B.Sc - Road & Railway Design I. *Lecture 8.*

MATERIALS OF ASPHALT MIXTURES & QUALITY CONTROL

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ASPHALT

- ***Asphalt*** **- that name is almost universally used for the road-paving material made from a mixture of gravel, sand (*mineral aggregates*) and other *fillers* (limestone dust) in a *bituminous binder***
- **It is a *composite material* laid in layers, and compacted, commonly used to surface roads, parking lots and airfields**

- **The terms "asphalt concrete", "bituminous asphalt concrete" and "bituminous mixture" are typically used only in engineering and construction documents, which define *concrete* as any *composite material* composed of mineral aggregate (crushed stones) adhered with a binder**

BITUMEN

- *Bitumen* is a black, dense, highly viscous, petroleum-based hydrocarbon that is found in deposits such as oil sands and pitch lakes (natural bitumen) or is obtained as a residue of the distillation of crude oil (refined bitumen)
- Blending the higher and lower viscosity residues in the required proportions can take place at the refinery, at terminals or at a third party facility
- Each processing technique results in different grades of bitumen products, including:
  - *Hard grade* or *coarse grade bitumens* – used for paving high class roads
  - *Cutback bitumens* - blends of penetration bitumens with a solvent such as kerosene or diesel oil used for paving secondary roads
  - *Bitumen emulsions* – stabilised suspensions of bitumen in water used for maintenance and surface coating of secondary roads
  - *Polymer modified bitumens* – mixtures of selected bitumens with polymers, such as thermoplastics or elastomers

REQUIRED PROPERTIES OF BITUMEN 1

- In general, the bitumen should possess the following desirable properties:
  - The bitumen should not be *highly temperature susceptible*: during the hottest weather the mix should not become too soft or unstable, and during cold weather the mix should not become too brittle causing cracks
  - The *viscosity* (internal friction) 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 & adhesion* between the bitumen and aggregates used in the mix

REQUIRED PROPERTIES OF BITUMEN 2

- Good *adhesion*: bitumen has the ability to adhere to a solid surface in a fluid state depending on the nature of the surface; the presence of water or dust on the surface will prevent adhesion
- Appropriate *resistance to hardening* (caused by oxydation): the viscous or flow properties of bitumen are of importance both at high temperature during processing and application and at low temperature to which bitumen is subjected during service; since they vary considerably with temperature, stress conditions and age (deterioration, or loss of the desirable flow properties takes the form of hardening)

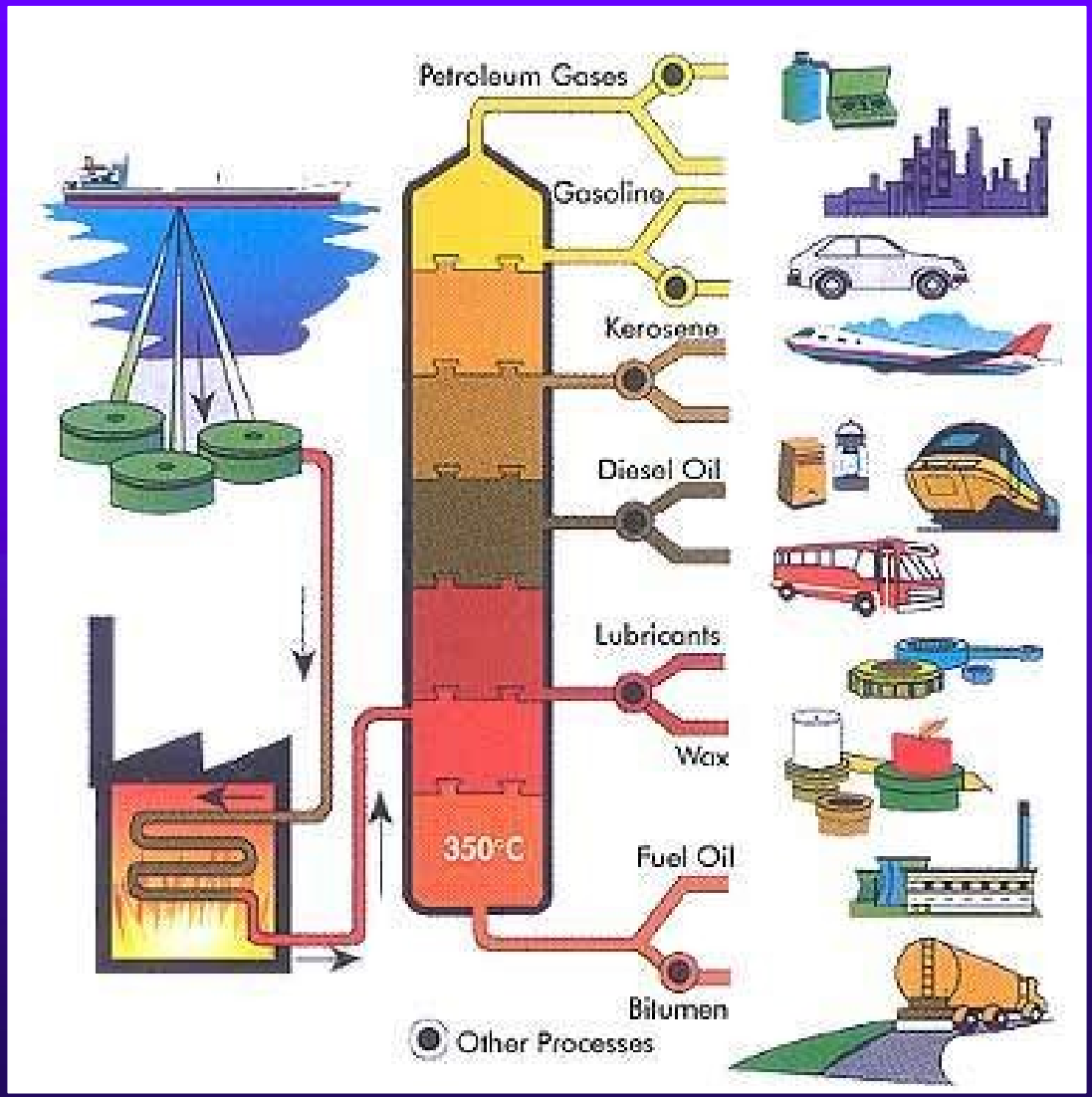
REFINED BITUMEN

Oil refinery

Transport

Storage

DISTILLATION OF CRUDE OIL (PETROLEUM)

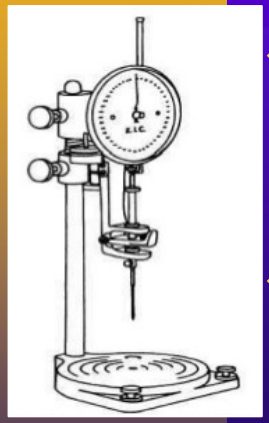


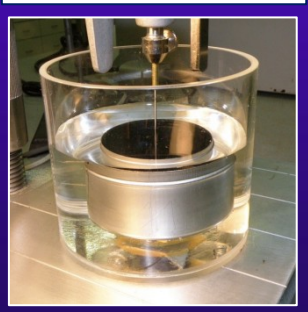
QUALITY CONTROL TESTS ON BITUMEN 1

- Experience in using bitumen in engineering projects has led to the adoption of certain test procedures that are indicative of the characte-ristics that identify adequate performance levels of bitumen as asphalt binder
- Some of the empirical tests have evolved with the development of the industry
- Consequently it is essential that they are carried out in strict compliance with the recommended procedures if they are to be accurate measurements of the bitumen's properties

