BITUMEN-BOUND MATERIALS
• **Asphalt or bitumen:**
  - The residuum produced from the distillation of crude petroleum at “atmospheric and under reduced pressures in the presence or absence of steam”.
  - Asphalt is a black or dark brown solid or viscous liquid at room temperature and insoluble in water at 20 °C

• **Natural asphalt or natural bitumen:**
  - It is naturally occurring deposits of asphalt-like material. While these deposits have physical properties that are similar to those of petroleum-derived asphalt, the composition is different.
• **Asphalt cement:**
  It is an asphalt that is refined to meet specifications for paving, roofing, industrial, and special purposes.
  Asphalt cements are used mainly as binders (4–10% of the mixture) in hot-mix asphalts and serve to hold the aggregate together.

• **Penetration-grade asphalts:**
  It is asphalt that that are further processed by air-blowing, solvent precipitation, or propane de-asphalting.
  A combination of these processes may be used to produce different grades that are classified according to their penetration value.
• **Cutback asphalt:**
  - Asphalt that is liquefied by the addition of diluents (typically petroleum solvents).
  - It is used in both paving and roofing operations, depending on whether a paving or roofing asphalt is liquefied.
  - It is further classified according to the solvent used to liquefy the asphalt cement to produce rapid-, medium-, or slow-curing asphalt.
  - Rapid-curing cutback asphalts are made by adding gasoline or naphtha and are mainly used as surface treatments, seal coats, and tack coats.
  - Medium curing cutback asphalts are made by the addition of kerosene, and slow-curing cutback asphalts are made by the addition of diesel or other gas oils.
  - Medium- and slow-curing cutback asphalts are mainly used as surface treatments, prime coats, tack coats, mix-in-place road mixtures, etc.
Bitumen is a petroleum product obtained by the distillation of petroleum crude.

Bitumen is a hydrocarbon material of either natural or pyrogenous origin, found in gaseous, liquid, semisolid or solid form.

Highway construction: hydrocarbon material which are cementitious in character:
- Natural product (lake asphalt, rock asphalt)
- Fractional distillation of petroleum
  - Asphalt cement (Penetration grade)
  - Oxidized asphalt (softening point grade)
  - Liquid asphalt
- Tar: destructive distillation of coal
Production

The portion of bituminous material present in petroleum may widely differ depending on the source.

Almost all the crude petroleum's contain considerable amounts of water along with crude oil.

Hence the petroleum should be dehydrated before the distillation.
BITUMEN BOUND MATERIALS
Petroleum Bitumen Flow Chart

- Crude Oil
  - Preheating unit
    - Atmospheric residue
      - 370 °C
      - 350 °C
    - White-spirit
    - Distillation products
      - Gas-oils
        - 400 °C
        - P = 9.1 bar
          - 350 °C
    - Vacuum residue
    - Solvents
  - Atmospheric distillation unit
  - Vacuum distillation

- Oxidatis unit
  - Oxidised bitumen
  - Deasphalting unit

- Blender
  - Paving grade bitumen
  - Pigmentable bitumen
  - Special bitumen
Desirable Properties of Bitumen

- It should be *fluid enough* at the time of mixing to coat the aggregate evenly by a thin film.
- It should have *low temperature susceptibility*.
- It should show *uniform viscosity* characteristics.
- Bitumen should have *good amount of volatiles* in it, and it should not lose them excessively when subjected to higher temperature.
- The bitumen should be *ductile and not brittle*.
- The bitumen should be capable of being heated to the temperature at which it can be easily mixed without any fire hazards.
- The bitumen should have *good affinity to the aggregate* and *should not be stripped off* in the continued presence of water.
• Quality control tests for **Bitumen**
  - Penetration
  - Ductility
  - Softening point
  - Specific gravity
  - Loss on heating
  - Flash & Fire point
  - Viscosity
  - Solubility
**Significance**

- The penetration test determines the hardness or softness of bitumen.
- The bitumen grade is specified in terms of the penetration value.
- 30/40 and 80/100 grade bitumen are commonly used.
- In hot climates, lower penetration grade bitumen is preferred, and vice versa.
- Basic principle of penetration test: measurement of penetration in units of $1/10$th of a mm of a standard needle of 100 gm in a bitumen sample kept at 25°C for 5 seconds.
- Higher penetration implies a softer grade.
- Purpose is classification.
BITUMEN BOUND MATERIALS
Penetration test for Bitumen

- Penetrometer
- Dial
- Water Bath
- Temperature Controller
- Weight
- Needle
- Mould
**BITUMEN BOUND MATERIALS**

Penetration test for Bitumen

**Procedure**

- Heat the bitumen to softening point +90º C
- Pour the bitumen into the container at least 10 mm above the expected penetration
- Place all the sample containers to cool in atmospheric temperature for 1 hour
- Place the sample containers in temperature controlled water bath at a temperature of 25º C ± 1º C for a period of 1 hour
- Fill the transfer dish with water from the water bath to cover the container completely
- Take off the sample container from the water bath, place in transfer dish and place under the middle of penetrometer
- Adjust the needle to make a contact with surface of the sample
- See the dial reading and release the needle exactly for 5 seconds
- Note the final reading
- Difference between the initial and final readings is taken as the penetration value in 1/10th of mm
BITUMEN BOUND MATERIALS

