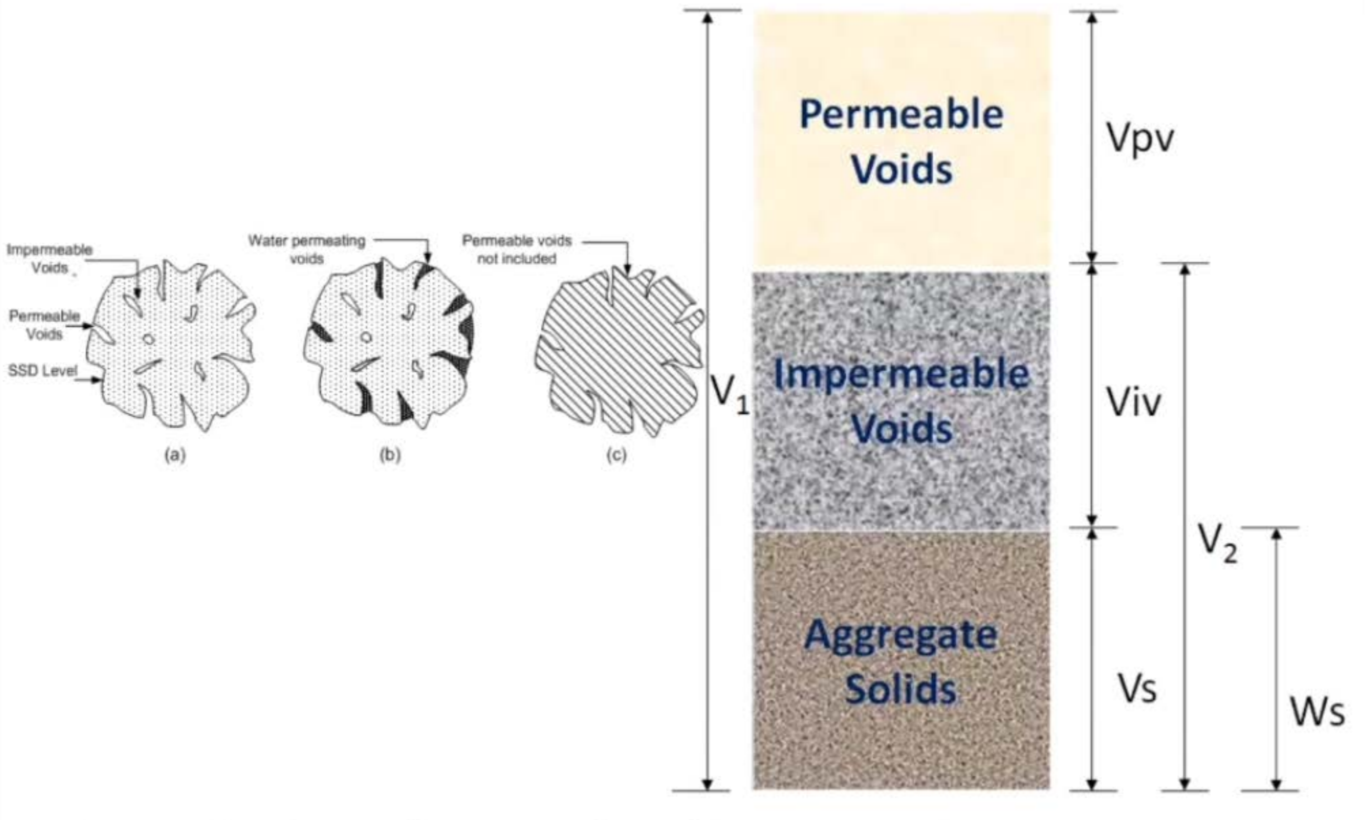


Diagram showing to illustrate Bulk and Apparent Sp. Gr

Bulk Specific Gravity

- Bulk specific gravity (G_{sb}) is the ratio of the oven dry weight of aggregate in air to the weight of an equal volume of water.
- This unit volume of aggregates is composed of the solid particle, permeable voids, and impermeable voids.
- $G_{sb} = \dfrac{\text{Weight of dry aggregate}}{(\text{Vol. of aggregate \& surface voids})\gamma_w} = \dfrac{W_s}{(V_s + V_{iv} + V_{pv})\gamma_w}$
- $G_{sb} = \dfrac{\text{Weight of dry aggregate}}{\text{Weight in SSD condition - Weight in Water}} = \dfrac{W_s}{(W_s + Wpv) - Ww}$

Apparent Specific Gravity

- It is the ratio of oven dry weight of the impermeable portion of aggregate in air to the weight of an equal volume of water.
- This unit volume of aggregates is composed of the solid particle, and impermeable voids.
- $G_{sa} = \dfrac{\text{Weight of dry aggregate}}{\text{Weight of dry aggregate - Weight in Water}} = \dfrac{W_s}{W_s - W_w}$

Water Absorption Test

- The water absorption is obtained by expressing the difference between the weights of the saturated and the oven dried sample in air as a percentage of later.
- Absorption, % = $\dfrac{\text{SSD Weight of Aggregate - Oven dried Weight of Aggregate}}{\text{Oven dried Weight of Aggregate}} = (\dfrac{W_s + W_{pv}) - W_s}{W_s} \times 100$

Significance

- Gives an idea on porosity of the aggregates.
- Aggregate with high water absorption are unsuitable.
- Additional binder material is required to satisfy the adsorption in porous aggregate. Also, porous aggregates usually show better adhesion (??)
- Water absorption values shall be less than 2% for material used in road surfacing, and up to 4% for road bases.

Test Procedure for Sp. Gravity & Water Absorption Tests

- Apparatus: A balance, an oven, a wire basket, a container for filling water an suspending the basket
- About 2 kg of aggregate sample is washed thoroughly to remove fines, drained and placed in wire basket.
- Immerse the basket and aggregate in water for a period of 24 hour.
- The basket and the sample are weighed while suspended in water (W_1).
- Measure the empty weight of basket suspended in water (W_2).
- The aggregates are dried with dry absorbent cloth. The surface dried aggregates are also weighed (W_3).
- The aggregates are dried in oven at 110^{o}C for 24 $\pm$ 0.5hrs and then weighed (W_4).

  Then,

  - $G_{sb} = \dfrac{W_4}{W_3 - (W_1 - W_2)}$
  - $G_{sa} = \dfrac{W_4}{W_4 - (W_1 - W_2)}$
  - Water Absorption $= \dfrac{W_3 - W_4}{W_4} \times 100$

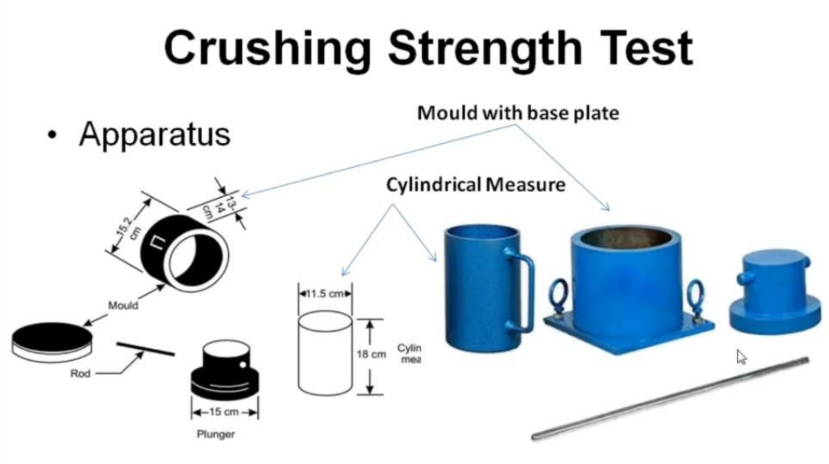
Destructive Test

- Destructive tests on aggregate result significant damage to original aggregates.
- Mechanical properties of aggregates such as strength, hardness, durability, toughness, soundness are only assessed by durability test.
- Abrasion test, impact test, crushing strength test and soundness tests are commonly used durability tests.

Crushing Strength Test

- The resistance of the aggregate to the gradually applied compressive load is known as crushing strength.
- The crushing strength of aggregate is examined through crushing value test.
- To achieve a highly durable pavement, aggregates with low crushing value should be preferred.

Test Procedure:

- 

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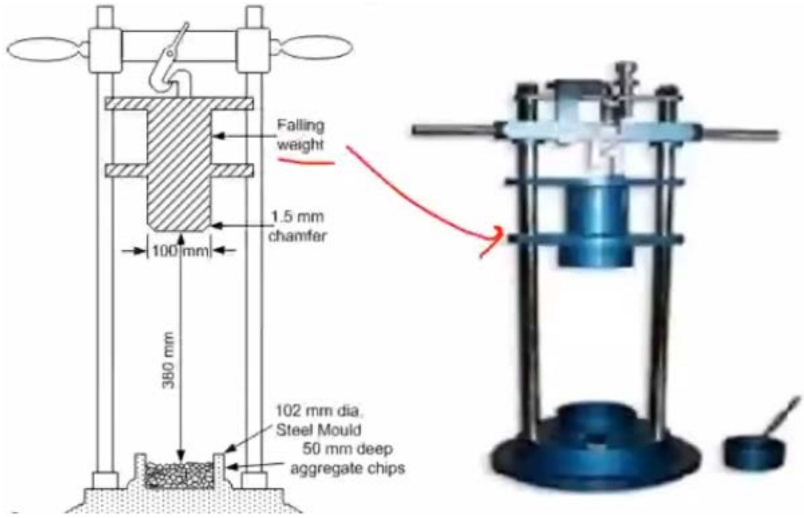
- Select oven dried (100 - 100^{o}C)material passing 12.5 and retained on 10 mm IS sieves.
- The aggregate is placed in measuring cylinder in 3 equal layers and find out weight of aggregate.
- Again, mould is placed on base plate and is filled with measured aggregate in 3 layers with tamping.
- Mould is placed on compression machine and load applied gradually at a uniform rate of 4 tonnes per minute for a period of ten minutes.
- The load is then released and the amount of material passing the 2.36 mm sieve is determined.
- Th amount of material passing the 2.36 mm IS sieve is expressed as the percentage of the total weight of the sample, which is termed as the **aggregate crushing value**.
  - Total weight of the oven dry aggregate sample $= W_1$
  - Weight of material passing 2.36 mm after test $= W_2$
  - Aggregate Crushing Value $= \dfrac{W_2}{W_1} \times 100\%$
- Lower crushing value indicates a strong aggregate and would give longer service life.
- ACV < 45% for base course and <30% for surface

Toughness Test - Aggregate Impact Value

- Aggregate shall be tough against the impact load due to traffic.
- The aggregate impact value gives a **relative** measure of the resistance of an aggregate to sudden shock or impact.