PENETRATION TEST

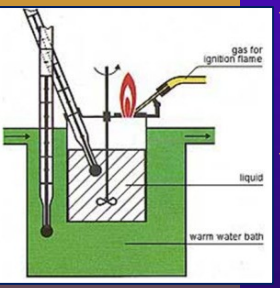
- *Penetration Test* is an empirical test that measures the consistency (hardness) of a bitumen at a specified test condition
- A standard needle of a total load of 100 g is applied to the surface of a liquid bitumen sample at a temperature of 25°C for 5 seconds
- The amount of penetration of the needle at the end of 5 seconds is measured in units of 0.1 mm (or penetration unit)
- A softer bitumen will have a higher, while a harder one will have a lower penetration
- It can be used to measure changes in hardness due to age or changes in temperature





FLASH POINT TEST

- *Flash point test* determines the temperature to which a bitumen can be safely heated in the presence of an open flame
- The test is performed by heating a bitumen sample in an open cup at a specified rate and determining the temperature at which a small flame passing over the surface of the cup will cause the vapors from the bitumen sample temporarily to ignite or flash



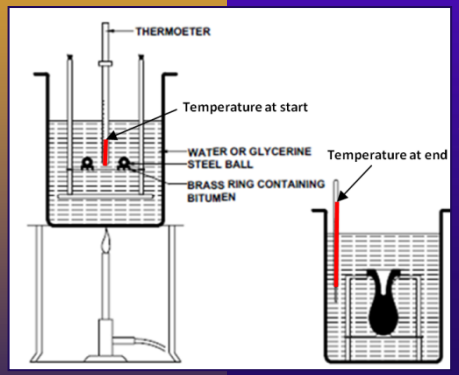
- Minimum flash point requirements are included in the specifications for bitumens for safety reasons
- Flash point tests can also be used to detect contaminating materials such as gasoline or kerosine in an asphalt binder
- Contamination of a bitumen in such materials can be indicated by a substantial drop in flash point

SOLUBILITY TEST

- In the standard test for bitumen content a small sample of about 2 g of the asphalt is dissolved in 100 ml of liquid solvent (e. g. carbon disulfide) and the solution is filtered through a filtering mat in a filtering crucible
- The material retained on the filter is then dried and weighed, and used to calculate the bitumen content as a percentage of the weight of the original asphalt
- The solubility test is used to detect contamination in asphalt cement; specifications for bitumen normally require a minimum solubility in an appropriately selected solvent of 99.0 percent

SOFTENING POINT TEST

- *Softening Point Test* defines the temperature at which a steel ball falls a known distance through the bitumen when the test assembly is heated at a known rate
- Usually the test consist of a 9.5 mm diameter steel ball, weight 3.5 gm, which is allowed to sink through a 16 mm diameter, 6.4 mm thick disk of bitumen in a brass ring

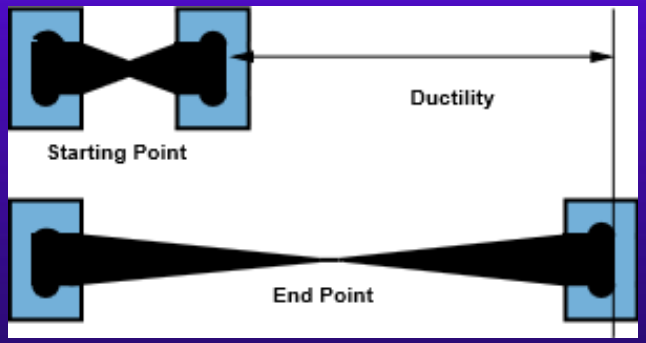


- The whole assembly is heated at a rate of 5°C per minute
- Typical values would be 115°C for hard grade bitumens used for asphalt concrete pavement construction

DUCTILITY TEST

- *Ductility Test* is conducted to determine the amount bitumen will stretch at temperature below its softening point
- Ductility is the property of bitumen that permits it to undergo deformation; it is defined as the distance in cm, to which a standard 1 cm^2 area briquette of the material will be elongated without breaking
- Bitumen samples are heated and poured in a mould assembly, then cooled in water bath at 27°C temperature before elongation

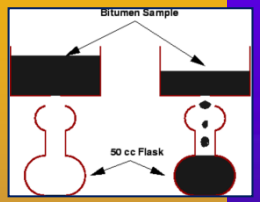
- Ductility values ranges from 0 to over 150, depending on the type of bitumen (min 75 is needed for hard grade bitumen)

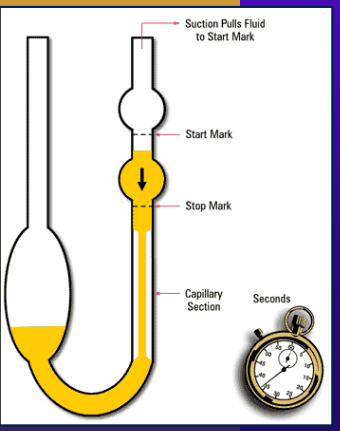


- It is generally considered that a bitumen with a very low ductility will have poor adhesive properties and thus poor performance in service

VISCOSITY TEST

- *Viscosity* denotes the fluid property of bituminous material and it is a measure of resistance to flow - at the application temperature, this characteristic greatly influences the strength of resulting paving mixes
- Low viscosity during compaction or mixing has been observed to result in lower stability values, while at high viscosity, it resist the compactive effort and thereby the resulting mix is heterogeneous, with low stability values
- Orifice type viscometers are used to indirectly find the viscosity of liquid binders; the viscosity expressed in seconds is the time taken by the 50 ml bitumen to pass through the orifice of a cup, under standard test conditions and specified temperature (60°C, since it represents the maximum temperature a pavement is likely to experience)





ASPHALT CONCRETE

- *Asphalt concrete* (AC) is basically a mixture of asphalt binder (bitumen) and mineral aggregates (stones), hot-mixed in an asphalt plant and then hot-laid to form the surface course of a *flexible* pavement
- The properties of asphalt concrete depend on:
  - the quality of its components (i.e. asphalt binder and aggregates)
  - the mix proportions
  - the construction process
- Asphalt concrete must provide a *stable*, *safe*, and *durable* road surface

ASPHALT CONCRETE – STABILITY

- *Stability* of the asphalt concrete depends on the strength and flexibility of the mixture and the degree of compaction during placing
- The strength must be sufficient to carry the load without shear occurring between particles - the structure must remain intact (the main contributor to strength is friction between grains)
- A dense-graded mixture, composed of particles with rough faces, with a relatively thin bitumen film between them is best for high- friction strength
- Flexibility is also important as the pavement distributes the imposed load by deflecting slightly as the load is applied, without cracking or permanent deformation
- To meet this requirement, a more open-graded mixture, with a higher asphalt content, is best

