Transportation Engineering

Highway Materials

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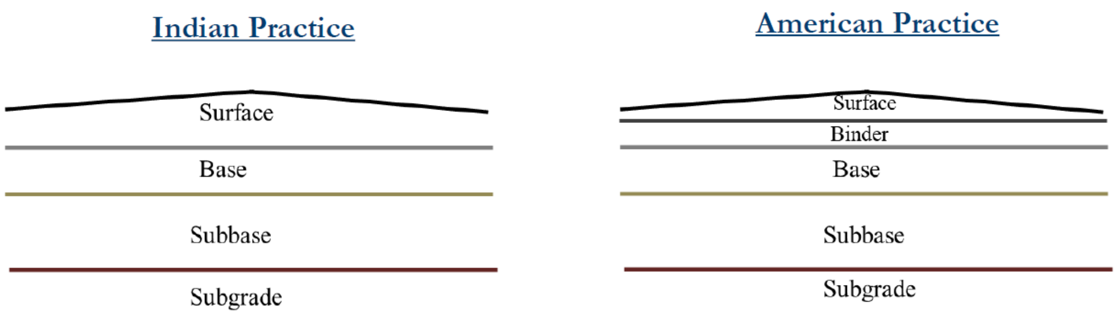
Highway Materials

Pavement

- A relatively stable layer constructed over the natural soil for the purpose of supporting and distributing the wheel loads and providing an adequate surface for the movement of the vehicles is defined as road pavement.
  - Designed to support the wheel loads imposed on it from moving traffic over it.
  - Designed to keep the temporary deformation within the permissible range.
- Should be strong enough to resist the stresses on it and should be thick enough to distribute the external loads on the earthen sub-grade, so that the sub-grade itself can safely withstand it.

Highway Materials

Pavement



Introduction and Classification of Road Materials

Introduction and Classification of Road Materials

- Materials which are extensively used in road construction practices with special reference as to their use, specifications, requirements, behavior in road construction and maintenance.
- Three groups
    - Mineral Materials
    - Binding Materials
    - Other Materials

Introduction and Classification of Road Materials

Introduction and Classification of Road Materials

Mineral Materials

- Either naturally occurring, semi processed or fully processed.
- Sub-grade soil, sand/stone dust (fine aggregate), stone chips, gravel/crushed aggregates (coarse aggregates), blast furnace slag, brick pebbles.
- Soils - Used extensively for embankment construction and in construction of soil stabilized layer.
- Stone aggregates – Used in pavement construction and road side structures. Also used as filter materials in the backfill behind retaining walls and in subsurface drainage.

Binding Materials

- Include a) stone dust or cohesive soil b) cement, lime and other inorganic binding materials c) bitumen, tar and other organic binding materials.
- a) results in semi-rigid and semi-flexible bond between mineral particles.
- b) forms rigid, irreversible bond
- c) provides thin film of binding action which is flexible and reversible in nature.

Other Materials

- Other common road construction materials as:
  - Reinforcement
  - Timber
  - Stones
  - Bricks
  - Boulders
  - Cobbles
  - Gabion wires
  - Geo-textiles, geo-grids
  - Chemical additives
  - HDP Pipes, Hume pipes, etc.

Introduction and Classification of Road Materials

Introduction and Classification of Road Materials

- Mineral Materials

- Binding Materials

- Other Materials

When mineral materials are mixed with binding materials, it produces several new forms of hard materials. These include water bound macadam, cement concrete, stabilized soil, cement soil, bitumen soil, lean concrete, lime concrete, cement mortar, bituminous bound macadam, bituminous concrete, grouted or penetration macadam, seal coat, etc.

Sub-grade Soil

Sub-grade Soil

- General
- Characteristics of Sub-grade Soil
- Desirable Properties of Sub-grade Soil

Sub-grade Soil

Sub-grade Soil

- **General**
  - Soil is an unconsolidated mineral materials formed by the disintegration or decomposition of rocks.
  - Soil contains air, water, organic matters and other chemicals dispersed around the mineral particles.
  - For highway engineering, soil refers to all the unconsolidated mineral materials lying above the bed rock with which and upon which highways are constructed.
  - In cuts, sub-grade consists of parent soil.
  - In filling sections, sub-grade consists of borrowed soil over the native ground or sometimes treated (in case of poor soil) in the form of an embankment.
  - The design of pavement is very much dependent on the sub-grade strength of soil.

Sub-grade Soil

Sub-grade Soil

- **Characteristics of Sub-grade soil**
  - Engineering properties of soil are largely dependent on the nature of parent rock.
  - The properties and behavior of soil is also generally influenced by the change in moisture content, density and degree of compaction.
  - Wide varieties of soil types are found in nature and therefore the suitability of soil is to be judged based on the study of their characteristics in one side and the requirement on the other side.
  - Characteristics of soil particles that are useful in predicting the performance and behavior of soil are:
    - Grain size
    - Shape
    - Surface texture
    - Chemical composition
    - Dry density and moisture content

Sub-grade Soil

Sub-grade Soil

- **Characteristics of Sub-grade soil**
  - **Grain size**
    - Coarse-grained soils or granular soils
      - Particle size greater than 0.075mm but less than 2.36mm
      - Sand, gravel
        - Sieve analysis for particle size distribution and gradation analysis
    - Fine-grained soils or cohesive soils
      - Particle size less than 0.075mm as silts (0.002 mm to 0.075mm) and clays (<0.002mm)
        - Hydrometer analysis for particle size distribution and gradation analysis

Sub-grade Soil

Sub-grade Soil

- **Characteristics of Sub-grade soil**
  - **Shape**
    - Important for coarse soil
    - Higher the angularity number, higher resistance to deformation
    - Round particles are generally strong
    - Flat and flaky particles are usually weak

Sub-grade Soil

Sub-grade Soil

- **Characteristics of Sub-grade soil**
  - **Soil Texture**
    - Indicates the relative content of particles of various sizes, as sand, silt and clay in the soil.
    - Determines the workability of soil and the water and air retention capacity of a soil sample.
    - Fine textured soil – silts and clays
    - Coarse textured soil – sands and gravels

Sub-grade Soil

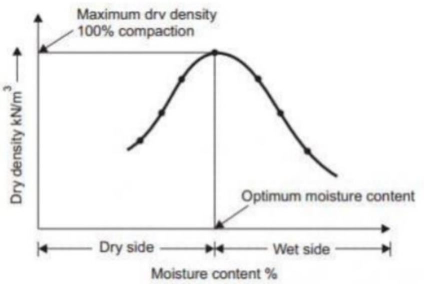
Sub-grade Soil

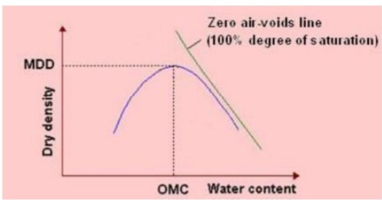
- **Characteristics of Sub-grade soil**
  - **Soil Composition**
    - Minerals, organic matter, water and air.
    - Commonly found minerals in soil are aluminosilicates, oxides.

Sub-grade Soil

Sub-grade Soil

- **Characteristics of Sub-grade soil**
  - **Moisture content and dry density**
    - Dry density refers to the mass of dry soil by total volume of soil.
    - Maximum dry density is obtained with minimum compaction effort at Optimum Moisture Content (OMC).
    - Soil is compacted to MDD in order to:
      - Increase the strength
      - Decrease the void ratio
      - Decrease the volume change due to variation in moisture content
      - Minimize settlement





Sub-grade Soil

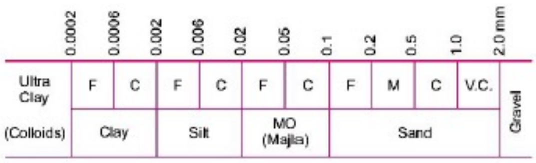
Sub-grade Soil

- **Soil Classification**
  - **Based on grain size**
    - MIT classification system

Sub-grade Soil

Sub-grade Soil

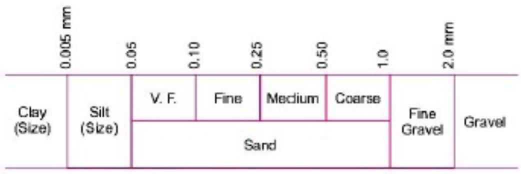
- **Soil Classification**
  - **Based on grain size**
    - International classification system



Sub-grade Soil

Sub-grade Soil

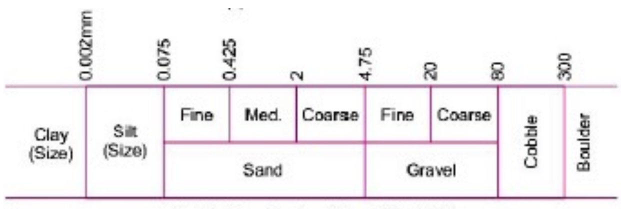
- **Soil Classification**
  - **Based on grain size**
    - US Bureau of soil classification



Sub-grade Soil

Sub-grade Soil

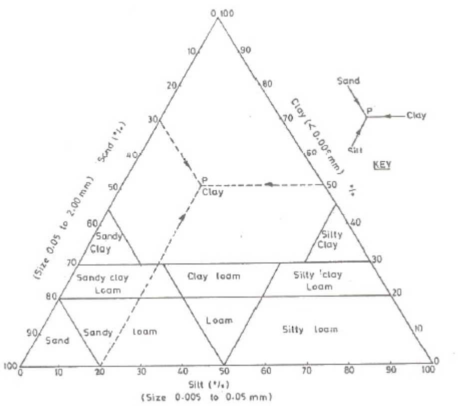
- **Soil Classification**
  - **Based on grain size**
    - IS classification

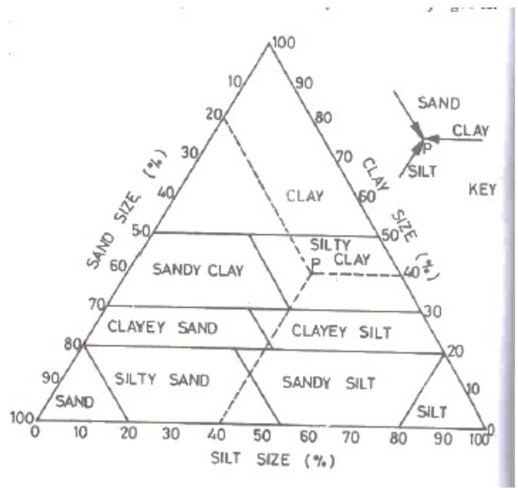


Sub-grade Soil

Sub-grade Soil

- **Soil Classification**
    - **Textural classification of soil**





Sub-grade Soil

Sub-grade Soil

- **Desirable Properties of Sub-grade Soil**
    - **Stability** - Resistance to permanent deformation under loads, resistance to weathering, ability to retain desired sub-grade support.
    - **Incompressibility** - Resistance to change in volume upon the application of pressure.
    - **Permanency in Strength** - Property of soil, which allows sub-grade to support pavement with the same degree of strength under varied condition of moisture and weather.
    - **Minimum change in volume and stability under adverse conditions of weather and ground water.**
    - **Good drainage** – Essential to avoid excessive moisture and frost action.
    - **Ease in compaction** – Property of soil, which ensures higher dry density with minimum compaction effort for increasing strength characteristics and permanency in strength.

Sub-grade Soil

Sub-grade Soil

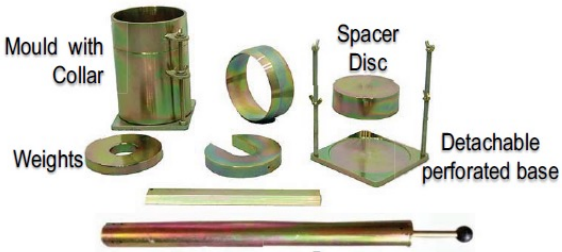
- **Test on Soil – CBR Test**
  - Developed by the California Division of Highway, USA.
  - Method to measure the relative strength of the material.
  - Defined as the ratio of force per unit area required to penetrate a soil mass with standard circular piston at the rate of 1.25 mm/min to that required for the corresponding penetration of a standard material (crushed aggregate).

$$\text{CBR} = \frac{\textit{Test Load}}{\textit{Standard Load}} * 100\%$$

Sub-grade Soil

Sub-grade Soil

- **CBR – Laboratory 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 19mm and 4.75mm, coarse filter paper, balance, etc.



Sub-grade Soil

Sub-grade Soil

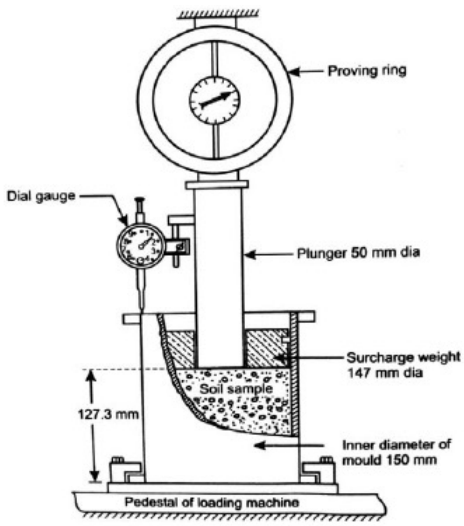
- **CBR – Laboratory Test – Preparation of Specimen**
  - Undisturbed Sample – Obtained by pushing the mould with steel cutting edge of 150mm into the ground till the mould is sufficiently full and trip the top and bottom.
  - Remolded Specimen – Soil sample shall pass a 19mm IS sieve and retained on 4.75 IS sieve and mixed with either field moisture of OMC and compacted statically or dynamically.

Compaction Method	No. of blow	Rammer Weight (kg)	Drop Height (mm)	Nos. of layer of soil
Light	56 nos.	2.6	310	3
Heavy	56 nos.	489	450	5

Sub-grade Soil

Sub-grade Soil

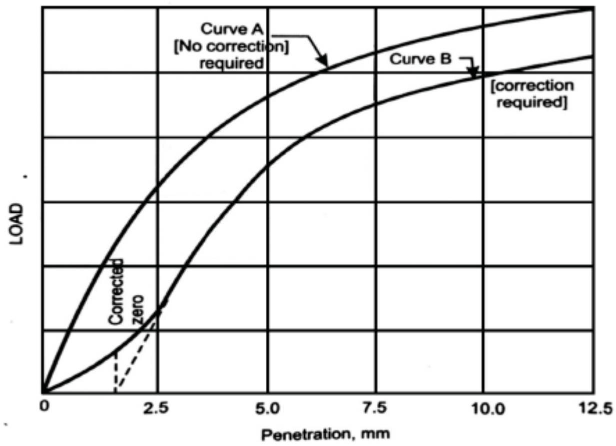
- **CBR – Laboratory Test – Test Procedure**
  - The specimen may be soaked or unsoaked.
  - Load is applied by the loading frame through a cylinder plunger of 50mm diameter and penetration is measured.
  - Rate of penetration is maintained at 1.25mm/minute.
  - Record the load readings at penetration of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10 and 12.5 mm.
  - Detach the mould, take about 20 to 50g of soil from the top 3cm layer to determine the moisture content.



