PART - A
PAVEMENT MATERIALS

UNIT - 1

AGGREGATES: Origin, classification, requirements, properties and tests on road aggregates, concepts of size and gradation - design gradation, maximum aggregate size, aggregate blending by different methods to meet specification. [6 Hours]

Introduction

Aggregates form the major portion of pavement structure and they form the prime materials used in pavement construction. Aggregates have to bear stresses occurring due to the wheel loads on the pavement and on the surface course they also have to resist wear due to abrasive action of traffic. These are used in pavement construction in cement concrete, bituminous concrete and other bituminous constructions and also as granular base course underlying the superior pavement layers. Therefore the properties of the aggregates are of considerable significance to the highway engineers.

Origin

Most of the road aggregates are prepared from:

1) Natural rock.
2) Slags derived from metallurgical process (steel plants)

Gravel aggregates are small rounded stones of different sizes which are generally obtained as such from some river beds. Sand is fine aggregate from weathering of rock. The properties of the rock, from which the aggregates are formed, depend on the properties of constituent materials and the nature of bond between them.

Based on the origin, natural rocks are classified as igneous, sedimentary and metamorphic rocks.

Igneous rocks

Predominantly crystalline and are formed by the cooling of molten rock magma.

Further igneous rocks are classified as below:

Classification based on grain size:

a) Course (>2mm)
b) Medium (2mm to 0.2mm)
c) Fine (<0.2mm)

Classification based on composition:

a) Acid rocks (>66% silica, light in colour & specific gravity <2.75)
b) Intermediate rocks (55 to 66% silica)
c) Basic rocks (<55% silica, dark in colour & specific gravity >2.75)

**Sedimentary rocks**

Formed either from the deposition of insoluble granular material resulting from the disintegration of pre-existing rocks, or form the inorganic remains of marine and animals which are deposited in great quantities on the sea floor. Sedimentary rocks are deposited in layers, they have stratified or laminated structure.

Classification based on predominating mineral:

a) Calcareous rock (chalk, lime stone & dolomite)
b) Siliceous rock (sand stone, flint & chert)
c) Argillaceous (clay & shale)

**Metamorphic rock**

These are sedimentary or igneous rocks that have been subjected to great heat or to great pressure or both, that has resulted in the formation of minerals and in textures different from those of the original rock.

Classification based on grain size:

a) Fine grain size (hornfels & schist)
b) Coarse grain size (gneiss & Granulite)

Based on the strength property, the coarse aggregates may be divided as hard aggregates and soft aggregates. Generally for the bearing course of superior pavement types, hard aggregates are preferred to
resist the abrading and crushing effects of heavy traffic loads and to resist adverse weather conditions. In the case of low-cost road construction for use in lower layers of pavement structures, soft aggregates can also be used. The soft aggregates include moorum, kankar, laterite, brick aggregates and slag. A different set of test specifications are adopted for soft aggregates.

**Classification:**
- The aggregates are specified based on their grain size, shape, texture and its gradation and it is specified by various agencies like ASTM, BSI, ISI and IRC.
- Based on strength property, the coarse aggregates are divided into hard aggregates and soft aggregates.

**Requirements:**
- They must be crushed aggregate.
- They shall be clean, hard, durable and cubical in shape.
- They must be free from the dust, organic matter and other deleterious matter.
- They not be flakey or elongated.
- They must not consist of injurious or harmful materials such that they reduce the strength of structure.
- They should resist wear due to abrasive action of traffic on the surface course.

**Properties of aggregates:**
The aggregate have three properties
1. Physical properties.
2. Mechanical properties.
3. Chemical properties.

Main desirable properties of aggregate are.

1) **Strength**
1. The aggregates to be used in road construction should be sufficiently strong to withstand the stresses due to traffic wheel loads.

2. The aggregates which are to be used in top layer of the pavements, particularly in the wearing course have to be capable of withstanding high stresses in addition to wear and tear; hence they should possess sufficient strength and resistance to crushing.

2) **Hardness**

1. The aggregates used in the surface course are subjected to constant rubbing or abrasion due to moving traffic.

2. They should be hard enough to resist the wear due to abrasive action of traffic.

3. Abrasive action may be increased due to the presence of abrasive material like sand between the tyres of moving vehicles and the aggregates exposed at the top surface.

4. This action may be severe in the case of steel tyred vehicles.

5. Heavy wheel loads can also cause deformations on some types of pavement resulting in relative movement of aggregates and rubbing of aggregates with each other within the pavement layer.

6. The mutual rubbing of stones is called attrition, which also may cause a little wear in the aggregates; however attrition will be negligible or absent in most of the pavement layers.

3) **Toughness**

1. Aggregates in the pavements are also subjected to impact due to moving wheel loads.

2. Severe impact like hammering is quite common when heavily loaded steel tyred vehicles move on water bound macadam roads where stones protrude out especially after the monsoons.

3. Jumping of the steel tyred wheels from one stone to another at different levels causes severe impact on the stones.

4. The magnitude of impact would increase with the roughness of the road surface, the speed of the vehicle and other vehicular characteristics.

5. The resistance to impact or toughness is hence another desirable property of aggregates.
4) **Durability**

1. The stone used in the pavement construction should be durable and should resist disintegration due to the action of weather.
2. The property of the stones to withstand the adverse action of weather may be called soundness.
3. The aggregates are subjected to the physical and chemical action of rain and ground water, the impurities there-in and that of atmosphere.
4. Hence it is desirable that the road stones used in the construction should be sound enough to withstand the weathering action.

5) **Shape of aggregates**

1. The size of the aggregates is first qualified by the size of square sieve opening through which an aggregate may pass, and not by shape.
2. Aggregates which happen to fall in a particular size range may have rounded, cubical, angular flaky or elongated shape of particles.
3. It is evident that the flaky and elongated particles will have less strength and durability when compared with cubical, angular or rounded particles of the same stone.
4. Hence too flaky and too much elongated aggregates should be avoided as far as possible.
5. The voids present in a compacted mix of coarse aggregates depend on the shape factors.
6. Highly angular, flaky and elongated aggregates have more voids in comparison with rounded aggregates.
7. Based on the shape of the aggregate particle, stones may be classified as rounded, angular, flaky and elongated.
8. Angular particles possess well-defined edges formed at the intersection of roughly plane faces and are commonly found in aggregates prepared by crushing of rocks.
9. Flaky aggregates have lesser thickness when compared to the length and width.
10. Elongated aggregates have one of the dimensions or the length higher than the width and thickness.
11) The shape factors of aggregates depend on the source, properties of the rock and the type and condition of the crushers.

12) The shape of aggregates is generally described in terms of its shape factors such as flakiness index, elongation index and angularity number.

13) Several researchers have indicated that in pavement construction flaky and elongated aggregates are to be avoided, particularly in surface course.

14) If flaky and elongated aggregates are present in appreciable proportions, the strength of the pavement layer would be adversely affected due to possibility of breaking down during compaction and under loads.

6) **Adhesion with Bitumen**

   The aggregates used in bituminous pavements should have less affinity with water when compared with bituminous material; otherwise the bituminous coating on the aggregates will be stripped off in presence of water.

### Tests on Road Aggregates and Properties Evaluated

<table>
<thead>
<tr>
<th>SL No.</th>
<th>Type of test</th>
<th>Required property</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Aggregate impact test</td>
<td>Toughness or resistance to impact</td>
</tr>
<tr>
<td>2</td>
<td>Los Angeles Abrasion Test</td>
<td>Hardness or resistance to abrasion</td>
</tr>
<tr>
<td>3</td>
<td>Aggregate Crushing Test</td>
<td>Strength or resistance to crushing</td>
</tr>
<tr>
<td>4</td>
<td>Soundness/Durability/ Accelerated weathering test</td>
<td>Durability or resistance to weathering</td>
</tr>
<tr>
<td>5</td>
<td>Shape test: Flakiness Index, Elongation Index and Angularity Number</td>
<td>Assessment of suitable shape or shape factors of coarse aggregates</td>
</tr>
<tr>
<td>6</td>
<td>Specific gravity Test</td>
<td>To measure the quality or strength of material</td>
</tr>
<tr>
<td>7</td>
<td>Water absorption Test</td>
<td>To measure the porosity</td>
</tr>
<tr>
<td></td>
<td>Bitumen adhesion/Stripping Test</td>
<td>Adhesion of bitumen</td>
</tr>
<tr>
<td>---</td>
<td>--------------------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>9</td>
<td>Polished stone value test or accelerated polishing test</td>
<td>Resistance to getting smooth or polished</td>
</tr>
</tbody>
</table>

**Aggregate Impact Test**

**Aim:** To determine the impact value of the given aggregate

**Apparatus:**
- Aggregate impact apparatus
- IS sieves (12.5 mm, 10.0 mm and 2.36 mm)
- Cylindrical measure and cylindrical cup
- Weighing balance.
- Tamping rod.

**Theory:**

Toughness is the property of a material to resist impact. Due to traffic loads the road stones are subjected to the pounding action or impact and there is possibility of stones breaking into smaller pieces. The road stones should therefore be tough enough to resist fracture under impact. A test designed to evaluate the toughness of stones i.e. the resistance of the stones to fracture under repeated impacts may be an impact test for road aggregate.

The aggregate impact value indicates a relative measure of the resistance of an aggregate to a sudden shock or an impact, which in some aggregate differs from its resistance to a slow compressive load. The method of tests specifies the procedure for determining the aggregate impact value of coarse aggregate.
Procedure

1. Take clean and dry aggregate and sieve on IS 12.5 mm and 10.00 mm sieve.
2. Collect the aggregate passing IS 12.5mm sieve and retained on IS 10.0 mm Sieve.
3. Find the weight of empty cylindrical measure. Let the weight be ‘a’ g.
4. Fill the aggregate in the cylindrical measure in three layers, tamping each layer 25 times with the rounded end of the tamping rod.
5. Roll the tamping rod over aggregate surface and remove excess aggregate, if any.
6. Find the weight of the cylindrical measure with aggregate. Let the weight be ‘b’ g. Thus the weight of aggregate = W1 = ( b-a )
7. Transfer all the aggregate from the cylindrical measure to the test cylinder in one layer and tamp the layer 25 times with the rounded end of the tamping rod.
8. Fix the test cylinder firmly to the base of the impact tester.
9. Adjust the height of fall of the plunger to 380+ 5mm and set the blow counter to zero.
10. Lift the plunger gently and allow it to drop. This is one blow. Give 15 such blows.
11. Take out the test cylinder and sieve the crushed material on IS 2.36 mm sieve. Find the weight of material passing the sieve. Let weight be W2 g.

12. Find the weight of aggregate retained on this sieve. Let the weight be W3 g. Then,

\[
\text{Aggregate impact value} = \frac{W2}{W1} \times 100\%
\]

And percentage of dust = \( \frac{W3}{W1} \times 100\% \)

**Tabular Column**

| Weight of empty cylindrical measure = ‘a’ g. |  
| Weight of cylindrical measure + Aggregate = ‘b’ g |  
| Initial weight of aggregate = (b-a)= W1 g |  
| Weight of aggregate passing IS 2.3 mm sieve after test = W2 g |  
| Weight of aggregate retained on IS 2.36 mm sieve after test = W3 g |  
| Aggregate impact value = \( \frac{W2}{W1} \) \times 100\% |  
| Percentage of dust = \( \frac{W3}{W1} \) \times 100\% |  

**Result**

The Impact value of given aggregate sample is = ............... \%.

**Desirable value**

Various agencies have specified the maximum permissible aggregate impact values for the different types of pavements, those recommended by the Indian Roads Congress are given below:

<table>
<thead>
<tr>
<th>Serial No.</th>
<th>Types of pavement material/layer</th>
<th>Aggregate impact value, maximum, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Water bound macadam (WBM), sub-base course</td>
<td>50</td>
</tr>
<tr>
<td>2</td>
<td>Cement concrete, base course (as per ISI)</td>
<td>45</td>
</tr>
<tr>
<td>3</td>
<td>(i) WBM base course with bitumen surfacing</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>(ii) Built-up spray grout, base course</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Bituminous macadam, base course</td>
<td>35</td>
</tr>
<tr>
<td>5</td>
<td>(i) WBM, surfacing course</td>
<td>30</td>
</tr>
</tbody>
</table>
(ii) Built-up spray grout, surfacing course
(iii) Bituminous penetration macadam
(iv) Bituminous macadam, binder course
(v) Bituminous surface dressing
(vi) Bituminous carpet
(vii) Bituminous/Asphalt concrete
(viii) Cement concrete, surface course

For deciding the suitability of soft aggregates in base course construction, this test has been commonly used. A modified impact test is also often carried out in the case of soft aggregates to find the wet impact value after soaking the test samples. The recommendations is given in the below table.

<table>
<thead>
<tr>
<th>Condition of sample</th>
<th>Maximum aggregate impact value, percent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sub-base and base</td>
</tr>
<tr>
<td>Dry</td>
<td>50</td>
</tr>
<tr>
<td>Wet</td>
<td>60</td>
</tr>
</tbody>
</table>

Aggregate impact value is used to classify the stones in respect of their toughness property as indicated below:

<10% Exceptionally strong
10-20% Strong
20-30% Satisfactory for road surfacing
>35% Weak for road surfacing

The aggregate impact value should not normally exceed 30% for aggregate to be used in wearing course of pavements. The maximum permissible value is 35% for bituminous macadam and 40% for water bound macadam base courses.
Aggregate Crushing Value

**Aim:** To determine the crushing value of the given sample of aggregate.

**Apparatus**

a) Steel cylinder with open ends and a square plate  
  b) Plunger with piston  
  c) Cylindrical measure  
  d) Weighing balance  
  e) IS sieves (12.5 mm, 10.0mm & 2.36 mm)  
  f) Compression testing machine  
  g) Steel Tamping Rod.

**Theory**

The Principal mechanical properties required in road stones are (i) Satisfactory resistance to crushing under the roller during construction and (ii) adequate resistance to surface abrasion under traffic. Also stresses under rigid tyre rims of heavily loaded animal drawn vehicles are high enough to consider the crushing strength of road aggregate as an essential requirement in India. Crushing strength of road aggregate may be determined either on aggregate or on cylindrical specimens cut out of rocks. These two tests are quite different is not only the approach but also is the expression of the results.

Aggregate used in road construction, should be strong enough to resist crushing under traffic wheel loads. If the aggregate are weak, the stability of the pavement stretches is likely to be adversely affected, the strength of coarse aggregate is assessed by aggregate crushing test. The aggregate crushing value provides a relative measure of resistance to crushing under gradually applied compressive load. To achieve a high quality of pavement, aggregate possessing low aggregate value should be preferred.
Procedure

1. Select clean and dry aggregate passing through IS 12.5 mm and retained on IS 10.0 mm sieve.
2. Weight the empty cylindrical measure. Let the weight be ‘a’ g
3. Fill the aggregate in the cylindrical measure in three layers, tamping each layer 25 times with the rounded end of the tamping rod. Weigh the cylindrical measure with aggregate. Let the weight be ‘b’ grams. Thus the weight of aggregate = W1 g
4. Transfer the aggregate into the steel cylinder again in three layers tamping each layer 25 times
5. Place the plunger in the steel cylinder such that the piston rests horizontally over the aggregate surface.
6. Keep the assembly of steel cylinder with plunger in the compression testing machine.
7. Set the pointer to read zero and apply the compressive load of 40 tonnes.
8. Stop the machine. Take out the assembly.
9. Sieve the crushed material on IS 2.36 mm sieve and find the weight of material passing this sieve. Let the weight be W2 g.
10. Then Aggregate crushing value = W2 / W1 * 100 %
Tabular Column

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight of empty cylindrical measure = ‘a’ g</td>
<td></td>
</tr>
<tr>
<td>Weight of cylindrical measure with aggregate = ‘b’ g</td>
<td></td>
</tr>
<tr>
<td>Weight of aggregate taken in the cylinder before test = (b-a) = W1 g</td>
<td></td>
</tr>
<tr>
<td>Weight of crushed material Passing IS 2.36 mm sieve = W2 g</td>
<td></td>
</tr>
<tr>
<td>Aggregate crushing value = W2 / W1* 100 %</td>
<td></td>
</tr>
</tbody>
</table>

Result
The aggregate crushing value of the given aggregate Sample is ______

Desirable value
Strong aggregates give low aggregate crushing value. IRC and ISI have specified that the aggregate crushing value of the coarse aggregate used for cement concrete pavement at surface should not exceed 30 percent. For aggregates used for concrete other than for wearing surfaces, the aggregates crushing value shall not exceed 45 percent, according to the ISS. However aggregate crushing values have not been specified by the IRC for coarse aggregates to be used in bituminous pavement construction methods.

Los Angeles Abrasion Test
Aim: To determine the abrasion of the given aggregate sample.

Apparatus:
Los Angles Abrasion Machine
Steel balls-11no.
Weighing balance
IS Sieves: 20, 12.5, 10, 1.7mm.

Theory
Due to the movement of traffic, the road stones used in the surfacing course are subjected to wearing action at the top. Resistance to wear or hardness is hence an essential property for road
aggregates especially when used in wearing course. Thus road stones should be hard enough to resist the abrasion due to the traffic.