ASPHALT CONCRETE - SAFETY

- *Safety* is very important for the surface course
- Safety is achieved by making the surface course skid resistant and able to allow quick drainage of water from the surface
- Skid resistance is enhanced by using smaller sized, very hard aggregates for the surface course
- This provides more points of contact for the development of friction forces
- Open-graded surface courses are used in very heavy traffic areas to allow immediate drainage of rainwater before it can result in hydroplaning

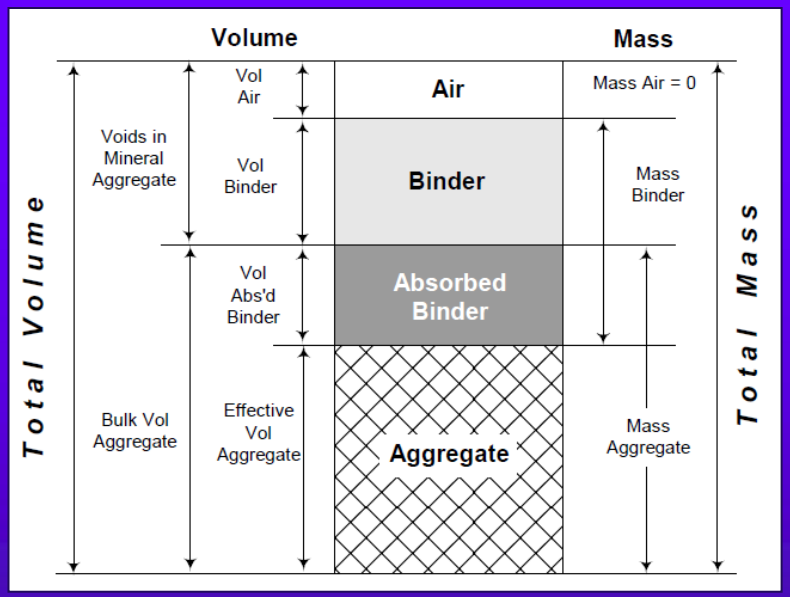
ASPHALT CONCRETE - DURABILITY

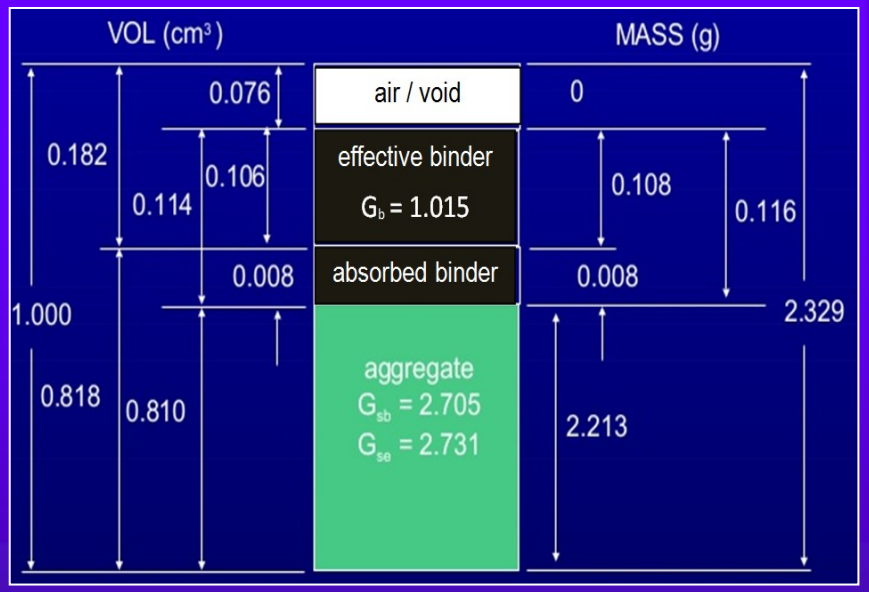
- Durability of the asphalt concrete is critical to ensure that it maintains the stability and skid resistance properties for the design service life
- Asphalt ages, and pavements become denser (i.e., aged) with time and traffic
- Pavements fail (i.e. durability of pavement is lost) due to:
  - changes in the aggregates
  - permanent deformation or rutting
  - cracking, either due to fatigue, or low temperatures
  - bleeding of asphalt to the surface

COMPOSITION OF ASPHALT MIXTURE

- Asphalt concrete mixture basically consists of asphalt *binder* (bitumen), *aggregates*, and *air*
- Out of the total asphalt binder added to the mixture, some of the bitumen is absorbed in the pores of the aggregate particles
- The portion of bitumen absorbed by aggregate particles is called “absorbed binder”
- The net amount of bitumen available to coat and bind aggregates together is called “effective binder”
- The mass/volume relationships of a compacted asphalt mixture are illustrated in the following figure