Test Procedure

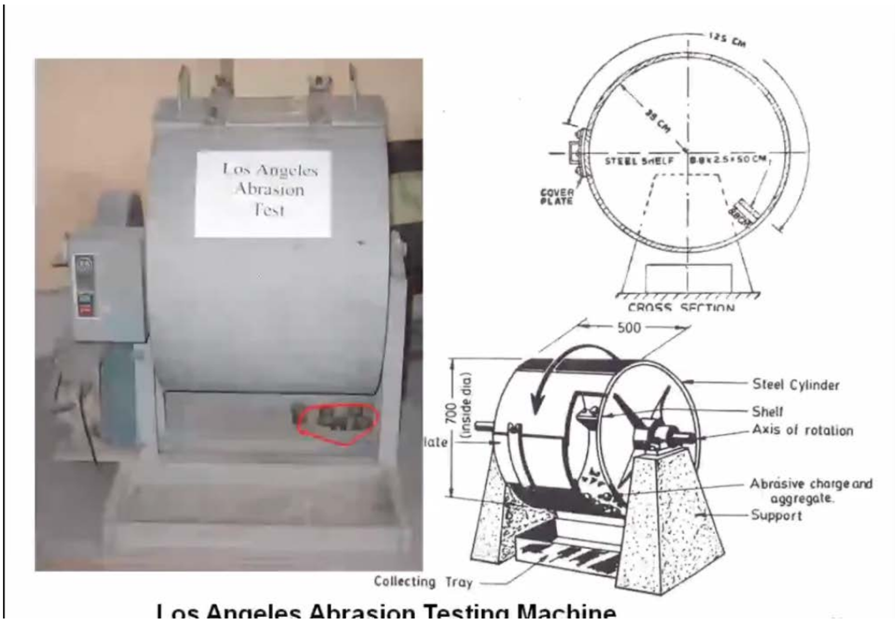
- 

- Select oven dried aggregates passing through 12.5mm sieve and retained on 10.0mm sieve.
- Fill the measuring cylinder by aggregate in 3 layers with 25 gentle blows in each layer.
- Determine the net weight of the aggregates (W_1).
- Transfer the whole sample to test-cup and give 25 gentle strokes.
- Raise the hammer and allow it to fall freely on the aggregate sample. Repeat for 15 such blows.
- Weigh the crushed aggregate fraction passing through 2.36mm sieve (W_2).
- AIV $= \frac{W_2}{W_1} \times 100$
- AIV between 20-30% are satisfactory for road (surface). Therefore, AIV <30% for surface course and <45% for base course.

Abrasion Test (Los Angeles Abrasion Value)

- The road aggregate are subjected to wear and tear due to traffic wheels.
- The aggregate used in road should be hard enough to resist abrasive (wear & tear) action of the wheel movement.
- Common test is Los Angeles Abrasion Test.
- In LAA test, the % wear due to the rubbing and pounding action between the aggregates and abrasive charge (steel ball) is measured as Los Angeles Abrasion Value.

Test Procedure

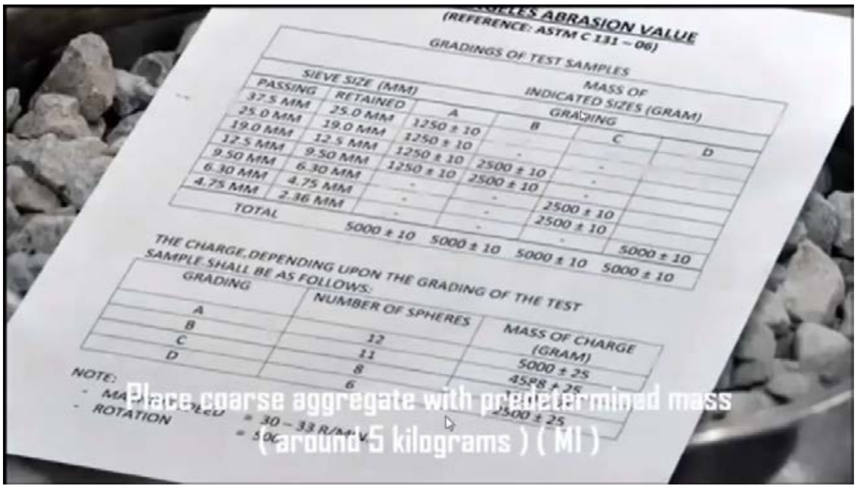
- 

Los Angeles Abrasion Testing Machine

- **Standard Grading Group for LAA Test**

Sieve Size (mm)		Weight of Test Sample (gm)						
Passing Through	Retained on	A	B	C	D	E	F	G
80	63	--	–	–	–	2500*	--	--
63	50	--	–	–	–	2500*	--	--
50	40	--	–	–	–	5000*	5000*	--
40	25	1250	–	–	–	--	5000*	5000*
25	20	1250	–	–	–	--	--	5000*
20	12.5	1250	2500	–	–	--	--	--
12.5	10	1250	2500	–	–	--	--	--
10	6.3	--	–	2500	–	--	--	--
6.3	4.75	--	–	2500	–	--	--	--
4.75	2.36	--	–	–	5000	--	--	--
Nos of Balls		12	11	8	6	12	12	12
Weight (gm)		5000 (±25)	4584 (±25)	3330 (±20)	2500 (±15)	5000 (±25)	5000 (±25)	5000 (±25)

- Take 5 (fine grading) or 10 kg (coarse grading) and place in a standard Los Angeles Abrasion Test cylinder along with 4.8 cm diameter steel spheres.
- The numbers of spheres is decided based on grading of aggregates (Table above).
- The cylindrical drum is rotated at a speed of 30-33 revolutions per minute for 500 (fine) - 1000 (coarse) revolutions.
- Upon completion, sample is removed and screened through 1.7mm sieve.
- The percentage loss in weight of the aggregate is called the abrasion value of the aggregate.

- 

- Original weight of the oven dry aggregate sample = W_1
- Weight of the aggregate retained on 1.7mm IS sieve after test = W_2
    - Weight passing is not accurate due to losses, could stick to steel ball.
- Los Angeles Abrasion Value (LAA) = $\dfrac{W_1 - W_2}{W_1} \times 100$
- Higher the LAA value means soft aggregates.
- LAA value <15% for cement concrete surface, <30% for bituminous surface, and <50% for base and sub base

Soundness Test

- Soundness test is carried out to find out the resistance of aggregates to weathering action and to judge the durability of the aggregate.
- Apparatus:
    - Balance, oven, wire mesh basket, container
    - Sieves 80mm, 63mm, 40mm, 31.5mm, 25mm, 20mm, 16mm, 10mm, 8.0mm, 4.75mm, 4.0mm, 2.36mm, 1.18mm, 600 micron, 300 micron, 150 micron
- Na_2SO_4 or $MgSO_4$ solution
- Select the sample such that it will yield not less than the following amount of the different sizes.

Retained on	4.75mm	10mm	20mm	40mm	80mm
Yield	300g	1000g	1500g	3000g	3000g

- Take individual samples in a wire mesh basket and immerse it in the solution of sodium sulphate or magnesium sulphate for not less than 16-18 hours.
- Remove the samples from solution and allow it to drain for 15 minutes and dry it in oven at 105-110$_o$C.
- After cooling again immerse it in the solution again and repeat the process alternate immersion and drying for at least 5 cycles.
- Sieve the aggregates over the same sieve on which sample was retained.

Significance

- Sound aggregates are less likely to disintegrate due to weathering action, and therefore durable.
- The average loss in weight after 10 such cycles should not exceed 12% for test with Sodium sulphate or 18% for test with Magnesium sulphate.

Bitumen Adhesion Test - Stripping Value Test

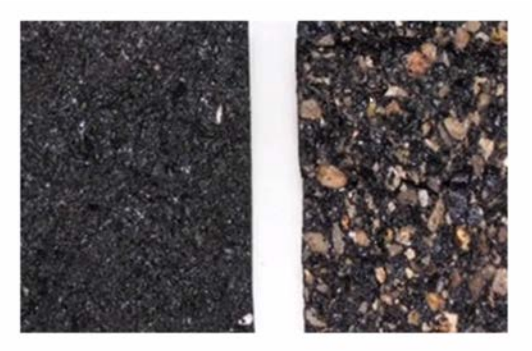
- Two Problems
  1. if aggregate is wet, it is normally not possible to coat with a bituminous binder.
  2. stripping of binder from coated aggregate due to presence of water
- Most road stones have surfaces that are electrically charged. For e.g.: silica has -ve charge, has greater attraction with water (hydrophilic).
- Lime stone has +ve charge, dislike water, hydrophobic; greater affinity with bitumen.
- Cationic (+) bitumen may be selected for electronegative aggregates and anionic (-) bitumen for electropositive aggregate.
- Stripping value is the ratio of the uncovered area observed visually to the total area of aggregates.
- Static immersion method is commonly used.

Test Procedure

- Apparatus:
  - Water bath, oven, sieves of size 20mm & 12.5mm, mixer, beaker, etc
- Aggregate passing 20mm sieve and retained on 12.5mm sieve is selected and heated.
- 5% bitumen is mixed with aggregate.
- Mix is transferred to beaker and allowed to cool for 2hrs.
- Distilled water is added to immerse coated aggregate and kept in water bath maintained at 40_oC for 24hrs.
- After 24hrs, extend of stripping is estimated visually while specimen is still under water.

Significance

- Stripping value of aggregates: <25% for use in bituminous surface dressing, penetration macadam constructions



- Here, Stripping value $\approx$ 35%

6.3.4 Comparing Gradation Specification and Method of Translating Specification

Aggregate Gradation Analysis

- Gradation test: gives aggregate particle size distribution
- Translating gradation: Aggregate specification requirements are expressed in two types:
  1. The total percentages passing (TPP) each individual sieve
  2. The percentages passing one sieve and retained on the next smaller sieve (PPR)
  - To compare with each other, convert PPR limits to TPP by analytical or graphical method.
- Combining the aggregates: mixing of aggregates stockpiled in different groups to get required specification

Translation

- A grading specification is given on the percentage passing-retained basis in Table. Convert these grading requirements to the total percentage-passing by (i) analytical and (ii) graphical methods.