Sub-grade Soil

Sub-grade Soil

- **CBR – Laboratory Test – Calculation**
  - Plot a load penetration curve
  - CBR = $\frac{x}{y} * 100$
    - where, 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 2.5mm of penetration = 1370 kg
      - For 5.0mm of penetration = 2055 kg



Road Aggregates

Road Aggregates

- **Definition and Classification of Road Aggregates**
  - Mineral materials as sand, gravel and crushed stone that are used with a binding medium to form compound materials as bituminous mixes and cement concrete, macadam, mortar, etc. or alone as in filter beds and various sub-surface drainage system.
  - By volume, aggregate generally accounts for 92 to 96 percent of bituminous concrete and about 70 to 80 percent of Portland cement concrete.
  - Aggregate is also used for base and sub-base courses for both flexible and rigid pavements.
  - Can be natural or manufactured.
  - Manufactured aggregate is often a by-product of other manufacturing industries.

Road Aggregates

Road Aggregates

- **Definition and Classification of Road Aggregates**
  - **Classification of Road Aggregates**
    - **Based on Source**
      - Natural aggregate
        - Stone aggregates collected from nature.
        - Processed mechanically involving crushing, screening, washing, sieving, etc. but do not undergo chemical processing.
        - Eg. Stones, boulder, sand, gravel, crushed stone chips, etc.
      - Artificial aggregate
        - Obtained as the by product of steel manufacturing plants and brick kilns.
        - Eg. Blast furnace slag and broken brick ballast.

Road Aggregates

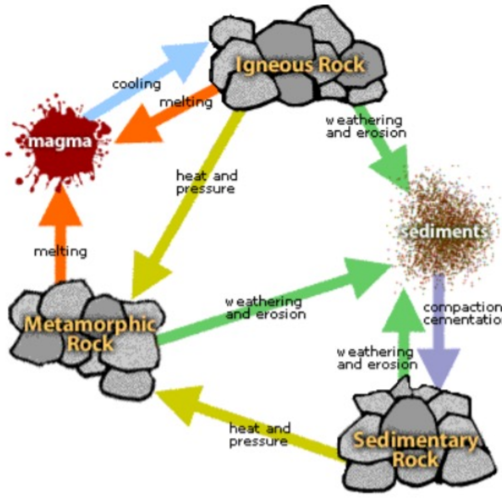
Road Aggregates

- **Definition and Classification of Road Aggregates**
  - **Classification of Road Aggregates**
    - **Based on Size**
      - Coarse aggregates
        - Either uncrushed natural gravel or crushed stone processed in the crusher plant or combining of natural gravel and crushed stones, most of which retained on 4.75 mm IS sieve.
      - Fine aggregates
        - Either natural sand or crushed stone and most of which passes 4.75mm IS sieve and retained on 75μ IS sieve.

Road Aggregates

Road Aggregates

- **Definition and Classification of Road Aggregates**
  - **Classification of Road Aggregates**
    - **Based on Geology of Origin**
      - Igneous Rock
      - Sedimentary Rock
      - Metamorphic Rock



Road Aggregates

Road Aggregates

- **Definition and Classification of Road Aggregates**
  - **Classification of Road Aggregates**
    - **Based on Geology of Origin**
      - Igneous
        - Rock formed by cooling of the molten magma. Eg. Basalts and granites.
      - Sedimentary
        - Rocks formed at the surface of the earth by the process of weathering, transportation and deposition by wind, water, snow or biological processes. Eg. Sandstone, siltstone, shale limestone, ,dolomite, etc.
      - Metamorphic
        - Rocks which have undergone significant changes after their formation due to pressure and temperature. Eg. Slate, phyllite, schist, gneiss, quartzite and marble.

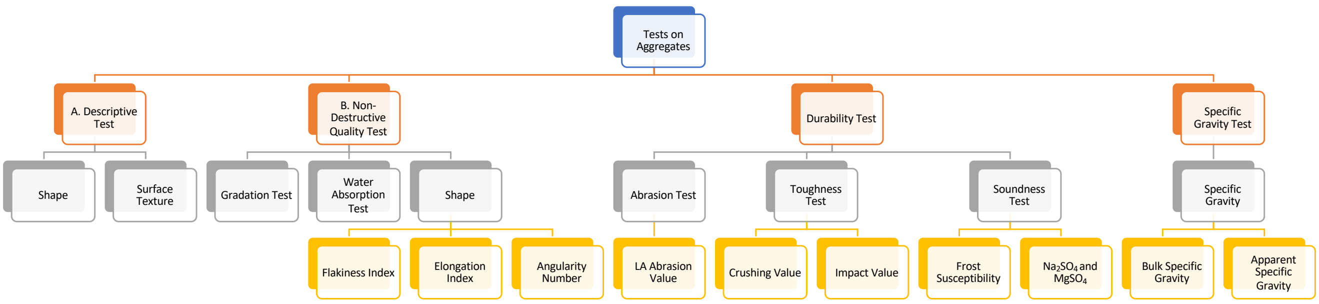
Road Aggregates

Road Aggregates – Desirable Properties

- **Strength** – Resistance to crushing and to withstand the stresses due to traffic wheel load. [Aggregate Crushing Value (ACV) test]
- **Hardness** – Resistance to abrasion (wear and tear) caused by movements of traffic. [Los Angeles Abrasion (LAA) test, Deval abrasion test, polished stone test, etc.]
- **Toughness** – Resistance of aggregates to impact. [Aggregate Impact Value (AIV) test]
- **Durability** – Resistance to weather action or ability to remain strong over long period. [Soundness test]
- **Shape of aggregates** – Determines interlocking and crushing properties. The use of proper shape of aggregate ensures the strength of the pavement. Too flaky and too elongated aggregates should be avoided. (Flaky – 0.6d, elongated – 1.6L). [Flakiness index, Elongation index, Angularity Number, etc.]
- **Proper Gradation** – An aggregate contains all standard fractions of aggregate in required proportion. [Sieve Analysis]
- **Adhesion with bitumen** – Should have less affinity with water when compared with bituminous materials. Hydrophobic aggregate (limestone) is preferred over hydrophilic aggregate (quartz, sandstone).
- **Freedom from deleterious particles** – Excessive amount of elongated pieces, dust, clay, etc.

Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance



Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance

- **Descriptive Tests**
  - Intended to define the visual examination of an aggregate that enables it to be descried in terms of both the shape and the surface texture of the particles.
  - Results in subjective descriptions of these mineral aggregate characteristics.

Road Aggregates

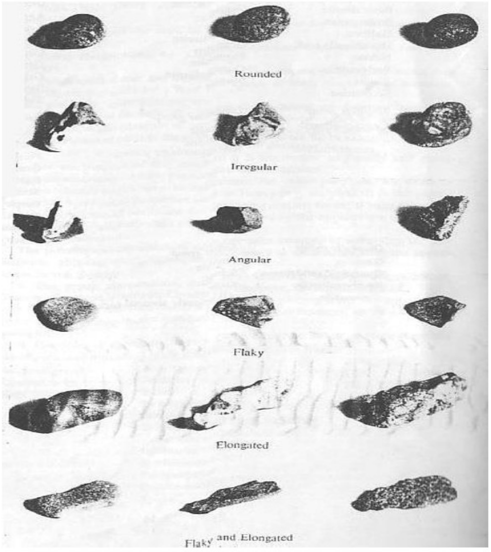
Road Aggregate – Tests on Road Aggregates and their Significance

- **Descriptive Tests**
  - **Shape**
    - Angular – Possess well defined edges, good interlocking and strength.
    - Rounded – Without well defined plane, minimum voids, good workability but poor interlocking behavior.
    - Flaky – It has small thickness (<60%) compared to width or length, less strength and durability.
    - Elongated – Elongated aggregates has large dimension (1.8 times) compared to other two dimension of aggregate, less strength and durability.
    - Flaky and elongated – Length is larger than width and width is larger than thickness.
    - Irregular – Irregular shaped aggregate does not have definite shape and well defined plane, less workability but high interlocking behavior than rounded aggregates.

Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance

- **Descriptive Tests**
  - **Shape**



Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance

- **Descriptive Tests**
  - **Surface Texture**
    - Measure of smoothness or roughness of the aggregate
      - Glossy – Looks like a block of glass
      - Granular – Consists of aggregation of mineral grains of approximately equal size
      - Rough – Provides more surface area to bond with binding materials resulting higher bond strength
      - Smooth – Free from irregularities
      - Crystalline – Have crystallized minerals
      - Honeycombed – Aggregate with hollow spaces and cavities
      - Porous – Consists of small pores, good adhesion

Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance

- **Descriptive Tests**
  - **Significance**
    - Useful in classifying aggregates.
    - Knowledge regarding internal friction. By internal friction is meant the properties, which resist the movements of aggregates pass each other.
      - Crushed basalt is generally considered an excellent road aggregate, since it has high internal friction as a result of having good interlocking qualities because of the angular shapes of the particles and a rough surface texture.
      - It is for this reason that most gravel aggregate specifications require that the gravel be artificially crushed to produce jagged edges and surfaces before being used in a highway pavement.

Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance

- **Non-Destructive Quality Tests**
  - Evaluate the properties of aggregate without significant damage to the original aggregate.
  - Carried out to determine its suitability for a specific use.
  - Results obtained are compared with aggregate specifications to see whether they comply with the desired properties and characteristics.
    - Gradation
    - Water absorption
    - Shape tests

Road Aggregates

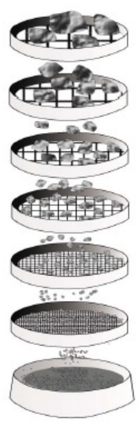
Road Aggregate – Tests on Road Aggregates and their Significance

- **Non-Destructive Quality Tests**
  - **Gradation Test**
    - Also known as sieve analysis, screen analysis and mechanical analysis.
    - Useful for particle size analysis.
    - A sample of dry aggregate of known weight is sieved through a series of sieves with progressively smaller openings.
    - The retained sample is expressed either as total percentage passing or retained on each sieve or as the percentages retained between successive sieves.
    - Apparatus:
      - IS sieves of sizes – 80mm, 63mm, 50mm, 40m, 31.5mm, 25mm, 20mm, 16mm, 12.5mm, 10mm, 6.3mm, 4.75mm, 3.35mm, 2.36mm, 1.18mm, 600μ, 300μ, 150μ and 75μ. **Balance: ($\pm$0.1%).**

Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance

- **Non-Destructive Quality Tests**
  - **Gradation Test**
    - **Procedure**
      - Take sample dried at 110$\pm$5^{O}C and weighed.
      - Select the sieve sizes suitable to the specification.
      - Sieved by using a set of IS sieves for 15 minutes.
      - Weight the material retained on each sieve.
      - The percentage retained is calculated as:



$$\% \text{ retained} = \frac{W_{sieve}}{W_{total}} * 100\%$$

W_{sieve} = Weight retained on given sieve size

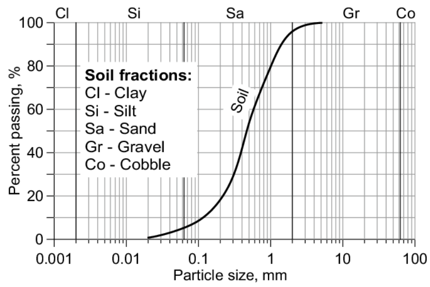
W_{total} = Total weight of sample

Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance

- **Non-Destructive Quality Tests**
  - **Gradation Test**
    - **Procedure**

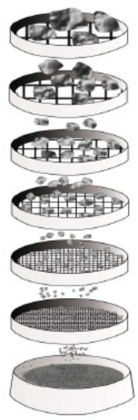
Sieve Size (mm)	Mass of soil retained (g)	Percentage mass retained (%)	Cumulative Percentage retained	% Finer (N)
4.75				
2.00				
1.00				
0.600				
0.425				
0.300				
0.212				
0.150				
0.075				
Pan				
Total				



Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance

- **Non-Destructive Quality Tests**
  - **Gradation Test**
    - Significance of Tests
      - Variation in the aggregate grading affect the amount of binder required.
      - Proper aggregate grading contributes to property such as strength, stability, durability, permeability, workability, skid resistance, etc.



Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance

- **Non-Destructive Quality Tests**
  - **Shape Test**
    - Three mechanical measures of particle shape may be included in the specifications for aggregates for road construction.
      - Flakiness Index
      - Elongation Index
      - Angularity Number

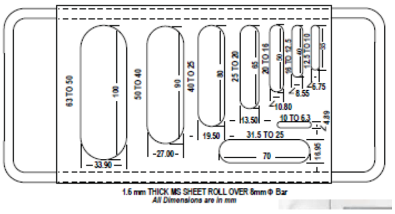
Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance

- **Non-Destructive Quality Tests**
  - **Shape Test**
    - **Flakiness Index**
      - Percentage by weight of particles, whose least thickness is less than three-fifth of their mean dimension.
      - Mean dimension as used in each instance is the average of two adjacent sieve sizes between which the particle being measured in retained by sieving.
      - Not applied to particles smaller than 6.35mm in size.

Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance

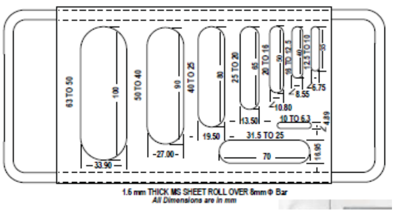


- **Non-Destructive Quality Tests**
  - **Shape Test**
    - **Flakiness Index**
      - Sieve the sample through the IS sieves.
      - Take a minimum of 200 pieces of retained on each sieve size.
      - Pass each aggregate from slots whose width are 0.6 times the individual mean dimensions.
      - The flakiness index is then reported as the total weight of the material passing the various thickness gauges or sieves, expressed as percentage of the total weight of the sample gauged.
      - Total original weight of the aggregate sample of various fractions = W1+W2+W3+….
      - Total weight of the aggregate passing the various thickness gauges = w1+w2+w3+….

$$\text{Flakiness Index (FI)} = \frac{w1+w2+w3+\cdots.}{W1+W2+W3+\cdots.} * 100\%$$

Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance



- **Non-Destructive Quality Tests**
  - **Shape Test**
    - **Flakiness Index**

Size of aggregate		Thickness gauge (0.6 times the mean sieve), mm	Length gauge (1.8 times the mean sieve), mm
Passing through IS sieve, mm	Retained on IS sieve, mm		
1	2	3	4
63.0	50	33.90	-
50.0	40.0	27.00	81.0
40.0	25.0	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

Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance

- **Non-Destructive Quality Tests**
  - **Shape Test**
    - **Flakiness Index**
      - Significance of Tests
        - Presence of flaky particles results the weak pavement due to the possibilities of breaking down under heavy loads.
        - Recommended values are:
          - Base/Sub-base < 35%
          - Bituminous carpet < 30%
          - Bituminous concrete, penetration macadam, surface dressing, etc. < 25%
          - Bituminous macadam, WBM < 15%

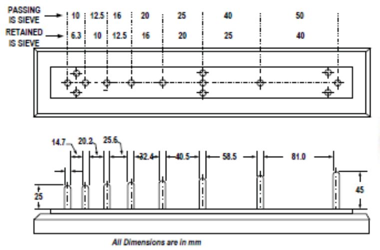
Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance

- **Non-Destructive Quality Tests**
  - **Shape Test**
    - **Elongation Index**
      - Percentage by weight of particles, whose greatest length is greater than 1.8 times their mean dimension.
      - Mean dimension is the average of two adjacent sieve apertures (sizes) between which the particle is retained.

Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance

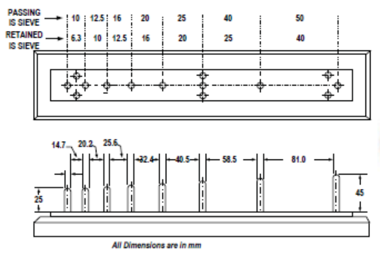


- **Non-Destructive Quality Tests**
  - **Shape Test**
    - **Elongation Index**
      - Sieve the sample through the IS sieves.
      - Take a minimum of 200 pieces of retained on each sieve size.
      - Pass each aggregate from slots whose width are 1.8 times the individual mean dimensions.
      - The elongation index is then reported as the total weight of the material passing the various thickness gauges or sieves, expressed as percentage of the total weight of the sample gauged.
      - Total original weight of the aggregate sample of various fractions = W1+W2+W3+….
      - Total weight of the aggregate retained on the various length gauges = w1+w2+w3+….

$$\text{Elongation Index (FI)} = \frac{w1+w2+w3+\cdots}{W1+W2+W3+\cdots} * 100\%$$

Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance



- **Non-Destructive Quality Tests**
  - **Shape Test**
    - **Elongation Index**

Size of aggregate		Thickness gauge (0.6 times the mean sieve), mm	Length gauge (1.8 times the mean sieve), mm
Passing through IS sieve, mm	Retained on IS sieve, mm		
1	2	3	4
63.0	50	33.90	-
50.0	40.0	27.00	81.0
40.0	25.0	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

Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance

- **Non-Destructive Quality Tests**
  - **Shape Test**
    - **Elongation Index**
      - Significance of Tests
        - Presence of longer particles results the weak pavement due to possibilities of breaking down under heavy loads.
        - Recommended values
          - Base/Sub base < 30%
          - Surface course < 15%

Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance

- **Non-Destructive Quality Tests**
  - **Shape Test**
    - **Angularity Number**
      - 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.
      - Angularity is estimated from properties of voids in a sample after compaction in a particular manner.
      - Angularity number measures the voids in excess of rounded gravel or 33% ranging from 0 to 11.

Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance

15.64 dia x 15.64 height

- **Non-Destructive Quality Tests**
  - **Shape Test**
    - **Angularity Number**
      - Sample is placed in the cylinder and tamped 100 times by the rod.
      - Second and third layers are placed and tamped.
      - Take weight of cylinder and aggregate, find the weight of aggregate (W), specific gravity of aggregate (G_s) and take the weight of water to fill the cylinder (W_W).

$$AN = 67 - \frac{100\,W}{W_W * G_s}$$

Where, W is the weight of aggregate, W_w is the weight of water to fill the cylinder and G_s is the specific gravity of aggregate.

Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance

- **Non-Destructive Quality Tests**
  - **Shape Test**
    - **Angularity Number**
      - Significance of the Test
        - The internal friction of an aggregate is the property, which, by means of the interlocking of particles and the surface friction between adjacent surfaces, resists particle movement under the action of an imposed load.
        - Higher AN value, more angular and less workable.
        - For Bituminous pavement, aggregate with higher AN is preferred as high stability due to interlocking of aggregates. (Values 7-10).

Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance

- **Non-Destructive Quality Tests**
  - **Water Absorption Test**
    - Normally carried out in conjunction with the specific gravity test.
    - The procedure consists of soaking the aggregate sample in distilled water for 24 hours, surface drying and weighing in air, and then oven drying and weighing in air again.
    - 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 the latter.

$$w_A = (w1-w2)*100\%$$

Where, W_A = Water absorption

w1 = Weight of surface dried aggregate in air

w2 = Weight of oven dried aggregate in air

Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance

- **Non-Destructive Quality Tests**
  - **Water Absorption Test**
    - Significance
      - Particularly important in bituminous surface design.
      - Porosity of aggregate affects the amount of binder required and additional binder material may have to be incorporated in the mixture to satisfy the absorption by the aggregate after the ingredients have been mixed.
      - On the beneficial side, porous aggregates usually show better adhesion to the binder due to the mechanical interlock caused by the binder penetrating the particles.
      - The water absorption values allowed for road aggregates normally range from less than 0.1 percent to about 2 percent for materials used in road surfacing while values of up to 4 percent may be accepted in road bases.

Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance

- **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.

Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance

- **Specific Gravity Test**

The test is carried out in the laboratory by soaking a sample of the aggregate in distilled water for 24 hours weighing it in water at the end of this period, surface drying and weighing in air and then weighing in air again after oven drying for 24 hours.

The test is usually carried out in conjunction with water absorption test.

Bulk specific gravity is given by:

$G_b = W/(W_2 - W_1)$

Where, W = weight of oven dry sample in air

W_2 = weight of saturated sample in air

W_1 = weight of saturated sample in water

Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance

- **Specific Gravity Test**

  The average specific gravity of an aggregate composed of fractions of different specific gravity can be calculated from the individual values

$$G_{avg} = \frac{100}{\frac{W1}{G1}+\frac{W2}{G2}+\frac{W3}{G3}}$$

Where G_{avg} is the average specific gravity of the mix materials (final aggregates), W1, W2, W3 are the weight of each sample of aggregate mix and G1, G2 and G3 are their respective specific gravity.

Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance

- **Specific Gravity Test**
  - **Bulk specific gravity and apparent specific gravity**

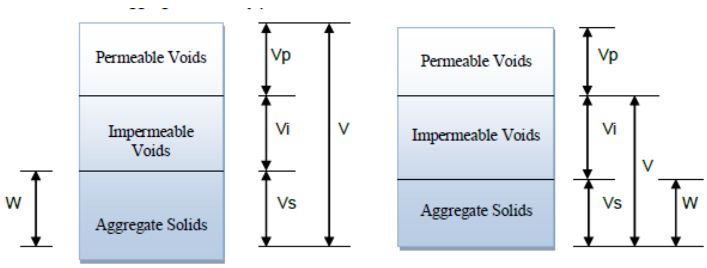


Figure 3.10 Diagram showing to illustrate Bulk and Apparent specific Gravity

$$\text{Bulk Sp. Gr. (G)} = \frac{W}{V} = \frac{W}{Vp + Vi + Vs}$$

$$\text{Apparent Sp. Gr. (G)} = \frac{W}{V} = \frac{W}{Vi + Vs}$$

Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance

- **Specific Gravity Test**
  - As road aggregates are usually proportioned by weight, a specific gravity value is of vital importance in determination of proper mixture.
  - Gradation specifications are valid only if the coarse and fine fractions have approximately the same specific gravity.
  - Fines with higher specific gravity result in harsh mix, lacking fines.
  - Coarse materials with higher specific gravity result in mixes that will be rich in fines.
  - In order to address this problem, i.e. when the specific gravity values of different components vary in a wide range, average specific gravity value may have to be used proper mixing.

Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance

- **Specific Gravity and Water Absorption Test**
  - Apparatus
    - A balance, oven, a wire basket, a container for filling water and suspending the basket.
  - About 2kg 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 hours.
  - The basket and the sample are weighed while suspended in water (W1).
  - Measure the empty weight of basket suspended in water (W2).
  - The aggregates are dried with dry absorbent cloth. The surface dried aggregates are also weighed (W3).
  - The aggregate dried in oven at 110^{o}C for 24$\pm$0.5 hrs and then weighed (W4).

Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance

- **Specific Gravity and Water Absorption Test**
  - Weight of saturated aggregate suspended in water with basket = W1 gm.
  - Weight of basket suspended in water = W2 gm.
  - Weight of saturated surface dry aggregate in air = W3 gm.
  - Weight of oven dry aggregate = W4 gm.
  - Weight of saturated aggregate in water = W1 – W2 gm.
  - Weight of water equal to the volume of the aggregate = W3 – (W1 – W2) gm

$$\text{Bulk specific gravity} = \frac{W4}{W3 - (W1 - W2)}$$

$$\text{Apparent specific gravity} = \frac{W4}{W4 - (W1 - W2)}$$

$$\text{Water absorption} = \frac{W3 - W4}{W4} * 100$$

Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance

- **Durability Tests (Destructive Test)**
  - Destructive tests on aggregate result significant damage to the 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.

Road Aggregates

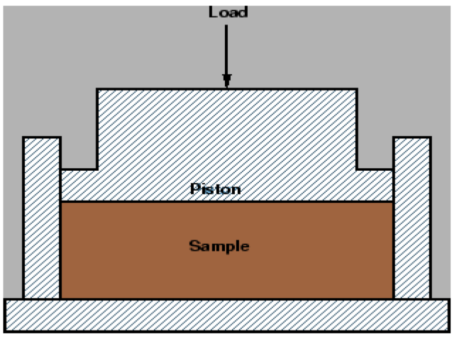
Road Aggregate – Tests on Road Aggregates and their Significance – Durability Tests

- **Crushing Strength Test**
  - The aggregate crushing value provides a relative measure of resistance to crushing under gradually applied crushing load.
  - Dry aggregates passing through 12.5mm sieves and retained on 10mm sieves are filled in a cylindrical measure of 11.5 mm diameter and 18 cm height in three layers.
  - Each layer is tampered 25 times with a standard tamping rod.
  - The test sample is weighed and placed in the test cylinder in three layers each layer being tampered again.
  - Specimen is subjected to a compressive load of 40 tonnes for ten minutes gradually applied at the rate of 4 tonnes per minute.
  - The crushed aggregates are then sieved through 2.36 mm sieve and weight of passing material (W1) is expressed as percentage of the weight of the total sample (W2) which is the aggregate crushing value.

Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance – Durability Tests

- **Crushing Strength Test**
  - Aggregate Crushing Value = $\frac{W1}{W2} * 100$
  - A value of less than 10 signifies an exceptionally strong aggregate while above 35 would normally be regarded as weak aggregate.



Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance – Durability Tests

- **Abrasion Test**
  - Carried out to test the hardness property of aggregates and to decide whether they are suitable for different pavement construction works.
  - Principle of Los Angeles abrasion test is to find the percentage wear due to relative rubbing action between the aggregate and steel balls used as abrasive charge.
  - Consists of circular drum of internal diameter 700mm and length 520mm.
  - Abrasive charge consisting of cast iron spherical balls of 48mm diameters and weight 340-445g is placed in the cylinder along with the aggregates.
  - Number of abrasive spheres varies according to the grading of the sample.
  - Quantity of aggregates (5-10) kg.
  - Cylinder is rotated at the speed of 30-33 rpm for a total of 500-1000 revolutions depending upon the gradation of aggregates.

Road Aggregates

Road Aggregate – Tests on Road A

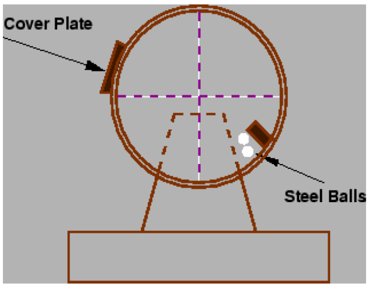
- Abrasion Test

Grading	No of balls	Sample wt, gm
A	12	5000+/-25
B	12	4584+/-25
C	12	3300+/-20
D	12	2500+/-15
E	12	5000+/-25
F	12	5000+/-25
G	12	5000+/-25

Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance – Durability Tests

- **Abrasion Test**
  - After specified revolutions, the material is sieved through 1.7 mm sieve and passed fraction is expressed as percentage total weight of the sample.
  - This value is called Los Angeles Abrasion Value.
    - WBM sub-base course = 60
    - WBM base course with bituminous base course = 50
    - BBM = 50
    - WBM surface course = 40
    - Bituminous penetration macadam = 40
    - Bituminous surface dressing/cement concrete surface course = 40
    - Bituminous concrete surface course = 35



Road Aggregates

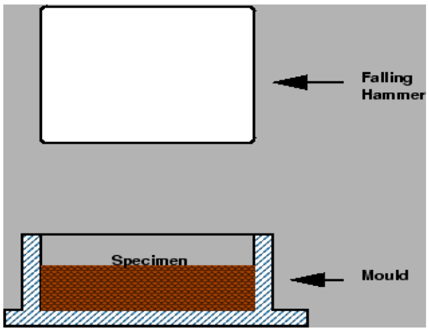
Road Aggregate – Tests on Road Aggregates and their Significance – Durability Tests

- **Impact Test**
  - Carried out to evaluate the resistance to impact of aggregates. AIV gives a relative measure of the resistance of an aggregate to sudden shock or impact.
  - Aggregates passing 12.5mm sieve and retained on 10mm sieve is filled in a cylindrical steel cup of internal diameter 10.2mm and depth 5cm which is attached to a metal base of impact testing machine.
  - Material is filled in 3 layers where each layer is tamped for 25 number of blows.
  - Metal hammer of weight 13.5 to 14 kg is arranged to drop with a free fall of 38 cm by vertical guides and the test specimen is subjected to 15 number of blows.
  - Crushed aggregate is allowed to pass through 2.36 mm IS sieve.
  - Impact value is measured as percentage of aggregates passing in sieve (W1) to the total weight of the sample (W2) Aggregate Impact Value = (W1/W2) * 100

Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance – Durability Tests

- **Impact Test**
  - Aggregates to be used for wearing course, the impact value shouldn't exceed 30%.
  - For bituminous macadam the maximum permissible value is 35%.
  - For Water Bound Macadam base courses, the maximum permissible value defined by IRC is 40%.



Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance – Durability Tests

- **Soundness Test**
  - Intended to study the resistance of aggregates to weathering action, by conducting accelerated weathering test cycles.
  - Porous aggregates subjected to freezing and thawing are likely to disintegrate prematurely.
  - Aggregates of specified size are subjected to cycles of alternated wetting in a saturated solution of either sodium sulphate or magnesium sulphate for 16-18 hours and then dried in oven at 105-110°C to a constant weight.
  - After five cycles, the loss in weight of aggregates is determined by sieving out all undersized particles and weighing.
  - The loss in weight should not exceed 12 percent when tested with sodium sulphate and 18 percent with magnesium sulphate solution.

Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance – Durability Tests

- **Bitumen adhesion test**
  - Bitumen adheres well to all normal types of road aggregates provided they are dry and free from dust.
  - In the absence of water, there is practically no adhesion problem of bituminous construction.
  - Adhesion problem occurs when the aggregate is wet and cold.
  - This problem can be dealt with by removing moisture from the aggregate by drying and increasing the mixing temperature.
  - Further, the presence of water causes stripping of binder from the coated aggregates.
  - This problem occurs when bitumen mixture is permeable to water.
  - Several laboratory tests are conducted to arbitrarily determine the adhesion of bitumen binder to an aggregate in the presence of water.
  - Static immersion test is one specified by IRC and is quite simple.

Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance – Durability Tests

- **Bitumen adhesion test**
  - The principle of the test is by immersing aggregate fully coated with binder in water maintained at temperature 40^oC for 24 hours.
  - The result is reported as the % of stone surface that is stripped off after specified time.
  - IRC has specified maximum stripping value of aggregates should not exceed 5%.