Penetration test for Bitumen
Observation Sheet

(i) Pouring temperature =

(ii) Period of cooling in atmosphere, minutes =

(iii) Room temperature =

(iv) Period of cooling in water bath, minutes =

(v) Actual test temperature =

<table>
<thead>
<tr>
<th>Penetrometer dial readings</th>
<th>Sample No 1</th>
<th>Sample No 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>Test 2</td>
<td>Test 3</td>
</tr>
<tr>
<td>Initial</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average Value =
Discussion

- Test is highly influenced by the pouring temperature, size of needle, weight of needle, test temperature, duration of release of needle
- High penetration grade is desirable in colder regions
- Penetration below 20 will result in cracking
- For lower penetration, bonding is difficult, but once achieved will remain for a long time
**Significance**

- The ductility of bitumen improves the physical interlocking of the aggregate bitumen mixes
- Under traffic loads the pavement layer is subjected to repeated deformation. The binder material of low 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
- Ductility is the distance in cm to which a standard briquette of bitumen can be stretched before the thread breaks
- Ductile materials is one which elongates when held in tension
**BITUMEN BOUND MATERIALS**

**Ductility Test**

- **Procedure**
- The bitumen sample is melted to temperature of $75^\circ C$ to $100^\circ C$ above the approx. softening point until it is fluid.
- It is strained through IS sieve 30, poured in mould assembly and placed on a brass plate, after a solution of glycerine or dextrine is applied over all surfaces of the mould exposed to bitumen.
- Thirty to forty minutes after the sample is poured into the moulds, the plate assembly along with the sample is placed in water bath maintained at $27^\circ C$ for 30 minutes.
- The sample and mould assembly are removed from water bath and excess bitumen material is cut off by leveling the surface using hot knife.
- After trimming the specimen, the mould assembly containing sample is replaced in water bath maintained at $27^\circ C$ for 85 to 95 minutes.
- The slides of the mould are then removed and the clips are carefully hooked on the machine without causing any initial strain.
- The pointer is set to read zero.
- The machine is started and the two clips are thus pulled apart horizontally.
- While the test is in operation, it is checked whether the sample is immersed in water up to a depth of at least 10mm.
- The distance at which the bitumen thread breaks is recorded (in cm) and reported as ductility value.
BITUMEN BOUND MATERIALS

Ductility Test

Ductility Machine
BITUMEN BOUND MATERIALS

Ductility Test

Briquette Moulds
BITUMEN BOUND MATERIALS

Ductility Test

Ductilometer In Operation
BITUMEN BOUND MATERIALS

Ductility Test

Breaking of Thread

HIGHWAY II - Bitumen Bound Materials
## Observation sheet

(i) Grade of bitumen
(ii) Pouring temperature °C
(iii) Test temperature
(iv) Period of cooling (minutes) in Air
In water bath before trimming
In water bath after trimming

<table>
<thead>
<tr>
<th>Test Property</th>
<th>Briquette Number</th>
<th>Mean Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a</td>
<td>b</td>
</tr>
</tbody>
</table>

**Repeatability**

- 5%

**Reproducibility**

- 10%

<table>
<thead>
<tr>
<th>Source of Paving Bitumen &amp; Penetration Grade</th>
<th>Minimum Ductility (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S 35</td>
<td>50</td>
</tr>
<tr>
<td>S 45, S 65 &amp; S 90</td>
<td>75</td>
</tr>
</tbody>
</table>

*Note: *S denotes sources other than Assam petroleum.
Discussion

- Ductility of bitumen is affected by the pouring temperature, briquette size, placement of briquette, test temperature, rate of pulling.
- Ductility value ranges from 5-100. Low value implies cracking. Some minimum ductility is needed for flexural strength.
- The lack of ductility does not necessarily indicate poor quality.
Significance

- Bitumen does not melt, but change gradually from solid to liquid
- Softening point is the temperature at which the bitumen attains particular degree of softening under specified test conditions
- Ring and ball apparatus is used for the test
BITUMEN BOUND MATERIALS
Softening Point Test

Ring & Ball Test Set-up

- Mechanical Stirrer
- Temp Controlled Heating Plate
- Thermometer
- Glass Beaker
- Metallic Support
- Steel Balls ø = 9.5 mm (2.5g)
- Brass Rings (In ø=15.9 Mm & Out ø=17.5mm)
**BITUMEN BOUND MATERIALS**