Passing	Retained	Percent of Material
-	25.4	0
25.4	12.7	25 – 45
12.7	4.76	10 – 25
4.76	2.36	6 – 15
2.36	1.18	6 – 9
1.18	0.425	8 – 13
0.425	0.18	7 – 13
0.18	0.075	7 – 12
0.075		2 – 8

Analytical Method

Solution (Analytical method)

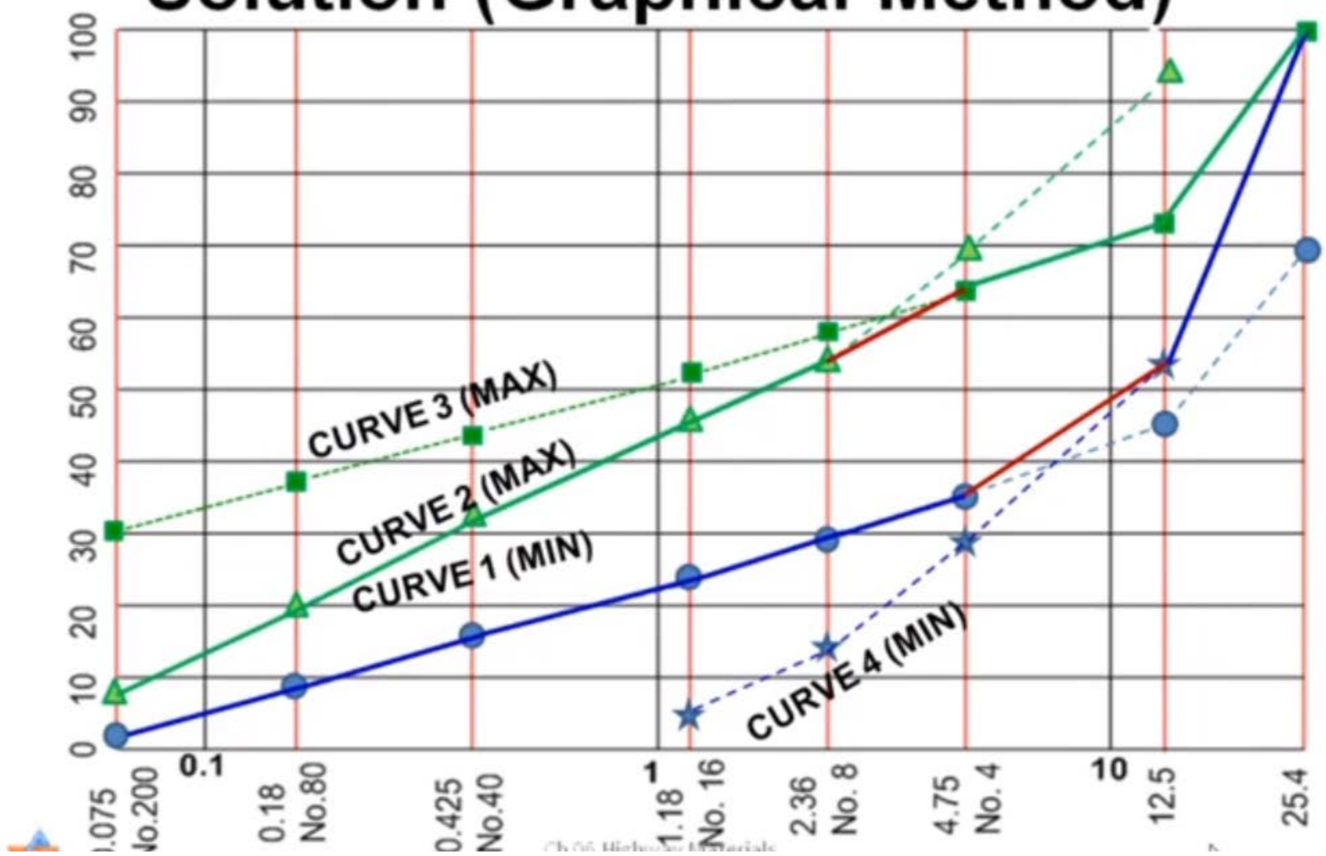
BS. Sieve	Cum% Passing		Cum% retained		Cum % Passing		Derived specification on % passing
	Min (1) ✓	Max (2) ✗	Min (1R) ↓	Max (2R) ↓	Max (3) ✗ 100-1R	Min (4) ✓ 100-2R	max of min / min of max
25.4	25+46 71	~~140~~	0	0	100-0 100	100	100
12.7	46	95	25	45	100-25 75	100-45 55	55 – 75
4.76	36	70	15+35 10	45+25 70	65	30	36 – 65
2.36	30	55	41	85	59	15	30 – 55
1.18	24	46	47	94	53	6	24 – 46
0.425	7+9 16	33	55	107	45	~~-7~~	16 – 33
0.180	7+2=9	8+12 20	62	120	38	~~-20~~	9 – 20
0.075	2	8	69	132	31	~~-32~~	2 – 8

Graphical Method

Solution (Graphical method)

BS. Sieve	Cum% Passing		Cum% retained		Cum % Passing		Derived specification on % passing
	Min (1)	Max (2)	Min (1R)	Max (2R)	Max (3) 100-1R	Min (4) 100-2R	
25.4	71	140	0	0	100	100	
12.7	46	95	25	45	75	55	
4.76	36	70	35	70	65	30	
2.36	30	55	41	85	59	15	
1.18	24	46	47	94	53	6	
0.425	16	33	55	107	45	-7	
0.180	9	20	62	120	38	-20	
0.075	2	8	69	132	31	-32	

Solution (Graphical Method)



Blending/Combination of Aggregate

- The grading requirement of road aggregates depends very much on the type of construction.
- The aggregate are stored beforehand into a number of closely graded 'single-sizes'.

- The aggregates are mixed in desired proportions in order to meet the gradation specified for use.
- Two Methods:
  1. Mathematical
  2. Graphical

Mathematical Method

- The linear equation method is the most common method.
- It is based on linear equation of the form:
  - a\timesA + b\times B + c\times C = T
  - where, a, b, c are percentage proportion of aggregates A, B, C and A, B, C are the percentage of material passing through given sieve size
  - T is the percentage of combined aggregate passing through given sieve size
  - Additionally, $a + b + c = 1$
- As many equations as the number of sieves used can be formed, and solving system of equation gives values of a, b, c.
-

Example 2: Mathematical Method

Blend an aggregate mixture consisting of three aggregate A, B, C such that the gradation of the final mix is within the specified limits

Sieve size (mm)	Per cent passing given sieve size				
	A	B	C	Specifications	
				Limits	Mid-Point
19.0	100.0	100.0	100.0	100	100.0
12.5	90.0	100.0	100.0	90-100	95.0
4.75	40.0	100.0	100.0	60-75	67.5
2.36	6.5	98.1	100.0	40-55	47.5
0.60	3.0	20.7	93.2	20-35	27.5
0.30	1.2	12.2	58.7	12-22	17.0
0.075	0.5	3.3	27.4	5-10	7.5

Example 2

$$a + b + c = 1 \quad \ldots\ldots \quad (1)$$

For 12.5 mm sieve,

$$90 \times a + 100 \times b + 100 \times c = 95 \quad \ldots\ldots \quad (2)$$

For 4.75 mm sieve, $10a + 0.b + 0c = 5$

$$40 \times a + 100 \times b + 100 \times c = 67.5 \quad \ldots\ldots \quad (3)$$

For 2.36 mm sieve,

$$6.5 \times a + 98.1 \times b + 100 \times c = 47.5 \quad \ldots\ldots \quad (4)$$

For 0.6 mm sieve

$$3.0 \times a + 20.7 \times b + 93.2 \times c = 27.5 \quad \ldots\ldots \quad (5)$$

For 0.3 mm sieve

$$1.2 \times a + 12.2 \times b + 58.7 \times c = 17.0 \quad \ldots\ldots \quad (6)$$

For 0.075 mm sieve

$$0.5 \times a + 3.3 \times b + 27.4 \times c = 7.5 \quad \ldots\ldots \quad (7)$$

-

Example 2

- Subtract equation (3) from (2), which gives
  $50 \times a = 27.5 \rightarrow a = 0.55$
- Replace value of a in equation (1), gives
  $b + c = 1 - 0.55 = 0.45 \rightarrow b = 0.45 - c$
- Replacing value of 'a' and 'b' in equation (4), gives
  $6.5 \times 0.55 + 98.1 \times (0.45 - c) + 100 \times c = 47.5$
  Therefore, $c = -0.12$ (not possible)
- Substituting value of 'a' and 'b' in eqn (5)
  $3 \times 0.55 + 20.7 \times (0.45 - c) + 93.2 \times c = 27.5$
  $c = 0.23$
- Substituting value of c,
  $b = 0.45 - 0.23 = 0.22$

-

Final Mix

Sieve size (mm)	Aggregate A = 55%	Aggregate B = 22%	Aggregate C = 23%	Combined
19.0	100.0 x 0.55 = 55	100.0 x 0.22 = 22	100.0 x 0.23 = 23	100.0
12.5	90.0 x 0.55 = 49.5	100.0 x 0.22 = 22	100.0 x 0.23 = 23	94.5
4.75	40.0 x 0.55 = 22.0	100.0 x 0.22 = 22	100.0 x 0.23 = 23	67.0
2.36	6.5 x 0.55 = 3.6	98.1 x 0.22 = 21.6	100.0 x 0.23 = 23	48.2
0.60	3.0 x 0.55 = 1.6	20.7 x 0.22 = 4.6	93.2 x 0.23 = 21.4	27.6
0.30	1.2 x 0.55 = 0.7	12.2 x 0.22 = 2.7	58.7 x 0.23 = 13.5	16.9
0.075	0.5 x 0.55 = 0.3	3.3 x 0.22 = 0.7	27.4 x 0.23 = 6.3	7.3

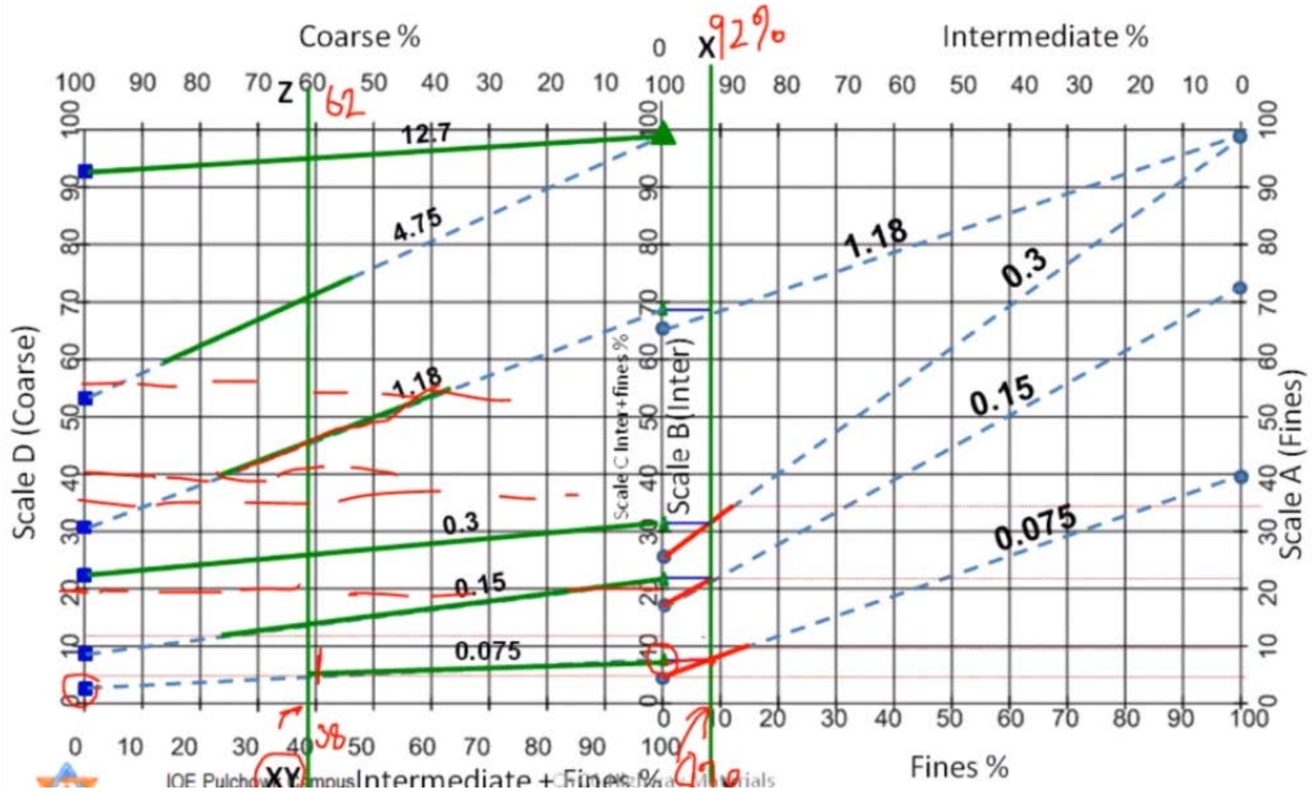
Graphical Method

Example 3: Graphical Method

Blend an aggregate mixture consisting of three aggregate A, B, C such that the gradation of the final mix is within the specified limits