Procedure
1) Take the clean and dried aggregates in an oven at 105-110° C.
2) Sieve the given aggregates in sieve size 20-12.5mm and weigh that aggregate in 2.5kg.
3) Again sieve the aggregate in sieve size is 12.5-10mm and take that aggregates in 2.5 k. i.e., W1 gm (2.5+2.5=5kg)
4) Pour the given taking aggregates into the los angles abrasion machine.
5) Put the steel balls into the abrasion machine after pouring the aggregates.
6) Start the machine and rotating the drum for 100 revolutions and stop the machine.
7) After stopping the machine, take out the aggregates and sieve the aggregates in 1.7mm sieve size and take the retained aggregates and note down its weight i.e, W2 gm.
8) Then, Los Angles Abrasion value= (W1-W2/W1)X100 %

Tabular Column

<table>
<thead>
<tr>
<th>Original weight of aggregate = W1 g</th>
<th></th>
</tr>
</thead>
</table>

Vinod.B.R, Asst.Professor Department of Civil Engg,BMSIT&M, Bangalore
Weight of aggregates retained on 1.7 mm IS sieve = W2 g
Loss in weight due to wear = (W1-W2) g
Los Angeles Abrasion value = (W1-W2/W1)*100 %

**Result**

The Los Angles Abrasion Value of given aggregates is _____% at ______revolution.

**Desirable value**

The maximum allowable Los Angeles abrasion values of aggregates as specified by IRC for different methods of construction are given in below table.
<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Types of pavement layer</th>
<th>Los Angeles abrasion value, Maximum %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Water bound macadam (WBM), sub-base course</td>
<td>60</td>
</tr>
<tr>
<td>2</td>
<td>(i) WBM base course with bituminous surfacing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(ii) Bituminous Macadam base course</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>(iii) Built-up spray grout base course</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>(i) WBM surfacing course</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>(ii) Bituminous Macadam binder course</td>
<td></td>
</tr>
<tr>
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<td>(iii) Bituminous penetration Macadam</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(iv) Built-up spray grout binder course</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>(i) Bituminous carpet surface course</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>(ii) Bituminous surface dressing, single or two coats</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(iii) Bituminous surface dressing, using precoated aggregates</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(iv) Cement concrete surface course (as per IRC)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>(i) Bituminous/Asphaltic concrete surface course</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>(ii) Cement concrete pavement surface course (as per ISI)</td>
<td></td>
</tr>
</tbody>
</table>

The Los Angeles abrasion value of good aggregates acceptable for cement concrete, bituminous concrete and other high quality pavement materials should be less than 30%. Values up to 50% are allowed in base courses like water bound and bituminous macadam.

**Shape Test**

**Aim**

To determine the Flakiness Index, Elongation Index and Angularity Number of the given sample of aggregate.

**Theory**

The particle shape of aggregate is determined by percentages of flaky and elongated particles contained in it. In case of gravel it is determined by its angularity number. For base course and construction of bituminous and cement concrete types, the presence of flaky and elongated particles...
are considered undesirable as they may cause inherent weakness with possibilities of breaking down under heavy loads. Rounded aggregate are preferred in cement concrete road construction as the workability of concrete improves. Angular shape of particles is desirable for granular base course due to increased stability derived from the better interlocking. Thus evaluation of shape of the particles, particularly with reference to flakiness, elongation and angularity is necessary.

1. **Flakiness Index**

   The Flakiness index of aggregate is the percentage by weight of particles whose least dimension [thickness] is less than three- fifths \( [0.6] \) times of their mean dimension. The test is not applicable to aggregate size smaller than 6.3 mm

**Apparatus**

a) Thickness gauge  
b) Weighing balance  
c) IS Sieves of sizes  
   63 mm, 50 mm, 40 mm, 31.5 mm, 25 mm, 20 mm, 16 mm, 12.5 mm, 10 mm and 6.3 mm

**Procedure**

1. The sieves are arranged such that the largest size sieve (63 mm) is at the top and the smallest size sieve (6.3 mm) is at the bottom.  
2. The given aggregate are sieved. A minimum of 200 pieces of each fraction to be tested are taken and weighed = \( W_1 \) g.
3. In order to separate flaky aggregate, each fraction is then gauged for thickness through the respective opening on the thickness gauge. For example, if the aggregate is from 50 – 40 fraction, it is gauged through the opening of 27.00 mm on the thickness gauge.

4. The flaky aggregate passing the respective openings are collected and accurately weighed = w1 g.

5. The procedure is repeated for other fractions having weights W2, W3, etc. and the flaky aggregate in them having weights w2, w3 respectively are weighed.

6. Then

\[
\text{Flakiness Index} = \frac{(w1+w2+w3+\cdots)}{(W1+W2+W3+\cdots)} \times 100
\]

\[= \text{………………%}
\]

**Result**

The flakiness Index of the given sample of aggregate is __________

2. **Elongation Index**

The elongation index of an aggregate is the percentage by weight of particles whose greatest dimension (length) is greater than one and four fifth times [1.8] times their mean dimension. The elongation test is not applicable to size smaller than 6.3 mm.

**Apparatus**

a) Length gauge

b) Weighing balance

c) IS Sieve of size as in flakiness Index test.
Procedure

1. The sample is sieved through the IS sieves specified and a minimum of 200 pieces of each fraction are taken and weighed = W1 g.

2. In order to separate elongated aggregate, each fraction is then gauged individually for length through the respective opening on the length gauge.

3. In each fraction, the aggregate retained on the respective opening on the length gauge is collected and weighed = X1 g.

4. The procedure is repeated for other fractions having weights W2, W3, etc, and the weights of elongated aggregate in them X2, X3 etc, are found.

5. Then

\[
\text{Elongation Index} = \frac{(X1+X2+X3)}{(W1+W2+W3)} \times 100 \%
\]

\[
X \times 100 = \text{.........} \%
\]

\[
W
\]
Result

The elongation Index of the given sample of aggregate = __________ %

3. Angularity Number

The angularity number of an aggregate is the amount by which the percentage voids exceeds 33, after being compacted in a prescribed manner. The angularity number is found from the expression \( (67 - 100 \times \frac{W}{CG}, \text{percent}) \). Here the value 67 represents the percentage volume of solids of most rounded gravel, which would have 33 percent voids

Apparatus

a) A metal cylinder closed at one end having 3 litre capacity, diameter and height approximately equal
b) A metal tamping rod, 16 mm in diameter and 600 mm long.
c) Weighing balance
d) IS sieves 25, 20, 16,12.5, 10, 6.3 and 4.75 mm

Procedure

1) The sieves for each fraction (as specified) are arranged such as 25 - 20 mm, etc.
2) The given sample of aggregate is sieved so that sufficient pieces are obtained in each fraction.
3) The empty cylinder is accurately weighed = ‘a’ g
4) Each aggregate fraction is separately filled in the cylinder in 3 (three) layers tamping each layer 100 (hundred) times with the rounded end of tamping rod. The excess aggregate are removed.
5) The cylinder along with aggregate is weights = ‘b’ g
6) The aggregate are removed from the cylinder. The cylinder is completely filled with water and after wiping its outer sides it is weighed with water = ‘d’ g
7) Then Angularity number may be calculated from the expression,

\[
\text{Angularity number} = 67 - 100 \frac{W}{CG}
\]

Where, \( W = \text{Mean weight of aggregate in the cylinder} \)

\( C = \text{Weight of water required to fill the cylinder} \)

\( G = \text{Average Specific gravity of aggregate} \)
**Result**

The angularity number of the given sample of aggregate = …………. %

**Observations**

<table>
<thead>
<tr>
<th>Weight of empty cylinder = a g</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight of cylinder + aggregate = b g</td>
<td></td>
</tr>
<tr>
<td>Weight of aggregate in the cylinder = (b-a) = W g</td>
<td></td>
</tr>
<tr>
<td>Weight of cylinder + water = d g</td>
<td></td>
</tr>
<tr>
<td>Weight of water in the cylinder = (d-a) = C g</td>
<td></td>
</tr>
</tbody>
</table>

**Flakiness Index and Elongation Index Observations**

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Size of aggregate</th>
<th>Weight of the fraction consisting of atleast 200 pieces, ‘g’</th>
<th>Thickness gauge size ‘mm’</th>
<th>Weight of aggregate in each fraction passing thickness gauge ‘g’</th>
<th>Length gauge size ‘mm’</th>
<th>Weight of aggregate in each fraction retained on length ‘g’</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Passing through IS sieve ‘mm’</td>
<td>Retained on IS sieve ‘mm’</td>
<td>[1]</td>
<td>[2]</td>
<td>[3]</td>
<td>[4]</td>
</tr>
<tr>
<td>1</td>
<td>63</td>
<td>50</td>
<td>W₁=</td>
<td>33.90</td>
<td>w₁=</td>
<td>----</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>40</td>
<td>W₂=</td>
<td>27.00</td>
<td>w₂=</td>
<td>81.0</td>
</tr>
<tr>
<td>3</td>
<td>40</td>
<td>31.5</td>
<td>W₃=</td>
<td>19.50</td>
<td>w₃=</td>
<td>58.0</td>
</tr>
<tr>
<td>4</td>
<td>31.5</td>
<td>25</td>
<td>W₄=</td>
<td>16.95</td>
<td>w₄=</td>
<td>----</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>20</td>
<td>W₅=</td>
<td>13.50</td>
<td>w₅=</td>
<td>40.5</td>
</tr>
<tr>
<td>6</td>
<td>20</td>
<td>16</td>
<td>W₆=</td>
<td>10.80</td>
<td>w₆=</td>
<td>32.4</td>
</tr>
<tr>
<td>7</td>
<td>16</td>
<td>12.5</td>
<td>W₇=</td>
<td>8.55</td>
<td>w₇=</td>
<td>25.6</td>
</tr>
<tr>
<td>8</td>
<td>12.5</td>
<td>10</td>
<td>W₈=</td>
<td>6.75</td>
<td>w₈=</td>
<td>20.25</td>
</tr>
</tbody>
</table>
Flakiness Index = \[
\frac{(w_1+w_2+w_3+\ldots)}{(W_1+W_2+W_3+\ldots)} \times 100 \text{ percent}
\]

Elongation Index = \[
\frac{[X_1+X_2+X_3 \ldots]}{(W_1+W_2+W_3+\ldots)} \times 100 \text{ percent}
\]

\[\text{Angularity Number} = 67 - 100 \frac{W}{CG}\]

**Tabular Column**

<table>
<thead>
<tr>
<th>Weight of aggregate in the cylinder = (W) g</th>
<th>Weight of water in the cylinder (= C) g</th>
<th>Angularity Number = 67 – 100 (\frac{W}{CG}) [Take (G=2.68)]</th>
</tr>
</thead>
</table>

**Desirable value**

IRC has recommended the maximum allowable limits of flakiness index values for various types of construction are given below:

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Type of pavement construction</th>
<th>Maximum limit of Flakiness Index, %</th>
</tr>
</thead>
</table>
### Specific Gravity and Water Absorption Test on Aggregates

#### Aim
To determine the specific gravity and water absorption of given sample of aggregates.

#### Apparatus
a) Density basket
b) Weighing balance
c) Water tank
d) Tray
e) IS sieves- 10mm and 20mm.

Theory

The specific gravity of an aggregate is considered to be a measure of strength or quality of the material. Stones having low specific gravity are generally weaker than those with higher specific gravity values. The specific gravity test helps in the identification of stone.

Water absorption gives an idea of strength of rock stones having more water absorption are more porous in nature and are generally considered unsuitable unless they are found to be acceptable based on strength, impact and hardness.

Procedure

1) Take about 2kg of given aggregates passing IS 20mm sieve and retained on 10mm sieve.
2) Keep the aggregate in density basket and then keep the basket in water.
3) Allow the aggregate and basket to be in water for 24 hours.
4) After 24 hours find the suspended weight of basket with aggregate.
5) Remove the basket out of water and remove the aggregate.
6) Keep the empty basket back in water and find the suspended weight.
7) Wipe the surface of aggregate using a cotton cloth to make them surface dry.
8) Find the weight of surface dry aggregate in air.
9) Keep the aggregate in oven at 110° C for 24 hours.
10) Now find the weight of dried aggregate in air.
11) Then specific gravity and Water absorption is calculated from the relation:

\[
\text{Specific gravity} = \frac{W_4}{W_3-(W_1-W_2)}
\]
Water absorption = \( \frac{W_3-W_4}{W_4} * 100 \% \)

**Observation**

Weight of aggregate taken = 2000gm

I.S. sieve used 20mm and 10mm

<table>
<thead>
<tr>
<th>Weight of saturated aggregate suspended in water + basket 'W1'gm</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight of empty basket in water 'W2' gm</td>
<td></td>
</tr>
<tr>
<td>Weight of saturated aggregate in water 'Ws' = (W1-W2) gm</td>
<td></td>
</tr>
<tr>
<td>Weight of surface dry aggregate 'W3' gm</td>
<td></td>
</tr>
<tr>
<td>Weight of equal volume of water to the aggregate = W3-Ws gm</td>
<td></td>
</tr>
<tr>
<td>Weight of oven dry aggregate 'W4' gm</td>
<td></td>
</tr>
</tbody>
</table>

Specific gravity = \( \frac{W_4}{W_3-(W_1-W_2)} \)

Water absorption = \( \frac{W_3-W_4}{W_4} * 100 \% \)

**Result**

The specific gravity of given aggregate sample = ....................

The water absorption of given aggregate sample = ....................\%

**Desirable value**

The specific gravity of aggregates normally used in road construction ranges from about 2.5 to 3.0 with an average value of about 2.68. though high specific gravity of an aggregate is considered as an indication of high strength, it is not possible to judge the suitability of a sample of road aggregate without finding the mechanical properties such as aggregate crushing, impact and abrasion values.

Water absorption of an aggregate is accepted as measure of its porosity. Sometimes this value is even considered as a measure of its resistance to frost action. Water absorption value ranges from 0.1
to about 2.0 percent for aggregate normally used in road surfacing. Stones with water absorption upto 4.0 percent have been used in base courses. Generally a value of less than 0.6 percent is considered desirable for surface course, though slightly higher values are allowed in bituminous constructions. IRC has specified the maximum water absorption value as 1.0 percent for aggregates used in bituminous surface dressing and built-up spray grout.

**Soundness Test**

**Aim**

To study the resistance of aggregates to weathering action, by conducting accelerated weathering test cycle

**Apparatus**

a) Sodium sulphate or magnesium sulphate  
b) Oven  
c) Weighing balance  
d) IS sieves

**Procedure**

1) In order, to quicken the effects of weathering due to alternate wet-dry or freeze-thaw cycles in the laboratory, the resistance to disintegration of aggregate is determined by using saturated solution of sodium sulphate or magnesium sulphate.  
2) Clean, dry aggregates of specified size is weighed and counted. Then immersed in the saturated solution of sodium sulphate or magnesium sulphate for 16 to 18 hours.  
3) Then the aggregates are dried in an oven at 105-110°C to a constant weight, thus making one cycle of immersion and drying.
4) The number of such cycles is decided by prior agreement and then the specimens are tested. After completing the final cycle, the sample is dried and each fraction of aggregate is examined visually to see if there is any evidence of excessive splitting, crumbling or disintegration of the grains.

5) Sieve analysis is carried out to note the variation in gradation from original. The coarse aggregate fraction of each size range is sieved on specified sieve sizes.

**Desirable value**

IRC has specified 12 percent as the maximum permissible loss in soundness test after 5 cycles with sodium sulphate, for the aggregate to be used in bituminous surface dressing, penetration macadam and bituminous macadam constructions.

**Bitumen Adhesion/Stripping Test**

Several laboratory tests have been developed to determine the adhesion of bituminous binder to an aggregate in presence of water. These tests may be classified into six types:

a) Static immersion test  
b) Dynamic immersion test  
c) Chemical immersion test  
d) Immersion mechanical test  
e) Immersion trafficking test and  
f) Coating test

The static immersion test is very commonly used as it is quite easy and simple. The principle of this type of test is by immersing aggregate fully coated with the binder in water maintained at specified temperature and by estimating the degree of stripping. The result is reported as the percentage of stone surface that is stripped off after the specified time periods.

**Desirable value**

IRC has specified the maximum stripping value as 25 percent for aggregate to be used in bituminous construction like surface dressing, penetration macadam, bituminous macadam and carpet.
IRC has specified that stripping value of aggregates should not exceed 25 percent for use in bituminous surface dressing, penetration macadam, bituminous macadam and carpet constructions, when aggregate coated with bitumen is immersed in water bath at 40°C for 24 hours.

**Polished Stone Value Test or Accelerated Polishing Test**

**Aim:** To determine polished stone value of the given aggregate sample.

**Apparatus**

Accelerated polishing machine

Pendulum type friction tester

Abrading material (sand and emery powder)

IS sieves: 10.8, 0.425, 0.3, 0.212 and 15 mm

Mould of size 90.5 mm x 44.5 mm

**Theory**

The aggregates used in the surface course of pavements are subjected to abrasion and rubbing action due to traffic movements and particularly during application of brakes. The presence of fine particles of sand and dust between the pavement surface and tyres of vehicles accelerates the process of the pavement surface getting smoothened along the wheel paths. The smoothened pavement surface becomes slippery under wet conditions, resulting in skidding of high speed vehicles when brakes are applied suddenly and the wheels are locked. Therefore the aggregates used in pavement surface course should have resistance from getting polished or smooth rapidly under traffic movement in order to prevent the pavement surface becoming too slippery resulting in accidents due to skidding of high speed vehicles under wet weather condition.

The test is conducted in two stages:
In the first stage, the sample of aggregates are placed in a mould and subjected to accelerated polishing action in machine, under standard test conditions.

In the second stage, the polished sample is subjected to friction test using a pendulum type skid resistance tester to determine the coefficient of friction expressed as percentage or polished stone value.
MOULD AND TEST SPECIMEN FOR ACCELERATED POLISHING
PENDULUM TYPE FRICTION TESTER

Procedure

Preparation of Test Specimen

About 3 kg of clean stone aggregate sample passing through 10 mm and retained on 8 mm IS test sieves (not flaky or elongated) are collected for the preparation of test specimen. A stiff paste of cement mortar is prepared using equal proportions of cement and sand, with required quantity of water. A thin layer of this mortar is placed in the mould and each particle of aggregate sample is set in the mortar in single layer by hand as closely as possible. The mortar is allowed to set so that the stone aggregate are held firmly in position.