*Softening Point Test*

**Procedure**

- Heat the bitumen to a temperature between 125°C to 150°C
- Heat the rings at the same temperature on a hot plate & place on glass plate coated with glycerin
- Fill up the rings with bitumen
- Cool for 30 minutes in air and level the surface with a hot knife
- Set the rings in the assembly and place in the bath containing distilled water at 5°C and maintain that temperature for 15 minutes
- Place the balls on the rings and Raise the temperature uniformly at 5°C per minute till the ball passes through the rings
- Note the temperature at which each of the ball and sample touches the bottom plate of the support
- Temperature shall be recorded as the softening point of bitumen
### Observation Table

(i) Grade of bitumen = 
(ii) Approximate softening point = 
(iii) Liquid used in water bath (water/Glycerin) = 
(iv) Period of air cooling (minutes) = 
(v) Period of cooling in water bath (minutes) =

<table>
<thead>
<tr>
<th>Softening Point</th>
<th>Repeatability (°C)</th>
<th>Reproducibility (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;30°C</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>30°C - 80°C</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>&gt;80°C</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

### Bitumen Grades

<table>
<thead>
<tr>
<th>Bitumen Grades</th>
<th>Softening Point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S 35</td>
<td>55-65</td>
</tr>
<tr>
<td>A 45, S 45 &amp; A 65</td>
<td>45-60</td>
</tr>
<tr>
<td>S 65</td>
<td>40-55</td>
</tr>
<tr>
<td>A 90 &amp; S 90</td>
<td>35-50</td>
</tr>
<tr>
<td>A 200 &amp; S 200</td>
<td>30-45</td>
</tr>
</tbody>
</table>

Note: S denotes sources other than Assam petroleum
Discussion

- Test is affected by quality of liquid, weight of ball, rate of heating etc
- It gives an idea of the temperature at which the bituminous material attains a certain viscosity
- Bitumen with higher softening point is used in warmer places
- Softening point is very critical for thick films like joint and crack fillers, to ensure they will not flow
• Assignment
  ○ Specific gravity
  ○ Loss on heating
  ○ Flash & Fire point
  ○ Viscosity
  ○ Solubility
• Bituminous materials, commonly referred to as premixes, are manufactured in asphalt mixing plants and laid hot (hence the other used designation, “hot-mix”).

• In-situ mixing can also be used for making base courses for lower standard roads.
The coarse aggregates for premixes should be produced by crushing sound, unweathered rock or natural gravel. The aggregate must be clean and free of clay and organic material; the particles should be angular and not flaky.

Aggregates for wearing course must also be resistant to abrasion and polishing. Highly absorptive aggregates should be avoided where possible, but otherwise the absorption of bitumen must be taken into account in the mix design procedure.

Hydrophilic aggregates which have a poor affinity for bitumen in the presence of water should also be avoided. They may be acceptable only where protection from water can be guaranteed.

The filler (material passing the 0.075 mm sieve) can be crushed rock fines, Portland cement or hydrated lime.

Portland cement or hydrated lime is often added to natural filler (1-2 % by mass of total mix) to assist the adhesion of the bitumen to the aggregate. Fresh hydrated lime can help reduce the rate of hardening of bitumen in surface dressings and may have a similar effect in premixes.
# BITUMEN BOUND MATERIALS

## Components of a Mix

### Table 7-1: Coarse Aggregate for Bituminous Mixes

<table>
<thead>
<tr>
<th>Property</th>
<th>Test</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleanliness</td>
<td>Sedimentation or 0.075mm sieve</td>
<td>&lt; 5 per cent passing</td>
</tr>
<tr>
<td>Decantation¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Particle shape</td>
<td>Flakiness index²</td>
<td>&lt; 45 per cent</td>
</tr>
<tr>
<td>Strength</td>
<td>Aggregate Crushing aggregates the Ten per Cent Fines Value Test (TFV) is used</td>
<td>&lt; 25</td>
</tr>
<tr>
<td>Value (ACV)³</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aggregate Impact Value (AIV)³</td>
<td></td>
<td>&lt; 25</td>
</tr>
<tr>
<td>Los Angeles Abrasion Value (LAA)⁴</td>
<td></td>
<td>&lt; 30 (wearing course) &lt; 35 (other)</td>
</tr>
<tr>
<td>Abrasion</td>
<td>Aggregate Abrasion</td>
<td>&lt; 15</td>
</tr>
<tr>
<td>Value (AAV)³</td>
<td>&lt; 12 (very heavy traffic)</td>
<td></td>
</tr>
<tr>
<td>Polishing (wearing course only)</td>
<td>Polished Stone Value³</td>
<td>Not less than 50-75 depending on location</td>
</tr>
<tr>
<td>Durability</td>
<td>Soundness:⁵</td>
<td>&lt; 12 per cent</td>
</tr>
<tr>
<td>Sodium Test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magnesium Test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water Absorption</td>
<td>Water Absorption⁶</td>
<td>&lt; 2 per cent</td>
</tr>
<tr>
<td>Bitumen Affinity</td>
<td>Coating and Stripping⁷</td>
<td>Non-striped area of aggregate &gt; 95 per cent</td>
</tr>
</tbody>
</table>