ASPHALT CONCRETE MIXTURE PHASE DIAGRAM





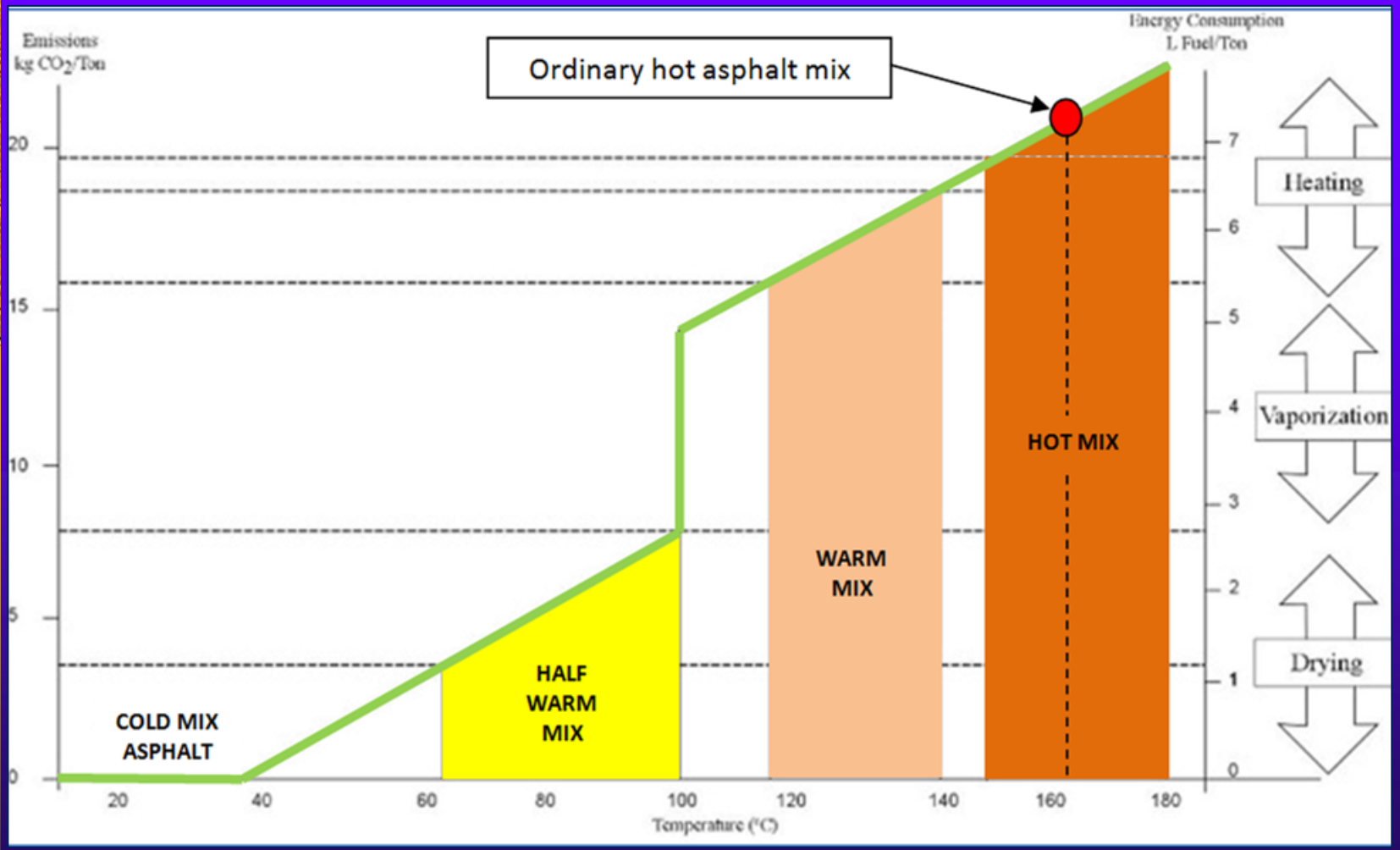
V_{ma} = Volume of voids in mineral aggregate (18.2%)
V_{fa} = Volume of voids filled with binder (58.2%)
V_{mb} = Volume of compacted mix *(100.0%)*
V_a = Volume of air filled voids (7.6%)
V_{mm} = Voidless volume of paving mix (92.4%)
V_b = Volume of binder (bitumen) (11.4%)
V_{ba} = Volume of absorbed binder (0.8%)
V_{sb} = Volume of mineral aggregate (81.8%)

P_{be} = per cent by mass of effective binder
P_b = per cent by mass of total binder
P_{ba} = per cent by mass of absorbed binder
MT = Total mass of compacted mix *(100.0%)*
M_s = Mass of solid aggregate (95.0%)
M_b = Mass of binder (bitumen) (5.0%)
G_b = Specific gravity of binder
G_{se} = Effective specific gravity of aggregate
G_{sb} = Bulk specific gravity of aggregate

TYPES OF ASPHALT CONCRETE MIXTURES 1

- Based on whether hot-mixed, hot laid or cold-mixed, cold-laid:
  - Hot-mixed, hot-laid asphalt (HMA) concrete mixture
  - Cold-mixed, cold-laid asphalt concrete mixture
- Based on whether in-situ-mixed or plant-mixed:
  - Road-mixed or in place-mixed asphalt concrete mixture
  - Plant-mixed asphalt concrete mixture
- Based on type of aggregate grading used:
  - Dense-graded HMA concrete mixture
  - Stone matrix asphalt (SMA) concrete mixture
  - Open-graded HMA concrete mixture
- Based on type additives used:
  - Rubber-modified asphalt concrete mixture
  - Polymer-modified asphalt concrete mixture
  - Sulfur-modified asphalt concrete mixture

TYPES OF ASPHALT CONCRETE MIXTURES 2



Asphalt technology classification based on the manufacturing temperature

CUTBACK BITUMEN 1

- To have fluid consistency at normal temperature, with low heating – cutback bitumen is used
- Paving grade bitumen is diluted in volatile solvents – kerosene, diesel-oil, light fuel oil etc.
- Hardening rate depends on the grade and characteristics of bitumen and solvent
  - *Rapid Curi*ng (RC) is recommended for surface dressing and patchwork
  - *Medium Curing* (MC) is recommended for premix with less quantity of fine aggregates
  - *Slow Curing* (SC) is used for premix with appreciable quantity of fine aggregates
- Cutback bitumen is used for cold weather bituminous road construction and maintenance; pavements built with cutback bitumen as binder are compacted further under the influence of traffic until the solvent evaporates completely

CUTBACK BITUMEN 2

Rapid Curing (RC) Asphalt + Naphtha	Medium Curing (MC) Asphalt + Kerosene	Slow Curing (SC) Asphalt + Oil
Surface Treatment	Stockpile Patch	
	Prime Coat	
	MC - 30	SC - 70
	MC - 70	SC - 250
	MC - 250	SC - 800
	MC - 800	SC - 3000
RC - 30		
RC - 70		
RC - 250		

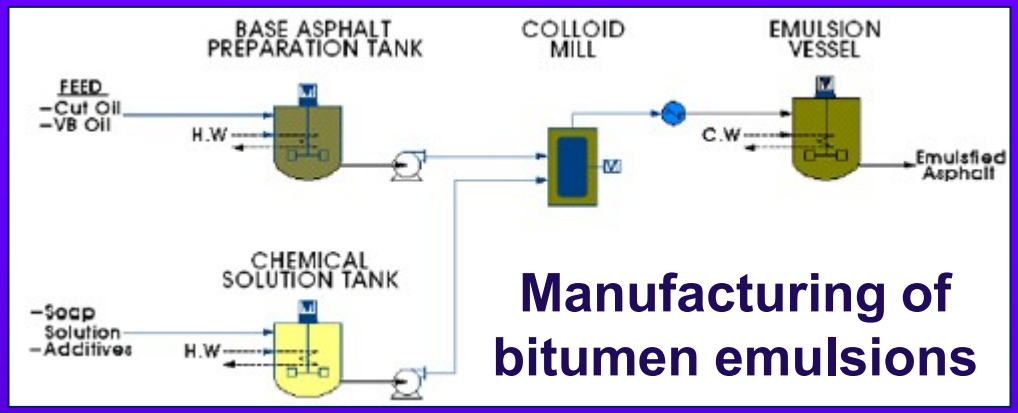
BITUMEN EMULSIONS 1

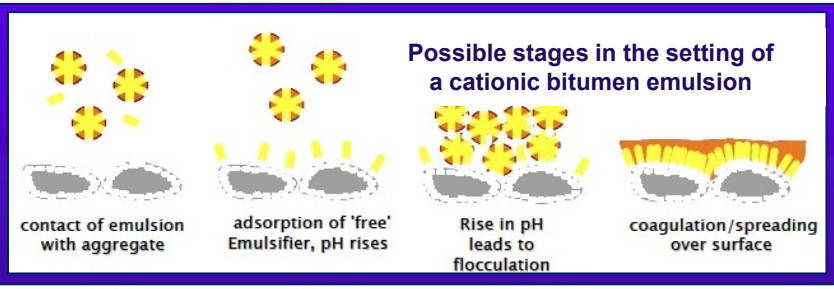
- ***Bitumen emulsion*** **is a liquid product in which bitumen is suspended in a finely divided condition in an aqueous medium and stabilised by suitable material**
- **The basic equipment to prepare an emulsion includes a high-speed, high-shear mechanical device (usually a *colloid mill*) to divide the bitumen into tiny droplets**
- **The *bitumen content* in the emulsion is around 60% and the remaining is water; when the emulsion is applied on the road it breaks down resulting in release of water and the mix starts to set**
- **The *time of setting* depends upon the grade of bitumen: *Rapid Setting* (RS) emulsions are used for surface dressing work, *Medium Setting* (MS) emulsions are preferred for premix jobs and patch repairs work, *Slow Setting* (SS) emulsions are preferred in rainy season**