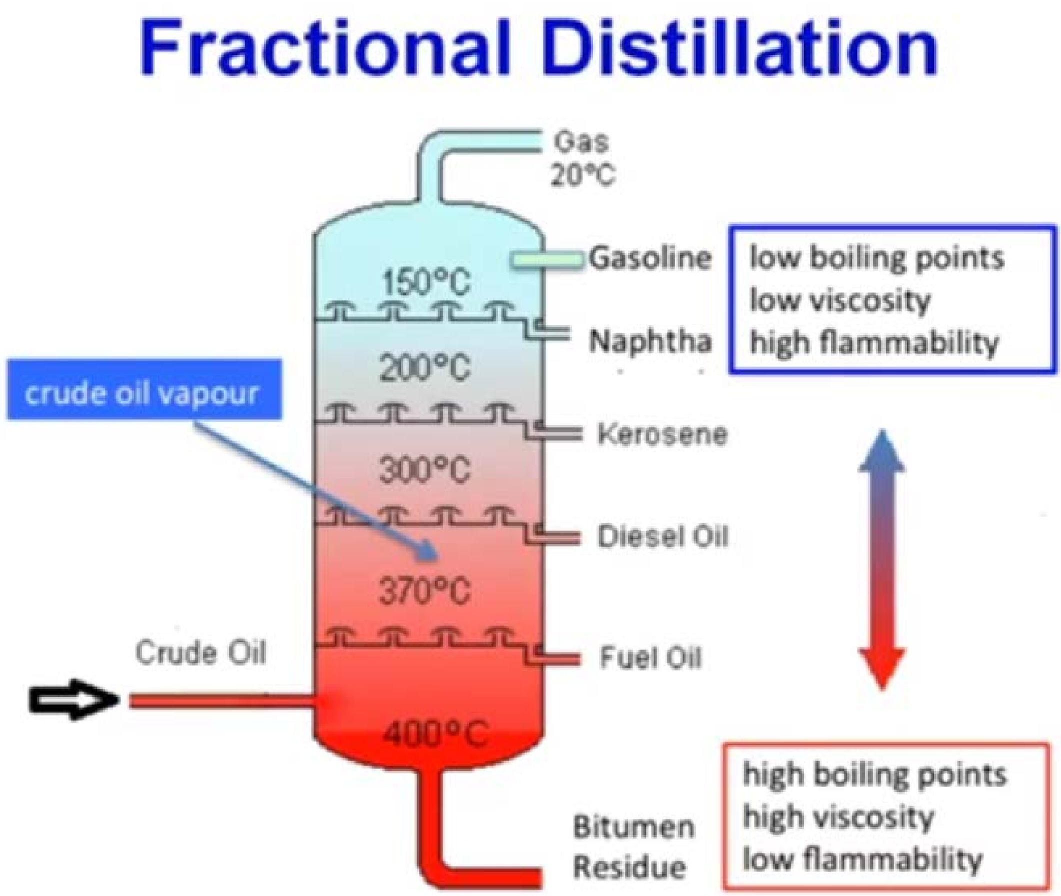
BS sieve size (mm)	Per cent passing given sieve size				
	Fine aggregate 'A'	Intermediate aggregate 'B'	Coarse aggregate 'C'	Specifications	
				Limits	Mid-Point
25.4	100.0	100.0	100.0	100	100.0
12.70	100.0	100.0	94.0	90-100	95.0
4.76	100.0	100.0	54.0	60-75	67.5
1.18	100.0	66.4	31.3	40-55	47.5
0.300	100.0	26.0	22.8	20-35	27.5
0.150	73.6	17.6	9.0	12-22	17.0
0.075	40.1	5.0	3.1	5-10	7.5

Example 3: Graphical Method

- 

6.4 Bituminous Road Binders

6.4.1 Definition and Classification of Road Binders

- A **Binder** is any material or substance that holds other materials (road aggregates) together to form a strong component.
- The binder is mixed with aggregate particles to create **bituminous concrete**.
- Two types:
  1. Bitumen
  2. Tar
- **Bitumen**: The viscous black/brown liquid or semi solid, non-crystalline having adhesive properties obtained as residual product of fractional distillation of crude oil or occurring naturally.
  - Bitumen are extensively used for roadway construction as:
    - Excellent binding characteristics
    - Water proofing properties, and
    - Relatively low cost
    - Bitumen are called hydrocarbon binder (organic binding material)
  - 

- **Tar**: The viscous black/ brown liquid obtained as by product of destructive distillation of organic material such as coal or wood.
  - destructive distillation: in the absence of air, coal & wood heated
  - Tar is the byproduct of coke industry for steel plant or gas industry.

- Tar is proven to cause cancer from occupational exposure and use has been reduced/ stopped.
- Two types:
    1. Coal Tar
    2. Wood Tar
- Categories:
    - Road Tar (RT) -1: very low viscosity, used for surface painting (water proofing, maintaining cracks) at cold environment
    - RT-2: standard surface painting
    - RT-3: surface painting and premixing chips
    - RT-4: premixing macadam
    - RT-5: highest viscosity; used for grouting purpose

Difference Between Bitumen & Tar

Bitumen	Tar
Byproduct of fractional distillation of crude oil	Obtained by destructive distillation of coal
Black to dark brown color	Brown color
Soluble in carbon disulphide and carbon tetrachloride	Soluble in toluene
Does not coat with aggregate in presence of water	Coat well in the presence of water as well
Contains less free carbon	Contains more free carbon
Soluble in petroleum oil	Does not lose viscosity in oil $\therefore$ can be used in roads near petroleum leakage

Requirements of Bitumen

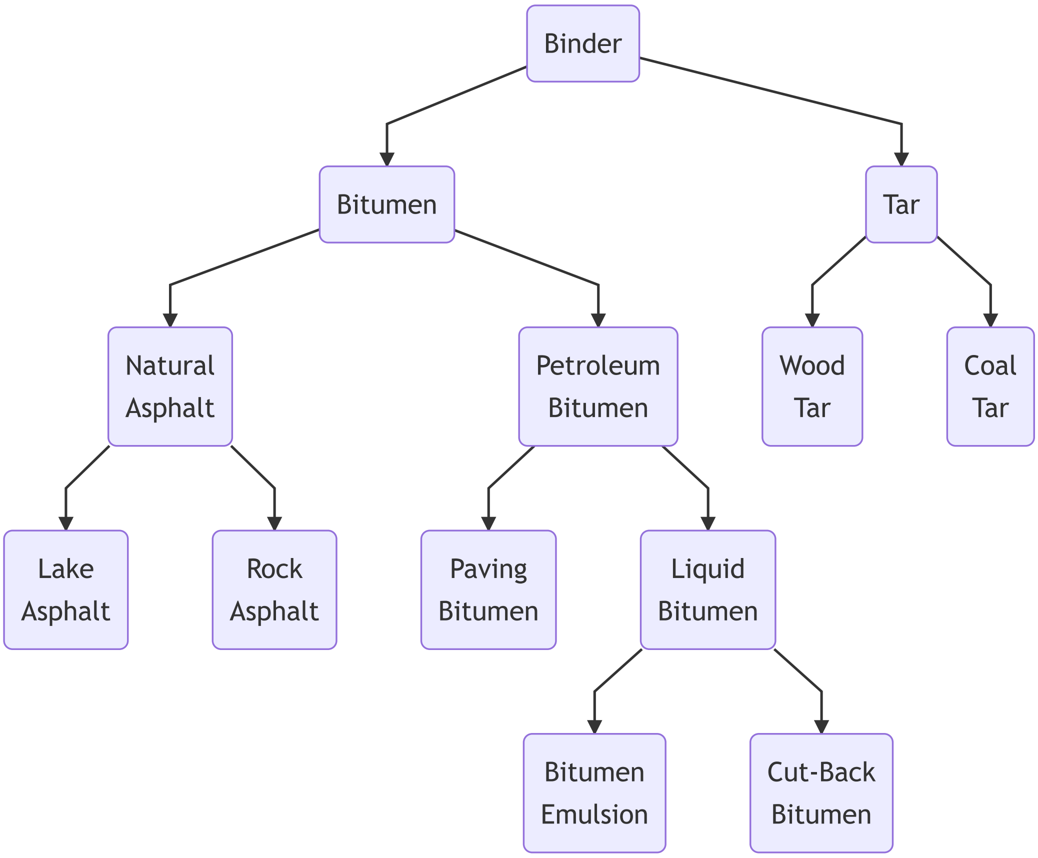
- Adequate viscosity for mixing and compaction
- Have proper adhesion with aggregate
- Should be temperature susceptible
- Retain the film of bitumen on coated aggregates in all-weather conditions
- Does not fail under predictable loads
- Safe to handle (e.g.: doesn't catch fire immediately)

Elemental Analysis

Specified proportions actually not necessary

- **Carbon**: 82-88%
- **Hydrogen**:8-11%
- Sulphur: 0-6%
- Oxygen: 0-1.5%
- Nitrogen: 0-1%

Classification of Binder



Natural Asphalt

- Naturally occurring (lake or rock) bituminous binder
- Less susceptible to temperatures and deformation performance issues
- Environmental friendly and water proof
- Lake Asphalt:
    - deposited in the lake from the discharge of spring
    - Biggest deposits in Trinidad
    - La Brea Tar Pits in Los Angeles
    -  
- Rock Asphalt:
    - A coarse grained sandstone thoroughly impregnated with bitumen
        - long time ago organic matter may be in between during the formation of sandstone
    - The asphalt content of about 80% to 85%, the rest are kind of limestone/ sandstone minerals
    - E.g.: Gilsonite

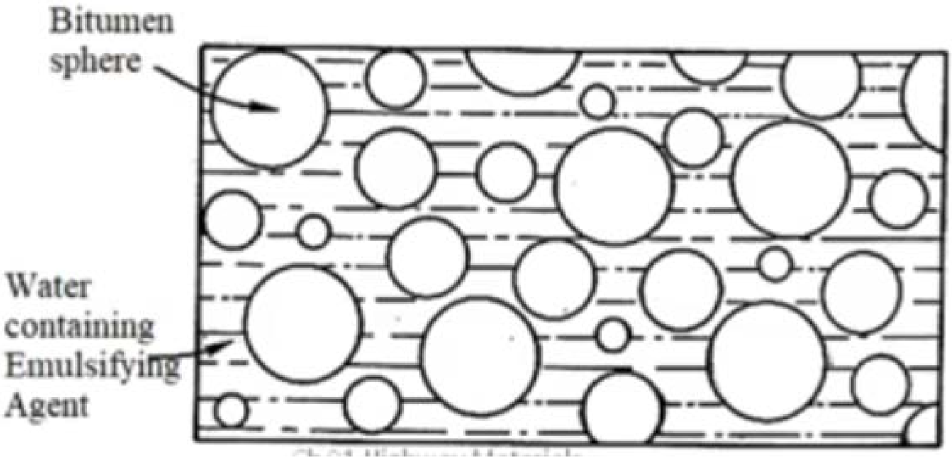
Paving Bitumen (Asphalt cement)