---

Notes:
1. BS 812, Part 103
2. BS 812, Part 105
3. BS 812, Part 110
4. ASTM C 131 and C535
5. ASTM C 88
6. ASTM C 127
7. AASHTO T-182
### Table 7-2: Fine Aggregate for Bituminous Mixes

<table>
<thead>
<tr>
<th>Property</th>
<th>Test</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleanliness</td>
<td>Sedimentation or Decantation$^1$</td>
<td>Per cent passing 0.075 mm sieve: Wearing courses:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt; 8% for sand fines</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt; 17% for crushed rock fines</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other Layers:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt; 22%</td>
</tr>
<tr>
<td>Sand Equivalent$^2$</td>
<td>Traffic</td>
<td>Wearing course</td>
</tr>
<tr>
<td>(material passing 4.75 mm sieve)</td>
<td>Light (&lt;T3)</td>
<td>&gt; 35%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium/Heavy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 40%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Base course</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 45%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 50%</td>
</tr>
<tr>
<td>Plasticity Index$^3$</td>
<td>&lt; 4</td>
<td></td>
</tr>
<tr>
<td>(material passing 0.425 mm sieve)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Durability</td>
<td>Soundness Test$^4$ (5 cycles)</td>
<td>Magnesium: &lt; 20 per cent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sodium: &lt; 15 per cent</td>
</tr>
</tbody>
</table>

Note: (1) See notes to Table 8-1  
(2) AASHTO T 176  
(3) ASTM D 4318  
(4) ASTM C 88
To perform satisfactorily as road surfacing, bitumen aggregate mixes need to possess the following characteristics:

- High resistance to deformation.
- High resistance to fatigue and the ability to withstand high strains i.e., they need to be flexible.
- Sufficient stiffness to reduce the stresses transmitted to the underlying pavement layers.
- High resistance to environmental degradation i.e. good durability.
- Low permeability to prevent the ingress of water and air.
- Good workability to allow adequate compaction to be obtained during construction.
The requirements of a mix which will ensure each of these characteristics are often conflicting.

Mixes suitable for areas carrying heavy, slow-moving traffic, such as on climbing lanes, or areas where traffic is highly channeled, will be unsuitable for flat, open terrain where traffic moves more rapidly.

A mix suitable for the latter is likely to deform on a climbing lane and a mix suitable for a climbing lane is likely to possess poor durability in flat terrain.
The main types of premix are asphaltic concrete, bitumen macadam and hot rolled asphalt.

Each type can be used in surfacing or base courses.

**ASPHALTIC CONCRETE**

Asphaltic concrete (AC) is a dense, continuously graded mix which relies for its strength on both the interlock between aggregate particles and, to a lesser extent, on the properties of the bitumen and filler.

The mix is designed to have low air voids and low permeability to provide good durability and good fatigue behavior.

The particle size distributions for wearing course material given in Table 7-3 have produced workable mixes that have not generally suffered from deformation failures.
### Table 7-3: Asphalitic Concrete Surfacing Spec.

<table>
<thead>
<tr>
<th>Mix designation</th>
<th>WC1</th>
<th>WC2</th>
<th>BC1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test sieve (mm)</td>
<td>Percentage by mass of total aggregate passing test sieve</td>
<td>Percentage by mass of total aggregate passing test sieve</td>
<td>Percentage by mass of total aggregate passing test sieve</td>
</tr>
<tr>
<td>28</td>
<td>-</td>
<td>-</td>
<td>100</td>
</tr>
<tr>
<td>20</td>
<td>100</td>
<td>-</td>
<td>80 – 100</td>
</tr>
<tr>
<td>10</td>
<td>60 – 80</td>
<td>100</td>
<td>60 – 80</td>
</tr>
<tr>
<td>5</td>
<td>54 – 72</td>
<td>62 – 80</td>
<td>36 – 56</td>
</tr>
<tr>
<td>2.36</td>
<td>42 – 58</td>
<td>44 – 60</td>
<td>28 – 44</td>
</tr>
<tr>
<td>1.18</td>
<td>34 – 48</td>
<td>36 – 50</td>
<td>20 – 37</td>
</tr>
<tr>
<td>0.6</td>
<td>26 – 38</td>
<td>28 – 40</td>
<td>15 – 27</td>
</tr>
<tr>
<td>0.3</td>
<td>18 – 28</td>
<td>20 – 30</td>
<td>10 – 20</td>
</tr>
<tr>
<td>0.15</td>
<td>12 – 20</td>
<td>12 – 20</td>
<td>5 – 13</td>
</tr>
<tr>
<td>0.075</td>
<td>6 – 12</td>
<td>6 – 12</td>
<td>2 – 6</td>
</tr>
<tr>
<td>Bitumen content (1) (per cent by mass of total mix)</td>
<td>5.0 – 7.0</td>
<td>5.5 – 7.4</td>
<td>4.8 – 6.1</td>
</tr>
<tr>
<td>Bitumen grade (pen)</td>
<td>60/70 or 80/100</td>
<td>60/70 or 80/100</td>
<td>60/70 or 80/100</td>
</tr>
<tr>
<td>Thickness (2) (mm)</td>
<td>40 – 50</td>
<td>30 – 40</td>
<td>50 – 65</td>
</tr>
</tbody>
</table>