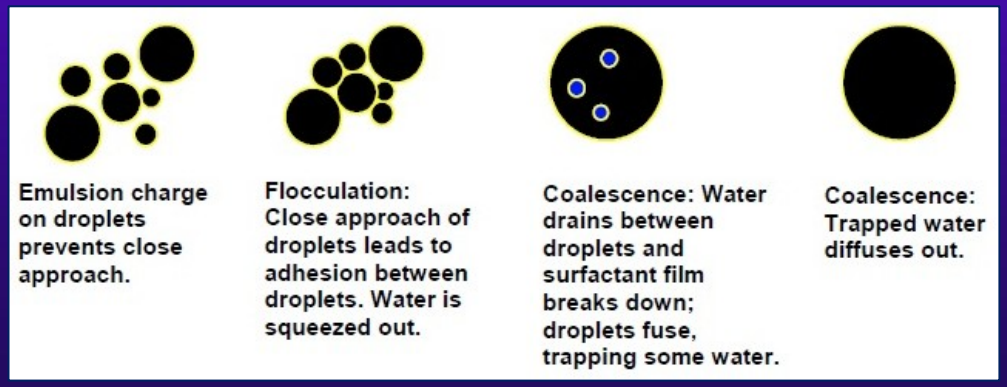
BREAKING & CURING

- **Breaking**
  - If the bitumen emulsion is to perform its ultimate function as a binder, water must separate from the bitumen phase and evaporate: this separation is called “breaking”
  - For the slow-setting grades, the breaking mechanism is mainly evaporation, for the medium-setting and rapid-setting grades, the breaking mechanism is mainly chemical
  - A rapid set emulsion will have a shorter breaking time, whereas a medium or a slow set material may take considerably longer
  - The specific type and concentration of emulsifying agent primarily controls the rate of breaking
- **Curing**
  - Curing involves the developments of the mechanical properties of the bitumen: for this to happen, the water must completely evaporate and the bitumen emulsion particles have to coalesce and bond to intended surface (the water is removed by evaporation and absorption)
  - Some bitumen emulsions may contain petroleum solvents to aid in the mixing and coating process

BITUMEN EMULSIONS 2







Stages in the breakdown of a bitumen emulsion

- Microscopic-sized bitumen droplets are dispersed in water in the presence of the chemical surfactant
- The surfactant causes a change in the surface tension at the contact area between bitumen droplets and the surrounding water, and this allows the bitumen to remain in the suspended state
- The bitumen particles, all having a similar electrical charge, repel each other, which aids in keeping them suspended

MODIFIED BITUMENS

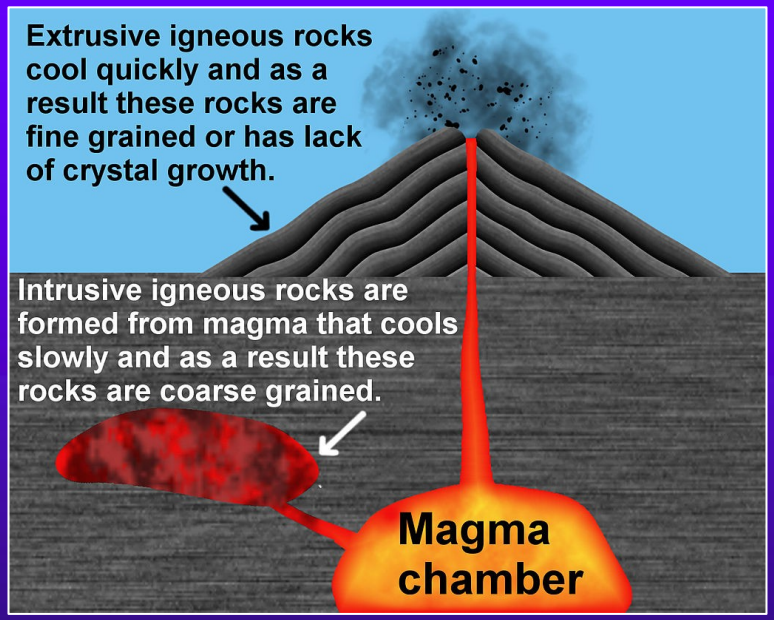
- Certain additives or blend of additives called as *bitumen modifiers* can improve properties of bitumen and bituminous mixes
- *Polymer modified bitumen* (PMB) and *crumb rubber modified bitumen* (CRMB) should be used only in wearing course depending upon the requirements of extreme climatic variations
- The advantages of using modified bitumen are as follows
  - Lower susceptibility to daily and seasonal temperature variations
  - Higher resistance to deformation at high pavement temperature
  - Better age resistance properties
  - Higher fatigue life for mixes
  - Better adhesion between aggregates and binder
  - Prevention of cracking and reflective cracking