Accelerated polishing Test Procedure

The test specimens are clamped around the rim of the wheel with the help of strips of polythene sheet beneath and in between the adjoining test specimens.

The rubber tyred test wheel is lowered until it rests on the surface of the test specimens fixed around the road wheel. The required weight is added at end of lever such that total effective load of 40 kg is applied on test wheel through the lever system.

The motor is switched on and the road wheel rotates at a speed of 320 to 325 rpm. Abrading sand and water are released at the specified rate and these are uniformly spread over the surface of test specimen and tyre of the test wheel where they are in contact.

The road wheel is continued to be rotated and the test specimens are subjected to abrading action or polishing for a period of 3 hours. The machine is stopped and the test specimens are thoroughly cleaned by washing with water to remove sand and other fine particles of stone.
The machine is operated for a further period of 3 hours after releasing emery powder and water at the specified rates (instead of sand). After 3 hours, the machine is stopped and test specimens and machine are cleaned.

**Measurement of Friction of Polished Specimens**

Machine used to determine the coefficient of friction or the skid resistance value is pendulum type friction tester.

The friction tester is placed on a firm level surface and levelling screws are adjusted such that the column is vertical. The pointer is set to zero.

One of the specimens of aggregate which was subjected to accelerated polishing is properly fixed in the slot provided, with its longer side in the track of the pendulum swing.

The surfaces of specimen and rubber shoe are wetted with clean water. The pendulum and pointer are released from horizontal position by pressing the button. The pointer reading is noted as the skid number or polished stone value from the graduated scale. Similarly the procedure is repeated using new specimens until two values are within this limit.

**Observations**

**Accelerated Polishing of Test Specimens**

Sample No. of stone aggregate:

Name of the quarry:

Number of test samples prepared:

Type of abrading sand used:

**Friction Measurement of Polished Specimens**

Type of friction tester:
Type of rubber slider used:

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Pointer reading: polished stone value or skid number or friction coefficient in percent</th>
<th>Mean value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Result

The polished stone value of the given aggregate sample is ____ %

Desirable value

As per the MORTH specifications for road and bridge works, the polished stone value of coarse aggregates used in bituminous concrete, semi dense bituminous concrete, open graded pre-mix carpet and close graded premix surfacing of roads, should be not less than 55 and for the aggregate used in surface dressing should be not less than 60.

Hydrophilic and Hydrophobic Aggregates

Most of the road stones have surfaces that are electrically charged. Silica, a common constituent of igneous rocks posses a weak negative charge and hence these have greater attraction with the polar liquid water than with bituminous binders having little polar activity. These aggregates which are electronegative are water-linking and are hydrophilic.

Basic aggregates like lime-stones have a dislike for water and greater attraction to bitumen, as they have positive surface charge. These aggregates are called hydrophobic.

Type of charge of aggregates used in road plays a vital role in bituminous construction. Bitumen is also available as cationic or positive and anionic or negative and hence a suitable selection may be made depending on aggregates available. Cationic (+) bitumen may be selected for electronegative aggregate and anionic (-) bitumen for electropositive aggregates.
Concepts of Size and Gradation

The gradation analysis or sieve analysis of weight the coarse and the fine aggregates available is carried out by sieving through the standard IS sieves.

Dry sieve analysis is generally used when aggregates contain fine slit or clay sticking to a coarser particle used sieve analysis is carried out.

Design Gradation

It is the gradation or distribution of particles or aggregates specified by the designer. The design gradation is obtained using a number of trials by mixing different size aggregate to satisfy the requirement of density and CBR value.

When the available aggregate sample does not satisfy the design gradation, the aggregates of different gradation are blended (mixed) using different trials or standard procedure suggested by Rothfuch’s Method.

Maximum Aggregate Size

Maximum aggregate size is the sieve size or mean size of the smallest sieve through which 100% of material will pass. The maximum size and the grading of the aggregate are controlled by the specification which describes the distribution of particle sizes to be used of a particular work. The aggregates contain finer fraction (75µ) liquid limit and plastic limit of the particles finer than 425µ are to be determined. The aggregates containing more than 2% fines and greater than 5% fines can be used only for bituminous courses.

Aggregate Blending

Aggregate blending is a method of mixing the aggregates of different sizes to obtain or to satisfy the design gradation. There are several techniques used to blend the aggregates. The trial method is the one in which the aggregates are blended by several trials to get the design gradation and to meet the
required specification.

Two graphical methods in common use for proportioning/blending are:

1) Triangular Chart
2) Rothfutch’s Method

**Triangular Chart**

This method is applicable when three materials are to be mixed together to achieve a desired gradation (for maximum density). The materials may be conveniently divided on a triangular chart as shown in figure.

Suppose three materials A, B and C are available which are respectively coarse, medium and fine grained materials. Points A, B and C are plotted on the triangular chart knowing the grain size distribution (or proportion of coarse aggregate, sand and fines) of the three materials. Next step is to obtain the desired gradation D based on some gradation criteria or by using a gradation formula (Fuller equation). The point D is also plotted in the triangular chart representing the desired gradation. Now the graphical construction for obtaining the proportions A, B and C is made, by producing the line CD to meet the line AB at E. The proportions of coarse aggregate, sand and fines are given by:
\[
\text{% coarse aggregate} = \frac{EB \times DC}{AB \times EC} \times 100
\]

\[
\text{% Sand} = \frac{AE \times DC}{AB \times EC} \times 100
\]

\[
\text{% Fines} = \frac{ED}{EC} \times 100
\]

**Rothfuch’s Method**

This method is used when a number of materials have to be mixed together for obtaining a desired or design gradation. The desired gradation may be decided either based on recommended grain size distribution charts or tables or using the below Fuller’s equation.

\[
P = 100 \left(\frac{d}{D}\right)^n
\]

Where,

\[D = \text{diameter of largest particle, mm}\]

\[P = \text{percent finer than diameter ‘d’ (mm) in the material}\]

\[n = \text{gradation index, which have values ranging from 0.5 to 0.3 depending upon the shape.}\]

On a graph paper, with Y-axis representing percent passing and X-axis representing particle size, as shown in figure. A diagonal line is drawn from point corresponding to (100 percent passing, maximum particle size of the material) to a point corresponding to (zero percent passing, smallest particle size of the materials)

The different particle sizes are marked on X-axis corresponding to the mean values of percentage
For different materials say A, B and C, sieve analysis has to be done and percentage finer has to be calculated for each range of particle size for all the materials and grain size distribution curves of these three materials are plotted as shown in fig and the balancing straight lines of A, B and C are obtained, allowing only minimum of the areas on either sides of the balancing lines.

The opposite ends of the balancing straight lines of A and B are joined (i.e., zero percent passing of materials A is joined with 100 percent passing of B). Similarly the opposite ends of balancing lines of B and C are joined.

The points where these lines meet the desired gradation line represent the proportion in which the materials A, B and C are to be mixed. These values may be read from the Y-axis by projecting the points of intersection as shown in fig.

1. List the various tests conducted on road aggregates in order to ascertain its suitability and indicate the desirable values of the test results.
2. Write a note on aggregate blending to meet the specified gradation.
3. Write short notes on Hydrophobic and Hydrophilic Aggregates

4. Indicate the suitability of the following tests on the selection of proper aggregates for various bituminous surfacing:
   i) Los angeles abrasion test
   ii) Aggregate impact test.
   iii) Aggregate shape test

5. Explain briefly the desirable properties of aggregates used in road construction.

6. Explain the desirable properties of road aggregates used in pavement construction.

7. Explain the Abrasion tests and soundness test on aggregates. Indicate the requirements as per IRC.

8. Explain the desirable properties of aggregates to be used in pavement construction.

9. List various tests to be carried out on aggregates used in road construction.

10. Distinguish between aggregate crushing value and aggregate impact value. Indicate the permissible values for the aggregates to be used in pavement construction.

   Classify the road aggregates based on petrology and origin.

11. List the different methods for aggregate blending to meet specified gradation. Explain any one in brief.

12. Classify the different types of aggregates.

13. Write a note on aggregate blending to meet the specified gradation.

14. Mention the desirable properties of load aggregates. Explain any one desirable property.

15. Classify different types of aggregates used in road construction. Mention at least one example of each locally available material.

16. Indicate the suitability of the following test on the selection of proper aggregate for various pavement surfacing:
   i) Aggregate crushing test
   ii) Aggregate impact test
   iii) Aggregate shape test
   iv) Loss angles abrasion test
   v) Water absorption test. Confirm the above test suitability with IS/IRC standards value or limitation.
UNIT - 2

BITUMEN AND TAR: Origin, preparation, properties and chemical constitution of bituminous road binders; requirements. [4 Hours]

***************************************************************************

Introduction

Bituminous binders used in pavement construction works include both bitumen and tar. Both bitumen and tar have similar appearance, black in colour though they have different characteristics.

Origin

Naturally occurring deposits of bitumen are formed from the remains of ancient, microscopic algae and other once-living things. When these organisms died, their remains were deposited in the mud on the bottom of the ocean or lake where they lived. Under the heat and pressure of burial deep in the earth, the remains were transformed into materials such as bitumen, kerogen, or petroleum. Deposits at the La Brea Tar Pits are an example. There are structural similarities between bitumens and the organic matter in carbonaceous meteorites. However, detailed studies have shown these materials to be distinct.

Asphalt or bitumen can sometimes be confused with "tar", which is a similar black, thermoplastic material produced by the destructive distillation of coal. During the early and mid-20th century when town gas was produced, tar was a readily available product and extensively used as the binder for road aggregates. The addition of tar to macadam roads led to the word tarmac, which is now used in common parlance to refer to road-making materials. However, since the 1970s, when natural gas succeeded town gas, asphalt (bitumen) has completely overtaken the use of tar in these applications.

BITUMEN is a petroleum product obtained by the distillation of petroleum crude.

TAR is a thermoplastic material obtained from the destructive distillation.

The grade of bitumen used for pavement construction work of roads and airfields are called paving grades and used for water proofing of structures and industrial floors etc. are called industrial grades.

The paving bitumen available in India is classified into two categories:

1) Paving bitumen from Assam petroleum denoted as A-type and designated as grades A35, A90, etc.
2) Paving bitumen from other sources denoted as S-type and designated as grades S35, S90 etc. The viscosity of bitumen is reduced some times by a volatile diluents this material is called Cutback. The bitumen is suspended in a finely divided condition in an aqueous medium and stabilized with an emulsifier; the material is known as Emulsion.

**Difference between Bitumen and Tar**

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Bitumen</th>
<th>Tar</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bitumen is found in black to brown in colour</td>
<td>Tar is usually found in brown colour</td>
</tr>
<tr>
<td>2</td>
<td>Bitumen is obtained from fractional distillation of crude oil</td>
<td>Tar is obtained by destructive distillation of coal or wood</td>
</tr>
<tr>
<td>3</td>
<td>Bitumen is soluble in carbon disulphide and carbon tetra chloride</td>
<td>Tar is soluble in toluene</td>
</tr>
<tr>
<td>4</td>
<td>Molecular weight range for road bitumen is 400 to 5000</td>
<td>Molecular weight range for road tar is 150 to 3000</td>
</tr>
<tr>
<td>5</td>
<td>Bitumen consists of large amount of aromatic hydrocarbon</td>
<td>Tar consist of large amount of oily matter with lower molecular weight</td>
</tr>
<tr>
<td>6</td>
<td>Bitumen show resistance to coating road aggregate and also does not retain in presence of water</td>
<td>Tar coats more easily and retain it better in presence of water</td>
</tr>
<tr>
<td>7</td>
<td>Free carbon content is less</td>
<td>Free carbon content is more</td>
</tr>
<tr>
<td>8</td>
<td>It shows more resistance to weathering action</td>
<td>It shows less resistance to weathering action</td>
</tr>
<tr>
<td>9</td>
<td>Less temperature susceptibility</td>
<td>More temperature susceptibility</td>
</tr>
</tbody>
</table>

**Bitumen**

The source of road bitumen is either formed from petroleum or by natural processes as a result of geological forces.

**Different forms of bitumen**

**Cutback bitumen**

Normal practice is to heat Bitumen to reduce its viscosity. In some situations preference is given to
use liquid binders such as cutback bitumen. In cutback bitumen Suitable solvent is used to lower the viscosity of the bitumen. From the environmental point of view also cutback bitumen is preferred. The solvent from the bituminous material will evaporate and the bitumen will bind the aggregate. Cutback bitumen is used for cold weather Bituminous road construction and Maintenance. The distillates used For preparation of cutback bitumen are naphtha, kerosene, diesel, oil and furnace oil. There are different types of cutback bitumen Like rapid curing (RC), medium curing (MC), And slow curing (SC). RC is recommended for Surface dressing and patchwork. MC is recommended For premix With less quantity of fine aggregates. SC is used For premix with appreciable quantity of fine aggregates.

**Bitumen Emulsion**

Bitumen emulsion is a liquid product in which bitumen is suspended in a finely divided condition in an aqueous medium and stabilized by suitable material. Normally cationic type emulsions are used in India. 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. The viscosity of bituminous emulsions can be measured as per IS:8887-1995. Threetypes of bituminous emulsions are available, which are Rapid setting (RS), Medium setting (MS), And Slow setting (SC). Bitumen Emulsions are ideal binders for hill road construction. Where Heating of bitumen or aggregates are difficult. Rapid Setting emulsions are used for surface dressing work. Medium Setting emulsions are preferred for premix jobs and patch repairs work. Slow setting Emulsions are preferred in rainy season.

**Bituminous primers**

In bituminous primer the distillate is absorbed by the road surface on which it is spread. The absorption there for depends on the porosity of the surface. Bitumen primers are use full on the stabilized surfaces and water bound macadam base courses. Bituminous primers are generally prepared on road sites by mixing penetration bitumen with petroleum distillate.

**Modified Bitumen**
Certain additives or blend of additives called as bitumen modifiers can improve properties of Bitumen and bituminous mixes. Bitumen treated with these modifiers is known as modified bitumen. Polymer modified bitumen (PMB)/crumb rubber modified Bitumen (CRMB) should be used only in wearing course depending upon the requirements of extreme climatic variations. The detailed specifications for modified bitumen have been issued by IRC: SP: 53-1999. It must be noted that the performance of PMB and CRMB is dependent on strict Control on Temperature during construction.

**The advantages of using modified bitumen are as follows:**

1. Lower susceptibility to daily and seasonal temperature variations
2. Higher resistance to deformation at high pavement temperature
3. Better age resistance properties
4. Higher fatigue life for mixes
5. Better adhesion between aggregates and binder

**Types**

1) **Rock Asphalt**
   
a) It consists of limestone, sand stone naturally impregnated with bitumen.
   
b) The mineral matter will be about 90% and bitumen content of 10%.

2) **Lake Asphalt**
   
a) Mineral matter will be finely divided and dispersed through the bitumen
   
b) The whole mass is capable of flow
   
c) Type of lake asphalt used in road making in United Kingdom is Trinidad lake asphalt.
   
d) It is used in flexible road construction and also in rolled asphalt wearing courses.
Preparation of Road Bitumen from Petroleum

The refining of petroleum is most complex procedure producing a tremendous range of products from the simplest hydrocarbon gas methane to the hardest bitumen with constituents of molecular weight of the order of several thousands.

The preparation of different forms of bitumen for road purposes from petroleum is illustrated in the above figure.

PREPARATION OF ROAD BITUMEN
a) Distillation of Petroleum

Bitumen is produced from selected crude oils by a process of concentration by distillation.

The distillate is obtained in the desired boiling point ranges by condensation in a fractionating column.

It is first to heat the crude oil to a temperature lower than 350°C under atmospheric pressure to drive off light fractions such as gasoline, kerosene and gas oil.

Further heating above 400°C is necessary to drive off heavier oils.

Refining of the topped crude is carried out by use of reduced pressures and steam injection in the fractionating column.

The incoming crude is pumped through a continuous pipe-still similar to that used in tar-distillation plants, where it is raised to desired temperature (between 200 and 400° C)

It is then injected into a fractionating column where at the reduced pressure volatile components flash into vapours.

The vapours are condensed into fractions of decreasing boiling point by condensation at points at higher levels in the fractionating column.

A flow diagram representing the distillation of topped oil in a modern refinery is given in figure below:

b) Air-Rectification of Refinery Bitumen

Bitumen produced by straight steam-refining from crude oils may be deficient in the components of high molecular weight which are insoluble in heptanes, asphaltenes fractions.

It is common practice to increase the asphaltene content by oxidation of the hot straight-run bitumen by a current of air blown through it.
These are bitumens of high softening point produced by an oxidation by air-blowing at high temperatures.

The oxidation is more extensive and the blown bitumens have rubbery qualities required for certain industrial purposes and not used as binders for road aggregates.

**Chemical Constitution of Bitumen**

Bitumen although formed from distillation process causes some changes which is closely related in chemical nature to its primary source i.e., the crude petroleum oil.

Bitumen is completely soluble in carbon-di-sulphide but most of them divide the bitumen soluble in carbon-di-sulphide into 3 fractions:

a) **Carbenes**: fraction insoluble in carbon tetrachloride.
b) **Asphaltenes**: fraction insoluble in light aliphatic hydrocarbon solvent such as petroleum ether.
c) **Maltenes**: fraction soluble in light aliphatic hydrocarbon solvent

The molecular weight of asphaltene fraction is estimated between 1800 and 1,40,000 and maltenes have molecular weight between 370 and 710.