- By product of distillation of crude oil
- A black, sticky, semisolid and highly viscous material but readily liquefied by applying heat for mixing with mineral aggregates
- Strong and durable, excellent adhesive, water proofing
- Classification:
    - Penetration Grades: *Obsolete*
        - Standard needle in bitumen for standard time
        - ASTM D946: 5 grades of bitumen
            - 200-300; 120-150, 65-100, 60-70, and 40-50 (higher the penetration, the softer the bitumen)
        - IS 73-161: 5 grades of bitumen
            - 30/40, 40/50, 60/70, 80/100, and 175/225 are designated as S35, S45, S65, S90 and S200
            - *3mm - 4mm penetration*
            - 80/100 used in Nepal, usually
    - Viscosity Grade: *more accurate*
        - ASTM D3381:
            - AC-5, AC-10, AC-20, AC-30 and AC-40
            - The numerical values indicate viscosity at 140^{o}F in hundreds of poise
        - IS 73-2013:
            - Bitumen is graded by viscosity at 60^{o}C
            - 4 grades:VG10, VG-20, VG-30 and VG-40
    - **Characteristics of Viscosity Grade Bitumen (IS73:2013)**

Sl No.	Characteristics	Paving Grades			
		VG10	VG20	VG30	VG40
(1)	(2)	(3)	(4)	(5)	(6)
i)	Penetration at 25°C, 100 g, 5 s, 0.1 mm, *Min*	80	60	45	35
ii)	Absolute viscosity at 60°C, Poises	800-1 200	1 600-2400	2 400-3 600	3 200-4 800
iii)	Kinematic viscosity at 135°C, cSt, *Min*	250	300	350	400
iv)	Flash point (Cleveland open cup), °C, *Min*	220	220	220	220
v)	Solubility in trichloroethylene, percent, *Min*	99.0	99.0	99.0	99.0
vi)	Softening point (R&B), °C, *Min*	40	45	47	50
vii)	Tests on residue from rolling thin film oven test:				
	a) Viscosity ratio at 60°C, *Max*	4.0	4.0	4.0	4.0
	b) Ductility at 25°C, cm, *Min*	75	50	40	25

6.4.2 Liquid Bitumen: Cut-back Bitumen and Bitumen Emulsion

Bitumen Emulsion

- A mixture of bitumen (55-75%), water (42-22%), and emulsifying agent (3%)
- An emulsifying agent is added to mix the bitumen with water
- Bitumen remain suspended in water
- 

- The hot bitumen, water, and the emulsifying agent pass under pressure through a colloid mill
- The colloid mill breaks up the bitumen and disperses it, in the form of very fine droplets (avg size 2 micron), in the water carrier
- The emulsion sets as the water evaporates

Types Based on Emulsifying Agent

1. Anionic emulsion
    - Electro-negatively charged bitumen droplets
    - Fatty acids and lignin mixed with sodium hydroxide forms soap
    - Adhere better to aggregate with positive surface charges (e.g.: limestone)
2. Cationic emulsion
    - Electro-positively charged bitumen droplets
    - Amines (tall oils) or animal fats (tallow)
    - Adhere better to aggregate with negative surface charges (e.g.: sandstone, quartz, siliceous, gravel)
    - Also, works better with wet aggregates

Types Based on Setting Time

- Based on Amount of Water
- When bitumen emulsions are applied on aggregates, water starts to evaporate causing separation of bitumen from water.
- Then bitumen spreads on the surface of the aggregate and acts as a binding material.
- Three types:
    1. Rapid setting emulsion (RS)
        - 20-30 minutes
        - Break rapidly in contact with aggregate
        - Surface treatments and penetration macadam
    2. Medium setting emulsion (MS)

- Does not break rapidly in contact with aggregate as RS
- Open-graded cold mixes

3. Slow setting emulsion (SS)
    - Does not break down easily in contact with aggregate
    - Tack coat (gravel base; so that bitumen penetrates, doesn't set), fog seal, dense-graded cold mixes, and slurry seals

Advantages of Emulsion

- Eliminates the need to heat aggregates and binder
- Reduce environment pollution
- Can be used when weather is relatively cold
- Useful for sealing of cracks, patching and repair work

Cut-back Bitumen

- A bitumen mixed with a solvent to reduce their viscosity to make them easier to use at ordinary temperatures.
- Upon evaporation of the solvent, they harden and bind the aggregate particles together.
- Solvent used: naphtha, kerosene

Types of cutback bitumen

- Rapid-Curing(RC)
    - Produced by adding a solvent of high volatility (e.g.: gasoline, naphtha)
    - Used primarily for tack coat and surface treatments
- MC
    - Produced by adding a solvent of intermediate volatility (e.g.: kerosene) to bitumen
    - Used for prime coat, patching, and road-mixing operations
- SC
    - Produced by adding oils of low volatility (e.g.: diesel or other gas oils) to bitumen
    - Also called road oils
    - Used for prime coat, and as dust palliatives

Advantages of cut-back

- substitute of heating
- suitable for direct application
- good mixing manual method
- mix can be transported for long haul without setting
- liquefying effect lasts over a long period

Emulsion Vs. Cut-back Bitumen

Emulsions are used in lieu *(place, stead)* of cut-back bitumen as:

- Emulsions are relatively pollution free.
- Solvents used in cut-back are high price energy which get wasted into atmosphere while curing.
- Emulsions are safer to use (cut-back easily catches fire; emulsions mixed with water).

- Emulsions can be applied at relatively low temperatures saving the fuel costs.
- Emulsions can also be applied effectively to damp pavements.

6.4.3 Tests on Bituminous Binders

Test Methods for Important Properties of Bitumen:

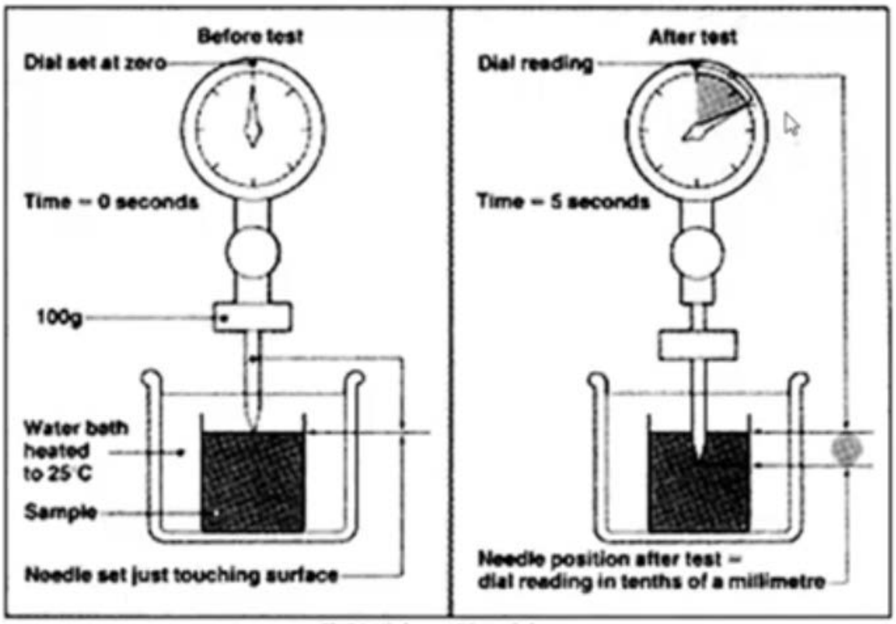
- Consistency
  - Penetration test
  - Viscosity test
  - Float test
  - Softening point test
  - Ductility test
- Specific Gravity
- Flash and fire point test/ Safety test
- Composition
  - Distillation test
  - Water content test
  - Loss on heating test
  - Ash content
  - Solubility test

Consistency

- The degree of fluidity of bitumen at any particular temperature
- Measured in terms of viscosity, penetration values and float test, ductility and softening point

Penetration Test

- Penetration test is used to measure the consistency of bitumen indirectly.
- It is the distance in tenths of a millimeter that a standard needle penetrates vertically into a specimen of the material under specified conditions of temperature (25^oC), load (10g) and duration of loading (5sec).
- Designated as e.g.: 80/100; it means a penetration of between 8 and 10 mm
- Bitumen has an upper limit on penetration value of 300 (i.e., 30mm)

- 

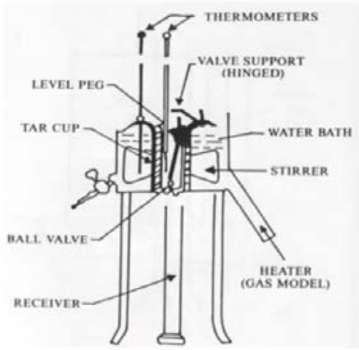
Test Procedure

- Bitumen is heated to pouring consistency: about 75 to 100^{o}C and poured into the container (to make it soft, so that can be poured into container).
- The sample is allowed to cool in the atmosphere between 15 to 30^{o}C for 1 to 3/2 hours.
- The sample is placed in water bath maintained at 25^{o}C for 60 to 90 minutes.
- The sample is placed on the stand of the apparatus & needle is then slowly lowered until it just touches the surface of the sample.
- The initial dial gauge reading is taken.
- The needle is then released for 5 sec and re-locked immediately.
    - 3 tests
    - Clean the needle with Trichloroethylene & cotton
    - Repeat with 10mm difference
- The final dial gauge reading is taken.
- Difference between final and initial value is taken as penetration value.
- E.g.: if the penetration is 8.4mm, the grade of the bitumen is 80/100.

Viscosity Test

- Viscosity is a measure of the resistance to flow.
- Viscosity decreases as temperature increases.
- Grades of bitumen and temperatures at which they are used depend on their viscosity.
- Ability to spread, penetrate into voids, and also coat the aggregate is affected by viscosity.
- **Time in seconds** taken by 50ml volume of bitumen to flow from a standard tar viscometer cup through an orifice of 10mm diameter at specified temperature.