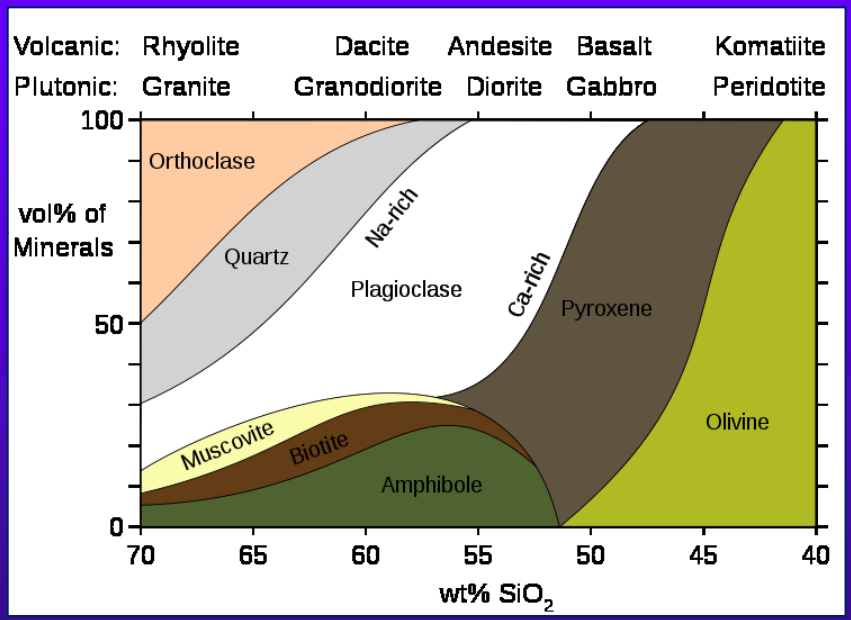
MINERAL AGGREGATES & FILLER

- In asphalt mixture, *mineral aggregates* may constitute about 70-75% by volume or 90-95% by weight
- The roles of aggregates in an asphalt pavement are to
  - *distribute wheel loads* through point-to-point contact (aggregate interlock) ensuring stability of pavement (i.e., resistance to pavement deformation under load)
  - *provide resistance* to abrasion and skid (a number of factors, such as quality, gradation, shape, stiffness and quantity of aggregates, determine effectiveness of aggregates in load transfer and the stability of pavement)
- *Mineral filler* (limestone dust) is often used in asphalt concrete mixtures to supply the fines (smaller than 75 μm), which are very important in producing a dense-graded, strong material

MAJOR CLASSES OF ROCKS AS AGGREGATES 1

- *Igneous or volcanic rocks* are formed from the cooling and solidification of magma or lava





- Coarse grained igneous rocks cooled slowly, fine igneous rocks cooled quickly

Coarse-grained	Granite	Diorite	Gabbro	Peridotite
Medium-grained			Diabase	
Fine-grained	Rhyolite	Andesite	Basalt	Komatiite

MAJOR CLASSES OF ROCKS AS AGGREGATES 2

- ***Sedimentary rocks*** **are formed from the solidification of chemical or mineral sediments deposited in the water of oceans**
- **Sedimentary rocks are deposited in layers as *strata* forming a structure called *bedding*, which often makes them *frost susceptible* i. e. unsuitable to use as aggregates in asphalt mixtures exposed to water in wintertime**
- ***Limestone*, *dolomite*** **and *sandstone*** **are well known types of sedimentary rocks**
- ***Metamorphic rocks*** **are either igneous or sedimentary rocks that have been changed due to intense heat and pressure (like marmor) – they are seldom used in road construction**

MINERAL AGGREGATES FROM CARRIES

BASALT

ANDESITE

DOLOMITE

LIMESTONE

A CARRY

GENERAL REQUIREMENTS

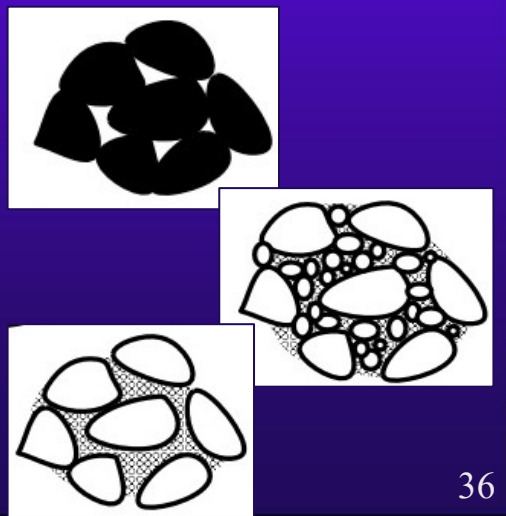
- **Aggregates should be:**
  - ***well-graded***
  - ***dense*, including mineral filler (if required) for strength**
  - ***hard* for resistance to wear and to polishing due to traffic**
  - ***sound* for resistance to breakdown due to freezing and thawing**
  - ***rough surfaced* (crushed rough surfaces give higher friction strength and a better surface for adhesion of the bitumen)**
  - ***free from cubical, thin, elongated* aggregate *particles* because they are broken easily**
  - ***hydrophobic* (or "water hating") some siliceous aggregates such as quartz are hydrophobic ("water liking"), meaning that they have a greater affinity for water than for bitumen, due to their surface charges (this may lead to stripping, as asphalt coating comes away from the particle in the presence of water)**
  - ***free from deleterious substances* - clay particles, dust, dirt, and lightweight pieces may lead to a lower quality bitumen film on the aggregate particles or may result in breaking of some of the particles**

CLASSIFICATION OF AGGREGATES

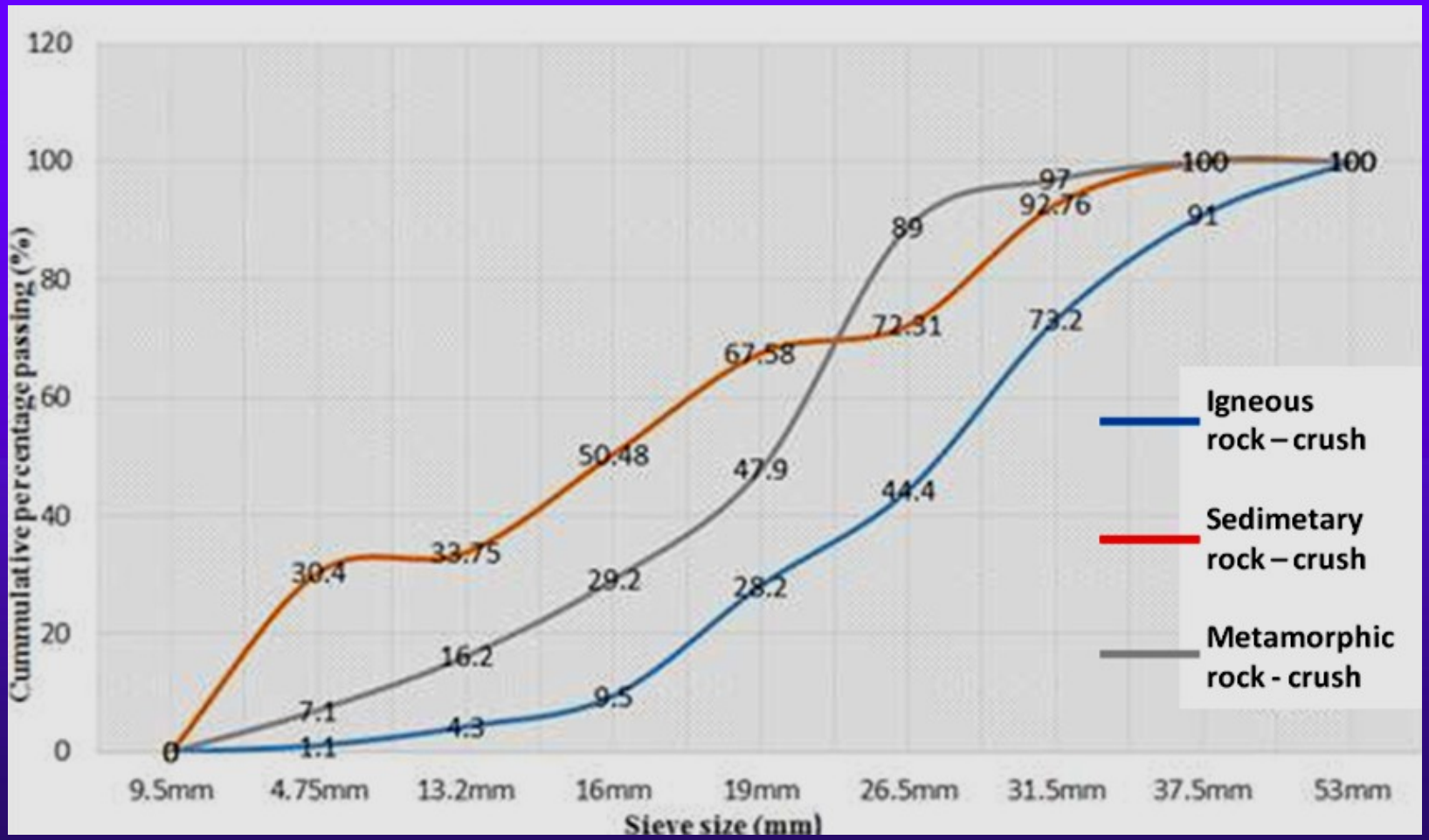
- **Based on *size*:**
  - ***fine* aggregates - aggregates which pass through 4.75 mm sieve or with size less than 5 mm**
  - ***coarse* aggregates - aggregates passing through 75 mm sieve and entirely retained on 4.75 mm sieve, or those with size greater than 5 mm**
- **Based on *source* or method of manufacture:**
  - ***Natural aggregate* / uncrushed aggregate - those from the river beds, river sand and ex-mines; normally rounded in shape and have smooth surface texture**
  - ***Manufactured aggregate* / crushed aggregate – those obtained by mechanically crushing rocks, boulders, or cobbles; normally angular in shape and have rough surface texture**
- **Based on specific gravity or *density* measured in bulk:**
  - ***Normal-weight aggregates* (crushed stone, gravel and ordinary sand); used in manufacture of normal weight concrete, asphalt concrete and roadway sub-base (the average values of sp.gr. for sand and gravel are 2.6 and 2.65 respectively, while bulk density is around 1520 to 1680kg/m3)**
  - ***Lightweight aggregates* used as ingredients in the manufacture of lightweight concrete elements by the building industry**
  - ***Heavy-weight aggregates* used primarily in the manufacture of heavyweight concrete, employed for protection against nuclear radiation and as bomb shelter**