Notes:
1. Determined by Marshall design method (ASTM D1559)
2. In practice the upper limit has been exceeded by 20% with no adverse effect
It is common practice to design the mix using the Marshall Test (ASTM D1559) and to select the design binder content by calculating the mean value of the binder contents for:

a) maximum stability,
b) maximum density,
c) the mean value for the specified range of void contents and
d) the mean value for the specified range of flow values.

Compliance of properties at this design binder content with recommended Marshall Criteria is then obtained (Table 7-4).
### Table 7-4: Suggested Marshall Test Criteria

<table>
<thead>
<tr>
<th>Total Traffic (10^6 ESA)</th>
<th>&lt; 1.5</th>
<th>1.5 - 10.0</th>
<th>&gt; 10.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic classes</td>
<td>T1,T2,T3</td>
<td>T4,T5,T6</td>
<td>T7,T8</td>
</tr>
<tr>
<td>Minimum stability (kN at 60^0C)</td>
<td>3.5</td>
<td>6.0</td>
<td>7.0</td>
</tr>
<tr>
<td>Minimum flow (mm)</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Compaction level (Number of blows)</td>
<td>2 x 50</td>
<td>2 x 75</td>
<td>2 x 75</td>
</tr>
<tr>
<td>Air voids (per cent)</td>
<td>3 - 5</td>
<td>3 - 5</td>
<td>3 - 5</td>
</tr>
</tbody>
</table>
A good method of selecting the Marshall Design binder content is:
- to examine the range of binder contents over which each property is satisfactory,
- define the common range over which all properties are acceptable, and then
- choose a design value near the center of the common range.

If this common range is too narrow, the aggregate grading should be adjusted until the range is wider and tolerances less critical.

To ensure that the compacted mineral aggregate in continuously graded mixes has a void content large enough to contain sufficient bitumen, a minimum value of the voids in the mineral aggregate (VMA) is specified, as shown in Table 7-5.
Table 7-5: Voids in the Mineral Aggregate

<table>
<thead>
<tr>
<th>Nominal maximum particle size (mm)</th>
<th>Minimum voids in mineral aggregate (per cent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>37.5</td>
<td>12</td>
</tr>
<tr>
<td>28</td>
<td>12.5</td>
</tr>
<tr>
<td>20</td>
<td>14</td>
</tr>
<tr>
<td>144</td>
<td>15</td>
</tr>
<tr>
<td>10</td>
<td>16</td>
</tr>
<tr>
<td>5</td>
<td>18</td>
</tr>
</tbody>
</table>
The Marshall mix design method consists of 6 basic steps:
- Aggregate selection.
- Asphalt binder selection.
- Sample preparation (including compaction).
- Stability determination.
- Density and voids calculations.
- Optimum asphalt binder content selection
• Aggregate Selection
• Determine aggregate physical properties.
• This consists of running various tests to determine properties such as:
  ○ **Toughness and abrasion**
  ○ **Durability and soundness**
  ○ **Cleanliness and deleterious materials**
  ○ **Particle shape and surface texture**
  ○ **Gradation and size**
  ○ **Specific gravity and absorption**

• **Perform blending calculations to achieve the mix design aggregate gradation.**
Asphalt Binder Evaluation

- The Marshall test does not have a common generic asphalt binder selection and evaluation procedure.
- Each specifying entity uses their own method with modifications to determine the appropriate binder and, if any, modifiers.
- Binder evaluation can be based on local experience, previous performance or a set procedure.
- Once the binder is selected, several preliminary tests are run to determine the asphalt binder's temperature-viscosity relationship.
Sample Preparation

The Marshall method, like other mix design methods, uses several trial aggregate-asphalt binder blends (typically 5 blends with 3 samples each for a total of 15 specimens), each with a different asphalt binder content.

Then, by evaluating each trial blend's performance, an optimum asphalt binder content can be selected.

In order for this concept to work, the trial blends must contain a range of asphalt contents both above and below the optimum asphalt content.

Therefore, the first step in sample preparation is to estimate an optimum asphalt content.

Trial blend asphalt contents are then determined from this estimate.
• Optimum Asphalt Binder Content Estimate
  The Marshall mix design method can use any suitable method for estimating optimum asphalt content and usually relies on local procedures or experience.