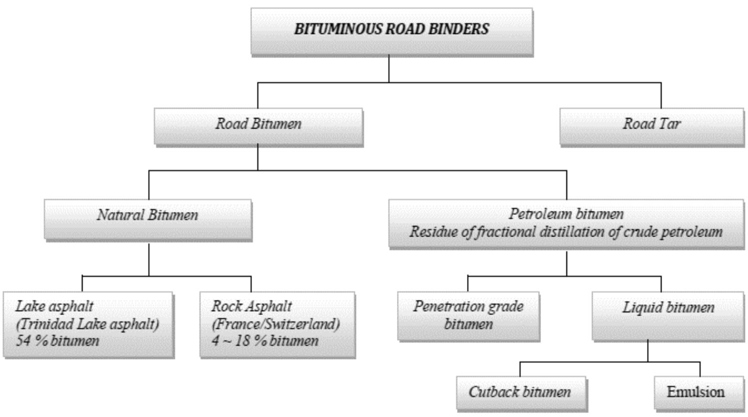
Road Aggregates

Road Aggregate – Tests on Road Aggregates and their Significance – Durability Tests

Property of Aggregate	Type of Test	Test Method
Crushing strength	Crushing test	IS : 2386 (part 4) -1963
Hardness	Los Angeles abrasion test	IS : 2386 (Part 5)-1963
Toughness	Aggregate impact test	IS : 2386 (Part 4)-1963
Durability	Soundness test- accelerated durability test	IS : 2386 (Part 5)-1963
Shape factors	Shape test	IS : 2386 (Part 1)-1963
Specific gravity and porosity	Specific gravity test and water absorption test	IS : 2386 (Part 3)-1963
Adhesion to bitumen	Stripping value of aggregate	IS : 6241-1971

Bituminous Road Binders

Bituminous Road Binders



Bituminous Road Binders

Bituminous Road Binders

- Definition and Classification of Road Binders
- Liquid Bitumen: Cut back & Emulsion
- Tests on Bituminous Binders

Bituminous Road Binders

Bituminous Road Binders

- **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 and aggregate are mixed to create bituminous concrete.
  - Two types of binder is:
    - Bitumen binder
    - Tar binder

Bituminous Road Binders

Bituminous Road Binders

- **Definition and Classification of Road Binders**
  - **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
      - Relatively low cost
    - Bitumen are called hydrocarbon binder

Bituminous Road Binders

Bituminous Road Binders

- **Definition and Classification of Road Binders**
  - **Tar**
    - The viscous black/brown liquid obtained as by product of destructive distillation of organic material such as coal or wood.
    - Also obtained as a byproduct of coke industry for steel plant or gas industry.
    - Proved to be carcinogenic.
    - Coal tar and wood tar.

Bituminous Road Binders

Bituminous Road Binders

- **Definition and Classification of Road Binders**
  - **Tar**
    - **Types of Tar**
      - RT-1, RT-2, RT-3, RT-4 and RT-5 based in part by their viscosity.
      - RT-1 grade have very low viscosity and RT-5 has highest.
      - RT-1 – surface painting in very cold climates
      - RT-2 – standard surface painting
      - RT-3 – surface painting and premixing chips
      - RT-4 – premixing macadam
      - RT-5 – for grouting

Bituminous Road Binders

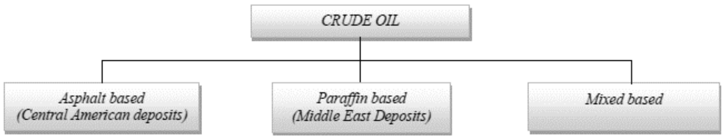
Bituminous Road Binders

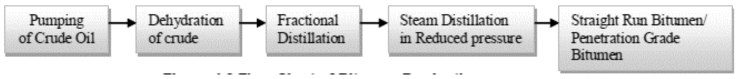
- **Definition and Classification of Road Binders**
  - **Difference between Bitumen and Tar**

Bitumen	Tar
• Byproduct of fractional distillation of crude oil.	• Obtained by destructive distillation of coal.
• Black to dark brown color.	• Brown color.
• Coats aggregate difficultly as compared to tar.	• Coats aggregate more easily in presence of water.
• Less temperature susceptible.	• More temperature susceptible.
• Superior weathering resistance.	• Inferior weathering resistance.
• Contains less free carbon.	• Contains more free carbon.
• Soluble in petroleum oil.	• Does not loss viscosity in oil.

Bituminous Road Binders

Bituminous Road Binders





Bituminous Road Binders

Bituminous Road Binders

- Bituminous materials or asphalts are extensively used for roadway construction, primarily because of their excellent binding characteristics, water proofing properties and relatively low cost.
- Black or dark colored solid or viscous cementing substances consists chiefly high molecular weight hydrocarbons derived from distillation (fractional and destructive) of petroleum or natural asphalt, has adhesive properties**, and is soluble in carbon disulphide/carbon tetrachloride.**
- Residue or by-product when the crude petroleum is refined.
- A wide variety of refinery processes, i.e. the straight distillation process, solvent extraction process, etc. may be used to produced bitumen of different consistency and other desirable properties.
- Depending on the sources and characteristics of the crude oils and on the properties of bitumen required, more than one processing methods may be employed.

Highway Materials

Bitumen – Vacuum Steam Distillation of Petroleum Oil

- Crude oil is heated and is introduced into a large cylindrical vessel.
- Steam is introduced into the still to aid in the vaporization of the more volatile constituents of the petroleum and to minimize decomposition of the distillates and residues.
- The volatile constituents are collected, condensed, and the various fractions stored for further refining, if needed.
- The residues from the distillation are then fed into a vacuum distillation unit, where residue pressure and steam will further separate out heavier gas oils.
- The bottom fraction from this unit is the vacuum-steam-refined asphalt cement.
- The consistency of asphalt cement from this process can be controlled by the amount of heavy gas oil removed.
- Normally, asphalt produced by this process is softer.
- As asphalt cools down to room temperature, it becomes a semi-solid viscous material.

Bituminous Road Binders

Bituminous Road Binders

- **Definition and Classification of Road Binders**
  - **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.
  - **Rock Asphalt**
    - A coarse grained sandstone thoroughly impregnated with bitumen.
    - Asphalt content of about 80-85%, rest are kind of limestone minerals.
      - Gilsonite.

Bituminous Road Binders

Bituminous Road Binders

- **Definition and Classification of Road Binders**
  - **Requirements of Bitumen**
    - Bitumen should not be high temperature susceptible.
      - Mix should not become too soft or unstable during hottest weather.
      - Mix should not become too brittle causing cracks during cold weather.
    - Viscosity of the bitumen at the time of mixing and compaction should be adequate. This can be achieved by use of cutbacks or emulsions of suitable grades or by heating the bitumen and aggregates prior to mixing.
    - There should be adequate affinity and adhesion between the bitumen and aggregates used in the mix.
    - Does not fail under predictable loads.
    - Safe to handle.

Bituminous Road Binders

Bituminous Road Binders

- **Definition and Classification of Road Binders**
- **Paving Bitumen (Asphalt Cement)**
  - By product of the distillation of crude oil.
  - A black, sticky, semisolid and a highly viscous material but readily liquefied by applying heat for mixing with mineral aggregates.
  - Strong and durable, excellent adhesive, water proofing.

Bituminous Road Binders

Bituminous Road Binders

- **Types of Penetration Grade Bitumen**
  - **ASTM D946: Five grades of bitumen**
    - 200-300, 120-150, 85-100, 60-70, 40-50 (higher the penetration, softer the bitumen)
  - **IS:73 – 1961: Five grades of bitumen**
    - 30/40. 40/50, 60/70, 80/100, 175/225 designated as S35, S45, S65, S90, S200
  - **ASTM D3381**
    - AC-5, AC-10, AC-20, AC-30 and AC-40.
    - The numerical values indicate the viscosity at 140°F in hundreds of poise.
  - **IS:73 – 2013**
    - Bitumen is graded by viscosity at 60°C.
    - 4 grades as VG10, VG20, VG30, VG40.

Bituminous Road Binders

Bituminous Road Binders

- **Characteristics of Viscosity Grade Bitumen (IS:73-2013)**

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

Bituminous Road Binders

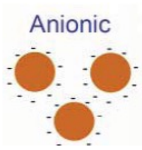
Bituminous Road Binders

- **Liquid Bitumen: Cutback and 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 remains 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, in the water carrier.
    - The emulsion sets as the water evaporates.

Bituminous Road Binders

Bituminous Road Binders

- **Liquid Bitumen: Cutback and Emulsion**
  - **Bitumen Emulsion**
    - Types Based on Emulsifying Agent
      - Anion Emulsion
        - Electro-negatively charged bitumen droplets.
        - Fatty acids and lignin mixed with sodium hydroxide forms soap.
        - Adhere better to aggregate with positive surface charges (eg. Limestone).
      - Cationic Emulsion
        - Electro-positively charged bitumen droplets.
        - Amines (tall oils) or animal fats
        - Adhere better to aggregate with negative surface charges (eg. Sandstone, quartz, siliceous gravel)
        - Also works better with wet aggregates.



Bituminous Road Binders

Bituminous Road Binders

- **Liquid Bitumen: Cutback and Emulsion**
  - **Bitumen Emulsion**
    - **Type Based on Setting Time**
      - 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:**
        - Rapid Setting Emulsion (RS)
        - Medium Setting Emulsion (MS)
        - Slow Setting Emulsion (SS)

Bituminous Road Binders

Bituminous Road Binders

- **Liquid Bitumen: Cutback and Emulsion**
  - **Bitumen Emulsion**
    - **Type Based on Setting Time**
      - **Rapid Setting Emulsion (RS)**
        - Breaks rapidly in contact with aggregate
        - Surface treatments and penetration macadam
      - **Medium Setting Emulsion (MS)**
        - Does not break rapidly in contact with aggregates as RS
        - Open-graded cold mixes
      - **Slow Setting Emulsion (SS)**
        - Does not break down easily in contact with aggregate
        - Tack coat, fog seal, dense-graded cold mixes, and slurry seals

Bituminous Road Binders

Bitumen – Different forms of bitumen

- **Liquid Bitumen: Cutback and Emulsion**
  - **Bitumen Emulsion**
    - **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

Bituminous Road Binders

Bitumen – Different forms of bitumen

- **Liquid Bitumen: Cutback and Emulsion**
  - **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)
      - Medium-Curing (MC)
      - Slow-Curing (SC)

Bituminous Road Binders

Bitumen – Different forms of bitumen

- **Liquid Bitumen: Cutback and Emulsion**
  - **Cut back Bitumen**
    - **Types of Cutback bitumen**
      - **Rapid-Curing (RC)**
        - Produced by adding a solvent of high volatility (eg. Gasoline, naphtha) to bitumen.
        - Used primarily for tack coat and surface treatments.
      - **Medium-Curing (MC)**
        - Produced by adding a solvent of intermediate volatility (eg. Kerosene) to bitumen.
        - Used for primary coat, patching and road-mixing operations.
      - **Slow-Curing (SC)**
        - Produced by adding oils of low volatililty (eg. Diesel or other gas oils) to bitumen.
        - Also called road oils.
        - Used for prime coat, and as dust palliatives.

Bituminous Road Binders

Bitumen – Different forms of bitumen

- **Liquid Bitumen: Cutback and Emulsion**
  - **Cut back Bitumen**
    - **Advantages of Cutback**
      - Substitute of heating
      - Suitable for direct application
      - Good mixing manual method
      - Mix can be transported for long haul without setting
      - Liquefying effect last over a long period

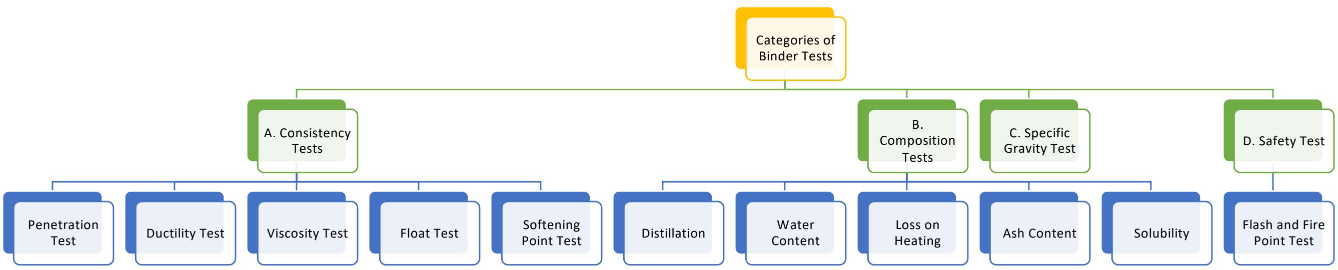
Bituminous Road Binders

Bitumen – Different forms of bitumen

- **Liquid Bitumen: Cutback and Emulsion**
  - **Emulsion vs Cutback Bitumen**
    - Emulsion are relatively pollution free.
    - Solvents used in cutback are high price energy which get wasted into atmosphere while curing.
    - Emulsions are safer to use.
    - Emulsions can be applied at relatively low temperatures saving the fuel costs.
    - Emulsion can also be applied effectively to a damp pavement.

Bituminous Road Binders

Tests on Bituminous Binders



Bituminous Road Binders

Bitumen – Tests on Bitumen – Consistency Tests

- **Consistency Tests**
  - Consistency indicates the property of the binder to flow. It is a function of temperature and types of material.
  - Consistency is measured in terms of penetration, ductility, viscosity, softening point.

Bituminous Road Binders

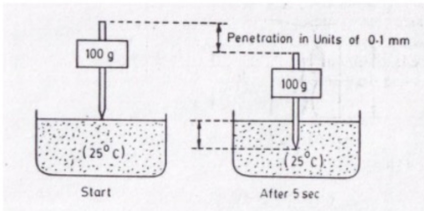
Bitumen – Tests on Bitumen – Consistency Tests

- **Penetration Test**
  - Determines whether the bitumen under specified temperature is hard or soft.
  - This test consists of determining how far a standard steel needle will penetrate vertically into binder under standard conditions of temperature, load and time.
  - The penetrometer consists of a needle assembly with a total of 100gm and device for releasing and locking in any position. There is a graduated dial to read penetration values to $1/10^{th}$ of a millimeter.

Bituminous Road Binders

Bitumen – Tests on Bitumen – Consistency Tests

- **Penetration Test [Procedure]**
  - Bitumen is heated to pouring consistency, stirred thoroughly and poured into testing container to a depth at least 15mm in excess of the expected penetration.
  - The sample containers are placed in a temperature controlled water bath at a temperature of 25^{O}C for one hour.
  - The sample container is taken out and the needle is arranged to make contact with the surface of the sample.
  - The dial is set to zero or the initial reading is taken and the needle is released for 5 seconds.
  - The final reading is taken on the dial gauge.
  - The difference between final and initial value is taken as penetration value.
  - Three penetration tests are made on this sample by testing at distances of at least 10mm apart.



Bituminous Road Binders

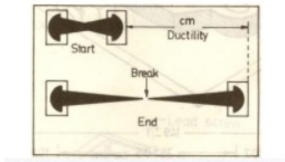
Bitumen – Tests on Bitumen – Consistency Tests

- **Penetration Test [Significance]**
  - Bitumen with low penetration values are known for bad cracking.
  - Lower penetration values are recommended for use in hot climates and higher penetration values in cold climates.
  - Penetration values below 20 have been associated with bad cracking of road surface while cracking rarely occurs when penetration exceeds 30.

Bituminous Road Binders

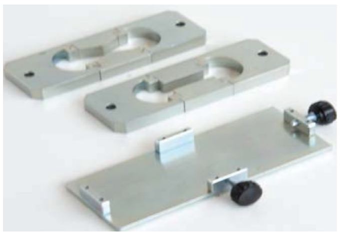
Bitumen – Tests on Bitumen – Consistency Tests

- **Ductility Test**
  - Ductility of bituminous binders is expressed as the distance in centimeters that a standard semi solid briquette will elongate before breaking.
  - The binder which does not possess sufficient ductility would crack under repeated traffic loads.
  - Specified conditions for ductility test are:
    - Mould – 8 shaped standard dimension
    - Temperature – 27°C
    - Pull rate – 50mm/min
    - Starting minimum width – 10mm*10mm
  - The ductility apparatus functions as a constant temperature water bath and a pulling device.