Test Procedure

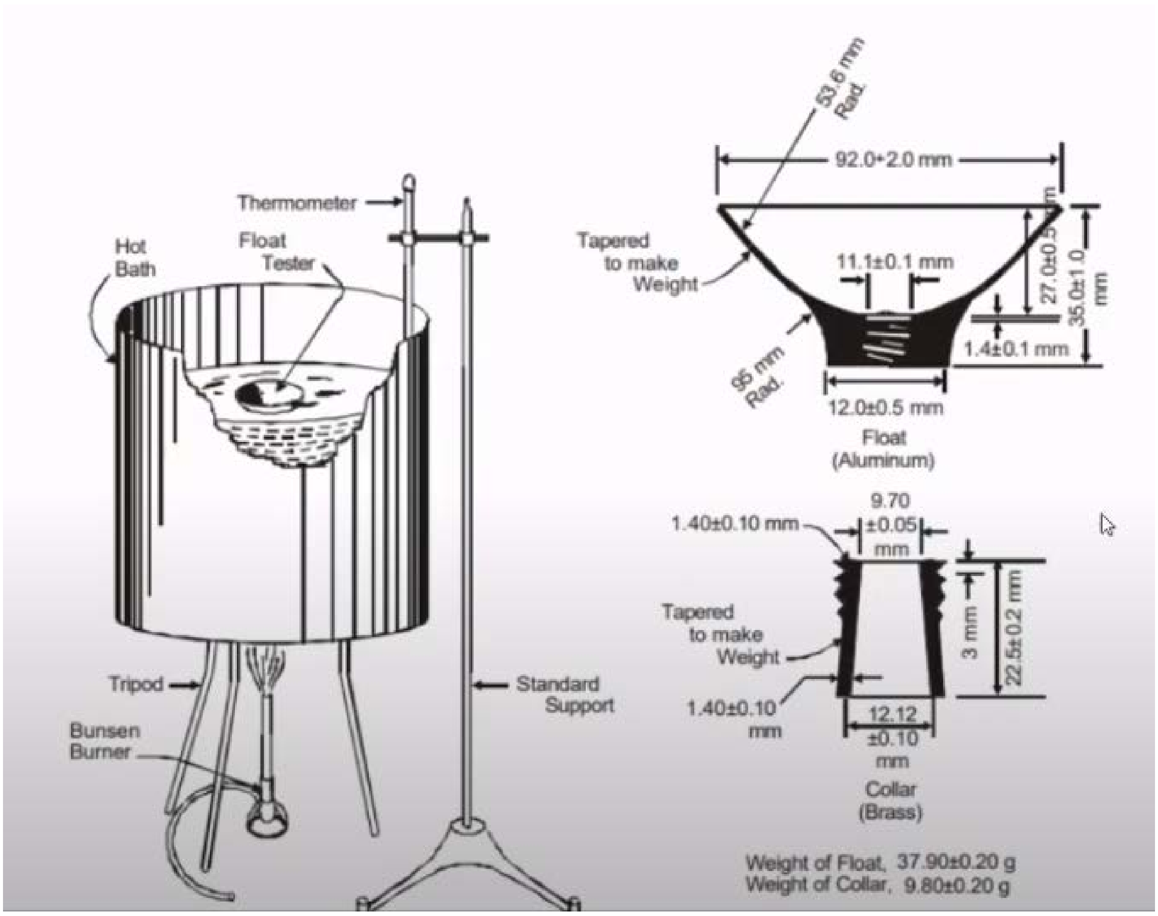
- 


- The bitumen is heated to 20_{o}C above the test temperature and allowed to cool.
- When temperature reaches slightly above test temp (40^{o}C), it is poured into cup of the viscometer up to levelling peg.
- Receiver is placed under the orifice. Valve is opened after applying kerosene in the receiver.
    - 25-50ml kerosene is poured prior so that the 50ml reading of bitumen is easier.
- Stop watch is started when cylinder records 50ml (kerosene). Time is recorded for flow up to a mark of 100ml (+50ml bitumen).

Float Test

- Float test is used as a measure of consistency bitumen with high viscosity.
- The **time in seconds**, between placing the apparatus on the water and the water breaking through the material
- Usually used for heavy tar/bitumen (high viscosity)

Test Procedure

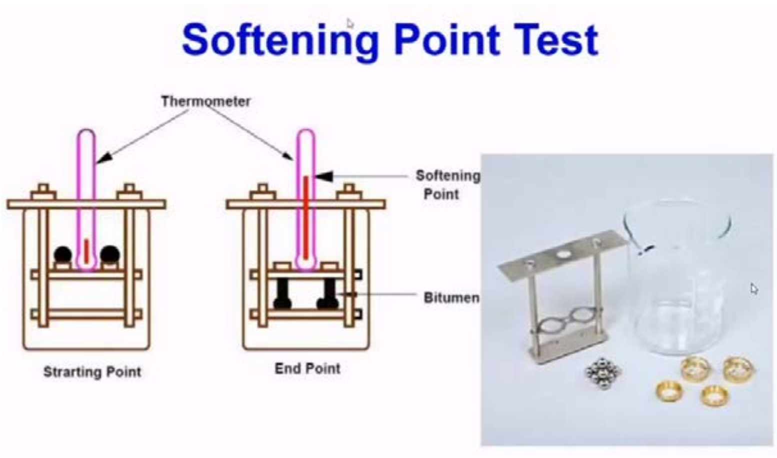
- 

- 
- Melt bitumen to pouring consistency and pour it into the brass collar.
- Cool it to room temperature for 15 minutes, then place in water maintained at 5^{o}C (ice water) for 5 minutes.
- Trim the bitumen flush with the top of the collar by means of a spatula.
- Remove and screw the collar into the aluminium float and immerse in water at 5^{o}C (ice water) for one minute.
- Remove the water if any inside the float and immediately float it in warm bath.
- Determine the time in seconds between placing the apparatus on the water bath and when the water breaks through.

Softening Point Test

- Instead of melting, bitumen has softening point.
- Softening point is the **temperature** at which bitumen cannot support the weight of a steel ball and starts flowing.
- Softening point is measured by ring and ball (R & B) method.
- Higher the softening point, lesser the temperature susceptibility. Bitumen with higher softening point is preferred in warmer places.

Test Procedure

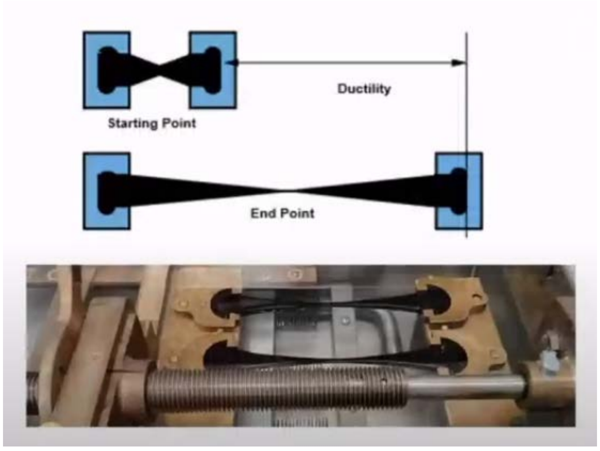
- 

- Heat the material to a temperature between 75-100^{o}C (above its softening point) & pour it in ring.
- After cooling for 30 minutes in air, level the material in the ring by a warm & sharp knife.
- Assemble the apparatus with the rings; thermometer and ball guides in position.
- Keep the sample in distilled water @ 5$_{o}$C for 15 minutes.
- Fill with distilled water to a height of 50mm above the upper surface of the rings and start heating.
- Heat in the water bath at a uniform rate of 5 $\pm$ 0.5^{o}C per minute.
- As the temperature increases, the bituminous material softens and the balls sink through the rings.
- Note the temperature when any of the steel balls with bituminous coating touches the bottom plate.
- Record the temperature when the second ball touches the bottom plate.
- The average of the two readings to the **nearest 0.5^{o}C** is reported as softening point.

Ductility Test

- Ductility test measures the **distance in centimeters** that a standard briquette bitumen will stretch (@5cm/min at 25^{o}C) before breaking.
- Ductility is used as **indirect** measure of adhesion and cohesion of asphalt.
- Ductility value varies between 5 to 100mm, the min. ductility value is 50mm.

Test Procedure

- 

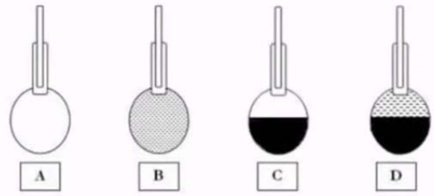
- Melt the bitumen at a temperature of 75-100^{o}C (above the appropriate softening point).
- To prevent sticking the mold and plate are coated with glycerin and dextrin.
- Pour it in the mould assembly, placed on a brass plate.
- Allow to cool for 30-40 minutes and trim the excess bitumen and level the surface using a hot knife.
- Place the mould assembly in water bath (27^{o}C) for 80 to 90 minutes.
- Remove the sides of the mould and hook the clips on the machine, and pull clips horizontally at a speed of 50cm/min.
    - $\approx$ 25mm of water above and below the specimen required
- Note the **distance** at which the bitumen thread of specimen breaks.
    - 3 specimens are prepared, and the average distance is taken.

Specific Gravity

- It is the ratio of mass of a given volume of a substance to the mass of an equal volume of water at temperature 27^{o}C.
- Petroleum bitumen have specific gravity values close to unity (0.95-1.05).
- Specific gravity is essential to determine the percentage of voids in a compacted material.
- It is used to convert the volume measurement of bitumen to the units of mass.

Test Procedure

- Apparatus:
    - specific gravity bottle (pycnometer) of 50ml capacity
    - Balance having least count of 1g, thermometer, water bath
- The sp. gravity bottle is cleaned, dried and weighed
- It is filled with fresh distilled water and kept in water bath for at least half an hour at temperature 27^{o}C.
- The bottle is then removed and cleaned from outside. The bottle with distilled water is weighed.
- The bitumen is heated to a pouring temperature and is poured in the empty bottle, up to the half.

- The sample bottle is allowed to cool to 27^{o}C for half an hour and then weighed.
- The remaining space is filled with distilled water and kept at 27^{o}C for half an hour.
- The bottle containing bitumen and water is removed, cleaned from outside and is again weighed.
- 

  $$Sp.Gravity = \frac{C-A}{(B-A)-(D-C)}$$

  Where, A = Weight of empty specific gravity bottle
  B = Weight of bottle + water
  C = Weight of bottle + bitumen
  D = Weight of bottle + water +bitumen

Flash and fire point test/ Safety test

- Bitumen heated to a high temperature may catch flame in the presence of spark or open flame.
- The flash point is the lowest temperature at which vapour of bitumen quickly catches fire in the form of flash but the fire will not last longer.
- The fire point is the lowest temperature at which bitumen catches fire and burns under definite conditions of test (usually for 5 sec).
- Minimum flash point value should be **175^{o}C** and min. fire point value should be = **175^{o}C + 5^{o}C**.

Test Procedure

- 

- Heat the bitumen to above its softening point, generally 75-100^{o}C.
- Pour the cup with softened bitumen up to the filling mark. Then place the lid and close the cup.
- Thermometer and flame exposure are suitably fixed in their respective positions.
- The bitumen heated is at the rate of 5-6^{o}C per minute.
- Stirring (@60 rev/min) of sample is done along with the heating using stirrer device.
- Apply the test flame for every 1^{o}C rise from 17^{o}C below actual flash.
- When the sample catches the flame and forms flash, it is the **flash point**.
- Heat the sample further with the same previous rate and apply the test flame for every 2^{o}C rise.
- When the material catches the fire and burns for at least 5 seconds, it is the **fire point**.

Composition

Water Content Test

- It is the quantity of water present in a material expressed as a percentage by mass of the material.
- Maximum value of water content is 0.2%.
- Water content more than the specified limit causes noise and frothing (bubbles) during heating of bitumen.
- Dean and Stark method is used (distillation apparatus).

Test Procedure

- 

- Place about 100g of sample in the flask and 100ml of petroleum.
- Attach the flask to the Dean and Stark apparatus and flash is heated to just above the boiling point of water.
- Continue distillation until condensed water is no longer visible in any part of the apparatus.
- Collected water is expressed in terms of mass percentage of sample.