AGGREGATE GRADATION 1

- Aggregates to be used for making asphalt concrete mixture should be well graded
- Gradation means the particle size distribution of aggregates; test for grading of aggregates is carried out using the sieve analysis method
- Gradation of aggregates to be used for various types of asphalt mixtures (aiming to obtain the required quality), are standardised
- Types of gradations:
  - Uniformly graded: few points of contact; poor interlock (shape dependent); high permeability
  - Well graded: good interlock; low permeability
  - Gap graded: only limited sizes; good interlock, low permeability



AGGREGATE GRADATION 2



Particle size distribution / gradation curve for the crush aggregates

AGGREGATE GRADATION 3

- Two types of aggregate gradation are commonly used in asphalt concrete pavement construction:
  - (i) open gradation and
  - (ii) dense gradation
- Open-graded aggregate is containing little or no fine aggregate, or one in which the void content in the compacted aggregate is relatively large (20%)
- Open-graded asphalt concrete provides good skid resistance and high permeability so as to permit good surface drainage
- Dense-graded aggregate is containing fine aggregate filling the voids in coarse aggregate, thus it provides a dense and impermeable layer and does not normally require surface treatment or seal coat

PHYSICAL PROPERTIES 1

- *Strength* - in practice, majority of normal aggregates are considerably stronger than concrete (a good average value of crushing strength of aggregates is 200N/mm2)
- *Hardness* - is the ability of the aggregate to withstand wear or load or applied pressure, it is depending on the type of parent rock (the test that can obtain the hardness is the *abrasion test* - a satisfactory aggregate should have an abrasion value of not more than 30% for aggregates used for wearing surfaces and 50% for aggregates used for non wearing surfaces)
- *Toughness* - is the resistance of aggregate to failure by impact, which can be determined by *aggregate impact test* (the aggregate impact value shall not exceed 45% by weight for an aggregate used for concrete other than those used for wearing surfaces and 30% for concrete for wearing surfaces)

PHYSICAL PROPERTIES 2

- *Durability* - is the ability of the aggregate to withstand external or internal damaging attack or in other words the soundness of aggregate; this can be obtained by carrying out the *soundness test*
- *Porosity* and *water absorption* - aggregates will absorb water in their pores when it is dry, but normally release water in the concrete mix when it is wet; the amount of water and its rate of permeation depends on the size and volume of aggregate (since the aggregate comprises 75% of the concrete volume, it is essential to note that porosity of an aggregate contribute to the overall porosity of concrete)
- Coarse and fine aggregates to be used for making concrete should be well graded (gradation means the particle size distribution of aggregates); test for grading of aggregates is carried out using the sieve analysis method

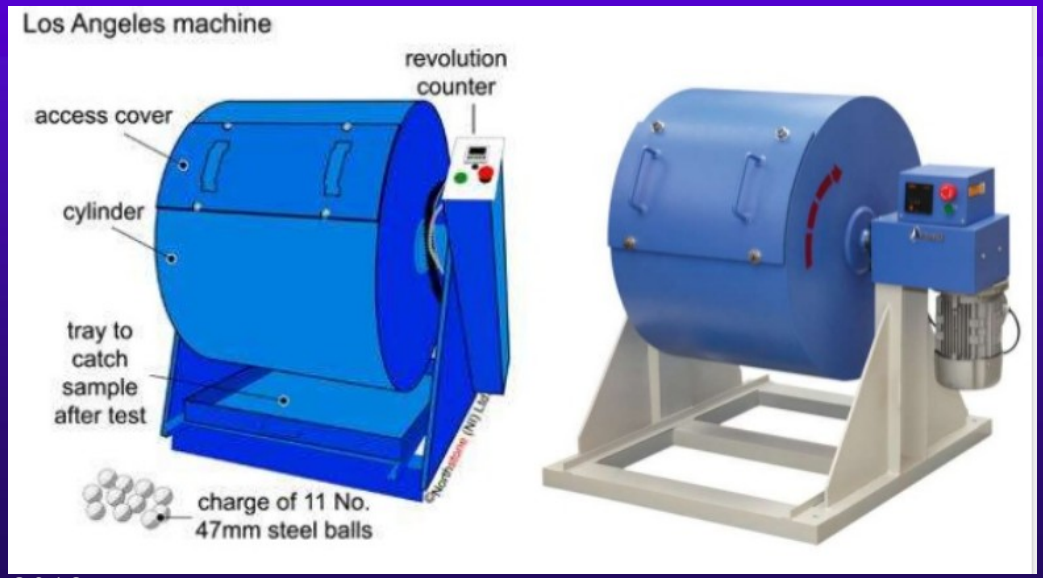
CRUSHING TEST

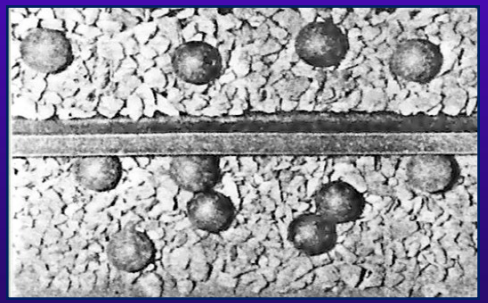
- *Aim*: to determine the crushing strength of aggregates
- *Material*: dry aggregates passing through 12.5 mm sieves and retained in 10 mm sieves