Bituminous Road Binders

Bitumen – Tests on Bitumen - Consistency Tests



- **Ductility Test [Procedure]**
  - The bitumen is heated to the pouring consistency, stirred thoroughly and poured in the mould assembly and placed on plain glass plate.
  - The plate assembly along with the sample is cooled in air and then in water bath maintained at 27°C.
  - The excess bitumen is cut off and the surface is levelled using a hot knife.
  - The mould assembly containing sample is placed in water bath for 85 to 95 minutes.
  - The sides of the mould are removed, the clips hooked to the sample in the ductility apparatus.
  - The distance up to the point of breaking of thread is reported in cm as ductility value.

Bituminous Road Binders

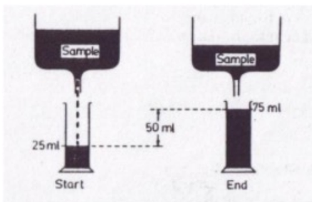
Bitumen – Tests on Bitumen - Consistency Tests

- **Ductility Test [Significance]**
  - The ductility is the measure of adhesives and elasticity of bitumen. It ranges from 5-100cm, the most appropriate value is 50cm. Ductile bitumen forms thin ductile films around aggregates, does not crack under lower temperature.
  - Brittle bitumen does not form ductile films, does crack under lower adverse temperature.
  - High ductility is also usually highly susceptible to temperature changes, while low ones are not.

Bituminous Road Binders

Bitumen – Tests on Bitumen - Consistency Tests

- **Viscosity Test**
  - The viscosity of bitumen in road construction practice is based on the arbitrary test results obtained with orifice type viscometer.
  - This test is carried out to determine the viscosity of bitumen which remains fluid under specified temperature of test.
    - Apparatus – Orifice type viscometer
    - Diameter of orifice – 4 and 10 mm
    - Temperature – 25^{o}C and 40^{o}C
    - Quantity of bitumen – 50cc

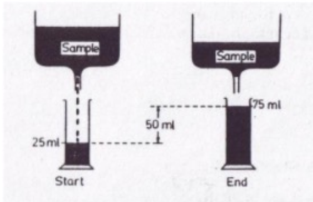


  - Used to determine the viscosity of liquid bitumen like cutback bitumen and emulsion.
  - The standard orifice viscometer test measure the time in second for a 50m of binder liquid to flow from a cup under the above specified test conditions.
  - Higher the viscosity of the binder, higher will be the time required.

Bituminous Road Binders

Bitumen – Tests on Bitumen - Consistency Tests

- **Viscosity Test [Procedure]**
  - Bitumen is heated to 20ºC above the test temperature and allowed to cool.
  - When temperature reaches slightly above the test temperature (40ºC), it is poured into cup of the viscometer upto levelling peg.
  - Receiver is placed under the orifice. Valve is opened after applying kerosene in the receiver.
  - Stop watch is started when cylinder records 50ml.
  - Time is recorded for flow up to a mark of 100ml.



Bituminous Road Binders

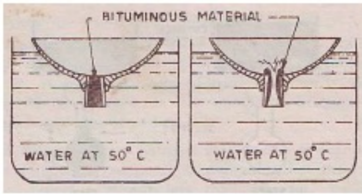
Bitumen – Tests on Bitumen - Consistency Tests

- **Viscosity Test [Significance]**
  - The degree of fluidity of binder at the application temperature determines the quality of mixing.
  - Binder of lower viscosity results in lubrication only.
  - Binder of reasonable viscosity results in uniform film (coat). It results in homogenous mix because of less resistance for mixing.
  - Binder of higher viscosity requires more compaction effort and may result in heterogenous mix.
  - Premix with higher viscosity binder is not easily workable.
  - Premix with lower binder will flow enroute while transporting from plant site to laying site.
  - Binder with low viscosity is required for surface dressing, but too low viscosity will also result in bleeding.

Bituminous Road Binders

Bitumen – Tests on Bitumen - Consistency Tests

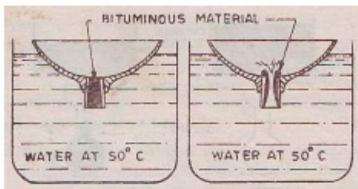
- **Float Test**
  - Float test is the means of determining consistency of bitumen of those ranges of bituminous binder for which both penetration and viscosity tests cannot be applied. (For bitumen with high viscosity).
  - Usually used for heavy tar/bitumen.
  - Viscosity is measured in terms of time taken for water in seconds to force its way through the bitumen plug put in a mould of float test apparatus.
  - The temperature of test is 50°C and the result is known as the float value.



Bituminous Road Binders

Bitumen – Tests on Bitumen - Consistency Tests

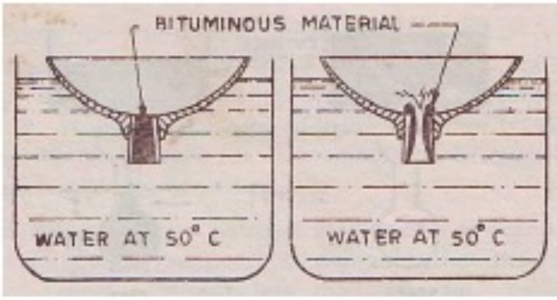
- **Float Test [Procedure]**
  - Melt bitumen to pouring consistency and pour it into the brass collar.
  - Cool it to room temperature for 15 minutes, then place in water maintained at 5°C for 5 minutes.
  - Trim the bitumen flush with the top of the collar by means of spatula.
  - Place the collar and plate in the ice water bath (5±1°C) for 15-30 minutes.
  - Remove and screw the collar into the aluminum float and immerse in water at 5°C 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 and when the water breaks.



Bituminous Road Binders

Bitumen – Tests on Bitumen - Consistency Tests

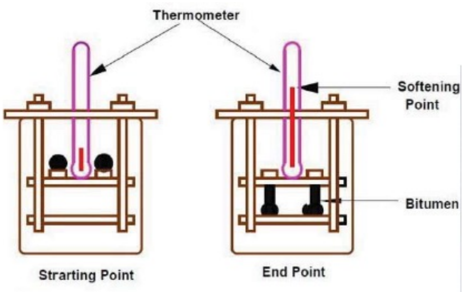
- **Float Test [Significance]**
  - Higher the float test value, stiffer is the bitumen.



Bituminous Road Binders

Bitumen – Tests on Bitumen - Consistency Tests

- **Softening Point Test**
  - Denotes the temperature at which the bitumen attains a particular degree of softening under the specifications of the test.
  - Conducted using Ring and Ball apparatus.



Bituminous Road Binders

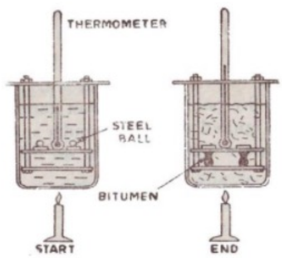
Bitumen – Tests on Bitumen - Consistency Tests

- **Softening Point Test [Procedure]**
  - Heat the material to a temperature between 75-100^{o}C above its softening point and pour it in ring.
  - After cooling for 30 minutes in air, level the material in the ring by a warmed and sharp knife.
  - Assemble the apparatus with the rings, thermometer and ball guides in position.
  - Fill with distilled water to a height of 50mm above the upper surface of the rings and start heating.
  - Heat the water bath at a uniform rate of 5$\pm$0.5^{o}C per minute.
  - As the temperature increases, the bitumen material softens and the ball 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.

Bituminous Road Binders

Bitumen – Tests on Bitumen - Consistency Tests

- **Softening Point Test [Significance]**
  - Higher softening point indicates lower temperature susceptibility (hard) and is preferred in hot climates.
  - Values: 35-70^{o}C.



Bituminous Road Binders

Bitumen – Tests on Bitumen – Composition Tests

- **Distillation test**
  - Used to determine the quantity and quality of volatile constituents and amount of non-volatile residues present in cutback bitumen, binder emulsion.
  - A specified amount of the binder under this test is heated up to 360°C in a standard flask attached to a glass water cooled reflux condenser and a graduated receiver.
  - Specified rate of heating is applied and then the amount of distillate removed from the binder is determined.
  - The result of distillation test can be used to identify the type of volatiles in the binder and on the rate at which these volatile sill be lost under field conditions, enable to close check to be done on the quality of the binders on the road projects, residue after this test can provide useful information ascertain the quality of materials.

Bituminous Road Binders

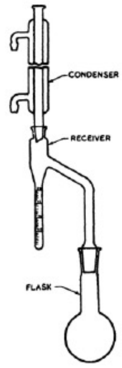
Bitumen – Tests on Bitumen - Composition Tests

- **Water content test**
  - The test is used to determine the amount of water present in a given sample of bitumen.
  - Water content may be determined from distillation test, too.
  - When only water content is to be determined, then this individual test is carried out by mixing pure petrol with the sample heating and distilling.
  - The condensed water is expressed in percentage of total weight of original sample.
  - Determined by Dean and Stark method.

Bituminous Road Binders

Bitumen – Tests on Bitumen - Composition Tests

- **Water content test [Significance]**
  - Place about 100g of sample in the flask and 100ml of petroleum.
  - Attach the flask to the Dean and Stark apparatus and flask 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.
  - Water content in bitumen should be less than 0.2% if bitumen is to be heated above 100ºC. Higher the water content results in foaming when heated.



Bituminous Road Binders

Bitumen – Tests on Bitumen - Composition Tests

- **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.
  - Apparatus consists of oven, aluminum rotating shelf, thermometer, container (55mm diameter and 35mm depth), balance.

Bituminous Road Binders

Bitumen – Tests on Bitumen - Composition Tests

- **Loss on heating test [Procedure]**
  - Heat the sample, stirring constantly to pouring consistency.
  - Place the sample in container and cool to room temperature and then, weight is taken.
  - Bitumen sample is placed in a small container and left for 5 hours in a revolving aluminum shelf oven, the temperature of which is maintained at 165°C.
  - At the end of the heating period, the sample is cooled to room temperature and weigh.
  - Loss in weight of the sample is then expressed as a percentage of the original weight.
  - Also the penetration test is carried out on the residue of the bitumen after loss on heating test.
  - The result obtained is expressed as a percentage of the penetration of the bitumen before loss on heating test.
  - The test is carried out to compare the maximum loss of weight and reduction in penetration value with the specified ones.

Bituminous Road Binders

Bitumen – Tests on Bitumen - Composition Tests

- **Loss on heating test [Significance]**
  - Loss on heating should not be more than 1% by weight and for bitumen 150/200 upto 2% by weight.

Bituminous Road Binders

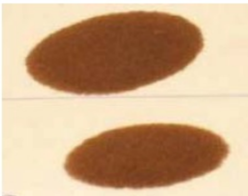
Bitumen – Tests on Bitumen - Composition Tests

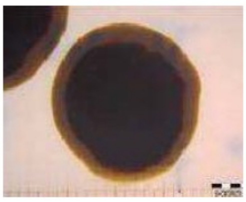
- **Ash content test**
  - The content of bitumen is the percentage by weight of the inorganic residue left after ignition of the bitumen sample.
  - A specified amount of bitumen sample is generally heated until it begins to burn and then it is fired till the ash is free from carbon.
  - The ash content is expressed in percentage of the total weight of the original sample.
  - This test is carried out on both penetration grade or cut back bitumen.
  - Test is used to ensure that undesirable amounts of mineral matters are not present. In general ash content should be less than 1%.

Bituminous Road Binders

Bitumen – Tests on Bitumen - Composition Tests

- **Spot Test**
  - The spot test is used to determine whether or not a bitumen has been damaged during processing due to overheating. This damage is called cracking.
  - A positive result indicates that an asphaltic material has been overheated.
  - 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.





Bituminous Road Binders

Bitumen – Tests on Bitumen - Composition Tests

- **Solubility test (Purity test)**
  - Refined bitumen consists of almost pure bitumen, which by definition is entirely soluble in carbon disulphide.
  - In determining the percentage of solubility of bitumen, different solvents can be used.
  - For bitumen, normally Carbon disulphide (CS_2) is accepted.
  - A specified quantity of bitumen is dissolved in a given quantity of solvent.
  - After filtering the solution through a fine-porosity filter paper, the residue retained is determined and the percentage of soluble material is calculated by the difference.
  - This test determines the amount of impurities in the bitumen expressed as a percentage of original sample.
  - The solubility requirement of bitumen is 99.5% of CS_2.

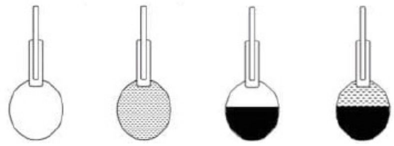
Bituminous Road Binders

Bitumen – Tests on Bitumen – Specific gravity test

- **Specific gravity test**
  - The specific gravity of bitumen is the ratio of the weight of a given volume of material at a given temperature to that of an equal volume of water at same temperature (27^{o}C).
  - Petroleum bitumen have specific gravity values close to unity (0.95-1.05).

Bituminous Road Binders

Bitumen – Tests on Bitumen – Specific gravity test



- **Specific gravity test**
  - **Pycnometer method**
    - The specific 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 27°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 half. The sample bottle is allowed to cool to 27°C and then weighed. The remaining space is filled with distilled water at 27°C.
    - The bottle containing bitumen and water is removed, cleaned from outside and is weighed again.

Bituminous Road Binders

Bitumen – Tests on Bitumen – Specific gravity test

- **Specific gravity test**
  - **Pycnometer method**

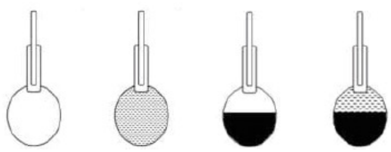
$$\text{Specific gravity} = \frac{(W3-w1)}{(W2-W1)-(W4-W3)}$$

where, w1 is the weight of specific gravity bottle (pycnometer)

w2 is the weight of the specific gravity bottle (pycnometer), filled with distilled water

w3 is the weight of the specific gravity bottle, about half filled with bitumen

w4 is the weight of the specific gravity bottle, about half filled with bitumen and rest with distilled water



Bituminous Road Binders

Bitumen – Tests on Bitumen – Specific gravity test

- **Specific gravity test**
  - **Balance method**
    - Specimen is prepared on brass mould of 12mm size

$$\text{Specific gravity} = \frac{w1}{w1 - w2}$$

where, w1 is the weight of the dry specimen

w2 is the weight of the specimen immersed in distilled water

  - Used to determine the percentage of voids in mixture designed of bitumen and mineral aggregates.

Bituminous Road Binders

Bitumen – Tests on Bitumen – Specific gravity test

- **Specific gravity test [Significance]**
  - Specific gravity is essential to determine the percentage of voids in compacted material.
  - Used to convert the volume measurement of bitumen to the units of mass.

Bituminous Road Binders

Bitumen – Tests on Bitumen – Safety Test

- **Safety test**
  - The flash and fire point tests are the two tests under safety test.
  - The flash point is the lowest temperature at which the vapor of the bitumen binder momentarily takes fire in the form of a flash under specified conditions of the test.
  - The fire point is the lowest temperature at which the bitumen binder gets ignited and burns under specified conditions of the test.
  - The flash point is determined by heating a sample of binder at uniform rate, while periodically passing a small flame across the surface of the material.
  - The temperature at which the vapor given off by the binder first burn with brief flash of blue flame is called the flash point.
  - If the heating is continued until the vapor continues to burn for a period at least by 5 seconds, the temperature is called fire point.

Bituminous Road Binders

Bitumen – Tests on Bitumen – Safety Test

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

Bituminous Road Binders

Bitumen – Tests on Bitumen – Safety Test

- **Safety test [Significance]**
  - Bitumen binders leave out volatile materials when heated at high temperatures depending upon their grade.
  - These volatile agents may catch fire causing flash.
  - The flash point indicates the maximum temperature to which the binder can be safely heated.
  - The flash point of most penetration grade bitumen lies in the range of 245-335^{O}C.
  - The minimum specified flash point of bitumen used in pavement construction is 175^{O}C.
  - The fire point of bitumen is not specified in most work specifications as this point, which is above the flash point, is of little significance in real work situations.