• Sample Asphalt Binder Contents
  Based on the results of the optimum asphalt binder content estimate, samples are typically prepared at 0.5 percent by weight of mix increments, with at least two samples above the estimated asphalt binder content and two below.
• **Compaction with the Marshall Hammer**

• Each sample is then heated to the anticipated compaction temperature and compacted with a Marshall hammer, a device that applies pressure to a sample through a tamper foot. Some hammers are automatic and some are hand operated. Key parameters of the compactor are:

  ○ *Sample size = 102 mm (4-inch) diameter cylinder 64 mm (2.5 inches) in height (corrections can be made for different sample heights)*

  ○ *Tamper foot = Flat and circular with a diameter of 98.4 mm (3.875 inches) corresponding to an area of 76 cm² (11.8 in²).*
Compaction with the Marshall Hammer

- Number of blows = Typically 35, 50 or 75 on each side depending upon anticipated traffic loading.
- Simulation method = The tamper foot strikes the sample on the top and covers almost the entire sample top area. After a specified number of blows, the sample is turned over and the procedure repeated.
The Marshall Stability and Flow Test

The Marshall stability and flow test provides the performance prediction measure for the Marshall mix design method.

The stability portion of the test measures the maximum load supported by the test specimen at a loading rate of 50.8 mm/minute (2 inches/minute).

Basically, the load is increased until it reaches a maximum then when the load just begins to decrease, the loading is stopped and the maximum load is recorded.

During the loading, an attached dial gauge measures the specimen's plastic flow as a result of the loading (Figure 2).

The flow value is recorded in 0.25 mm (0.01 inch) increments at the same time the maximum load is recorded.
Figure 2. Marshall stability testing apparatus.
**The Marshall Stability and Flow Test**

Table 1. Typical Marshall Design Criteria (from Asphalt Institute, 1979)

<table>
<thead>
<tr>
<th>Mix Criteria</th>
<th>Light Traffic ((&lt; 10^4) ESALs)</th>
<th>Medium Traffic ((10^4 - 10^6) ESALs)</th>
<th>Heavy Traffic ((&gt; 10^6) ESALs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min.</td>
<td>Max.</td>
<td>Min.</td>
<td>Max.</td>
</tr>
<tr>
<td>Compaction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(number of blows on each end of the sample)</td>
<td>35</td>
<td>50</td>
<td>75</td>
</tr>
<tr>
<td>Stability</td>
<td>2224 N (500 lbs.)</td>
<td>3336 N (750 lbs.)</td>
<td>6672 N (1500 lbs.)</td>
</tr>
<tr>
<td>Flow (0.25 mm (0.01 inch))</td>
<td>8</td>
<td>8</td>
<td>18</td>
</tr>
<tr>
<td>Percent Air Voids</td>
<td>3</td>
<td>3</td>
<td>5</td>
</tr>
</tbody>
</table>
• **Density and Voids Analysis**

• All mix design methods use density and voids to determine basic HMA physical characteristics. Two different measures of densities are typically taken:
  
  - **Bulk specific gravity** \((G_{mb})\).
  - **Theoretical maximum specific gravity** \((TMD, G_{mm})\).  
    
    These densities are then used to calculate the volumetric parameters of the HMA. Measured void expressions are usually:
  
  - **Air voids** \((V_a)\), sometimes expressed as voids in the total mix (VTM)
  - **Voids in the mineral aggregate** (VMA)
  - **Voids filled with asphalt** (VFA)
• Generally, these values must meet local or State criteria..

Table 2. Typical Marshall Minimum VMA
(from Asphalt Institute, 1979)

<table>
<thead>
<tr>
<th>Nominal Maximum Particle Size (mm)</th>
<th>(U.S.)</th>
<th>Minimum VMA (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>63</td>
<td>2.5 inch</td>
<td>11</td>
</tr>
<tr>
<td>50</td>
<td>2.0 inch</td>
<td>11.5</td>
</tr>
<tr>
<td>37.5</td>
<td>1.5 inch</td>
<td>12</td>
</tr>
<tr>
<td>25.0</td>
<td>1.0 inch</td>
<td>13</td>
</tr>
<tr>
<td>19.0</td>
<td>0.75 inch</td>
<td>14</td>
</tr>
<tr>
<td>12.5</td>
<td>0.5 inch</td>
<td>15</td>
</tr>
<tr>
<td>9.5</td>
<td>0.375 inch</td>
<td>16</td>
</tr>
<tr>
<td>4.75</td>
<td>No. 4 sieve</td>
<td>18</td>
</tr>
<tr>
<td>2.36</td>
<td>No. 8 sieve</td>
<td>21</td>
</tr>
<tr>
<td>1.18</td>
<td>No. 16 sieve</td>
<td>23.5</td>
</tr>
</tbody>
</table>
Selection of Optimum Asphalt Binder Content

The optimum asphalt binder content is finally selected based on the combined results of Marshall stability and flow, density analysis and void analysis.

Optimum asphalt binder content can be arrived at in the following procedure:

Plot the following graphs:

- Asphalt binder content vs. density. Density will generally increase with increasing asphalt content, reach a maximum, then decrease. Peak density usually occurs at a higher asphalt binder content than peak stability.
Selection of Optimum Asphalt Binder Content

- Asphalt binder content vs. Marshall stability. This should follow one of two trends:
  - Stability increases with increasing asphalt binder content, reaches a peak, then decreases.
  - Stability decreases with increasing asphalt binder content and does not show a peak. This curve is common for some recycled HMA mixtures.