- *Apparatus*:
  - a steel cylinder (both side open ends) of internal dia. 15.2 cm
  - a square base plate
  - plunger having piston dia. 15 cm
  - a cylindrical measure of internal dia. 11.5 cm and height 18 cm
  - steel tamping rod : dia. 1.6 cm and length 45 -60 cm
  - balance of capacity 3 kg / accuracy up to 1 gm
  - compression testing machine capable of applying load of 40 tons, rate of loading 4 tons/min

ABRASION TEST

- *Aim*: to test the hardness property of aggregates and to decide whether they are suitable for different pavement construction works
- *Apparatus*: carried out as *Los Angeles* or *Deval* test
- *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





SOUNDNESS TEST

- *Aim*: to study the resistance of aggregates to weathering action, by conducting accelerated weathering test cycles
- The porous aggregates subjected to freezing and thawing are likely to disintegrate prematurely
- Aggregates of specified size are subjected to cycles of alternate 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

SHAPE TEST

- *Flakiness index* is the percentage by particles whose least dimension (thickness) is less then 3/5th (0.6) of their mean dimension
- *Elongation index* is the percentage by weight of particles whose greatest dimension (length) is greater then 1 and 4/5th times (1.8times) their mean dimension (the test is not applicable to size smaller then 6.3. mm)
- *Angularity number* of an aggregate is the amount by which the percentage of voids exceeds 33 after being compacted in a prescribed manner
- Minimum allowable *combined index* of aggregates used in surface course in different types of pavement is 30%)

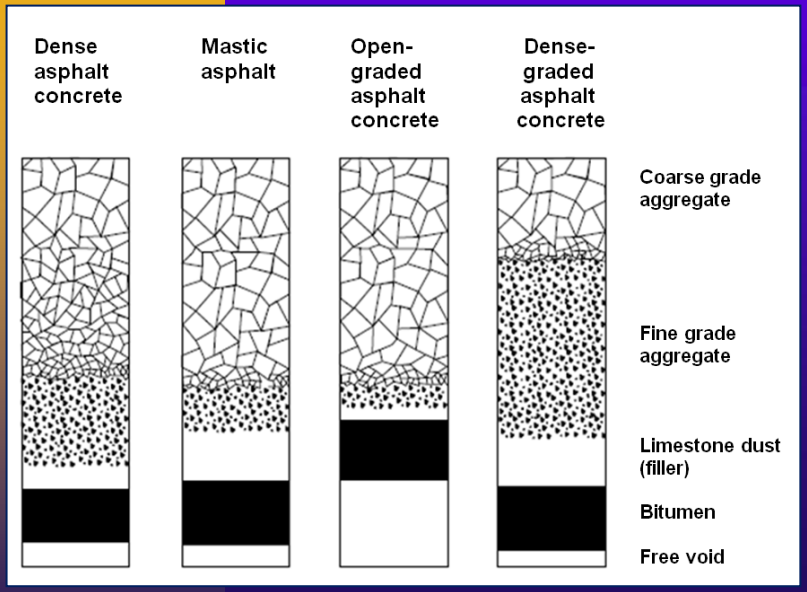
Angularity Number = $67 - \frac{100W}{CG}$ where,

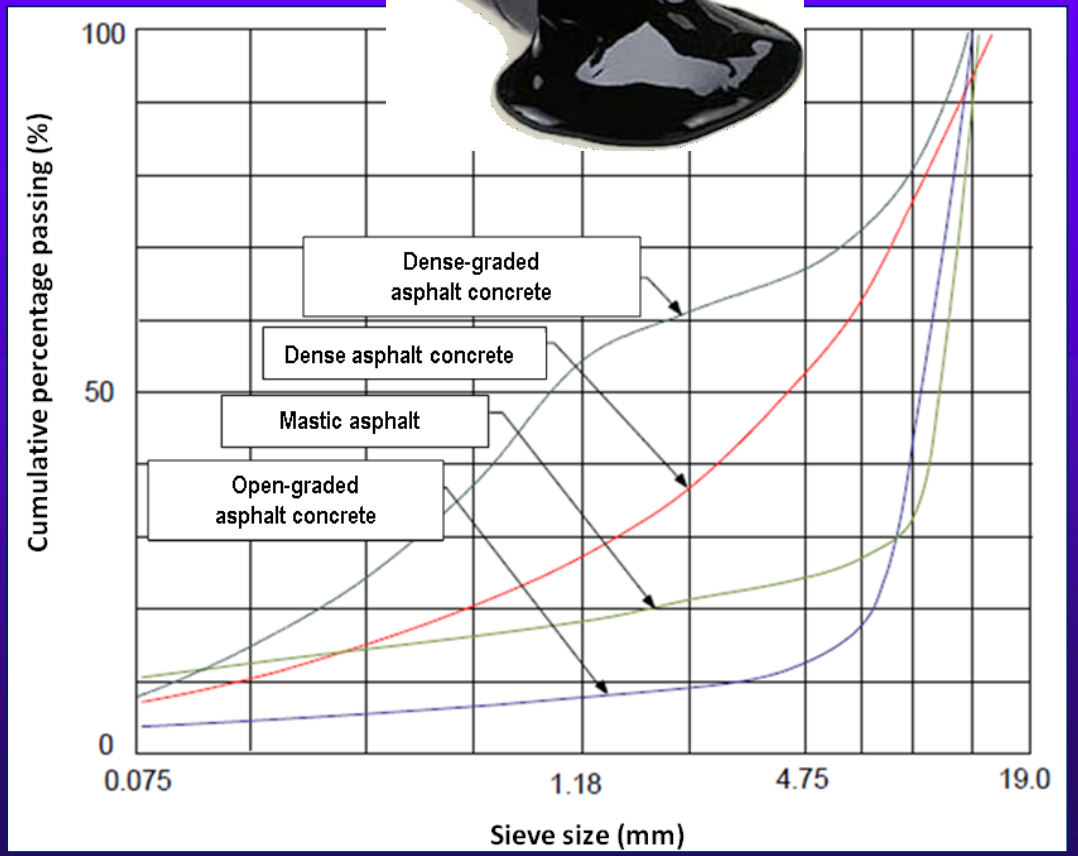
W = Mean weight of aggregates in the cylinder, gm.

C = Weight of water required in the cylinder, gm.

G = Specific gravity of aggregate.

GRADATION CURVES OF ASPHALT MIXTURES





MOTORWAY WITH ASPHALT PAVEMENT *(M7; HUNGARY)*