Bituminous Mixes

- **Definition and Classification**

- **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
    - Fine Aggregates
    - Filler
    - Binder

Bituminous Mixes

- **Definition and Classification**

- **Constituent of a mix**
  - **Coarse Aggregates**
    - Material retained on 4.75 mm sieve.
    - Contribute to stability by interlocking properties.
    - Resist compressive strength and abrasive action of traffic.
  - **Fine Aggregates**
    - Material passing through 4.75mm sieve and retained on 75μ sieve.
    - Fills the voids and add stability.
    - Increase resistance due to increase contact surface.

- **Constituent of a mix**
  - **Filler**
    - Material passing through 75μ sieve.
    - Fills the voids, stiffens the binder.
    - Offer impermeability and temperature susceptibility.
  - **Binder**
    - Lubricate all the aggregates, cause particle adhesion, provides flexibility.
    - Eg. Bitumen, Tar

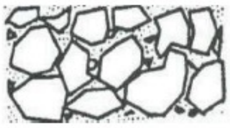
Bituminous Mixes

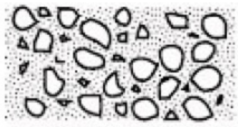
- **Definition and Classification**

- **Desirable Properties**
  - **Stability:** Sufficient stability to bear traffic load without distortion or deformation.
  - **Durability:** Durability is a measure of the resistance of the paving mix against environment and abrasive actions of traffic.
  - **Flexibility**: It is a measure of the ability of the 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:** Mixes should have the highest possible skid resistance to prevent skidding of vehicles.
  - **Workability:** Mix should be capable of being placed and compacted with reasonable effort. Rounded aggregates and reducing sand and filler improve workability.
  - **Sufficient voids:** Sufficient amount of air voids should be available to allow space or expansion of bitumen.

Bituminous Mixes

- **Definition and Classification**
- **Types of Mixes**
  - **Open-graded mix**
    - Only crushed stone and fine aggregates but fillers are missing.
    - Porous but offers good friction.
  - **Gap-graded mix**
    - Kind of grading which lacks one or more intermediate size.
    - Has good fatigue and tensile strength, low workability and is permeable.
  - **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.





Bituminous Mixes

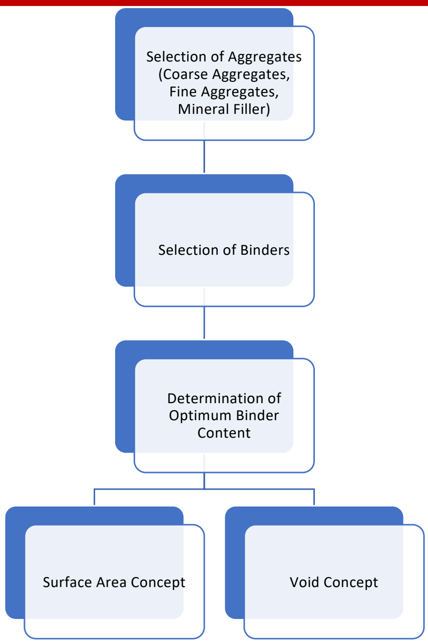
- **Definition and Classification**
- **Types of Mixes as per mixing method**
  - **Hot Mix**
    - Mixture of aggregate (coarse and fine), filler and bitumen are heated and mixed at the production facility at 300-350^{o}C
    - Cools quickly allowing quick setting and is strong but cannot be installed 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.

Bituminous Mixes

- **Definition and Classification**
- **Types of Mixes 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.
  - **Plant Mixed**
    - A mixture of aggregates and bitumen prepared at a central mixing plant.
    - Spread and compacted at the jobsite at near ambient temperature.

Bituminous Mixes

- **Bituminous Mix Design**



Bituminous Mixes

- **Bituminous Mix Design**
- **Selection of Aggregates**
  - Criteria:
    - Proper shape (FI and EI < 30)
    - Strength (ACV < 30%)
    - Hardness (LAA < 30%)
    - Toughness (AIV < 25%)
    - Soundness (12-18%)
    - Water Absorption (<2%)
    - Availability and economic considerations

Bituminous Mixes

- **Bituminous Mix Design**
- **Selection of Binder**
  - Criteria:
    - Consistency sufficiently soft to workability
    - Adequate ductility
    - Resistance to moisture

Penetration Grade	Viscosity Grade	Atmospheric °C
30/40	VG40	15 – 55
50/60	VG30	10 – 50
60/70	VG20	0 – 40
80/100	VG10	- 10 – 30

Bituminous Mixes

- **Bituminous Mix Design**
- **Determination of Optimum Binder Content**
  - Use of optimum binder that gives maximum possible stability.
  - Types include:
    - Surface Area Concept
    - Void Concept

Bituminous Mixes

- **Bituminous Mix Design**
- **Determination of Optimum Binder Content**
  - **Surface Area Concept**
    - Determine amount of binder sufficient to coat the aggregate particles.
    - Use as a guidance at the start of mix design and determine bitumen content in the mix design for low cost roads.
    - The optimum quantity of bitumen content in surface area concept method is determined by Nebraskan formula.

P = AG (0.02a) + 0.06b + 0.10c + Sd

where, P = % by weight of bitumen in the mix

A = absorption modifying factor for aggregates retained on ASTM no. 50 (300micron) sieve

G = Specific gravity correction factor for aggregates retained on ASTM no. 50 sieve and is given by:

G = 2.62/Apparent specific gravity of aggregate

Bituminous Mixes

- **Bituminous Mix Design**
- **Determination of Optimum Binder Content**
  - **Surface Area Concept**

$$P = AG\ (0.02a) + 0.06b + 0.10c + Sd$$

where,

a = % by weight of aggregates retained on ASTM no. 50

b = % by weight of aggregates passing ASTM 50 and retained on ASTM 100 (150 micron)

c = % by weight of aggregates passing ASTM 100(150 micron) and retained on ASTM 200(75 micron)

d = % by weight of aggregates passing ASTM No. 200 (75 micron) sieve

S = an experimental factor depending on the fineness and absorptive characteristics of the material passing ASTM no. 200 sieve (nearly 0.2)

Bituminous Mixes

- **Bituminous Mix Design**
- **Determination of Optimum Binder Content**
  - **Void Concept**
    - It is assumed that the amount of binder content is controlled by the void space in the aggregate framework and the desired volume of voids in the final compacted mixture.
    - 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.
    - Void concept can be applied for the design for the dense bituminous mix and not open graded ones.
    - **Marshall Stability test procedure is used.**

Bituminous Mixes

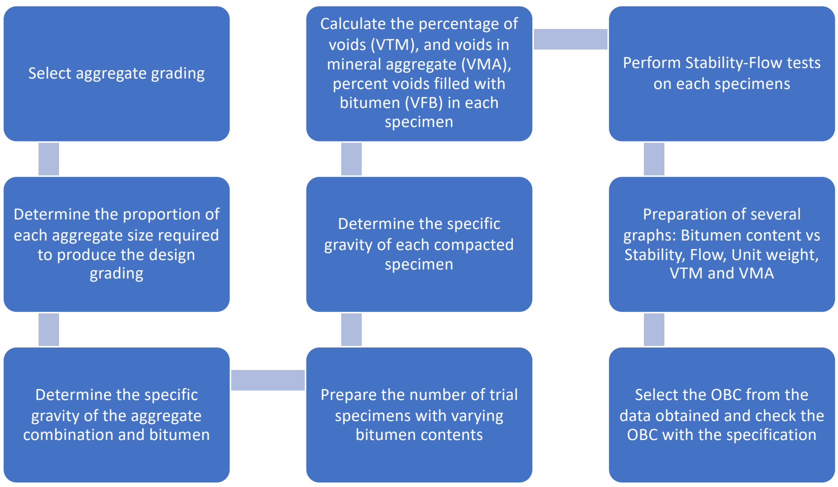
- **Marshall Method of Bitumen Mix Design**

- **Marshall Method of Bitumen Mix Design**
    - Also called wet mix design.
    - Provides the performance prediction measure for the Marshall Mix design method.
    - The stability portion of the test measures the maximum load supported by the test specimen at a loading rate of 50.8 mm/minute.
    - Load is applied to the specimen till failure, and the maximum load is designated as stability.
    - During the loading, an attached dial gauge measures the specimen's plastic flow (deformation) due to the loading.
    - The flow value is recorded in 0.25mm (0.01 inch) increments at the same time when the maximum load is recorded.
    - Two major features of the Marshall method of mix design are: a) Stability-flow tests and b) density-voids analysis.

Bituminous Mixes

- **Marshall Method of Bitumen Mix Design**

- **Marshall Method of Bitumen Mix Design**
    - **Steps**



Bituminous Mixes

- **Marshall Method of Bitumen Mix Design**
- **Marshall Method of Bitumen Mix Design**
  - **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 50.8 mm per minute.
    - The maximum load in kg before failure is stability value and the flow value is the deformation of the specimen in 0.25mm units at failure.
  - **Apparatus**
    - Cylindrical mould, Base plate and collar
    - Compaction pedestal and hammer
    - Sample extruder
    - Breaking head, Dial gauge (flow meter)

Bituminous Mixes

- **Marshall Method of Bitumen Mix Design**
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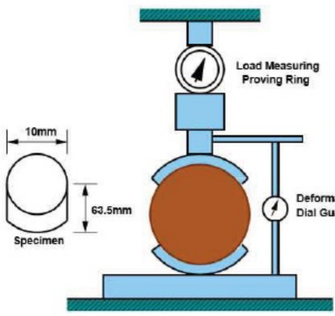

Bituminous Mixes

- **Marshall Method of Bitumen Mix Design – Stability Flow Test**
- **Preparation of Test Specimens**
  - Approximately 1200gm of aggregates and filler is heated to a temperature of 175-190^{o}C.
  - Bitumen is heated to a temperature of 121-125^{o}C with the first trial percentage of bitumen (say 3.5 or 4% by weight of the mineral aggregates).
  - The heated aggregates and bitumen are thoroughly mixed at a temperature of 154-160^{o}C.
  - The mix is placed in a preheated mould and compacted by a rammer with 50 blows on either side at temperature of 138-149^{o}C.
  - The weight of mixed aggregates taken for the preparation of the specimen may be suitably altered to obtain a compacted thickness of 63.5 ± 3 mm.
  - Vary the bitumen content in the next trial by +0.5% and repeat the above procedure. Number of trials are predetermined.

Bituminous Mixes

- **Marshall Method of Bitumen Mix Design – Stability Flow Test**
- **Test Procedure**
  - The diameter and mean height of specimens are measured and then find its weight in air, water and saturated surface dry condition.
  - Immerse specimen in water bath at 60 ± 1^{o}C for 30-40 minutes.
  - Specimens are taken out one by one and tested to determine Marshall stability and flow values.
  - Stability correction:
    - It is possible while making the specimen the thickness slightly vary from the standard specification of 63.5 mm.
    - Stability values need to be corrected to those which would have been obtained if the specimens had been exactly 63.5 mm.
    - This is done by multiplying each measured stability value by an appropriate correlation factors.

- **Marshall Method of Bitumen Mix Design – Stability Flow Test**

- **Test Procedure**
  - Stability correction

Table: 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

- **Marshall Method of Bitumen Mix Design – Stability Flow Test**

- **Test Procedure**
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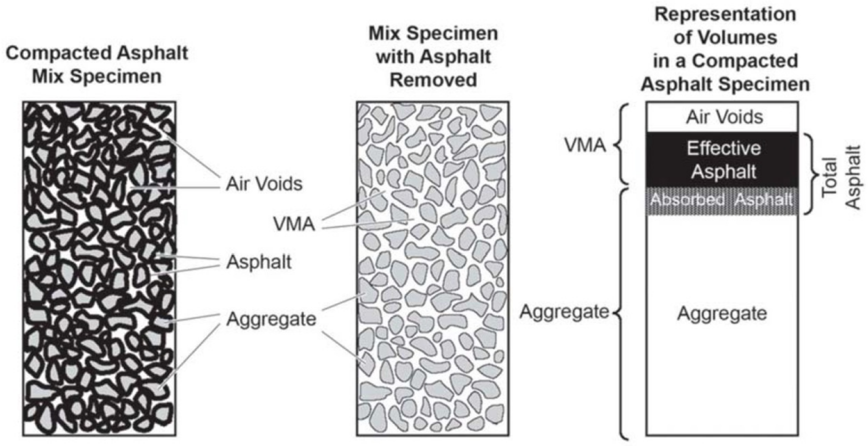
- **Marshall Method of Bitumen Mix Design – Density Void Analysis**

- **Density Void Analvsis**

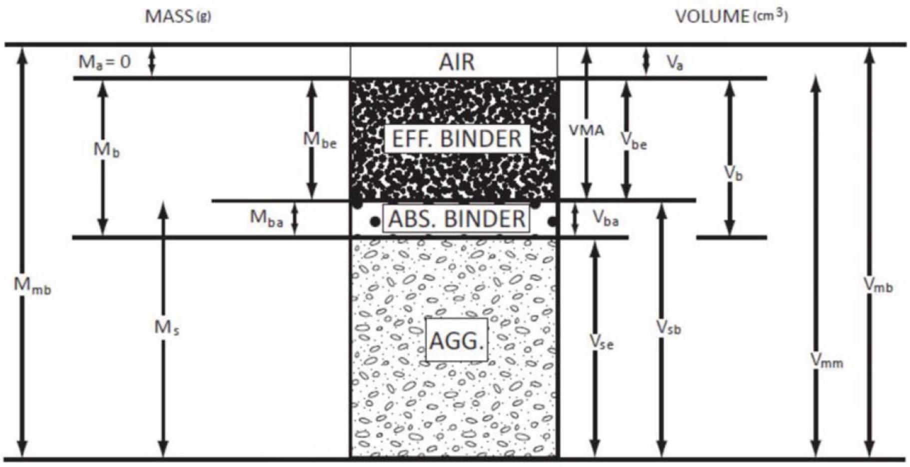


Note: For simplification, the volume of absorbed asphalt is not shown.