Loss on Heating Test

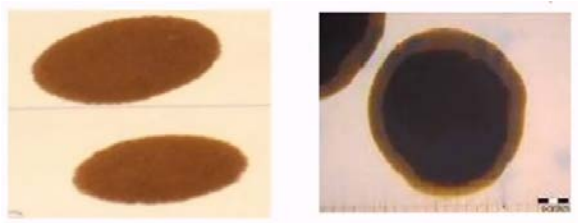
- The loss in weight (exclusive of water) of a bituminous material when heated to a standard temperature and under specified conditions.
- Loss on heating should not be more than 1% by weight and for bitumen 150/200, up to 2% by weight.
- The residue after heating when subjected to penetration test shows a reduction in penetration value. The reduction in penetration value should be less than 40% of the original penetration value of the bitumen.

Test Procedure

- Apparatus:
  - oven (capacity 180^{o}C), Aluminium rotating shelf, Thermometer (0-360^{o}C), Container (dia. 55mm and depth 35mm), Balance
- Heat the sample, stirring constantly to pouring consistency.
- Place the sample in container and cool to room temperature and then weigh.
- Bring the oven to the temperature of 163^{o}C and place the container in oven for a period of 5hrs.
- Remove the sample from the oven, cool to room temperature, and weigh it.
- Calculate the loss due to heating.

Spot Test

- Over heated or cracked bitumen

- About 2gm bitumen is dissolved in 10ml of naphtha.
- A small drop of prepared bitumen is dropped onto a filter paper.
  - If the spot formed is uniformly brown then the test is negative.
  - If the spot formed is brown with a black center, then the test is positive. (bitumen is burnt; can't be used)
  - 

Solubility (Purity)

- Refined bitumen consists of almost pure bitumen, which by definition is entirely soluble in carbon disulfide.
- The impurities, i.e., amount of insoluble material contained in the bitumen is determined by solubility test.

Test Procedure

- Apparatus:
  - Gooch crucible, conical glass flask (200ml), solvent (Carbon disulphide or Trichloroethylene
  - 

- A sample of about 2gm of bitumen is dissolved in about 100ml of solvent.
- The solution is filtered through the Gooch crucible and the insoluble material retained is washed, dried and weighted.
- It expressed as percentage of original sample.
- The insoluble material should be preferably less than 1%.

6.5 Bituminous Mixes

6.5.1 Definition and Classification

- The bituminous mix design aims to determine the proportion of bitumen, filler, fine aggregates, and coarse aggregates to produce a mix which is workable, strong, durable and economical.

Constituent of a mix

- Coarse Aggregates:
  - Material retained on 4.75mm sieve, e.g.: crushed agg.
  - Contribute to stability by interlocking properties
  - Resist compressive strength and abrasive action of traffic
- Fine Aggregates:
  - Materials passing through 4.75mm sieve and retained on 75 micrometer sieve, e.g.: sand, stone dust
  - Fill the voids and add stability
  - Increase resistance to deformation due to increase in contact surface
- Filler:
  - Material passing through 75 micron sieve, e.g.: stone dust, cement, lime, ash
  - Fill the voids, stiffens the binder
  - Offer impermeability and temperature susceptibility
- Binder:
  - Lubricate all the aggregates, cause particle adhesion, provide flexibility
  - e.g.: bitumen, tar

Desirable Properties

- Stability
  - sufficient stability to bear traffic load without distortion or deformation
- Durability
  - measure of the resistance of the paving mix against environment and abrasive actions of traffic
- Flexibility
  - measure of the ability of bituminous mixture to bend repeatedly under traffic load without cracking the surface
- Fatigue resistance
  - the mix should not crack when subjected to repeated loads over a period of time.
- Skid resistance
  - the mix should have the highest possible skid resistance to prevent skidding of vehicles.
- Workability
  - the mix must be capable of being placed and compacted with reasonable effort. Rounded aggregates and reducing sand and filler improve workability.

- Sufficient voids
  - a sufficient amount of air voids should be available to allow space for expansion of bitumen in summer and compaction by road traffic (during its service life)

Classification

As per Gradation

- Well graded (dense mix):
  - has good proportion of all constituents
  - space between larger particles is effectively filled by smaller particles to produce a well-packed structure
  - offers good compressive strength and impermeable
- Gap graded mix:
  - a kind of grading which lacks one or more intermediate sizes
  - has good fatigue and tensile strength, low workability and permeable
- Open graded mix:
  - only crushed stones; fine aggregate & filler are missing
  - porous but offers good friction

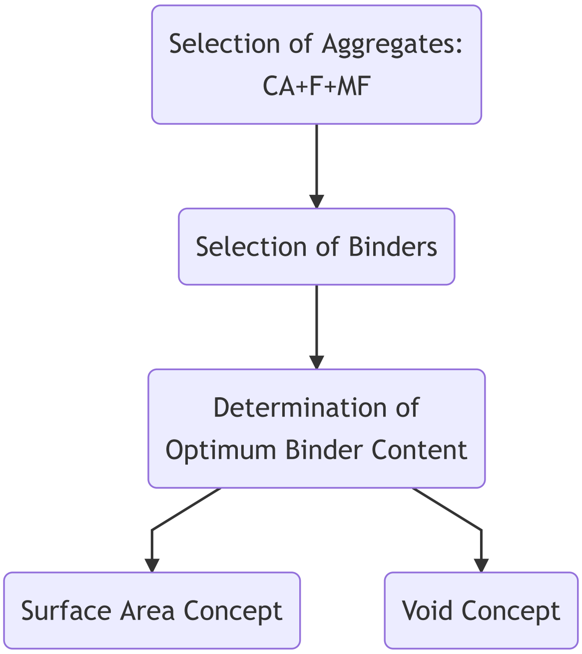
As per method

- Hot mix:
  - a mixture of aggregate (coarse and fine), filler and bitumen are heated and mixed at the production facility at 300-350^{o}C
  - cools quickly allowing quick setting and is strong
  - but can't be installed at wet climate
- Cold mix:
  - does not require heating for application
  - most useful for repairs like small cracks and potholes or patches when outside temperature is too cold
  - can be laid in wet climate, but not as strong as hot mix

As per site of mixing

- Road mixed:
  - a bituminous surface or base course produced by mixing aggregates and asphalt at the jobsite
  - also called **mixed in-place** asphalt concrete
  - obsolete
- Plant mixed:
  - a mixture of aggregates and bitumen prepared at a central mixing plant
  - spread and compacted at the job site at near ambient temperature

Bituminous Mix Design



Selection of Aggregate

Apart from specified gradation, select aggregates which possess:
- proper shape (FI & EI <30)
- strength (ACV<30%)
- hardness (LAA<30%)
- toughness (AIV<25%)
- soundness (12-18%)
- water absorption (<2%)

Also, consider:
- availability
- economic considerations

Selection of Binder

- Select the binder of consistency sufficiently soft to workability, adequate ductility and resistance to moisture.
- Governed by atmospheric temperature

Atmospheric ^{o}C	Penetration Grade	Viscosity grade
15-55	30/40	VG40
10-50	50/60	VG30
0-40	60/70	VG20
-10-30	80/100	VG10

Determination of Optimum Binder Content

- Use of optimum binder content that give maximum possible
- Two types:
  1. Surface area concept
  2. Void concept

Surface Area Concept

- Determines amount of binder sufficient to coat the aggregate particles
- Less accurate
- Used as a good guidance at the start of mix design, and determine bitumen content in the mix design for low cost roads
- Commonly used formula: Nebraskan formula
    - $P = AG(0.02a) + 0.06b + 0.10c + Sd$
        - P = % by weight of bitumen in the mix
        - A = absorption factor for aggregate retained on ASTM No. 50 (300μm) sieve
            - A = 1 for sand gravel and (1+0.67 $\times$ water absorption for other agreggates)
                - e.g. $1 + 0.67 \times 1$ for water absorption = 1%
        - G = specific gravity correction factor for aggregates retained on ASTM No. 50 sieve
            - because app. sp. gr. is not exact for smaller aggregates
            - $G = \frac{2.62}{\text{App. sp. gr. of aggregate}}$
        - a = % by weight of aggregates retained on ASTM No. 50 sieve
        - b = % by weight of aggregates passing ASTM No. 50 sieve and retained on ASTM No. 100 (150μm) sieve
        - c = % by weight of aggregates passing ASTM No. 100 sieve and retained on ASTM No. 200 (150μm) sieve
        - d = % by weight of aggregates passing ASTM No. 200 sieve
        - S = an experimental factor depending on the fineness and absorptive characteristics of the material passing ASTM No. 200 sieve (≈ 0.2)

Void Concept

- The void in the mix is minimized to ensure stability, by selecting appropriate grading of aggregate and optimum bitumen.
- Also, there should be sufficient voids to allow for a slight amount of additional compaction under traffic and a slight amount of asphalt expansion due to temperature rise.
- **Marshal Stability Test** is used.

6.5.2 Marshal Method of Bitumen Mix Design

- Also called **wet mix design**
- Two major features of the Marshall method of mix design are:
    1. density-voids analysis
    2. stability-flow tests (experiment)
- An attempt is made to obtain optimum binder content for the type of aggregate mix used

Procedure

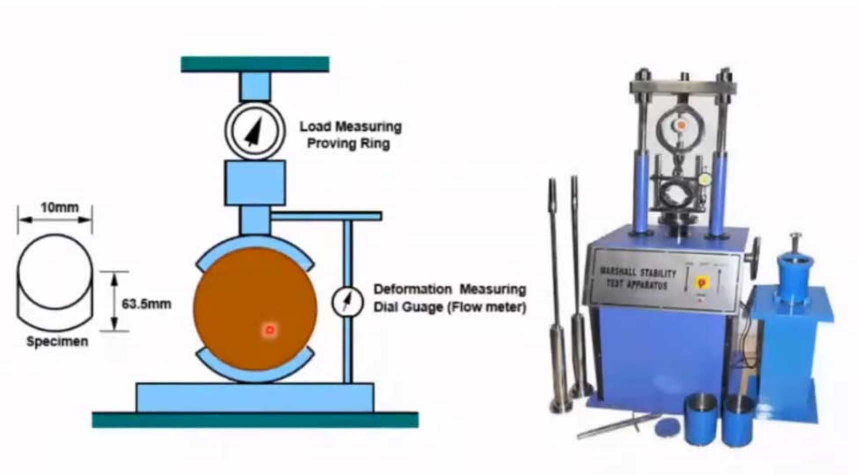
- Select aggregate grading to be used.
- Determine the proportion of each aggregate size required to produce the design grading.
- Determine the specific gravity of the aggregate combination and bitumen.