The hydrocarbons in petroleum are of four basic forms:

a) Saturated aliphatic groups or paraffins
b) Naphthenic groups or cycloparaffins
c) Aromatic ring compounds
d) Aliphatic groups with olefin double bonds

Aliphatic group normally does not present in road bitumen. The approximate proportions of the other three groups in the molten groups can be obtained from modified Waterman analysis.

Many properties of bitumen, particularly the non-Newtonian flow properties suggest that bitumen is a colloidal system. The colloidal nature of bitumen is due to the presence of asphaltenes in association with high molecular weight material from the maltenes fraction, form a disperse phase. This complex is normally referred as ‘micellar phase’.

On the basis of flow properties, bitumen can be divided into two types, ‘sol’ type, in which there is little interaction between micelles or a ‘gel’ type in which interaction of micelles are
great enough to cause a loose structure formation. Most of the distilled road bitumens are sol type, blowing leads to gel type structures.

**Requirements of Bitumen**

The desirable properties of bitumen depend on the mix type and construction.

a) Mixing: type of materials used, construction method, temperature during mixing, etc.

b) Attainment of desired stability of the mix

c) To maintain the stability under adverse weather conditions

d) To maintain sufficient flexibility and thus avoid cracking of bituminous surface and

e) To have sufficient adhesion with the aggregates in the mix in presence of water

**Desirable Properties of Bitumen**

1) **Viscosity**
The viscosity of the bitumen at the time of mixing and compaction should be adequate. This is achieved by heating the bitumen and aggregate prior to mixing or by use of cutbacks or emulsions of suitable grade.

2) **Temperature Susceptibility**
The bituminous material should not be highly temperature susceptible. During the hottest weather of the region the bituminous mix should not become too soft or unstable. During cold weather the mix should not become too hard and brittle, causing cracking. The material should be durable.

3) **Adhesion Property**
In presence of water the bitumen should not strip off from the aggregate. There has to be adequate affinity and adhesion between the bitumen and aggregate used in the mix.

**Tests on bitumen**

There are a number of tests to assess the properties of bituminous materials. The following tests are usually conducted to evaluate different properties of bituminous materials.

1. Penetration test
2. Softening point test
3. Ductility test
4. Viscosity test
5. Specific gravity test
6. Heat stability test
   a. Flash point test
   b. Fire point test
   c. Loss on heating test
7. Solubility test
8. Thin film oven test
9. Float test
10. Water content test

1. **Penetration test:**
An indirect method of measuring viscosity is the measure of penetration of a standard needle under standard conditions of load, time & temperature. The test measures the hardness or softness of bitumen in terms of penetration expressed in mm/10\(^{th}\) of std needle.

Temperature= 25\(^{0}\)C [test to be performed after sample is kept for 1hr in H\(_2\)O bath at this temperature]
Load on needle = 100 g
Time in which penetration is recorded = 5 s
The penetration is measured by a graduated dial.
Bitumen is softens to a poring consistency a depth more than 15mm in the container is poured. The expected penetration sample is cooled in 60 min in air and 60 min in water before testing. The standard needle is positioned to get a penetration value for 5sec and is noted.

The penetration value obtained is represented in 80-100 or 80/100 grade bitumen at standard consistence and it range from 20-225mm.
In cold region bitumen with High penetration value is used.
In warm region low penetration value is used ex. 30/40 grade.
The factors which affect the Penetration test is test temperature, needle size and weight and period of cooling.

1. **Softening point:**
The softening point is the temperature at which the substance attains a particular degree of softening under specified condition of test. A viscosity material like bitumen or tar doesn’t have a well defined softening point. However a std test determines the temperature at which a std ball will pass through a disc of bitumen contained in ring. The test is known as ring & ball test.

A brass ring of internal dia 17.5 mm at top and 15.9 mm at bottom and of depth 6.4mm. The steel ball of 9.5mm dia and 2.5g. Support distance is 25mm between the bottom of the ring and top surface of the bottom plate of support is provided. Glass container of 85mm dia and 120mm depth is used. The bitumen is heated to poring consistency and poured into ring and cooled for half an hour before testing. A brass ring containing the bitumen sample is suspended in H₂O or glycerin at given temperature a steel ball is placed on the disc of bitumen. The liquid medium is then heated at a rate of 5°C increase per minute. Metal plate placed at a specified bituminous material touches the bottom at the softening point. With increase in temperature bitumen melts and come down with the weight of ball at particular temperature it touches the bottom plate that point temperature is noted.

The softening point is range between 35 to 75°C.

The liquid water is used for bitumen having softening point less than 80°C and Glycerine is for softening point more than 80°C.

Higher softening point indicates lower temp. susceptibility and in warm climet.

The factors which affect the softening points are quality and type of liquid used, weight of ball, distance between bottom of the ring and bottom base plate and rate of temperature.

2. **Ductility test:**

In flexible pavement construction it is important that the binders form ductile thin film around the aggregate. This serves as a satisfactory binder in improving the physical
interlocking of the aggregate bitumen mixes. Under traffic loads the bitumen layer is subjected to repeated deformation and recoveries. The binder material which does not possess sufficient ductility would crack and thus provide pervious pavement surface. The test is believed to measure the adhesive property of bitumen and its ability to stretch. The ductility of a binder is an indication of its elasticity & ability to deform under load & return to original condition upon removal of the load. A material which doesn’t possess adequate ductility would crack under a load.

This is unsatisfactory since water can penetrate into the surfacing through there cracks. The property is determined by measuring the distance that a std briquette of bitumen, necked to a cross section of 1 sq-cm will stretch without breaking when elongated at a rate of 5 cm/min at 27°C. The ductility values should be a minimum of 50 as per IS.

The briquette mould is filled with bitumen and cool for 30 min in air and 30 min in water before testing. Then it is fixed to expanding machine assembly which stretches the bitumen at a rate of 5cm/min and expands till to break and the point is noted by scale.

The factors which affect the ductility is pouring and test temperature, dimension of briquette mould, rate of pulling and period of cooling.

3. **Viscosity Test:**

Viscosity is the property of a fluid that determines the resistance offered by the fluid to a shearing force under laminar flow conditions, it is thus the opposite of fluidity.

The determination of viscosity is generally done by efflux viscometers. They work on common principles, though they differ in detail. The liquid under test is poured to a specified
level into a container surround by water or oil bath providing temperature control at the base of the container is a small orifice with a simple valve control on opening valve, the time in seconds is recorded for a stated quantity of liquid to discharge into a measuring liquid below. The different type of viscosity testing operator is there they are Efflux viscometer, Standard tar viscometer (10mm dia orifice and 50ml fluid to discharge), Saybolt furol viscometer (3mm dia orifice and 60ml fluid to discharge).

The bitumen is placed in to a standard tar viscometer or efflux viscometer and its temperature is raised to test temperature specified (35, 40, 45, 55\& 60°C). When the temperature reaches respective test temperature orifice valve is open time elapse is noted to collect the bitumen of 50ml. The time required to collect a bottom container of 50ml is five indirectly the viscosity of bitumen. Then is specified in VG 10, VG20, VG 30 and VG 40.

4. Specific gravity test:

In most applications bitumen is weighed, but finally in use with aggregate the bitumen content is converted on volume basis. Hence determine of specific gravity value is required for conversion of weight to volume. Specific gravity of a binder doesn’t influence its behavior but all the same, its value is needed for mix design.

Specific gravity of bitumen varies from 0.97 to 1.02.
Specific gravity of tar varies from 1.16 to 1.28.
There are two methods to test the specific gravity of bitumen
a. Pycnometer method
b. Balance method

Generally balance method is used in that a cup of 50ml capacity is used and it is oiled before using. The bitumen is poured in to cup and cooled and its weight is noted and weight of cup
with bitumen when immersed in distilled water is weighed $f$. Specific gravity of bitumen is the ratio of $e$ to the difference between ($e$ and $f$).

It is used to convert the weight in to volume. Determines Purity of bitumen if the impurity present in the bitumen by showing high value of specific gravity.

5. **Heat stability test:**

When a bituminous binder is heated continuously it starts emitting volatile vapors above a certain temperature and these volatile vapors can momentarily catch fire in form of flash and continued heating get fired.

a. **Flash point:**

The flash point of bitumen is that temperature at which it gives off vapors, which ignites in the pressure of a flame, but don’t continue to burn. The flame point is an induction of critical temperature at & above which suitable precautions should be taken to eliminate fire hazards. The ISI test describes the Penske-Martin method. The method involves a cup into which the bitumen is filled. The bitumen sample is then heated at a rate of 5-6°C/min stirring the material continuously.

The test flame is applied at intervals. The flash point is taken at the temperature read on the thermometer when flame causes a bright flash in the interior of cup in a closed system & at the surface of material in open system. It is 220°c.

b. **Fire point test:**

If heating is continued beyond the flash point, the vapors ignite in the pressure of a flame & continue to burn indicating the fire point temperature. There is no standard method to determine the spontaneous ignition temperature, which can only broadly indicate.

c. **Loss on heating test:**

The effect of heat on a bituminous binder is the loss of volatile constituents. This loss causes the binder to harden. Thus one method of testing the desirable property of a binder is to find out the loss on heating. This is achieved by an accelerated heating test a 50gm sample is weight is taken and maintained at a temperature of 160°c for 5hours. Then it expressed as a percentage of loss in original weight is determined.

6. **Solubility test:**

It has already been indicated that all bitumen are substantially soluble in CS$_2$. This is one of the points that define bitumen. Hence any impurity in bitumen in the form of inert minerals,
carbon, salts etc. could be quantitatively analyzed by dissolving the samples of bitumen in any of the two solvents.

A sample of 2g of bitumen is dissolved in 100ml of solvent and filtered in soluble material is washed, dried and weighed then it is expressed in percent of original sample. The Indian specifications require 99% solubility.

7. Thin film oven test:

In this test, a sample of bitumen is subjected to hardening conditions as would be expected during hot mixing operations. A 50ml sample of bitumen is placed in a flat bottomed sample pan 140mm inside diameter & 10mm deep, the weighed sample & container are placed in a shelf which rotates at 5 to 6 rpm for 5 hrs in a ventilated oven maintained at 163°C. The loss in weight of the sample is expressed as % of the original weight. This method is then used for identify short term aging or hardening of bitumen.

Tar

Tar is the viscous liquid obtained when natural organic materials such as wood and coal carbonized or destructively distilled in the absence of air. Based on the materials from which tar is derived, it is referred to as wood tar or coal tar. It is more widely used for road work because it is superior.

There are five grades of roads tar: RT-1, RT-2, RT-3, RT-4 and RT-5, based on their viscosity and other properties.

RT-1 has the lowest viscosity and is used for surface painting under exceptionally cold weather as this has very low viscosity.

RT-2 is recommended for standard surface painting under normal Indian climatic conditions.

RT-3 may be used for surface painting, renewal coats and premixing chips for top course and light carpets.

RT-4 is generally used for premixing tar macadam in base course.

RT-5 is adopted for grouting purposes, which has highest viscosity among the road tars.
The various tests carried out on road tars are:

a) Specific gravity test  
b) Viscosity test on standard tar viscometer  
c) Equiviscous temperature (EVT)  
d) Softening point  
e) Softening point of residue  
f) Float test  
g) Water content  
h) Phenols, percent by volume  
i) Naphthalene, percent by weight  
j) Matter insoluble in toluene, percent by weight  
k) Distillation fraction on distillation upto 200°C, 200°C to 270°C and 270°C to 330°C
The properties and requirements for five grades of road tars based on the above test results are given by the ISI are given in below table.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Property</th>
<th>RT-1</th>
<th>RT-2</th>
<th>RT-3</th>
<th>RT-4</th>
<th>RT-5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Viscosity by standard tar viscometer (10 mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(a) at temperature, °C</td>
<td>35</td>
<td>40</td>
<td>45</td>
<td>55</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>(b) viscosity range, seconds</td>
<td>33-55</td>
<td>30-55</td>
<td>35-60</td>
<td>40-60</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>Equiviscous temperature (EVT) range, °C</td>
<td>32-36</td>
<td>37-41</td>
<td>43-46</td>
<td>53-57</td>
<td>63-67</td>
</tr>
<tr>
<td>3</td>
<td>Softening point, °C</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>45-50</td>
</tr>
<tr>
<td>4</td>
<td>Specific gravity range at 27°C</td>
<td>1.16-1.26</td>
<td>1.16-1.26</td>
<td>1.18-1.28</td>
<td>1.18-1.28</td>
<td>1.18-1.28</td>
</tr>
<tr>
<td>5</td>
<td>Softening point of residue, °C Max.</td>
<td>48</td>
<td>50</td>
<td>52</td>
<td>54</td>
<td>56</td>
</tr>
<tr>
<td>6</td>
<td>Water content, percent by weight, Max.</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>7</td>
<td>Phenols, percent by volume, Max.</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>Naphthalene, percent by weight, Max.</td>
<td>4</td>
<td>3.5</td>
<td>3</td>
<td>2.5</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>Matter insoluble in toluene, percent by weight, Max.</td>
<td>22</td>
<td>22</td>
<td>24</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>10</td>
<td>Distillation fractions, percent by weight (g per 100 g) distilling:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(a) upto 200°C, Max.</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>(b) from 200° to 270°C</td>
<td>5-12</td>
<td>2-9</td>
<td>1-6</td>
<td>0.5-4</td>
<td>0-4</td>
</tr>
<tr>
<td></td>
<td>(c) from 270° to 300°C</td>
<td>4-10</td>
<td>4-8</td>
<td>3-6</td>
<td>2-7</td>
<td>1-5</td>
</tr>
<tr>
<td></td>
<td>Total distillation (b+c), Max.</td>
<td>16</td>
<td>14</td>
<td>12</td>
<td>10</td>
<td>7</td>
</tr>
</tbody>
</table>

**Preparation of Tar**

There are three stages in the production of road tar:

1) Carbonization of coal to produce crude tar
2) Refining or distillation of crude tar
3) Blending of distillation residue with distillate oil fractions to give the desired road tar.

**a) High-Temperature Carbonization of Coal**

The carbonization or destructive distillation of coal consists essentially of heating a thin layer of coal enclosed in a chamber of refractory brick-work for several hours at temperature about 1000° C. Majority there are two major methods for carbonization, they are:

a) Carbonization in Coke-ovens

b) Carbonization in gas-works retorts

**Carbonization in Coke-Ovens**

A batch of about 16 tons of coal is loaded into a coke-oven.

Coke oven consists of large thin box lined with brick, 40 feet long, 14 feet high and 1 ½ feet wide.

The charge of coal is heated for 18 hours at a temperature of 1200° C.

Each ton of coal yields 8 gallons of crude tar.

**b) Distillation of Crude Tar**

![Diagram of distillation process]

The crude tar obtained by the condensation of the vapours emitted from coal in the course of carbonization is subjected to distillation process.
The distillation or refining of tar is carried out by tar distillers.

The process consists, first heating the crude tar to remove water and some light oils (Benzole), then heating further and condensing the heavier vapour in a fractionating column.

The operation is carried out in two stages:

In the first stage, the tar passes through the tubes in the cooler part of the furnace at a temperature of 140°C.

It is then passed to a dehydration chamber where the pressure is released and water and light oil is released.

The remaining tar is then passed to the second stage of the pipe-still at a temperature of 300°C.

From pipe-still, tar passes to a chamber at a lower pressure where vaporization takes place.

The vapours are condensed in a fractionating column which forms fractions of different boiling point ranges.

The residue which is not distilled is base-tar or pitch.

In order of increasing boiling points they may be classified as light oil, carbolic oil, naphthalene oil, wash oil, anthracene oil.

c) Blending of Tar-Distillation Fractions to Produce Road Tar

It is evident from the above that a tar of a suitable viscosity for use on the roads could be left as residue simply by stopping the distillation at the appropriate point.

Road tar 1 and 2, on the basis of viscosity, having viscosities of 10 to 40 and 40 to 125 seconds at Standard Tar Viscosity (STV) at 30°C.

Type-A having high softening point is used for surface dressings and base courses. Type-B is used for wearing courses and carpets.
Type A = Base tar + Naphthalene oil  
Type B = Base tar + Wash oil + Anthracene oil

**Chemical Constitution of Tar**

It is estimated that there are over 10,000 compounds in tar. Out of this 300 have been separated. The distillate oils consist largely of aromatic hydrocarbons, with one or more methyl groups attached to the nucleus, with smaller quantities of aromatic hydroxy compounds, paraffinic hydrocarbons and heterocyclic compounds with oxygen, nitrogen or sulphur in the ring.

Dickinson developed a method called ‘solvent fractionation’ which uses n-hexane, benzene and pyridine as solvents to give five fractions. He divided up in this way tars produced from vertical-retort, horizontal-retort and coke-oven crudes and by measurement of mean molecular weights. Typical structures for the solvent fractions have been suggested by spectroscopic examination on the basis of molecular weight and C/H ratio.

The differences in chemical structure between tars from different carbonization processes are reflected in different in their properties. Tars produced by carbonization in coke-ovens or horizontal retorts have more purely aromatic hydrocarbons compared to vertical retorts. Thus, where as in coke-oven tar distillate oils over 90 percent may consist of aromatic hydrocarbon of benzene, naphthalene, anthracene and phenanthrene series, similar oils from vertical retort tars contain up to 25% of phenolic material and the same amount of paraffins, this is because temperature reached in coke-ovens and horizontal retorts will be higher than continuous vertical
retorts and the vapours evolved during carbonization are in contact with hot coke for a longer period.