Bituminous Mixes

- **Marshall Method of Bitumen Mix Design – Density Void Analysis**

- **Density Void Analysis**



Bituminous Mixes

- **Marshall Method of Bitumen Mix Design – Density Void Analysis**

- **Properties of the Mix**
  - V_a = Volume of air voids
  - $M_{b,}$ V_b, G_b = Weight, Volume and Specific gravity of binder
  - M_{be}, V_{be} = Effective weight and volume of binder
  - M_{ba}, V_{ba} = Absorbed weight and volume of binder
  - $V_{se,}$ V_{sb} = Effective, bulk volume of aggregate
  - M_s = Weight of aggregate
  - $M_{mb,}$ M_{mb}, G_{mb} = Bulk weight, volume, specific gravity of the mix
  - V_{mm}, G_{mm} = Maximum volume, specific gravity of the mix
  - VMA = % Voids in Mineral Aggregate
  - VFB = % Voids Filled with Bitumen

Bituminous Mixes

- **Marshall Method of Bitumen Mix Design – Density Void Analysis**

- **Properties of the Mix**
  - 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:

$$G_{mb} = \frac{m_a}{m_a' - m_w}$$

where, m_a = weight of mix in air

m_a' = SSD weight of mix in air

m_w = weight of mix in air

Bituminous Mixes

- **Marshall Method of Bitumen Mix Design – Density Void Analysis**
- **Properties of the Mix**
  - Theoretical specific gravity of the mix (G_{mm})

$$G_{mm} = \frac{m_a}{V_b+V_c+V_f+V_{mf}} = \frac{m_a}{\frac{m_b}{G_b}+\frac{m_c}{G_c}+\frac{m_f}{G_f}+\frac{m_{mf}}{G_{mf}}}$$

$$G_{mm} = \frac{m_a}{m_a-m_w}$$

where, G_c, G_f, G_{mf}, G_b = specific gravity of coarse, fine, mineral filler and bitumen respectively

m_a, m_f, m_{mf}, m_b = weight of coarse, fine, mineral filler and bitumen respectively

Bituminous Mixes

- **Marshall Method of Bitumen Mix Design – Density Void Analysis**
- **Properties of the Mix**
  - Air Voids (V_V)
    - Air between the bitumen coated aggregate particles. Percentage air voids is represented as:

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

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

where, P_a = % air voids in compacted mixture

G_{mm} = maximum theoretical specific gravity of paving mixture

G_{mb} = bulk specific gravity of paving mixture

- **Marshall Method of Bitumen Mix Design – Density Void Analysis**
- **Properties of the Mix**
  - Voids in Mineral Aggregate (VMA)
    - Volume of voids in the aggregates, and is the sum of air voids and volume of bitumen and is calculated as

$$VMA = \frac{V_a + V_{be}}{V_{mb}} * 100\%$$

$$VMA = 100 - \frac{G_{mb} * P_s}{G_{sb}}$$

where, V_a = % air voids in the mix

V_{be} = % bitumen content in the mix

- **Marshall Method of Bitumen Mix Design – Density Void Analysis**
- **Properties of the Mix**
  - Voids Filled with Bitumen (VFB)
    - Voids in the mineral aggregate framework filled with bitumen.

$$VFB = \frac{V_b}{VMA} * 100$$

$$VFB = \frac{VMA - P_a}{VMA} * 100$$

where, V_b = % bitumen content in the mix

VMA = % voids in the mineral aggregate

Bituminous Mixes

- **Marshall Method of Bitumen Mix Design – Density Void Analysis**
- **Properties of the Mix**
  - Effective Specific Gravity of Aggregate (G_{se})
    - Ratio of mass of an aggregate excluding permeable voids to bitumen at a stated temperature to the mass of equal volume of distilled water.

$$G_{se} = \frac{P_{mm} - P_b}{\frac{P_{mm}}{G_{mm}} - \frac{P_b}{G_b}}$$

where, P_{mm} = Total loose mixture in % by total weight of mixture (100%)

P_b = Bitumen % by total weight of mixture

G_{mm} = Maximum theoretical specific gravity of paving mix (no air voids)

G_b = Specific gravity of bitumen

Bituminous Mixes

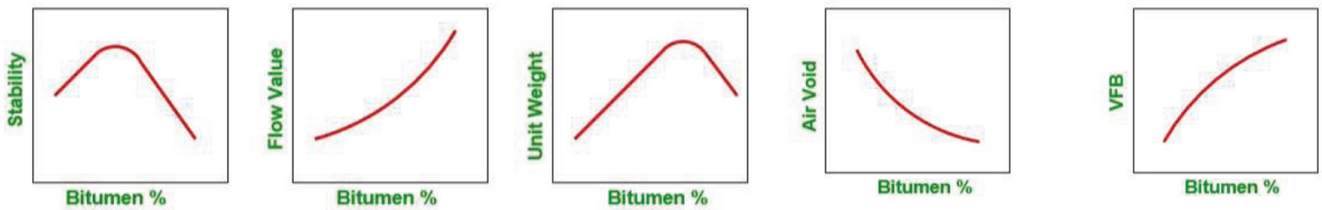
- **Marshall Method of Bitumen Mix Design – Density Void Analysis**
- **Properties of the Mix**
  - Bitumen Absorption (P_{ba}) and Effective Bitumen Content (P_{be})

$$P_{ba} = G_b * \frac{G_{se} - G_{sb}}{G_{sb} * G_{se}} * 100$$

$$P_{be} = P_b - \frac{P_{ba} * P_s}{100}$$

Bituminous Mixes

- **Marshall Method of Bitumen Mix Design**
- **Graphical Plots**
  - Binder content versus corrected Marshall Stability
  - Binder content versus Marshall flow
  - Binder content versus percentage of air voids (P_a) in the total mix
  - Binder content versus voids filled with bitumen (VFB)
  - Binder content versus unit weight or bulk specific gravity (G_{mb})



Bituminous Mixes

- **Marshall Method of Bitumen Mix Design**
- **Determination of Optimum Binder Content**
  - Determine the optimum binder content for the mix design by taking average value of the following three bitumen contents found from the graphs obtained
    - Binder content corresponding to maximum stability (a)
    - Binder content corresponding to maximum unit weight (b)
    - Binder content at specified percent air voids in the total mix (c)

$$OBC = (a+b+c) / 3$$

    - The stability value, flow value and percent voids filled with bitumen at the average value of bitumen content are checked with the Marshall Stability Design specification chart.
  - Mixes with very high stability value and low flow value are not desirable as the pavements constructed with such mixes are likely to develop cracks due to heavy moving loads.

Bituminous Mixes

- **Marshall Method of Bitumen Mix Design**

- **Desired Values**

Minimum Stability (KN at 60°C)	9.0
Minimum Flow (mm)	2
Maximum Flow (mm)	4
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)	
Percent voids filled with bitumen (VFB)	65-75
Loss of stability on immersion in water at 60°C	Minimum 75% retained strength

Bituminous Mixes

- **Marshall Method of Bitumen Mix Design**

- Find the optimum binder content from the laboratory results below. Bulk specific gravity of aggregate (G_{sb}) = 2.628, specific gravity of bitumen (G_b) = 1.02. Also find effective specific gravity of mix, absorbed bitumen, effective bitumen content.

% Bitumen	Diameter of specimen (mm)	Max. theoretical specific gravity (G_{mm}) (gm)	Weight of specimen in air (gm)	Weight of specimen in water (gm)	SSD weight of specimen in air (gm)	Stability (kg)	Flow (mm)
4.5	66.2	2.47	1240.2	712.6	1248.3	1109	3.3
4.75	65.4	2.461	1244.3	722.7	1251.5	1231	3.57
5.0	64.5	2.452	1238.8	723.1	1244.9	1266	4.1
5.25	64.9	2.443	1250.2	730.5	1255.8	1175	4.34
5.5	64.8	2.434	1248.5	728.8	1253.9	1027	4.68

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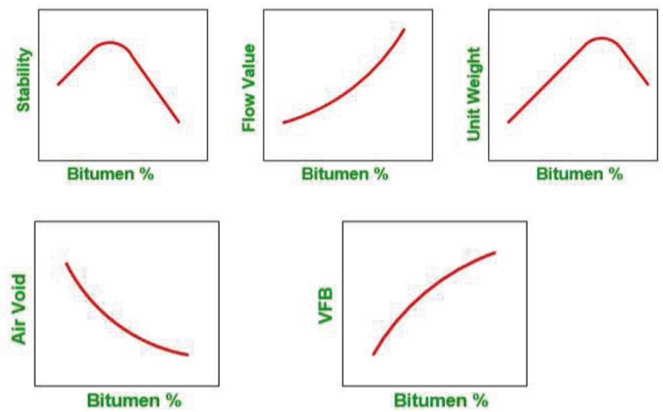

Bituminous Mixes

- **Marshall Method of Bitumen Mix Design**

% Bitumen	Diameter of specimen (mm)	Max. theoretical specific gravity (G_{mm}) (gm)	Weight of specimen in air (gm)	Weight of specimen in water (gm)	SSD weight of specimen in air (gm)	Stability (kg)	Flow (mm)	Correction Factor
4.5	66.2	2.47	1240.2	712.6	1248.3	1109	3.3	0.94
4.75	65.4	2.461	1244.3	722.7	1251.5	1231	3.57	0.95
5.0	64.5	2.452	1238.8	723.1	1244.9	1266	4.1	0.97
5.25	64.9	2.443	1250.2	730.5	1255.8	1175	4.34	0.965
5.5	64.8	2.434	1248.5	728.8	1253.9	1027	4.68	0.967

Table: Correction factors for Marshall stability values

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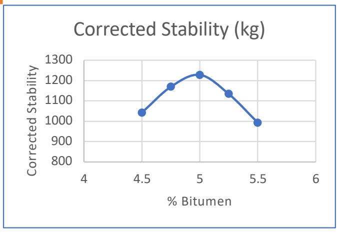
Bituminous Mixes

- **Marshall Method of Bitumen Mix Design**

% Bitumen	Diameter of specimen (mm)	Max. theoretical specific gravity (G_{mm}) (gm)	Weight of specimen in air (gm)	Weight of specimen in water (gm)	SSD weight of specimen in air (gm)	Stability (kg)	Flow (mm)	Correction Factor	Corrected Stability (kg)
4.5	66.2	2.47	1240.2	712.6	1248.3	1109	3.3	0.94	1042.46
4.75	65.4	2.461	1244.3	722.7	1251.5	1231	3.57	0.95	1169.45
5.0	64.5	2.452	1238.8	723.1	1244.9	1266	4.1	0.97	1228.02
5.25	64.9	2.443	1250.2	730.5	1255.8	1175	4.34	0.965	1133.875
5.5	64.8	2.434	1248.5	728.8	1253.9	1027	4.68	0.967	993.109



Bituminous Mixes

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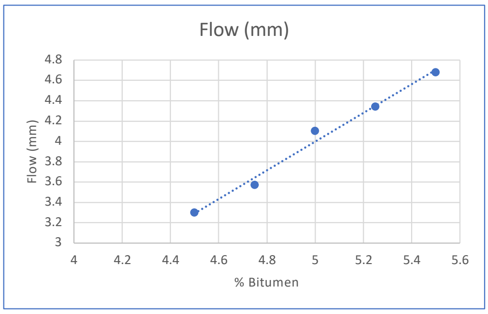

Bituminous Mixes

- **Marshall Method of Bitumen Mix Design**

- Bulk specific gravity of aggregate (G_{sb}) = 2.628, specific gravity of bitumen (G_b) = 1.02.

% Bitumen	Diameter of specimen (mm)	Max. theoretical specific gravity (G_{mm}) (gm)	Weight of specimen in air (gm)	Weight of specimen in water (gm)	SSD weight of specimen in air (gm)	Stability (kg)	Flow (mm)	Bulk (actual) specific gravity of the mix (Gmb)
4.5	66.2	2.47	1240.2	712.6	1248.3	1109	3.3	2.315101736
4.75	65.4	2.461	1244.3	722.7	1251.5	1231	3.57	2.35306354
5.0	64.5	2.452	1238.8	723.1	1244.9	1266	4.1	2.37408969
5.25	64.9	2.443	1250.2	730.5	1255.8	1175	4.34	2.379973349
5.5	64.8	2.434	1248.5	728.8	1253.9	1027	4.68	2.377642354

$$G_{mb} = \frac{m_a}{m_a' - m_w}$$

where, m_a = weight of mix in air

m_a' = SSD weight of mix in air

m_w = weight of mix in air

Bituminous Mixes

- **Marshall Method of Bitumen Mix Design**

% Bitumen	Diameter of specimen (mm)	Max. theoretical specific gravity (G_{mm}) (gm)	Weight of specimen in air (gm)	Weight of specimen in water (gm)	SSD weight of specimen in air (gm)	Stability (kg)	Flow (mm)	Bulk (actual) specific gravity of the mix (Gmb)
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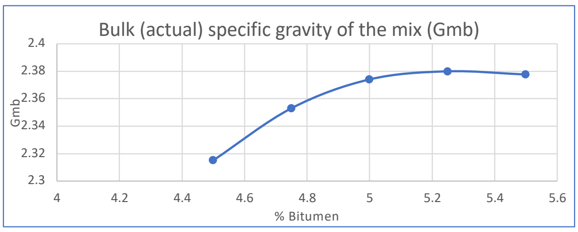

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% Bitumen	Diameter of specimen (mm)	Max. theoretical specific gravity (G_{mm}) (gm)	Weight of specimen in air (gm)	Weight of specimen in water (gm)	SSD weight of specimen in air (gm)	Stability (kg)	Flow (mm)	Percentage air voids
4.5	66.2	2.47	1240.2	712.6	1248.3	1109	3.3	6.271184775
4.75	65.4	2.461	1244.3	722.7	1251.5	1231	3.57	4.385878095
5.0	64.5	2.452	1238.8	723.1	1244.9	1266	4.1	3.177418861
5.25	64.9	2.443	1250.2	730.5	1255.8	1175	4.34	2.579887492
5.5	64.8	2.434	1248.5	728.8	1253.9	1027	4.68	2.315433285

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

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

where, P_a = % air voids in compacted mixture

G_{mm} = maximum theoretical specific gravity of paving mixture

G_{mb} = bulk specific gravity of paving mixture

Bituminous Mixes

- **Marshall Method of Bitumen Mix Design**

% Bitumen	Diameter of specimen (mm)	Max. theoretical specific gravity (G_{mm}) (gm)	Weight of specimen in air (gm)	Weight of specimen in water (gm)	SSD weight of specimen in air (gm)	Stability (kg)	Flow (mm)	Percentage air voids
4.5	66.2	2.47	1240.2	712.6	1248.3	1109	3.3	6.271184775
4.75	65.4	2.461	1244.3	722.7	1251.5	1231	3.57	4.385878095
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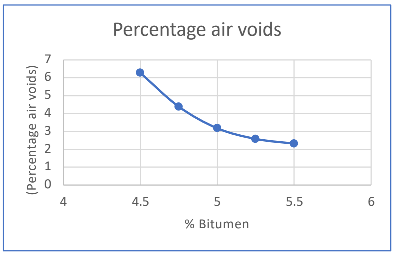
5.5	64.8	2.434	1248.5	728.8	1253.9	1027	4.68	2.315433285



Bituminous Mixes

- **Marshall Method of Bitumen Mix Design**

- Bulk specific gravity of aggregate (G_{sb}) = 2.628, specific gravity of bitumen (G_b) = 1.02.