- Asphalt binder content vs. flow.

- Asphalt binder content vs. air voids. Percent air voids should decrease with increasing asphalt binder content.

- Asphalt binder content vs. VMA. Percent VMA should decrease with increasing asphalt binder content, reach a minimum, then increase.

- Asphalt binder content vs. VFA. Percent VFA increases with increasing asphalt binder content.
Selection of Optimum Asphalt Binder Content

Determine the asphalt binder content that corresponds to the specifications median air void content (typically this is 4 percent).

This is the optimum asphalt binder content.

Determine properties at this optimum asphalt binder content by referring to the plots.

Compare each of these values against specification values and if all are within specification, then the preceding optimum asphalt binder content is satisfactory.

Otherwise, if any of these properties is outside the specification range the mixture should be redesigned.
BITUMEN BOUND MATERIALS
MIX DESIGN

- Graph 1: % Air Voids vs. % Asphalt by Weight
- Graph 2: Unit Weight (pcf) vs. % Asphalt by Weight

HIGHWAY II - Bitumen Bound Materials
BITUMEN BOUND MATERIALS
MIX DESIGN

HIGHWAY II - Bitumen Bound Materials
BITUMEN BOUND MATERIALS
MIX DESIGN

HIGHWAY II - Bitumen Bound Materials
• **DESIGN TO REFUSAL DENSITY**

• Under severe loading conditions asphalt mixes must be expected to experience significant secondary compaction in the wheel paths.

• Severe conditions cannot be precisely defined but will consist of a combination of two or more of the following:
  - High maximum temperatures
  - Very heavy axle loads
  - Very channeled traffic
  - Stopping or slow moving heavy vehicles

• Failure by plastic deformation in continuously graded mixes occurs very rapidly once the VIM is below 3 per cent.

• Therefore the aim of refusal density design is to ensure that at refusal there is still at least 3 per cent voids in the mix.
**DESIGN TO REFUSAL DENSITY**

For sites which do not fall into the severe category, the method can be used to ensure that the maximum binder content for good durability is obtained.

This may be higher than the Marshall optimum but the requirements for resistance to deformation will be maintained.

Where lower axle loads and higher vehicle speeds are involved, the minimum VIM at refusal can be reduced to 2 per cent.

Refusal density can be determined by two methods:
- Extended Marshall Compaction
- Compaction by vibrating hammer
• Bituminous Base Courses
  
  They should possess properties similar to bituminous mix surfacing but whenever they are used in conjunction with such a surfacing the loading conditions are less severe, hence the mix requirements are less critical.

  Nevertheless, the temperatures of base courses may be high and the mixes are therefore prone to deformation in early life, and aging and embrittlement later.

• **PRINCIPAL MIX TYPES**
  
  Particle size distributions and general specifications for continuously graded mixes are given in Table 7-8.

  No formal design method is generally available for determining the optimum composition for these materials because the maximum particle size and proportions of aggregate greater than 25 mm precludes the use of the Marshall Test.
### Table 7-8: Bitumen Macadam Base Course

<table>
<thead>
<tr>
<th>Mix designation</th>
<th>RB1 Percentage by mass of total aggregate passing test sieve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test sieve (mm)</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>37.5</td>
<td>95 – 100</td>
</tr>
<tr>
<td>28</td>
<td>70 – 94</td>
</tr>
<tr>
<td>14</td>
<td>56 – 76</td>
</tr>
<tr>
<td>10</td>
<td>44 – 60</td>
</tr>
<tr>
<td>5</td>
<td>32 – 46</td>
</tr>
<tr>
<td>0.3</td>
<td>7 – 21</td>
</tr>
<tr>
<td>0.075</td>
<td>2 – 8 (1)</td>
</tr>
<tr>
<td>Bitumen content (per cent by mass of total mix)</td>
<td>4.0 (2) ± 0.5</td>
</tr>
<tr>
<td>Thickness (mm)</td>
<td>65 – 125</td>
</tr>
<tr>
<td>Voids (per cent)</td>
<td>4 – 8</td>
</tr>
<tr>
<td>Bitumen grade (pen)</td>
<td>60/70 or 80/100</td>
</tr>
</tbody>
</table>
The following principles should be adopted for all bituminous layers but are particularly important for recipe type specifications:

- Trials for mix production, laying and compaction should be carried out to determine suitable mix proportions and procedures.
- Durable mixes require a high degree of compaction and this is best achieved by specifying density in terms of maximum theoretical density of the mix.
- Mixing times and temperatures should be set at the minimum required to achieve good coating of the aggregates and satisfactory compaction.
- The highest bitumen content commensurate with adequate stability should be used.
SAND-BITUMEN MIXES

For light and medium trafficked roads and in areas lacking coarse aggregates, bitumen stabilized sands are an alternative.