Vertical-retort tars are often referred as low-aromatic tars while coke-oven and horizontal-retort tars as high-aromatic tars. In general, the high-aromatic class is distinguished by wider molecular weight range, higher specific gravity, higher pitch content and low phenolic content.

1. What are the differences between bitumen and tar? How is asphalt produced?
2. What are the tests conducted on bitumen? Mention the importance of each.
3. Enumerate the properties of Bitumen and Tar
4. Write a note on Bitumen and Tar. Explain the chemical constituents of bituminous road binders.
5. Explain the physical requirements of aggregates and bitumen.
6. What are the tests conducted on bitumen? Mention the importance of each.
7. Briefly explain the preparation of bitumen with neat figure.
8. Describe penetration test to be carried out on bitumen with standard values recommended for construction.
9. Mention the various tests conducted on Bitumen. Explain any three tests with neat sketches.
10.Differentiate between Bitumen and Tar. How is asphalt produces?
11. What are the important requirements of test to be carried out on bitumen for road work? explain important aspects or IS standard of each.
12. Explain briefly the procedure adopted in the laboratory along with neat sketch and limitations to be considered as per IS/IRC standards for bitumen.
13. Explain in brief the preparation of bitumen with a flow chart.
14. Explain the desirable properties of bitumen.
15. Describe the softening point test and thin film oven test and their significance.
UNIT - 3

BITUMINOUS EMULSIONS AND CUTBACKS: Preparation, characteristics, uses and tests. Adhesion of Bituminous Binders to Road Aggregates: Adhesion failure, mechanism of stripping, tests and methods of improving adhesion. [8 Hours]

Emulsions

An emulsion is a two-phase system consisting of two immiscible liquids (unmixable or unblendable). The dispersed or internal phase is the liquid that is broken up into globules and the surrounding liquid is known as the continuous or external phase. Oil-in-water emulsions have the oil as the dispersed phase and water as the continuous phase. The reverse occurs when the emulsion is of water-in-oil type. Oil phase consisting of bitumen or tar.

In the preparation of emulsion of asphaltic bitumen or tar, emulsifiers have to be added in small proportions both to facilitate the formation of dispersion and to keep the globules of dispersed binder in permanent suspension.

If no emulsifier is present, a dispersion of oil droplets in water brought about by stirring will rapidly separate into 2 layers. With emulsifier present, an adsorbed film of the emulsifier is formed round each globule in the emulsion.

Emulsion are classified into 3 types based on setting time

1. **Rapid setting**: If the bitumen emulsion is intended to break rapidly, the emulsion is said to possess rapid-set quality and this type is used in surface dressing & penetration macadam.

2. **Medium setting**: Emulsion which does not break spontaneously on contact with stone but break during mixing or by fine mineral dust are MC. Used in premixing with coarse aggregate.

3. **Slow setting**: When specified type of emulsifying agent is used to make the emulsion relatively stable, they are called slow setting grade. Used in surface course along with the coarse aggregate.

Emulsifiers for road emulsions may be divided into four main groups:

- a) Anionic emulsifiers
- b) Cationic emulsifiers
- c) Non-ionic emulsifiers
- d) Colloidal emulsifiers
Anionic Emulsifiers

It is characterised by having a large organic anion forming a salt with an alkali. A typical example of sodium stearate $\text{CH}_3(\text{CH}_2)_{16}\text{COONa}$. When dissolved in water, this dissociates into the (negative) stearate anion $\text{CH}_3(\text{CH}_2)_{16}\text{COO}^-$ and the (positive) sodium cation $\text{Na}^+$. The long-chain fatty-acid stearate anion is soluble in bitumen, the carboxylic group ($\text{COO}^-$) which carries the negative charge being the least soluble part. Each bitumen globule is surrounded by stearate ions with negative charge on the surface and it becomes much more difficult for the globules to coalesce because all have surface negative charges and so tend to repel each other.

Cationic Emulsifiers

These are compounds in which it is the cation which is the large organic fraction soluble in bitumen. Typical example is cetyl trimethyl-ammonium bromide $\text{C}_{16}\text{H}_{33}(\text{CH}_3)_3\text{NBr}$ dissociates in water into the (positive) cetyl trimethyl-ammonium cation and the (negative) bromine anion $\text{Br}^-$. The cation is soluble in bitumen and when this compound is present in a system of globules of bitumen in water is established, so that each globule of bitumen is surrounded by a positively charged layer.
Non-Ionic Emulsifiers

The non-ionic emulsifiers do not ionise in aqueous solution, are limited in use. They comprise esters and ethers of fatty acids and alcohols.

Colloidal Emulsifiers

It includes naturally occurring fine powders which are used for industrial purpose than for road emulsions. Examples of these are casein and gelatine and fine powders such as clays and bentonites.

Preparation of Emulsion

Materials

Almost all grades of bitumen can be emulsified, from hard penetration grades to softer grades. Harder grades of bitumen are used for industrial purposes.

Methods of Making Road Emulsion

a) Colloid mill method
b) High-speed mixer method
The main difference between the methods is that with the colloid mill the emulsion is produced continuously where as with the high-speed mixer a number of separate batches are produced.

a) Colloid Mill Method

The colloid mill consists of a high-speed rotor which revolves in a stator, the clearance between the rotor and the stator being approximately 15 to 20 thousands of an inch.

A hot solution of the emulsifiers in water and the heated bitumen are fed separately at a constant rate into the machine in the appropriate constant proportions so that an emulsion of uniform binder content is continuously produced. It has been shown that the degree of hardness of the water used has an influence on the degree of dispersion and water-softening plants may need to be installed in areas of very hard water. Road emulsions can be continuously produced in colloid mills at rates of up to 2500 gallons per hour.

b) High-Speed Mixer Method

This method is not widely used because it is a batch process and therefore more labour is required.

The procedure is to run appropriate amount of water at just below boiling point into a 200 or 300 gallon mixer, the diameter of which is equal to depth of liquid it is proposed to mix. The mixer is fitted with a high speed propeller type. Stirrer mounted off-centre to avoid the production of a vortex. Alkali is added to the water in the mixer and bitumen at about 100°C is slowly run in with continuous stirring.

Dispersions obtained by this method are not so uniform as those obtained in a colloidal mill. After emulsification by either method, the material is pumped into storage tanks where it is allowed to cool.

Properties of Emulsion

The following are the properties pertaining largely to the constitution of emulsion before use.

a) Residue on sieving
b) Stability to mixing with coarse-graded aggregate
c) Stability to mixing with cement
d) Water content
e) Viscosity
f) Coagulation at low temperature
g) Sedimentation
h) Stability on long-period storage

**Residue on Sieving**

Practically all road bitumen and tars are slightly heavier than water and the globules of binder will tend to sediment in emulsion; the rate at which it sediments depends on the size of the particle. Hence percentage of large particles should be controlled and hence is to ensure that not more than 0.25% by weight of emulsion consists of particles greater than 0.006 inch in diameter.

**Stability to Mixing With Coarse-Graded Aggregate**

When mixing bitumen emulsions with coarse aggregates, break down of the emulsion and coating off the aggregates with bitumen should not take place too early in the mixing cycle. Stable emulsions should have sufficient mechanical and chemical stability for all purposes involving mixing with fines and cement.

**Stability to Mixing With Cement**

Stable emulsions should have sufficient mechanical and chemical stability for all purposes involving mixing with aggregates including those containing large proportions of fines. Cement is used as a standard fine aggregate.

**Water Content**

Road emulsions may contain up to 65% of water. It is essential to know this percentage if the quantity of bituminous binder actually used in the surfacing is to be measured accurately. The water content of an emulsion is often varied to suit particular forms of application.

**Viscosity**

It is determined by the proportion of bitumen or tar in the emulsion and by the particle-size distribution. The viscosity of the emulsion should be low enough to spray through conventional jets or to coat stone. It is measured by Engler out flow viscometer.

**Coagulation at Low Temperature**
All emulsions contain water they are affected by extremes of heat and cold. Exposure to temperatures below 0°C will result in freezing and the degree of recovery on thawing depends on type of emulsion.

**Sedimentation**

Some sedimentation may occur when a drum of emulsion is left standing before use; provided however the sediment redisperses on agitation, the emulsion can be used satisfactory.

**Stability on Long-Period Storage**

When stored in drums under normal atmospheric conditions, the emulsion should not separate in a form which cannot be redispersed by agitation.

**Classification of Emulsions**

Bitumen emulsions are divided into 3 main classes depending on the rates at which they break. The classes are sub-divided, depending on the bitumen contents and viscosity ranges of the emulsions.

**Class-1: Labile or Quick-Breaking**

This class embraces emulsions characterized by rapid breakdown on application and suitable for surface-dressing and grouting work. They are normally unsuitable for mixing with aggregate and subdivided into following classes: 1A, 1B, 1C.

**Class-2: Semi-Stable**

These are emulsions of sufficient stability to permit mixing with certain grades of aggregate before breakdown occurs. They contain more stabilizer than the labile emulsions and are sub-divided as class 2A, 2B.

**Class-3: Stable**

These are emulsions with sufficient mechanical and chemical stability for all purposes involving mixing with aggregates including fines like cement, hydrated lime, etc.

**Uses of Emulsions:**

* They are more tolerant than penetration grade bitumen, of the presence of dampness, although they should not be used in the presence of free water on the road surface or on aggregate.
* Because emulsion is of relatively low viscosity at normal temperature, they eliminate the need to heat the aggregate and binder and thus they conserve energy.
* They can be used when the weather is relatively cold
* They are ideal for patching and repairing work, particularly they do not require heating before use.
* They are used for surface dressing, grouting, pre-mixing, sealing, and soil stabilization with cement.

**Disadvantages**
* Emulsions are however, costly.
* Since they contain a substantial quantity of water, the transportation coat is higher.

**Tests for Road Emulsions**

**a) Determination of Water Content**

Road emulsions may contain up to 65% of water and it is essential to know this percentage. The determination is made by Dean and Stark method.

The sample is placed in a round-bottomed flask fitted with a graduated receiver (Dean and Stark tube) and a condenser. An organic liquid immiscible with water. Ex: Benzene and xylene, white spirit or solvent naphtha is added and the flask is heated. The organic liquid distils into the reciver, carrying with it, water which then separates into lower layer. The excess carrier liquid over flows into the flask.

![Apparatus for Determination of Water Content](image)

*APPARATUS FOR DETERMINATION OF WATER CONTENT*  
*(Dean-and-Stark Method)*
b) Measurement of Viscosity

The viscosity of an emulsion is a measure of flow properties of emulsion itself and has no relation to the viscosity of the bitumen or tar and it is determined by means of Engler viscometer.

Emulsions are available having viscosities in the range 5 to 20°Engler. The viscosity must be chosen so that the emulsions is sufficiently fluid to flow and coat the stone but at the same time is viscous enough not to drain from the stone.

It is first calibrated by filling to the level with distilled water which is adjusted to 20°C by the surrounding water bath. The time in seconds for 200 ml to run out is recorded. The viscometer is dried and the test is repeated using emulsion. The viscosity in Engler degrees is the ratio of the times of flow for emulsion and water.
ENGLER VISCOMETER

c) Determination of Residue on Sieving

This test determines the amount of binder present in a bituminous road emulsion in particles large enough to be retained on a gauge of specified mesh. Emulsions must not give more than 0.25 g of residue per 100 ml of emulsion when passed through appropriate sieve.

The appropriate sieve is washed, dried, weighed and moistened. 100 ml of emulsion are poured through and the sieve is washed with distilled water, after drying in a vacuum desiccator, the residue is weighed.

d) Coagulation on Storage (Short-Period Test)

This test indicates the tendency of the particles of binder in an emulsion to agglomerate when the emulsion is stored or transported in ordinary commercial containers. Not more than 0.1 g of coagulain per 100 ml of emulsion should be produced under the conditions of test.

100 ml of sieved emulsion are allowed to stand for 7 days in a stoppered measuring cylinder. At the end of this period the emulsion is again sieved and the residue weighed after washing and drying. The weight of residue is reported as coagulated binder per 100 ml of emulsion.

e) Long-period storage stability

This method indicates the tendency of the binder in a bituminous road emulsion stored in drums to separate in a form which cannot be redispersed by agitation. An emulsion should not possess more than 2% of water content difference between before and after storage.

A drum of emulsion is selected and the water content is determined by Dean and Stark method. The emulsion is transferred to a clean drum leaving 5% air space. The drum is sealed and left for 3 months at temperature range 5 to 30°C. At the end of storage period, the test portion is sieved and the water content determined. The difference between the water content of the emulsion before and after storage is reported as storage stability.

f) Coagulation at Low Temperature
This test is intended to show if any coagulation of the binder occurs on exposure to low temperatures. This emulsion is first sieved and preheated to 60°C and it is then cooled in a series of baths to a temperature of -3°C to -4°C. After remaining quiescent for 30 minutes. The temperature of the emulsion is allowed to regain air-temperature, when the emulsion is sieved. Any coagulated binder will be retained, the emulsion fails the test if any coagulation occurs.

**g) Sedimentation**

Some sedimentation may occur when a drum of emulsion is left standing before use. 10 g of bitumen emulsion is weighed into a glass tube which is then centrifuged for five minutes to sediment the emulsion. 30 ml of 1% soft soap is added and tube is stoppered. The tube is then rotated end-over-end at one complete inversion per second, after each five turns the table is allowed to drain towards the stopper for ten seconds to observe if any sediment remains. The number of inversions until the sediment disperses is noted and should not be less than 50 for the emulsion.

**Cutback Bitumen**

Cutback bitumen is defined as the bitumen, the viscosity of which has been reduced by a volatile diluents. For use in surface dressings, some type of bitumen macadam and soil-bitumen stabilization, it is necessary to have a fluid binder which can be mixed relatively at low temperatures. Hence to increase the fluidity of the bituminous binder at low temperatures the binder is blended with volatile solvent. After the cutback mix is used in construction work, the volatile gets evaporated and the cutback develops the binding properties. The viscosity of cutback and rate of which it hardens on the road depend on the characteristics and quantity of both bitumen and volatile oil used as the diluents.

**Types of Cutback Bitumen and Uses**

Cutback bitumen is available in three types, namely:

a) Rapid Curing (RC)

b) Medium Curing (MC)

c) Slow Curing (SC)
This classification is based on the rate of curing or hardening after the application.

**Rapid Curing Cutbacks (RC)**

These are bitumens, fluxed or cutbacks with a petroleum distillate such as naphtha or gasoline, which will rapidly evaporate after using in construction, leaving the bitumen binder. The grade of the RC cutback is governed by the proportion of the solvent used. The penetration value of residue from distillation upto 360°C of RC cutback bitumen 80 to 120.

**Medium Curing Cutbacks (MC)**

This bitumen fluxed to greater fluidity by blending with an intermediate boiling-point solvent like kerosene or light diesel oil. MC cutbacks evaporate relatively at slow rate because the kerosene-range solvents will not evaporate rapidly as the gasoline-range solvents used in the manufacture of RC cutbacks.

MC products have good wetting properties and so satisfactory coating of fine grain aggregate and sandy soils is possible.

**Slow Curing Cutbacks (SC)**

These are obtained either by blending bitumen with high-boiling-point gas, oil or by controlling the rate of flow and temperature of the crude during the first cycle of refining. SC cutbacks or wood soils hardens or set way slowly as it is a semi volatile material.

**Tests on Cutback Bitumen**

Various tests carried out on cutback bitumen are:

a) Viscosity test: Same as bitumen at specified temperature using specified size orifice.

b) Penetration test, ductility test and test for matter soluble in carbon-disulphide on residue from distillation up to 360°C.

c) Flash point test on cutback using Pensky Martens’s closed type apparatus.

d) Distillation test to find distillation fractions, up to specified temperature and to find the residue from distillation up to 360° C.
CUT-BACK BITUMEN DISTILLATION APPARATUS

The apparatus is as shown in figure. 22 ml of cutback bitumen is introduced into flask and the apparatus is assembled, note that the thermometer reaches almost to the bottom of flask. Heat is applied so that the distillation commences in 5 to 15 minutes and the distillation is continued at a rate of 50 to 70 drops per minute. The volume of distillate is observed at 175°C and at 25°C intervals thereafter up to 325°C, the heat source is removed when the temperature reaches 360°C. The total volume of oil is observed after draining the condenser. The bitumen residue is poured immediately into an open tin and allowed to cool below its fuming point.

Adhesion of Bituminous Binders to Road Aggregates

Introduction

One of the principal functions of a bituminous binder is, as its name suggests, acting as an adhesive either between road stones or between road stone and the underlying road surface. Neither bitumen nor tar can be regarded as an ideal adhesive but in general when proper precautions are exercised, both are adequate.

Road stones are wetted can lead to difficulties, either in the initial coating of damp road stone in maintaining an adequate bond between the binder and stone. Failure of a bond already formed is commonly referred to as ‘stripping’ which is brought about by the displacement of the
bituminous binder from the stone surface by water. The greater the viscosity, the less readily and the more slowly does the binder wet the stone. The problems with water mixing in two ways, firstly due to aggregates being wet before laying, secondly due to effect of rain after it has been laid.

Types of Adhesion Failure

a) Wet-Weather Damage to Surface Dressings

Wet chippings are frequently used for surface dressing. With untreated stone and binder, adhesion will not take place until the stone dries out. In good weather, this process is rapid but with high atmospheric humidity the chippings may remain wet for several hours or even days. Rain may cause displacement of the binder from stone. Once the chippings have been removed, the binder is carried by vehicle tyres and extensive damage may be expected.