% Bitumen	Diameter of specimen (mm)	Max. theoretical specific gravity (G_{mm}) (gm)	Weight of specimen in air (gm)	Weight of specimen in water (gm)	SSD weight of specimen in air (gm)	Stability (kg)	Flow (mm)	Bulk (actual) specific gravity of the mix (Gmb)	PS	Voids in Mineral Aggregates (VMA)	Percentage air voids	Voids Filled with Bitumen (VFB)
4.5	66.2	2.47	1240.2	712.6	1248.3	1109	3.3	2.315101736	95.5	15.87054194	6.271184775	60.48537724
4.75	65.4	2.461	1244.3	722.7	1251.5	1231	3.57	2.35306354	95.25	14.7148774	4.385878095	70.19426003
5.0	64.5	2.452	1238.8	723.1	1244.9	1266	4.1	2.37408969	95	14.17864517	3.177418861	77.59010947
5.25	64.9	2.443	1250.2	730.5	1255.8	1175	4.34	2.379973349	94.75	14.1923612	2.579887492	81.82199948
5.5	64.8	2.434	1248.5	728.8	1253.9	1027	4.68	2.377642354	94.5	14.50258659	2.315433285	84.03434263

$$VMA = 100 - \frac{G_{mb} * P_s}{G_{sb}}$$

where, V_a = % air voids in the mix

V_{be} = % bitumen content in the mix

$$VFB = \frac{VMA - P_a}{VMA} * 100$$

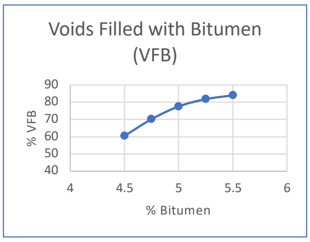
where, V_b = % bitumen content in the mix

VMA = % voids in the mineral aggregate

Bituminous Mixes

- **Marshall Method of Bitumen Mix Design**

% Bitumen	Diameter of specimen (mm)	Max. theoretical specific gravity (G_{mm}) (gm)	Weight of specimen in air (gm)	Weight of specimen in water (gm)	SSD weight of specimen in air (gm)	Stability (kg)	Flow (mm)	PS	Voids in Mineral Aggregates (VMA)	Voids Filled with Bitumen (VFB)
4.5	66.2	2.47	1240.2	712.6	1248.3	1109	3.3	95.5	15.87054194	60.48537724
4.75	65.4	2.461	1244.3	722.7	1251.5	1231	3.57	95.25	14.7148774	70.19426003
5.0	64.5	2.452	1238.8	723.1	1244.9	1266	4.1	95	14.17864517	77.59010947
5.25	64.9	2.443	1250.2	730.5	1255.8	1175	4.34	94.75	14.1923612	81.82199948
5.5	64.8	2.434	1248.5	728.8	1253.9	1027	4.68	94.5	14.50258659	84.03434263



Bituminous Mixes

- **Marshall Method of Bitumen Mix Design**

% Bitumen	Diameter of specimen (mm)	Max. theoretical specific gravity (G_{mm}) (gm)	Weight of specimen in air (gm)	Weight of specimen in water (gm)	SSD weight of specimen in air (gm)	Stability (kg)	Flow (mm)	Bulk (actual) specific gravity of the mix (Gmb)	Percentage air voids	PS	Voids in Mineral Aggregates (VMA)	Voids Filled with Bitumen (VFB)	Correction Factor	Corrected Stability (kg)
4.5	66.2	2.47	1240.2	712.6	1248.3	1109	3.3	2.315101736	6.271184775	95.5	15.87054194	60.48537724	0.94	1042.46
4.75	65.4	2.461	1244.3	722.7	1251.5	1231	3.57	2.35306354	4.385878095	95.25	14.7148774	70.19426003	0.95	1169.45
5	64.5	2.452	1238.8	723.1	1244.9	1266	4.1	2.37408969	3.177418861	95	14.17864517	77.59010947	0.97	1228.02
5.25	64.9	2.443	1250.2	730.5	1255.8	1175	4.34	2.379973349	2.579887492	94.75	14.1923612	81.82199948	0.965	1133.875
5.5	64.8	2.434	1248.5	728.8	1253.9	1027	4.68	2.377642354	2.315433285	94.5	14.50258659	84.03434263	0.967	993.109

Bituminous Mixes

- **Marshall Method of Bitumen Mix Design**

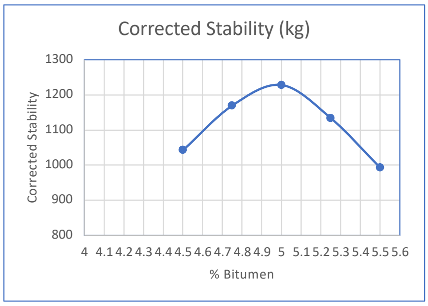
- **Determination of Optimum Binder Content**
  - Determine the optimum binder content for the mix design by taking average value of the following three bitumen contents found from the graphs obtained
    - Binder content corresponding to maximum stability (a)
    - Binder content corresponding to maximum unit weight (b)
    - Binder content at specified percent air voids in the total mix (c) – Take for 4%

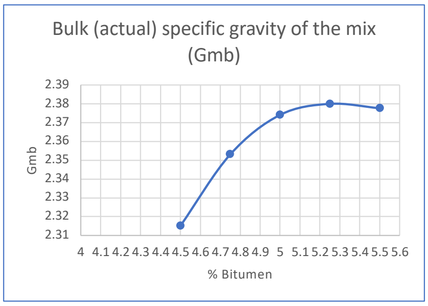
$$OBC = (a+b+c) / 3$$

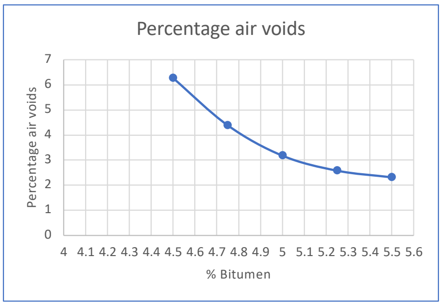
    - The stability value, flow value and percent voids filled with bitumen at the average value of bitumen content are checked with the Marshall Stability Design specification chart.
  - Mixes with very high stability value and low flow value are not desirable as the pavements constructed with such mixes are likely to develop cracks due to heavy moving loads.

Bituminous Mixes

- **Marshall Method of Bitumen Mix Design**







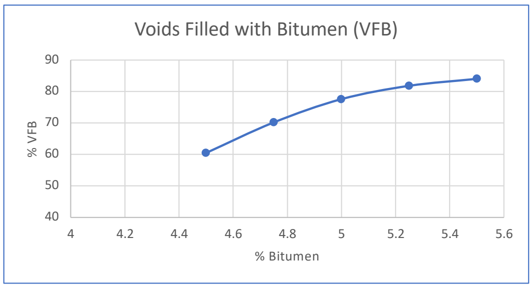
- Binder content corresponding to maximum stability (a) = 5%
- Binder content corresponding to maximum unit weight (b) = 5.25 %
- Binder content at specified percent air voids in the total mix (c) – Take for 4% = 4.82%

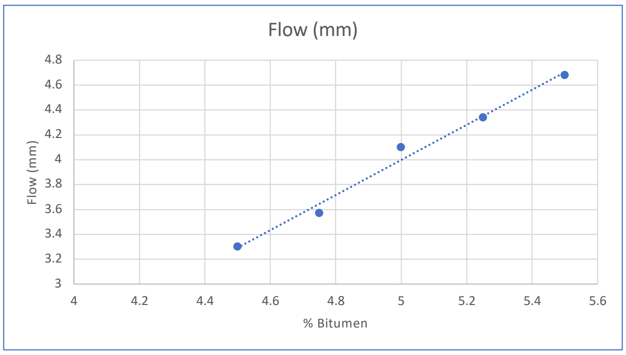
OBC = (a+b+c) / 3

OBC = (5+5.25+4.82)/3 = 5.02%

Bituminous Mixes

- **Marshall Method of Bitumen Mix Design**





Bituminous Mixes

- **Marshall Method of Bitumen Mix Design**

Bulk specific gravity of aggregate (G_{sb}) = 2.628, specific gravity of bitumen (G_b) = 1.02.

% Bitumen	Diameter of specimen (mm)	Max. theoretical specific gravity (G_{mm}) (gm)	Weight of specimen in air (gm)	Weight of specimen in water (gm)	SSD weight of specimen in air (gm)	Stability (kg)	Flow (mm)	Bulk (actual) specific gravity of the mix (Gmb)	Percentage air voids	PS	Voids in Mineral Aggregates (VMA)	Voids Filled with Bitumen (VFB)	Correction Factor	Corrected Stability (kg)
4.5	66.2	2.47	1240.2	712.6	1248.3	1109	3.3	2.315101736	6.271184775	95.5	15.87054194	60.48537724	0.94	1042.46
4.75	65.4	2.461	1244.3	722.7	1251.5	1231	3.57	2.35306354	4.385878095	95.25	14.7148774	70.19426003	0.95	1169.45
5	64.5	2.452	1238.8	723.1	1244.9	1266	4.1	2.37408969	3.177418861	95	14.17864517	77.59010947	0.97	1228.02
5.25	64.9	2.443	1250.2	730.5	1255.8	1175	4.34	2.379973349	2.579887492	94.75	14.1923612	81.82199948	0.965	1133.875
5.5	64.8	2.434	1248.5	728.8	1253.9	1027	4.68	2.377642354	2.315433285	94.5	14.50258659	84.03434263	0.967	993.109

$$P_{ba} = G_b * \frac{G_{se} - G_{sb}}{G_{sb} * G_{se}} * 100$$

$$P_{be} = P_b - \frac{P_{ba} * P_s}{100}$$

$$G_{se} = \frac{P_{mm} - P_b}{\frac{P_{mm}}{G_{mm}} - \frac{P_b}{G_b}}$$

where, P_{mm} = Total loose mixture in % by total weight of mixture (100%)

P_b = Bitumen % by total weight of mixture

G_{mm} = Maximum theoretical specific gravity of paving mix (no air voids)

G_b = Specific gravity of bitumen

- **Marshall Method of Bitumen Mix Design**

% Bitumen	Diameter of specimen (mm)	Max. theoretical specific gravity (G_{mm}) (gm)	Weight of specimen in air (gm)	Weight of specimen in water (gm)	SSD weight of specimen in air (gm)	Stability (kg)	Flow (mm)	Bulk (actual) specific gravity of the mix (Gmb)	Percentage air voids	PS	Voids in Mineral Aggregates (VMA)	Voids Filled with Bitumen (VFB)	Correction Factor	Corrected Stability (kg)	Gse	Pba	Pbe
4.5	66.2	2.47	1240.2	712.6	1248.3	1109	3.3	2.315101736	6.271184775	95.5	15.87054194	60.48537724	0.94	1042.46	2.647331243	0.283417264	4.229336513
4.75	65.4	2.461	1244.3	722.7	1251.5	1231	3.57	2.35306354	4.385878095	95.25	14.7148774	70.19426003	0.95	1169.45	2.6475229	0.286206452	4.477388354
5	64.5	2.452	1238.8	723.1	1244.9	1266	4.1	2.37408969	3.177418861	95	14.17864517	77.59010947	0.97	1228.02	2.647635391	0.287843343	4.726548824
5.25	64.9	2.443	1250.2	730.5	1255.8	1175	4.34	2.379973349	2.579887492	94.75	14.1923612	81.82199948	0.965	1133.875	2.64766718	0.288305883	4.976830175
5.5	64.8	2.434	1248.5	728.8	1253.9	1027	4.68	2.377642354	2.315433285	94.5	14.50258659	84.03434263	0.967	993.109	2.647616715	0.287571596	5.228244842

Bituminous Mixes

- **Marshall Method of Bitumen Mix Design**
- A specimen of asphaltic concrete has a height of 6.35cm and diameter 10.2cm. The weights of compacted specimen in air and water are 1180.5gm and 678.6gm respectively. The analysis of the specimen yielded the following:

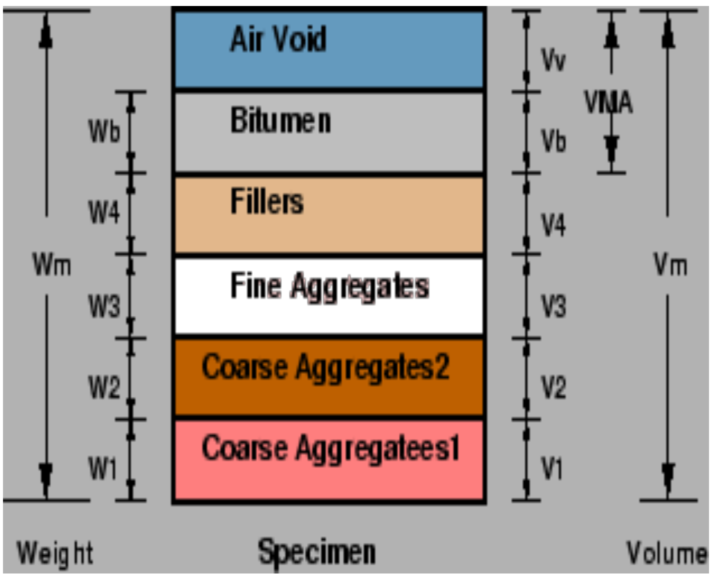
Material	Bulk specific gravity	Mix composition (% wt. of mix)	Aggregate composition (% by of total aggregates)
Bitumen	1.02	6	
Coarse aggregate	2.6	54	55.3
Fine aggregate	2.72	33.5	36.8
Mineral filler	2.7	6.5	7.9
	Total	100	100

- Calculate:
  - Bulk density of specimen from dimension and immersion test.
  - Air voids percentage in compacted mix.
  - VMA and VFB.

Bituminous Mixes

Marshall Mix Design (Wet Mix)

- Marshall Mould
  - Properties of the mix
    - Theoretical specific gravity G_t
    - Bulk specific gravity of the mix G_m
    - Percent air voids V_v
    - Percent volume of bitumen V_b
    - Percent void in mixed aggregate VMA
    - Percent voids filled with bitumen VFB



Theoretical specific gravity of the mix G_t

Theoretical specific gravity G_t is the specific gravity without considering air voids, and is given by:

$$G_t = \frac{W_1 + W_2 + W_3 + W_b}{\frac{W_1}{G_1} + \frac{W_2}{G_2} + \frac{W_3}{G_3} + \frac{W_b}{G_b}} \quad (1)$$

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

Bulk specific gravity of mix G_m

The bulk specific gravity or the actual specific gravity of the mix G_m is the specific gravity considering air voids and is found out by:

$$G_m = \frac{W_m}{W_m - W_w} \quad (2)$$

where, W_m is the weight of mix in air, W_w is the weight of mix in water, Note that $W_m - W_w$ gives the volume of the mix. Sometimes to get accurate bulk specific gravity, the specimen is coated with thin film of paraffin wax, when weight is taken in the water. This, however requires to consider the weight and volume of wax in the calculations.

Air voids percent V_v

Air voids V_v is the percent of air voids by volume in the specimen and is given by:

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

where G_t is the theoretical specific gravity of the mix, given by equation 26.1. and G_m is the bulk or actual specific gravity of the mix given by equation 26.2.

Percent volume of bitumen V_b

The volume of bitumen V_b is the percent of volume of bitumen to the total volume and given by:

$$V_b = \frac{\frac{W_b}{G_b}}{\frac{W_1+W_2+W_3+W_b}{G_m}} \quad (4)$$

where, W_1 is the weight of coarse aggregate in the total mix, W_2 is the weight of fine aggregate in the total mix, W_3 is the weight of filler in the total mix, W_b is the weight of bitumen in the total mix, G_b is the apparent specific gravity of bitumen, and G_m is the bulk specific gravity of mix given by equation 26.2.

Voids in mineral aggregate VMA

Voids in mineral aggregate VMA is the volume of voids in the aggregates, and is the sum of air voids and volume of bitumen, and is calculated from

$$VMA = V_v + V_b \quad (5)$$

where, V_v is the percent air voids in the mix, given by equation 26.3. and V_b is percent bitumen content in the mix, given by equation 26.4. (4).

Bituminous Mixes

Voids filled with bitumen VFB

Voids filled with bitumen VFB is the voids in the mineral aggregate frame work filled with the bitumen, and is calculated as:

$$VFB = \frac{V_b \times 100}{VMA} \quad (6)$$

where, V_b is percent bitumen content in the mix, given by equation 26.4. and VMA is the percent voids in the mineral aggregate, given by equation 26.5.

Marshall Mix Design (Wet Mix)

- Determination of Optimum Binder Content (OBC)

Table: Marshall mix design specification

Test Property	Specified Value
Marshall stability, kg	340 (minimum)
Flow value, 0.25 mm units	8 - 17
Percent air voids in the mix %	3 - 5
Voids filled with bitumen %	75 - 85

Thank You!

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