- Prepare the numbers of trial specimens with varying bitumen contents. (min. 3 specimens for one bitumen content)
- Determine the specific gravity of each compacted specimen.
- Calculate the percentage of voids (VTM), and voids in mineral aggregate (VMA), percent voids filled with Bitumen (VFB) in each specimen.
- Perform stability-flow tests on each specimens.
- Prepare several graphs: Bitumen content versus stability, flow, unit weight, VTM and VMA
- Select the optimum binder content (OBC) from the data obtained
- Check the OBC with the specification

Stability-Flow Test

- The resistance to plastic deformation of a compacted cylindrical specimen of bituminous mixture is measured when the specimen is loaded diametrically at a deformation rate of 50mm per minute.
- The maximum load in kg before failure is the **stability value** and the **flow value** is the deformation of the specimen in 0.25mm units at failure

Procedure of Stability-Flow Test

- Apparatus:
  - cylindrical mould, 101.6mm dia. and 63.5mm height
  - 
  - base plate and collar
  - a compaction pedestal and hammer
  - sample extruder
  - a breaking head
  - a dial gauge (flow-meter)
  - 

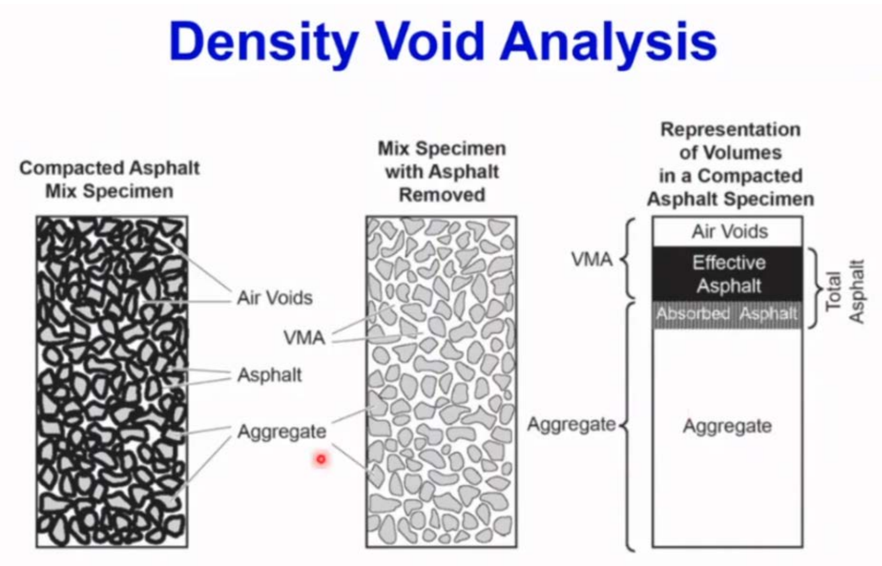
- Preparation of test specimens
  - Approx. 1200gm in total of aggregates and filler is heated to a temperature of 154-160^{o}C. (to remove moisture).
  - Bitumen is heated to a temperature of 121-125^{o}C.

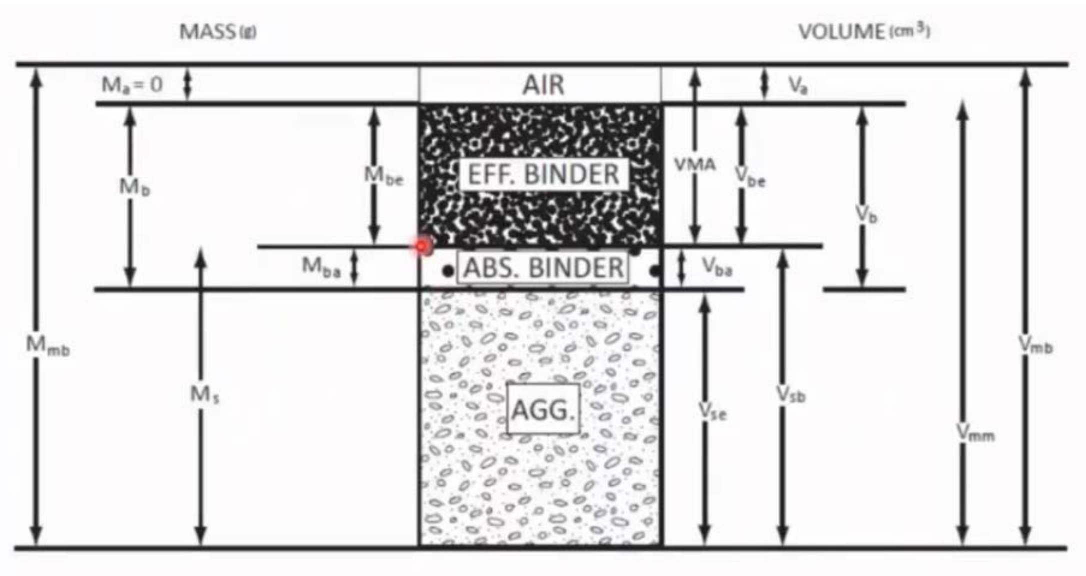
- The heated aggregates and trial bitumen (3.5-4% of 1200gm) are thoroughly mixed at a temperature of 154-160^oC.
- The mix is placed in a preheated mould and compacted by a rammer with 50 blows (done in single layer).
  - but compaction is done twice, i.e., from both sides
- A compacted thickness of sample be 63.5 ± 3mm
- Vary the bitumen content by +0.5% and repeat the above procedure to prepare several specimens (e.g.: 4.5%, 5%).

- The diameter and mean height of specimens are measured and their weights in air, water and SSD condition are taken.
- Then the specimen are kept immersed in water bath at 60 ± 1^oC for 30 to 40 minutes.
- The specimens are taken out one by one and tested in the Marshall test apparatus to determine Marshal stability and flow value.
- Correction is applied if the specimen height is not equal to 63.5mm. Measured stability is multiplied by correction factor.

Table of Correction factors for Marshall stability values

Volume of specimen (cm^3)	Thickness of specimen (mm)	Correction Factor
457-470	57.1	1.19
471-482	68.7	1.14
483-495	60.3	1.09
496-508	61.9	1.04
509-522	63.5	1.00
523-535	65.1	0.96
536-546	66.7	0.93
547-559	68.3	0.89
560-573	69.9	0.86





- V_a = Vol. of air voids
- M_b, V_b, G_b = Wt., Vol. & Sp. gr. of binder
- M_{be}, V_{be} = Effective Wt., Vol. of binder
- M_{ba}, V_{ba} = Absorbed Wt., Vol. of binder
- V_{se}, V_{sb} = Effective, Bulk vol. of aggregate (excluding and including permeable voids)
- M_s = Wt. of aggregate
- M_{mb}, V_{mb}, G_{mb} = bulk Wt., Vol., Sp. gr. of the mix
- V_{mm}, G_{mm} = Max. Vol., Sp. gr. of the mix
- VMA = % void in mixed aggregate
- VFB = % void in filled with bitumen

Bulk Specific Gravity of Mix (G_{mb})

- The bulk (actual) specific gravity of the mix (G_{mb}) is the specific gravity considering air voids and is found out by:
  - $G_{mb} = \dfrac{m_a}{m'_a - m_w}$

- m_a = Weight of mix in air
- m'_a = SSD Weight of mix in air
- M_w = weight of mix in water

Theoretical Specific Gravity of Mix (G_{mm})

- $G_{mm} = \dfrac{m_a}{V_b + V_c + V_f + V_{mf}} = \dfrac{m_a}{m_b/G_b + m_c/G_c + m_f/G_f + m_{mf}/G_{mf}}$
  - G_c, G_f, G_{mf}, G_b = sp. gr. of course fine, filler and bitumen
- $G_{mm} = \dfrac{m_a}{m_a - m_w}$

Air Voids (P_a)

- The air voids in a bituminous mix are the air between the bitumen coated aggregate particles. The percentage of air voids (P_a) is:
  - $P_a = \dfrac{V_a}{V_{mb}} \times 100$
- Most commonly used equation is:
  - $P_a = 100 - \dfrac{G_{mb} \times 100}{G_{mm}}$

Voids in mineral aggregate (VMA)

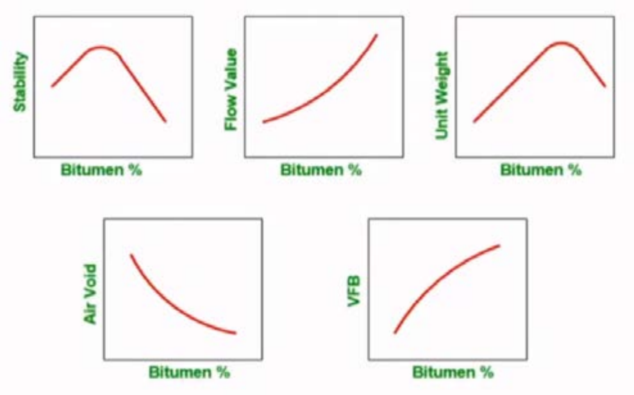
- VMA is the volume of voids in the aggregates, and is the sum of air voids and volume of bitumen, and is calculated as
  - $\%VMA = 100\dfrac{V_a + V_{be}}{V_{mb}}$
    - V_a = % air voids in the mix
    - V_{be} = % bitumen content in the mix
- The commonly used formula:
  - $\%VMA = 100 - \dfrac{G_{mb} \times P_s}{G_{sb}}$
    - P_s = percentage of aggregate solid = 100 - % of bitumen

Voids filled with bitumen (VFB)

- VFB is the voids in the mineral aggregate framework filled with the bitumen and is calculated as:
  - $VFB = \dfrac{V_b}{VMA} \times 100$
    - V_b = % bitumen content in the mix
    - VMA = % voids in the mineral aggregate
- Commonly used formula:
  - $VFB = \dfrac{VMA - P_a}{VMA} \times 100$

Graphical Plots

Binder content versus:

- corrected Marshall stability
- Marshall flow
- percentage of Air void (P_a) in the total mix
- voids filled with bitumen (VFB)
- unit weight or bulk specific gravity (G_{mb})
- 

Effective Specific Gravity of Aggregate (G_{se})

- The ratio of the mass of an aggregate excluding void permeable to bitumen at a stated temperature to the mass of equal volume of distilled water
- $G_{se} = \dfrac{P_{mm} - P_b}{\dfrac{P_{mm}}{G_{mm}} - \dfrac{P_b}{G_b}}$
  - P_{mm} = Total loose mixture in % by total weight of mixture (equals to 100%)
  - P_b = Bitumen % by total weight of mixture
  - G_{mm} = Max. Theoretical sp. gr. of paving mix (no air voids)
  - G_b = Specific gr. of Bitumen

Bitumen Absorption (P_{ba}) & Effective Bitumen Content (P_{be})

- The % by weight of aggregate,
  - $P_{ba} = G_b \left[\dfrac{G_{se} - G_{sb}}{G_{sb}.G_{se}}\right] \times 100$
- The bitumen content that retains as a coating on the outside of the aggregate particles is,
  - $P_{be} = P_b - \dfrac{P_{ba} \times P_s}{100}$

Optimum Bitumen Content (OBC)

- OBC for the mix design is the average value of the following three bitumen contents found from the graphs of the test results:
  - $OBC = \dfrac{B_1 + B_2 + B_3}{3}$
    - B_1 = % asphalt content at maximum unit weight
    - B_2 = % asphalt content at maximum stability
    - B_3 = % asphalt content at specified percent air voids in the total mix (usually 4%)

- The Marshall Stability Value, Flow value and percent voids filled with Bitumen at the average value of bitumen content are checked with the Marshall Stability design criteria/ specification.

Desired/ Standard Values

Description	Values
Minimum Stability (kN at 60_oC)	9.0
Minimum Flow (mm)	2
Compaction level (No. of blows)	75 blows on each of two faces of the specimen
Percent air voids	3.6
Percent voids in mineral aggregate (VMA)	See Table No. ?
Percent voids filled with bitumen (VFB)	65-75
Loss of stability on immersion in water at 60^oC (ASTMD 1075)	Min. 75% retained strength