In other words, under the higher atmospheric humidity condition, the surface dressing materials will be generally in wet condition. These chips will be loosened under the wheel loads, resulting in extensive damages.

b) Stripping in Pre-Mixed Bituminous Materials

The problem of stripping is experienced only with bituminous mixtures which are permeable in water. If the material is really impermeable such as with rolled asphalt, then stripping is most improbable.

Permeable bituminous surfacing materials are widely used and an average life of five or six years is commonly obtained from bitumen-macadam wearing courses before surface treatment of some kind is required. The binder displaced from the stone surface generally moves upwards under the action of traffic and collects in the surface forming ‘fat patches’. If the stripping becomes extensive, the strength of the bituminous mixture is impaired and deformation takes place under traffic.

It is characteristic of stripping failures of pre-mixed surfacing that the stripping is found only in those parts of the road subjected to medium or heavy traffic.
In other words; it is the stripping of the bituminous mixtures which are permeable too water. It is the displacement of the binder from aggregate. The process is popularly explained by the theory or mechanism of stripping.

**Mechanism of Stripping**

Stripping is the displacement of the binder from the surface of aggregates by water. The process of displacement depends on the viscosity of the binder. The binders of high viscosity resist displacement by water than those of low viscosity.

It has been shown practically that water may penetrate through a film of binder and reach the stone surface. The transfer of water to the stone surface may occur with water in liquid or vapour form.

The speed with which water can penetrate and detach the binder depends on:

a) Type and viscosity of the binder  
b) Thickness of binder film  
c) Nature of road stone

Stripping was found throughout the length of the surface but failure was observed only on the parts of the flexible base. If the failure occurs it may be due to the following ways:

a) The binder is undetached and hence unstripped  
b) The binder is partially detached but unstrapped  
c) The binder is attached but unstripped  
d) The binder is detached and stripped leading to the disintegration and failure.

**Fundamental Properties of Binder/Stone/Water System**

The displacement of one liquid by another on a solid surface arises from the physic-chemical forces acting in the system. Road stones have surfaces that are electrically charged. For example, silica possesses weak negative surface charge. Constituents of bituminous binders have little polar activity. The bond between bituminous binder and stone is therefore primarily due to relatively weak ‘dispersion’ forces. The polar liquid water is strongly attracted to charged road stone surfaces by ‘orientation’ forces.
Both water and hydrocarbon such as bitumen or tar will adhere to a stone surface, the forces of attraction are appreciably greater in the water. The stone surface possesses hydrophilic properties. Two important conclusions follow from this at once:

a) If a stone is already coated with water, it is impossible for a normal bituminous binder to displace the water and adhere to the stone.

b) If a stone is already coated with a binder; it is possible for water to ‘strip’ the binder from the stone.

The indication of strength of bond for heat of wetting between silica surface by water and by benzene which which gives 600 and 150 ergs/sg.cm respectively. Shows that water is more attracted to aggregates than a bitumen product. Again heat of wetting is an expression of tendency of a liquid to wet a solid surface. Greater is the heat of wetting, greater is the energy released and stronger is the bond between solid and liquid. Hence if a aggregate is already coated by water it is impossible for a normal binder to displace the water where as if a aggregate is already coated by bitumen is possible for water to strip binder from road stone.

If the angle of contact between the 3 phases is ‘θ’ and the energies of solid/binder, solid/water and binder/water interfaces are \( \gamma_{sb} \), \( \gamma_{sw} \), \( \gamma_{bw} \) respectively, then the work displacing water from unit area of stone is given by:

\[
W = \gamma_{sb} + \gamma_{bw} - \gamma_{sw} \tag{i}
\]

For equilibrium, Young and Dupre’s equation

\[
\gamma_{sb} = \gamma_{sw} + \gamma_{bw} \cos \theta \tag{ii}
\]

\[
W = \gamma_{bw} (1+\cos \theta)
\]

*Diagrammatic Illustration of a Drop of Bituminous Binder Placed on a Solid Surface under Water*
Hence the work required to displace water by binder is directly proportional to interfacial energy between binder and water and it is also related to the angle of contact.

**Adhesion Test**

Numerous tests have been described, most of which fall into 6 basic types. A sample of aggregates is coated with a bituminous binder and then immersed in water under controlled conditions. The degree of stripping of binder from the aggregate after a known period of time is measured. Six types of tests are:

- a) **Static Immersion Test**
  i. In this type of test, aggregate coated with binder is immersed in water and the degree of stripping is estimated.
  ii. Single-sized chippings are coated with a constant quantity of binder under controlled conditions.
  iii. Coated stone is immersed in distilled water for 48 hours.
  iv. The percentage of stripped surface is estimated visually.
  v. One more approach is to measure the quantity of light reflected by sample of coated aggregate before and after immersion in water.

- b) **Dynamic Immersion Test**
  i. It is similar to static immersion test but the sample is agitated mechanically by shaking or kneading.
  ii. Coated aggregates are shaken in water for a known time and then the amount of stripping is estimated visually.
c) **Chemical Immersion Test**  
   i. Stone coated with binder is boiled in distilled water and if necessary, solutions of sodium carbonate is added.  
   ii. The strength of the solution of sodium carbonate in which stripping is first observed is used as a measure of the adhesivity.  
   iii. Attempts have been made to improve this test, for example by reducing the temperature and using larger stone or by measuring the amount off uncoated aggregate which separates from coated mass.

d) **Immersion Mechanical Test**  
   i. Degree of stripping of the binder from aggregate is observed indirectly by measuring the change in a specified mechanical property of a bituminous material after it has been immersed in water.  
   ii. In this test, a number of identical cylindrical specimens of the bituminous mixture to be tested are prepared.  
   iii. After few hours ‘curing’ some are used to determine the compressive strength under constant rate of strain.  
   iv. The remainder are immersed in water for some days and then tested similarly.  
   v. The reduction in strength gives an indication of the extent of any damage by water that has occurred.

e) **Coating Test**  
   i. In this test an attempt is made to obtain adhesion between an aggregate and binder when water is also present.  
   ii. Test involves immersion of tray of binder in water and then the application of chippings to the surface of the binder. It is known as Immersion tray test.  
   iii. No adhesion is obtained under these conditions with normal road stones and binders but the test is helpful for examining how surface-active agents improve adhesion between binders and aggregates in surface dressing under wet conditions.
Immersion Trafficking Test

Traffic may plan an important role in stripping. A number of tests have been described in which the bituminous sample is subjected not only to the action of water but also to stresses produced by some form of traffic.

These tests may be carried out on circular track machines or on machines where traffic simulated by reciprocating wheels which passes over the specimens while it is immersed in water.

Wheel Tracking Test: This consist of three solid tyred wheels each 8 inch in diameter and 2 inch wide which traverse three specimens of road material. The wheels travel with a reciprocating motion of frequency 25 cycles/minute and stroke of about 11 inch. Each wheel is coated to give a total weight of 30 lb per sq. inch bearing on the specimen. The Specimens are contained in Perforated metal moulds 1½ inch deep, 12 inch long and 4 inch wide, maintained horizontally in water level is well above the top of the specimens. The road material is compacted in moulds under standardized conditions and cured for short time before immersion. The temperature of the water bath is 40° C. The test machine is shown in diagram below.
**TEST MACHINE FOR IMMERSION WHEEL-TRACKING TEST**

The criterion which is adopted to measure stripping is that of the time necessary to produce failure, if the depth of penetration of the wheels, in the specimen of road material is recorded with time, it is found that, at first there is a small and steady compaction of the specimen under the loaded wheels and then suddenly there is a sharp break in the curve where the wheels penetrate into the Specimen at a greater rate.
FAILURE RECORDS OBTAINED FROM IMMERSION WHEEL-TRACKING TEST

Methods of Improving Adhesion

1) Binder of high viscosity resists stripping more readily than those of low viscosity & hence there is an advantage that the viscosity of the binder should be as high as possible.

2) It is usually necessary to compromise between the lower viscosity needed to give the best initial coating on the aggregate & the higher viscosity desirable to give better protection against stripping.

3) Addition of filler to a mixture increases the viscosity of the binder & hence it will control the rate of stripping.

4) There are certain fillers, hydrated lime & portland cement which when added to bituminous mixture in 1 to 2% weight of total mix will reduce or even completely prevent stripping.

5) Chemically active fillers are also used in the mixing of cold & wet aggregate with bituminous binders.
6) Organic acids present in binders react with filler to form calcium naphthanete or calcium phenate to improve adhesion.

7) Addition of upto 10% of road tar to bitumen improves adhesion in some coated macadam wearing courses.

8) By adding surface-active chemicals to the binder, it has been claimed that some soaps of metals (Ca, Pb, Fe) may improve adhesion.

9) Additives which show cationic surface activity such as cetyl pyridinium bromide & cetyl trimethyl ammonium bromide increases the adhesive bond.

10) Powerful agents like organic amines which have high molecular weight are sprinkled on the surface dressing to increase adhesion.

1. What are emulsions and cutbacks? How are they prepared? Mentions under what conditions these are used.
2. Explain the different tests conducted on bituminous emulsions.
3. Explain the common adhesion problem in bituminous construction. List the various lab tests to determine the adhesion of bituminous binder to an aggregate and explain any one.
4. Briefly explain the mechanism of stripping of bituminous binder and the methods of improving adhesion.
5. What are cutbacks? What are their characteristics?
6. Explain Anionic, cationic and non-ionic emulsions.
7. Write short notes on types of cutback Bitumen.
8. Explain the common adhesion problem in bituminous construction. List the various laboratory tests to determine the adhesion of bituminous binder to an aggregate and explain any one.
9. Explain the constituents of a bituminous mix.
10. Explain the desirable properties of a bituminous mix.
11. What are emulsions? Discuss their merits and list out the various tests on emulsions.
12. Explain the mechanism of stripping of bituminous binder and method to improve adhesion.
13. List the different types of modifies binders used in construction and explain briefly the
requirements of modified binders.

14. What are adhesion tests? Explain any one briefly.

15. Explain mechanism of its adhesion failure.

16. How do you improve the adhesion?

17. List difference adhesion tests. Explain immersion trafficking test with neat sketches.

18. Mention difference types of emulsions and cut backs. Under what conditions they are used.

19. What are bituminous emulsions? Mention the types of emulsions and advantages of emulsions.

20. Mention the various laboratory tests to determine adhesion. Briefly explain any one test.

21. Write a note on the symptoms, causes and the treatment for stripping distress.

22. Explain proportioning of materials by rotfuch’s method with the help of a graph.

23. Define fuller’s curve equation. List different factor’s contributing mechanical strength in soil-aggregate stabilization of well graded materials.
PART - B
PAVEMENT CONSTRUCTION
UNIT - 5

EQUIPMENT IN HIGHWAY CONSTRUCTION: Various types of equipment for excavation, grading and compaction – their working principle, advantages and limitations. Special equipment for bituminous and cement concrete pavement and stabilized soil road construction. 6 Hours

INTRODUCTION

Highway engineering project involves different types of equipment for Earth Excavation, Earth moving, and Earth cutting, grading, and hauling of excavated earth, aggregate spreader, roller, binder sprayer and paver finisher etc...

1. EXCAVATION EQUIPMENT:
   a. Dipper or Power shovel
   b. Dragline
   c. Clamshell
   d. Hoe

2. COMPACTION EQUIPMENT:
   a. Smooth wheel roller
   b. Pneumatic type roller
   c. Sheepsfoot roller
   d. Vibratory roller
   e. Hand operated vibratory roller

3. EARTH MOVING EQUIPMENT:
   a. Dozer
   b. Grading
   c. Wheel Loader
   d. Hydraulic Excavator
   e. Scrapper

4. SPECIAL EQUIPMENT FOR CEMENT CONCRETE AND BITUMEN PAVEMENT:
   a. Batching plant
   b. Mixers
   a. Paver finisher
   b. Hot mix plant or Bitumen mixer
c. Concrete Pumps
c. Bitumen sprayer
d. Mini Mixers
d. Bitumen storage equipment

TRACTORS

Tractor is a multipurpose machine. It includes light models used for agricultural and small hauling works. It is versatile equipment having a variety of uses in road construction, such as To pull rippers and rooters. To pull towed scrapers. To pull sheepfoot rollers. To push load scrapers. To pull towed pneumatic rollers

There are two main types of tractors:

1. Crawler type
2. Pneumatic wheel type

Crawler tractors have a low maximum speed, around 10kmph and are used primarily where high speeds are sacrificed in order to obtain good traction and high draw-bar pull. They are also preferred where the ground is not firm. Crawler mounted dozers have a digging and travelling with load speed of about 2.5kmph.

Pneumatic wheeled tractors are used for moving at high speeds (up to 50kmph) on firm ground. Pneumatic wheeled dozers have a digging and travelling with load speed of about 4 to 5 kmph. Now a days wheeled tractor units are used commonly for all earth moving jobs.

TRACTOR DOZERS

A tractor dozer, popularly called bull-dozer, is a tractor with a 3-3.5m long, 0.9-1.2m height blade mounted in front of it. If the blade of the equipment is set at angle, it is called an angle dozer. The blade of some dozers can be tilted in the vertical plane to a tilt of about 1 in 10. The equipment is versatile and can perform the following operations:

1. Clearing and grubbing land of vegetation and tree stumps.
2. Removing top soil from borrow areas.
3. Moving earth for short distances, say up to 100m.
4. Box- cutting a formation for laying pavement layers.
5. Opening up pilot road formations in steep hill sides to such a width that other equipment can move in and complete the work.
6. Spreading earth in layers.

Type of dozers:

**Angle dozer:** Meant to push its loads at an angle of approximately $30^\circ$ to the direction of travel of the tractor.

Specially useful in side-hill work where the material is to be piled in a long wind row to one side of the line of travel.

**Tilt dozer:** Designed such that the blade can be tilted by raising one corner up to 10 inches above the other so that the machine can open up an excavation in hard ground or start excavation for a ditch or a trench.

**Tree dozer:** It has a V-blade at the front end attachment so that trees can be pushed by the upper frame of the blade while the lower edge is fitted with a stumper that can drive into the root.

**SCRAPERS**

Scrapers dig their own load, as they move forward. They combine the operations of digging, loading, hauling and discharging. There are main three operators is there:

**Bowl or Bucket:** The bowl is the loading and carrying component of a scraper. It has a cutting edge that extends horizontally across its front bottom edge. The bowl is lowered for loading and raised during travel.

**Apron or Lip:** The apron is the front wall of the bowl. It is independent of the bowl. It is raised during the loading and dumping operations to enable the material to flow into or out of the bowl. The apron is lowered during hauling to prevent material spillage.

**Ejector or Tail gate:** The ejector is the rear vertical wall of the bowl. The ejector is in the rear position during and hauling. During spreading, the ejector is activated and moves forward, providing positive discharge of the material in bowl.

The working principle of scraper is a cutting blade, which can be raised or lowered up to 20 cm, is pulled through the earth causing it to travel up the face of the blade into the bowl of the scraper. Some of the earth falls forward into a carrying apron. When the bowl is full, the aprons are lowered to prevent spillage and the cutting edge is raised. After hauling, the material is dumped by lowering the cutting edge to the desired height above the fill and opening the front
apron. Two type of scrappers Towed and Motorized scrapers. Towed scrapers are available in size of 7-12cum and used for short hauling, say 150-500m, at a maximum speed of 10kmph. Motorized scrapers of size up to 25cum and haul for 500-1500m with 30kmph speed.

USES
1. Better loading ability in loose free flowing material
2. It can operated independently.
3. Additional of ripper teeth to cutting hard compacted mate.

GRADERS
It principally consist a blade below a framework. The blade be lowered, lifted or rotated. Graders are used for a number of purposes:
1. For spreading heaped earth into layers.
2. For shaping the cross-section during construction.
3. For maintaining the cross-section of embankment.
4. For maintaining gravel surface.
Graders are of two types Towed and Motorized. The towed grader is by a tractor and is usually made in small size.
Motor grader has a blade of about 3.5m, but its effective length during spreading becomes 2.75m. The blade can be set at any angle (360° horizontal) and some time vertically tilted depend upon work. A 100-110HP motor grader is a popular size. The normal grading speed is 3kmph. The output of a grader for spreading the earth, which is achieved generally in 4 passes, is about 1300sqm per hour, assuming 65% operating efficiency and a 50min working hour. Assuming a normal compacted thickness of layer of 15cm, the output in terms of compacted volume becomes about 200cum per hour.

APPLICATION
1. used for leveling or finishing earth work, making and maintaining project roads, construction of air fields and land reclamation.
2. the rollers can be attached to the rear, to compact the graded surface.
3. used in material mixing, hard surface cutting and snow clearance.
4. used particularly base course spreading, leveling bank cutting etc.

**EXCAVATION EQUIPMENT**

1. **Dipper or Power shovel**

These are used primarily to excavate earth & load into trucks or tractor pulled wagons. They are capable of excavating all classes of earth, except solid rock without prior loosening. They are mounted on crawlers tracks or mounted on rubber tyred wheel crawler mounted shovels have very low speeds which permit them to operate on soft ground. Single engine self propelled units are powered & operated from the excavator cab.

Working principle is digging above the machine base level to upwards. It consists of mounting cab, boom, dipper stick & dipper. When shovel is in correct position near the earth, the dipper is lowered to the floor of the pit, with the teeth pointing into the face. To start the machine a crowding force is applied through the shipper shaft & at the sometime tension is applied to the hoisting line to pull the dipper up the face of pit. If the depth of the face is deep considering the type of soil & the size of the dipper the dipper will be filled as it reaches the top of the face. If the depth of face is shallow it’ll not be possible to fill the dipper completely without excessive crowding & hoisting tensions. This subjects the equipment to excessive strains & reduces the output of the unit. If the depth of the face is greater than required to fill the dipper when operating under favorable crowd & hoist. It’ll be necessary to reduce the depth of penetration of the dipper into the face if the full face is to be excavated. The pit will be excavated after the upper portion of the face is removed.
APPLICATION
1. It can effectively operate from a lower level where it stands & depth of face to be excavated is not too shallow.
2. It carries large load and loading effect is very good to truck.
3. If blasted rock is to be excavated the large size dipper will handle bigger rocks. If the material to be excavated is hard & tough, the dipper of the large shovel which exists higher pressures will handle the material more easily.

LIMITATIONS OF POWER SHOVEL
1. The cost of transporting a large shovel is higher than for a smaller one.
2. Not possible to excavate soil below ground.
3. Distance between foot & digging is less and not well suitable for wet soil.
3. If high output rate is needed in the project a large shovel must be used.
4. More shovels rotation required.
5. More wears parts.

DRAGLINE:
In dragline, larger booms are provided, which allows digging & dumping over long distances as compared to the power shovel. It is most suitable for excavating the channels & canal, can handle wet material & suitable for excavation under water. One advantage of dragline is machine
can be positioned on a higher elevation where trenches are excavated. It can dig materials below its track level & can handle only soft material. Capacity of the dragline is indicated by the bucket capacity measured in cum & generally available in 1 to 15 cum capacities.

Working principle of dragline is by bucket is thrown out from the dragline on the top of the earth to be excavated and then pulled back towards the base of the machine. Dragline consists of the boom, bucket, hoist cable, dump cable & drag line. Excavating is accomplished by pulling the bucket towards the machine while regulating the digging depth by means of the tension maintained in the hoist cable. When the bucket is filled, the operator takes in on the hoist. The bucket is so constructed that it’ll not dump its contents until it is desired. Hoisting, swinging & dumping of the loaded bucket follow in that order then the cycle is repeated. Dumping is accomplished by releasing the drag cable.

Draglines have following types of buckets,
- **Light**: These are suitable for loose, dry soils, sand & gravel.
- **Medium**: These are used for clays & compacted gravel….etc. where bucket teeth penetrates with difficulty.
- **Heavy**: These buckets are used for handling hard materials & broken rocks.

It is necessary to consider the weight of the bucket, since weight of the bucket with weight of the material in it is determined by the boom strength.

**APPLICATION**
1. Below ground level is excavated easily.
2. where close trimming is required.
3. it swing horizontally at any angle and loading process is quick.
LIMITATIONS
1. keep bucket teeth sharp and built up to the proper size.
2. dig in layers, not in ditches.
3. keep digging surface sloped up towards shovel.
4. swing bucket unit with load cause twisted.

CLAM SHELL
It is a machine having most of the characteristics of dragline & crane in common. Clam shell consists of a bucket of two halves or shell which is hinged together at top. The shells may be attached to the shovel-crane units or at the boom of a drag line. The open clam-shell bucket is thrown on the top of the loose material to be dug and as the bucket is lifted, the two halves close entrapping the material into the bucket. This equipment is useful for excavation of soft to medium materials and loose material at or below existing ground surface.

APPLICATION
1. Where digging or dumping in a vertical plane i.e., below at or above ground level is required.
2. For digging trenches.
3. Where materials relatively soft or medium hard.
4. For charging the materials in a bin or a stock pile.
5. Where accurate dumping is required.

HOE
This equipment also known as drag shovel or pull shovel. The equipment has ability to penetrate even the toughest of material. Due to this ability these are commonly used in quarries which have tough digging conditions & one prom to flooding. As the name itself indicates digging of the earth is done by dragging or pulling of the earth is done by dragging or pulling of the bucket towards machine whereas in power shovel bucket makes outward strokes while digging.
This shovel consists of bucket & stick, a jack boom, the stick in hoe is hinged by a pin with a boom as shown in the figure & thus enables to take any desired turn best suited for digging or dumping operations. The lower end of the stick carries the bucket, while the upper end comes a sheave having a hoist cable supported on a jack boom at the other end & passes on to the hoist drum. Therefore when a pull is applied to a hoist cable, the reaction at the hinge enables boom with stick to move up or down. Thus the boom can take any position in vertical plane.

**APPLICATION**

1. For digging the trenched, footings or basements.
2. To dig materials which is hard.
3. When excavation is required below the ground level & digging done at the short span.
4. When close trimming is required during excavation.

**COMPARISON**

<table>
<thead>
<tr>
<th>Point of consideration</th>
<th>Dipper shovel</th>
<th>Dragline</th>
<th>Backhoe</th>
<th>Clamshell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation in hard soil or rock.</td>
<td>good</td>
<td>Poor</td>
<td>Good</td>
<td>good</td>
</tr>
<tr>
<td>Operation in wet soil or mud.</td>
<td>poor</td>
<td>Fair</td>
<td>Poor</td>
<td>fair</td>
</tr>
<tr>
<td>Distance b/w footing and digging.</td>
<td>small</td>
<td>Long</td>
<td>Small</td>
<td>long</td>
</tr>
<tr>
<td>Loading efficiency into the vehicles.</td>
<td>Very good</td>
<td>Fair</td>
<td>Good</td>
<td>Precise but slow</td>
</tr>
<tr>
<td>Digging level.</td>
<td>At or above footing level</td>
<td>Below footing level</td>
<td>Below footing level</td>
<td>At or above footing level</td>
</tr>
<tr>
<td>Cycle time as</td>
<td>-</td>
<td>More</td>
<td>Slightly more</td>
<td>High</td>
</tr>
</tbody>
</table>
COMPACTION EQUIPMENT

1. Three-wheeled road roller
This is the most common rolling equipment and is versatile in applications. It is diesel powered; the diameter of the front roll is around 105cm, its width being around 100cm. The diameter of the rare roll is around 145cm, its width being around 50cm. The rolling width is around 2m. The front roll gives a load of around 35-40 kg/cm width and the front roll gives a load of 70-80kg/cm width. The speed of rolling is in the range 1.5-6.0kmph. The output of a three wheel roller, 8-10 T, for various jobs. The smooth wheel roller is suitable to roll a wide range of soil, preferably granular soil and pavement materials for the various layers. Generally 6-12 passes are needed.

2. Pneumatic tyred roller
Pneumatic tyred rollers consist of a box mounted over two axle, the rear axle having one more wheel than the front and the wheels of the front axles so arranged that they are located in plan in b/w the rear wheels. Generally there are four wheel in front and five at rare. Weight is in the range of 12-45 tonnes. The roller is suitable for compacting non-plastic soils and silty soils. The optimum speed is 4kmph.
Pneumatic tyred rollers are also used for intermediate rolling of dense asphaltic concrete. Rolling of 12-18 T is used. The tyre pressure should be a minimum of 0.5MN/m². The no. of passes required is about 8-12.

3. Sheepsfoot rollers
Sheepsfoot rollers consist of hollow circular drums of steel 1.2-1.5m long and 0.9-1.2m dia, with legs or tamping feet on the circumferential area at the rate of 12-18 per square meter of area. The tamping feet on the drums are staggered into rows. The rollers can be ballasted with water or wet soil. The weight of a single drum is in the range 1200-1800kg when empty and 2200-2800kg when ballasted. A tractor of 45HP can pull a single drum. A speed of 4kmph is common.
Sheepsfoot rollers are suitable for cohesive soil and the moisture content of the soils should be preferably near their plastic limit. The no. of passes of sheepsfoot rollers depends upon the type of soil, moisture content and density desired. Generally 8-16 passes are needed. Using a sheepsfoot compactor has one definite benefit. Because the top lift of soil is always being fluffed, the process helps aerate and dry out wet clays and silts.

But the disadvantages of sheepsfoot compactors are numerous. The loose top-lift material can act as a sponge when it rains and slow the compaction process. The loose material also slows hauling units that deposit fill material, so haul cycle times are increased.

4. **Vibratory rollers**

Vibratory rollers have become very popular in highway engineering applications in recent years with the growing need to compact pavement layers and subgrade to high density. Compacting to such high density by static roller is very difficult and costly. Since vibratory rollers induce oscillations, they are able to 1. Achieve break-down of internal friction between particles of road construction materials and 2. Bring about better orientation of particles caused by cyclic deformation. Both cohesive and non-cohesive materials can be compacted by vibratory rollers.

Vibratory rollers are used for compacting soils and granular layers, a frequency of 1500-2500 vibrations per minute and amplitude of 0.8-1.5mm are recommended.

<table>
<thead>
<tr>
<th>SL. NO.</th>
<th>Compaction equipment</th>
<th>Applications</th>
</tr>
</thead>
</table>
| 1      | Smooth wheel roller         | 1. Earth rolling  
2. Soil stabilization  
3. Rolling granular base  
4. Rolling surface dressing, premix carpet, mix seal, bituminous macadam, built-up-spray grout. |
| 2      | Sheepsfoot roller           | 1. Rolling cohesive soils                                                    |
| 3      | Pneumatic tyred roller      | 1. Rolling non-plastic silty and silty soils  
2. Intermediate rolling of asphaltic concrete |
| 4      | Vibratory roller            | 1. Compacting sand and cohesionless soil  
2. Compacting all type of soils for obtaining high densities                   |
3. Compacting granular bases and sub-bases to obtain high densities
4. Compacting bituminous bases and surfaces to obtain high degree of compaction

<table>
<thead>
<tr>
<th>5</th>
<th>Hand operated vibratory rollers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Compacting sand and cohesionless soil</td>
</tr>
<tr>
<td>2</td>
<td>Compacting in restricted space.</td>
</tr>
</tbody>
</table>

### SPECIAL EQUIPMENT FOR BITUMEN AND CEMENT CONCRETE PAVEMENT

1. **Bitumen storage equipment:**
   
   Bitumen is stored in drums or in special bulk handling depots. The capacity of one drum is 155-162kg of bitumen. The bitumen tank-lorry has a capacity in the range of 6-12 T. A pump with a capacity of about 200-300 liters per minute is provided. The tank is adequately insulated and arrangement for heating and pumping is provided.

2. **Bitumen boilers:**
   
   Bitumen boilers are needed for heating bitumen obtained in packed form. Boilers of a wide range of capacity are available. 100-10,000 liters capacity boilers are standardized by ISI.

3. **Bitumen pressure distributers:**
   
   A bitumen pressure distributer is a tank of capacity 5000-20,000 liters mounted on a lorry, having oil-fired burners and a pump. Bitumen can be applied at a pressure on to the road surface in connection with specifications like surface dressing, grouted macadam, built-up-spray grout, seal coat, tack coat etc. The quantity of bitumen can be accurately controlled by a metering device and also with speed at which vehicle operates.

4. **Bituminous Hot-Mix Plants:**
   
   In a batch mixing plant, various sizes of hot aggregates in storage bins are withdrawn in predetermined quantities to make one ‘batch’ before mixing with a predetermined quantity of bitumen. It comprises the following:
   
   a. **Cold aggregate storage bins of different aggregate sizes:** These should be at least four in number, with discharge gates to control the flow of aggregates of different sizes in the desired amounts.
b. **Conveyor and cold elevator**: The cold aggregate feeding system discharges onto a conveyor in pre-set quantities to give the required grading and then into the cold elevator which discharges into the dryer.

c. **Dryer**: The main functions of a dryer are (i) removal of moisture from the aggregates, and this vapour is drawn off by the draught (ii) to heat the aggregate so that they are of the right temperature for mixing with bitumen in the pug mill.

d. **Temperature measuring device**: It is essential for the control of quality of the mix

e. **Hot elevators**: These consist of a system of bucket elevators housed within a covered chamber.

f. **Hot screening unit**: The hot materials carried by the elevators are discharged over a multi-deck vibrating table screen which separates the different aggregate fractions into the different hot bins.

g. **Hot aggregate bins**: These are the temporary storage for the hot aggregates of different sizes. They have discharge gates opening at the bottom.

h. **Fill silo**: Because of its fineness, the filler material is stored separately in a filler silo and, after weighing, the hopper discharges the filler material into the mixer, generally after bitumen has been admitted into the mixer.

i. **Bitumen supply arrangement**: bitumen is pumped into a special bucket of known weight and weighed on a scale or it may be measured in volume by a meter.

j. **Measuring and mixing of aggregate and bitumen**: The aggregate is drawn from hot bins in predetermined quantities and dropped into a pug mill mixer in batches; the required amount of bitumen is added and mixed with aggregate. The hot aggregates and the hot bitumen are thoroughly mixed in the pugmill mixer.

k. **Discharge into truck or hot storage silo**: After the mixing operation has been completed, the final mixture is discharged from the bottom of the pug mill mixer directly to the hauling truck below or taken to a hot storage silo for temporary storing the mix, before hauling.

5. **Paver finisher**:
A paver finisher is indispensable for laying hot-mix hot-laid bituminous specifications. The equipment is self-propelled and is capable of laying the bituminous material to any desired thickness and partially compact it by means of a vibrating screed. The paver has a hopper into which the rear-dump trucks can discharge the mix. The paver may be crawler mounted (tracked) or equipped with rubber tyres which permit a greater degree of freedom for movement. The crawler-mounted machines are more stable and can support greater width of the screed. The screed width can be adjusted, generally in the range 2 to 5m. The bituminous mix discharged for a tipper lorry into the receiving hopper in the front portion of the paver is carried along the conveyor through flow control gates to the augers which distribute the material in front of the screed, to the full width of the screed. A strike of beam, which also tamp the mat, controls the layer thickness. The paver finisher operates at speeds 1.5-10m/min. A speed of 3-5m/min will be found generally acceptable. The width of the mat can be adjusted in the range 2-5m. The cross-profile can be controlled by adjusting the screws of the strike-off beam. Paver finisher of capacity 45-75 T/hr are generally used for roadwork.

1. **Batching and mixing plants:**

   The ingredients for concrete are always proportioned by weight in a weigh batching equipment. Mixing of concrete is done by concrete mixers which are available in a variety of sizes, mixing is continued for a period of not less than one and half minutes after all the materials are introduce. Tilting drum type mixers are available in small sizes, whereas not-tilting drum type mixers are available in large sizes.

2. **Transportation, placing and compaction concrete:**

   Generally, 5 to 10 m³ tippers are ideal for transportation and placing concrete. Concrete discharged on the carriageway is spread over the whole width with the help of screw spreader. Concrete paver finisher consists of spreading, consolidating, screening, finishing, texturing and curing operation. Slip form pavers are much heavier and more powerful equipments which move on tracks compared to the fixed form machines. A typical slip form train consists of paver, intended for spreading the mix over the width of the carriageway, a finisher which vibrates, forms an appropriate mould and finishes the surface and lastly, a piece of equipment capable of
texturing and spraying the curing compound. Slip form paving is more popular than fixed form paving.

STABILIZED SOIL ROAD CONSTRUCTION
The soil stabilization means the improvement of stability or bearing power of the soil by the use of controlled compaction, proportioning and/or the addition of suitable admixture or stabilizers.

BASIC PRINCIPLES OF SOIL STABILIZATION
Evaluating the properties of given soil
Deciding the lacking property of soil and choose effective and economical method of soil stabilization

NEED FOR SOIL STABILIZATION
1. Designing the Stabilized soil mix for intended stability and durability values
2. Limited Financial Resources to provide a complete network Road System to build in conventional method
3. Effective utilization of locally available soils and other suitable stabilizing agents.
4. Encouraging the use of Industrial Wastages in building low cost construction of roads.

METHODS OF SOIL STABILIZATION
1. Mechanical Stabilization
2. Soil Cement Stabilization
3. Soil Lime Stabilization
4. Soil Bitumen Stabilization
5. Lime Fly ash Stabilization

1. Mechanical Stabilization
a. This method is suitable for low volume roads i.e. Village roads in low rainfall areas.
b. This method involves the correctly proportioning of aggregates and soil, adequately compacted to get mechanically stable layer
c. The Basic Principles of Mechanical Stabilization are Correct Proportioning and Effective Compaction.

**Factors Affecting Mechanical Stabilization**

1. Mechanical Strength of aggregates
2. Gradation
3. Properties of the Soil
4. Presence of Salts
5. Compaction

**Mechanical Strength**
When the soil is used in small proportion to fill up the voids the crushing strength of aggregates is important

**Gradation**
A well graded aggregate soil mix results in a mix with high dry density and stability values

**Properties of soil**
A mix with Plasticity Index, results poor stability under soaking conditions. Hence it is desirable to limit the plasticity index of the soil

**Presence of Chemicals**
Presence of Salts like Sulphates and mica are undesirable
Presence of Calcium Chloride is Beneficial

**Compaction**
Effective Compaction is desirable to produce high density and stability mix

**2. Soil Cement Stabilization**
1. Soil Cement is an intimate mix of soil, cement and water, compacted to form a strong base course.
2. Cement treated or cements modified soil refers to the compacted mix when cement is used in small proportions to impart some strength.
3. Soil Cement can be used as a sub-base or base course for all types of Pavements
Factors affecting soil cement stabilization
1. Soil
2. Cement
3. Pulverisation and Mixing
4. Compaction
5. Curing
6. Additives

3. Soil Lime Stabilization
1. Soil- Lime has been widely used as a modifier or a binder
2. Soil-Lime is used as modifier in high plasticity soils
3. Soil Lime also imparts some binding action even in granular soils

Factors affecting Properties of Soil-Lime
1. Generally increase in lime content causes slight change in liquid limit and considerable increase in Plasticity index
2. The rate of increase is first rapid and then decreases beyond a certain limit
3. The point is often termed as lime fixation point
4. This is considered as design lime content

4. Soil- Bituminous Stabilization
1. The Basic Principles of this stabilization are Water Proofing and Binding
2. By Water Proofing inherent strength and other properties could be retained
3. Most Commonly used materials are Cutback and Emulsion
4. Bitumen Stabilized layer may be used as
5. Sub-base or base course for all the roads

5. Lime fly ash stabilization
1. A mixture of fly ash and soil when stabilized using lime is called lime flyash stabilization.
2. This material can be used for constructing sub base or base course of rural roads.
3. This would be particularly attractive where fly ash is easily available.

6. **Lime fly ash bound macadam**

1. In conventional WBM, low plastic materials, with screenings are used as filler materials.
2. Filler is made up of a mixture of lime, fly ash and moorum in suitable proportion improves the performance.
3. This is termed s LFBM
4. The load bearing capacity of LFBM will be superior to that of WBM.

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1. Explain the procedure of the compacting equipment’s used for highway construction? Mention its specific uses.
2. List any four types of equipment’s used for i) Grading ii) Compaction and explain any one equipment for each.
3. Explain the working principle of i) Power shovel ii) Drag line with neat sketch iii) scrapers iv) pavers.
4. Mention the equipment’s used for excavation in the construction of bituminous pavements. Explain any two, with neat sketches. for wet mix macadam.
5. List various equipment’s used for the road construction. state the merits and demerits of any three sophisticated equipment.
6. Explain any one test procedure of quality control test used to evaluate adequacy of sub base compaction.
7. List and explain types of compacting equipment used for highway construction. bring out advantages and disadvantages of sheep foot rollers.
8. Mention any four types of equipment’s used for i) excavation ii) cement concrete pavement construction and explain any one equipment for each.
9. Describe the specification and working principle of a paver finisher.
10. Enumerate the steps in the preparation of subgrade. how is the adequacy of the compaction in the field evaluate?
PART - B
PAVEMENT CONSTRUCTION
UNIT - 6

SUBGRADE: Earthwork grading and construction of embankments and cuts for roads. Preparation of subgrade, quality control tests. 6 Hours

Highway construction is generally preceded by detailed surveys and subgrade preparation. The methods and technology for constructing highways has evolved over time and become increasingly sophisticated. This advancement in technology has raised the level of skill sets required to manage highway construction projects. This skill varies from project to project, depending on factors such as the project's complexity and nature, the contrasts between new construction and reconstruction, and differences between urban region and rural region projects.

There are a number of elements of highway construction which can be broken up into technical and commercial elements of the system. Some examples of each are listed below:

Technical Elements
- Materials
- Material quality
- Installation techniques
- Traffic

Commercial Elements
- Contract understanding
- Environmental aspects
- Political aspects
- Legal aspects
- Public concerns

Typically, construction begins at the lowest elevation of the site, regardless of the project type, and moves upward. By reviewing the geotechnical specifications of the project, information is given about:
Existing ground conditions
Required equipment for excavation, grading, and material transportation to and from the site
Properties of materials to be excavated
Dewatering requirements necessary for below-grade work
Shoring requirements for excavation protection
Water quantities for compaction and dust control

Subbase course construction
A subbase course is a layer designed of carefully selected materials that is located between the subgrade and base course of the pavement. The subbase thickness is generally in the range of 4 to 16 inches, and it is designed to withstand the required structural capacity of the pavement section. Common materials used for a highway subbase include gravel, crushed stone, or subgrade soil that is stabilized with cement, fly ash, or lime. Permeable subbase courses are becoming more prevalent because of their ability to drain infiltrating water from the surface. They also prevent subsurface water from reaching the pavement surface. When local material costs are excessively expensive or the material requirements to increase the structural bearing of the sub-base are not readily available, highway engineers can increase the bearing capacity of the underlying soil by mixing in Portland cement, foamed asphalt, or with emerging technologies such as the cross-linking styrene acrylic polymer that increases the California Bearing Ratio of in-situ materials by a factor 4 – 6.

Base course construction
The base course is the region of the pavement section that is located directly under the surface course. If there is a subbase course, the base course is constructed directly about this layer. Otherwise, it is built directly on top of the subgrade. Typical base course thickness ranges from 4 to 6 inches and is governed by underlying layer properties. Heavy loads are continuously applied to pavement surfaces, and the base layer absorbs the majority of these stresses. Generally, the base course is constructed with an untreated crushed aggregate such as crushed stone, slag, or gravel. The base course material will have stability under the construction traffic and good drainage characteristics.
The base course materials are often treated with cement, bitumen, calcium chloride, sodium chloride, fly ash, or lime. These treatments provide improved support for heavy loads, frost susceptibility, and serves as a moisture barrier between the base and surface layers.

**Surface course construction**

There are two most commonly used types of pavement surfaces used in highway construction: hot-mix asphalt and Portland cement concrete. These pavement surface courses provide a smooth and safe riding surface, while simultaneously transferring the heavy traffic loads through the various base courses and into the underlying subgrade soils.

**Road surface or pavement** is the durable surface material laid down on an area intended to sustain vehicular or foot traffic, such as a road or walkway. In the past, gravel road surfaces, cobblestone and granite setts were extensively used, but these surfaces have mostly been replaced by asphalt or concrete laid on a compacted base course. Road surfaces are frequently marked to guide traffic. Today, permeable paving methods are beginning to be used for low-impact roadways and walkways.

**Asphalt** (specifically, asphalt concrete), sometimes called flexible pavement due to the nature in which it distributes loads, has been widely used since the 1920s. The viscous nature of the bitumen binder allows asphalt concrete to sustain significant plastic deformation, although fatigue from repeated loading over time is the most common failure mechanism. Most asphalt surfaces are laid on a gravel base, which is generally at least as thick as the asphalt layer, although some 'full depth' asphalt surfaces are laid directly on the native subgrade. In areas with very soft or expansive subgrades such as clay or peat, thick gravel bases or stabilization of the subgrade with Portland cement or lime may be required. Polypropylene and polyester geosynthetics have also been used for this purpose and in some northern countries, a layer of polystyrene boards have been used to delay and minimize frost penetration into the subgrade.

Depending on the temperature at which it is applied, asphalt is categorized as hot mix, warm mix, or cold mix. Hot mix asphalt is applied at temperatures over 300 °F (150 °C) with a free floating screed. Warm mix asphalt is applied at temperatures of 200–250 °F (95–120 °C), resulting in reduced energy usage and emissions of volatile organic compounds. Cold mix asphalt
is often used on lower volume rural roads, where hot mix asphalt would cool too much on the long trip from the asphalt plant to the construction site.

An asphalt concrete surface will generally be constructed for high-volume primary highways having an average annual daily traffic load greater than 1200 vehicles per day.[5] Advantages of asphalt roadways include relatively low noise, relatively low cost compared with other paving methods, and perceived ease of repair. Disadvantages include less durability than other paving methods, less tensile strength than concrete, the tendency to become slick and soft in hot weather and a certain amount of hydrocarbon pollution to soil and groundwater or waterways.

**Hot-mix asphalt (HMA) layers**

Hot-mix asphalt surface courses are referred to as flexible pavements. The Superpave System was developed in the late 1980s and has offered changes to the design approach, mix design, specifications, and quality testing of materials.

The construction of an effective, long-lasting asphalt pavement requires an experienced construction crew, committed to their work quality and equipment control.

**Construction issues:**
- Asphalt mix segregation
- Laydown
- Compaction
- Joints

A prime coat is a low viscosity asphalt that is applied to the base course prior to laying the HMA surface course. This coat bonds loose material, creating a cohesive layer between the base course and asphalt surface.

A tack coat is a low viscosity asphalt emulsion that is used to create a bond between an existing pavement surface and new asphalt overlay. Tack coats are typically applied on adjacent pavements (curbs) to assist the bonding of the HMA and concrete.
Portland cement concrete (PCC)

Portland cement concrete surface courses are referred to as rigid pavements, or concrete pavements. There are three general classifications of concrete pavements - jointed plain, jointed reinforced, and continuously reinforced.

Traffic loadings are transferred between sections when larger aggregates in the PCC mix interlock together, or through load transfer devices in the transverse joints of the surface. Dowel bars are used as load-transferring devices to efficiently transfer loads across transverse joints while maintaining the joint's horizontal and vertical alignment. Tie-bars are deformed steel bars that are placed along longitudinal joints to hold adjacent pavement sections in place.

**Built up spray grout [BSG]** – it consists of 2 layer composite construction of compacted crushed aggregates with application of bituminous binder after each layer with key aggregates at top to provide a total thickness, 75mm. It is used for strengthening of existing bituminous pavement. A suitable wearing course is invariably provided over this & opened to traffic.

**Subgrade** is that portion of the earth roadbed which after having been constructed to reasonably close conformance with the lines, grades, and cross-sections indicated on the plans, receives the base or surface material. In a fill section, the subgrade is the top of the embankment or the fill. In a cut section the subgrade is the bottom of the cut (Figure 1). The subgrade supports the sub base and/or the pavement section. To ensure a stable, long-lasting, and maintenance free roadway, the subgrade is required to be constructed using certain proven procedures that provide satisfactory results.

After the rough grading is completed, the fine grade stakes are set and the final processing of the subgrade may begin. The rough grade is the top grade of the embankment as built using the information provided on the grade sheets. The grade is normally within 2 in. at this point. The finish grading operation consists of trimming the excess material down to the final grade. Filling any low spots with thin lifts of materials tends to slide these lifts around if not properly worked into the underlying materials.
Construction Procedure –

Setting out – After the site has been cleared, the work should be setout. The limits of embankment are marked by fixing batter pegs on both sides at regular intervals. The subgrade should be wider than the design dimension so that surplus material may be trimmed.

Dewatering – If the foundation of the embankment is in an area with stagnant water, it is feasible to remove it by bailing out or pumping.

Stripping & Storing top soil – In localities where most of the available embankment materials are not conductive to plant growth, the top soil from all areas of cutting shall be stripped to specified depths not exceeding 150mm & stored in stock piles of height not exceeding 2m for covering embankment slopes.

Compacting ground supporting embankment / subgrade – where necessary, the original ground shall be leveled to facilitate placement of first layer of embankment, scarified, mixed with water and then compacted by rolling so as to achieve minimum dry density as given in table. In case difference in subgrade level and ground level is less than 0.5m & the ground does not have 97% relative compaction, the ground shall be loosened up to a level 0.5m below the subgrade level, watered & compacted in layers to not less than 97% of dry density.
Spreading material in layers & bringing to appropriate moisture content –
a. The embankment & subgrade material shall be spread in layers of uniform thickness not exceeding 200mm compacted thickness over the entire width of embankment by mechanical means, finished by a motor grader & compacted.
b. Moisture content of the material shall be checked at this site of placement prior to commencement of compaction, water shall be sprinkled from a water tanker filled with sprinkler capable of applying water uniformly.
c. Moisture content of each layer should be checked with respect to table – 1 in accordance with IS – 2720.
d. Clods or hard lumps of earth shall be broken to have max size of 75mm when placed in embankment & max size of 50 mm when placed in subgrade.
e. Embankments & other areas of unsupported fills shall not be constructed with steeper side slopes, or to greater widths.
f. Whenever fills is to be deposited against the face of a natural slope, steeper than 1 verticle on 4 horizontal, such faces shall be benched.

Compaction –
a. Smooth wheeled, vibratory, pneumatic tyred, sheep foot or pad foot rdlers of suitable size and capacity should be used for different types & grades of materials.
b. Mostly compaction will be done with vibratory roller of 80 to 100KN static weight or heavy pneumatic tyred roller.
c. Each layer of the material shall be thoroughly compacted to the densities in table – 1, subsequent layers should be laid only after the finished layer has been tested.
d. The measurement of field dry density is recorded by nuclear moisture / density guage.
e. When density measurement revel any soft areas in embankment, further compaction is carried out.

Drainage – The surface of embankment at all times during construction shall be maintained at such across fall as will shed water and prevent pending.
Repairing of damages caused by rain / spillage of water –

a. The soil in the affected portion shall be removed in such areas before next layer is laid & refilled in layers & compacted using small vibratory roller, plate compactor or power rammer to achieve the required density.

b. Tests shall be carried out to ascertain the density requirements of the repaired area.

Finishing operations –

a. It shall include the work of shaping & dressing the shoulders / verge / road bed & side slopes to conform to alignment, levels, cross sections & dimensions.

b. Both the upper & lower ends of side slopes shall be rounded off & to merge the embankment with adjacent terrain to improve appearances.

c. The top soil, removed & conserved earlier shall spread over the fill slopes, before spreading the slopes should be roughened and moistened slightly to provide bond and is provided at a depth of 75mm to 150mm for plant growth.

d. When earthwork is completed, the road area shall be cleared of all debris & ugly scars.

Fine Grading

Fine grade is required to be provided for the final trimming and checking of the cross section and grade. Stakes are usually set at 50 ft intervals near each edge of the subgrade with a grade mark established at some known distance above the actual finish subgrade elevation. A string line is stretched across the grade marks on two adjoining stakes and the subgrade 7-3 elevation is checked by measuring down the known offset distance from the stringline to the dirt grade. The appropriate corrections for a crown in the typical cross section are used in calculating the correct offset distance. The tolerance for finishing the earth subgrade is 1/2 in. from the true grade. Any low areas in the grade requiring less than 3 in. additional fill material are scarified prior to placing the fill material so the thin layer of fill is tied into the previous layer when compacted.

Fine Grading the subgrade for aggregate or asphalt base courses is usually conducted with a motor grader and checked with a stringline, but may be conducted with an automatic grading machine controlled from a stringline. The automatic grading machine is required to be used for preparing the subgrade for concrete base and pavement. When underdrains are specified, special care is required to be taken to ensure that there is no damage to the drains and that the aggregate backfill does not become contaminated with soil.
Drainage
Providing surface drainage for the undercut areas is usually not possible. The size of the undercut areas is limited, and the undercutting schedule regulated so that an area is not left open when rain is likely. Water ponding in the undercut area would likely worsen the excess moisture problems that the undercut was designed to alleviate. The final moisture and density testing, and proof rolling are conducted on the top 8 in. of the completed subgrade near the beginning of the paving operation.

Grading in civil engineering and landscape architectural construction is the work of ensuring a level base, or one with a specified slope, for a construction work such as a foundation, the base course for a road or a railway, or landscape and garden improvements, or surface drainage. The earthworks created for such a purpose are often called the sub-grade or finished contouring

Construction of Embankments
A road, railway line or canal is normally raised onto an embankment made of compacted soil (typically clay or rock-based) to avoid a change in level required by the terrain, the alternatives being either to have an unacceptable change in level or detour to follow a contour. A cutting is used for the same purpose where the land is originally higher than required.

Materials
Embankments are often constructed using material obtained from a cutting. Embankments need to be constructed using non-aerated and waterproofed, compacted (or entirely non-porous) material to provide adequate support to the formation and a long-term level surface with stability.

Intersection of embankments
To intersect an embankment without a high flyover, a series of tunnels can consist of a section of high tensile strength viaduct (typically built of brick and/or metal) or pair of facing abutments for a bridge.

Cuts for roads: In civil engineering, a cut or cutting is where soil or rock material from a hill or mountain is cut out to make way for a canal, road or railway line. In cut and fill construction it
keeps the route straight and/or flat, where the comparative cost or practicality of alternate solutions (such as diversion) is prohibitive. Contrary to the general meaning of cutting, a cutting in construction is mechanically excavated or blasted out with carefully placed explosives. The cut may only be on one side of a slope, or directly through the middle or top of a hill. Generally, a cut is open at the top (otherwise it is a tunnel). A cut is (in a sense) the opposite of an embankment. When used in reference to transportation routes, it reduces the grade of the route.

Cuts can be created by multiple passes of a shovel, grader, scraper or excavator, or by blasting. One unusual means of creating a cut is to remove the roof of a tunnel through day lighting. Material removed from cuts is ideally balanced by material needed for fills along the same route, but this is not always the case when cut material is unsuitable for use as fill. The word is also used in the same sense in mining, as in an open cut mine.

**Quality Control Tests**

**Quality control tests for Embankment, Subgrade construction.**

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Type of test</th>
<th>Frequency of tests</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Sand content</td>
<td>2 tests per 3000 cubic meter of soil.</td>
</tr>
<tr>
<td>2</td>
<td>Plasticity test</td>
<td>2 tests per 3000 cubic meter of soil.</td>
</tr>
<tr>
<td>3</td>
<td>Density test</td>
<td>2 tests per 3000 cubic meter of soil.</td>
</tr>
<tr>
<td>4</td>
<td>Deleterious content</td>
<td>As &amp; when required.</td>
</tr>
<tr>
<td>5</td>
<td>Moisture content</td>
<td>1 test for 250 cubic meter of soil.</td>
</tr>
<tr>
<td>6</td>
<td>CBR test [soaked &amp; unsoaked]</td>
<td>1 test per 3000 cubic meter of soil.</td>
</tr>
</tbody>
</table>

a) **Compaction Control** – At least one measurement of density for each 1000sqm of compacted area, test locations should be chosen with random sampling techniques. Control should be based on the mean value of 5 – 10 density determinations. The number of tests in one set of measurements shall be 6. For earth work in shoulders at least one density
measurement for every 500sqm for the compacted area should be made and the number of tests in each set shall be at least 10.

1. Enumerate the steps in the preparation of sub grade. How is the adequacy of the compaction in the field evaluated? What are the quality control tests or checks at the lab and in the field?

2. Explain the steps in the formation of an embankment.

3. Write a brief note on i) surface dressing ii) Mastic Asphalt iii) Built up Spray Grout.

4. Explain the evaluation of soil strength properties.

**TEXT BOOKS:**


**REFERENCES BOOKS:**


2. RRL, DSIR, ‘Soil Mechanics for Road Engineers’, HMSO Publication.

3. Relevant IRC codes and MoRT & H specifications.