Best results are achieved with well-graded angular sands in which the proportion of material passing the 0.075mm sieve does not exceed 10% and is non-plastic.

The bitumen can range from a viscous cutback that will require heating to a more fluid cutback or emulsion that can be used at ambient temperatures.

The most viscous cutbacks that can be properly mixed at ambient temperatures are RC or MC 800 or equivalents. In general, the more viscous the bitumen the higher will be the stability of the mix.
**SAND-BITUMENMIXES**

- The amount of bitumen required will generally lie between 3 and 6 per cent by weight of the dry sand, the higher proportions being required with the finer-grained materials.
- The Marshall Test (ASTM D1559) can be used for determining the amount of bitumen required.
- *Table 7-9: Criteria for Sand-Bitumen Base Course Materials*

<table>
<thead>
<tr>
<th>Traffic Classes</th>
<th>T1</th>
<th>T2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marshall stability at 60°C (min)</td>
<td>1 kN</td>
<td>1.5 kN</td>
</tr>
<tr>
<td>Marshall flow value at 60°C (max)</td>
<td>2.5 mm</td>
<td>2 mm</td>
</tr>
</tbody>
</table>
MANUFACTURE AND CONSTRUCTION

- It is normal practice to carry out preliminary design testing to determine the suitability of available aggregates and their most economical combination to produce a job mix formula.
- The importance of detailed compaction trials at the beginning of asphalt construction work cannot be over emphasized.
- During these trials, compaction procedures and compliance of the production-run asphalt with the job-mix formula should be established.
- Adjustments to the job-mix formula and, if necessary, redesign of the mix are carried out at this stage to ensure that the final job mix satisfies the mix design requirements and can be consistently produced by the plant.
• Tolerances are specified for bitumen content and for the aggregate grading to allow for normal variation in plant production and sampling.
• Good quality control is essential to obtain durable asphalt and the mean values for a series of tests should be very close to the job-mix formula which, in turn, should have a grading entirely within the specified envelope.
• Mixing must be accomplished at the lowest temperatures and in the shortest time that will produce a mix with complete coating of the aggregate and at a suitable temperature to ensure proper compaction.
• Very little additional compaction is achieved at the minimum rolling temperatures shown in the table and only pneumatic tired rollers should be used at these temperatures.
### Table 7-10: Job-Mix Tolerances for a Single Test

<table>
<thead>
<tr>
<th>Combined aggregate passing test sieve (mm)</th>
<th>Bitumen content</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mix type</td>
</tr>
<tr>
<td>Test sieve</td>
<td>Per cent</td>
</tr>
<tr>
<td>12.5+</td>
<td>± 5</td>
</tr>
<tr>
<td>10.0</td>
<td>± 5</td>
</tr>
<tr>
<td>2.36</td>
<td>± 5</td>
</tr>
<tr>
<td>0.60</td>
<td>± 4</td>
</tr>
<tr>
<td>0.30</td>
<td>± 3</td>
</tr>
<tr>
<td>0.15</td>
<td>+2</td>
</tr>
<tr>
<td>0.075</td>
<td>+2</td>
</tr>
</tbody>
</table>

### Table 7-11: Manufacturing and Rolling Temperatures (°C)

<table>
<thead>
<tr>
<th>Grade of bitumen (pen)</th>
<th>Bitumen Mixing</th>
<th>Aggregate Mixing</th>
<th>Mix Rolling (minimum)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80 – 100</td>
<td>130 - 160</td>
<td>130 – 155</td>
<td>80</td>
</tr>
<tr>
<td>60 – 70</td>
<td>150 – 175</td>
<td>150 - 170</td>
<td>90</td>
</tr>
<tr>
<td>40 – 50</td>
<td>160 - 175</td>
<td>160 - 170</td>
<td>100</td>
</tr>
</tbody>
</table>
Heavy pneumatic tired rollers are usually employed, the kneading action of the tires being important in orientating the particles.

Vibratory compaction has been used successfully but care is needed in selecting the appropriate frequency and amplitude of vibration, and control of mix temperature is more critical than with pneumatic tired rollers.

Steel-wheeled deadweight rollers are relatively inefficient and give rise to a smooth surface with poor texture but are required to obtain satisfactory joints.

Rolling usually begins near the shoulder and progresses towards the center.

It is important that directional changes of the roller are made only on cool compacted mix and that each pass of the roller should be of slightly different length to avoid the formation of ridges.
The number of joints to cold, completed edges should be minimized by using two pavers in echelon of a full-width paver to avoid cold joints between adjacent layers.

If this is not possible, repositioning of the paver from lane to lane at frequent intervals is another option.

If a layer is allowed to cool before the adjacent layer is placed, then the edge of the first layer must be “roller over” and thoroughly compacted. Before laying the second lane, the cold joint should be broomed if necessary and tack coated.

The paver screed should be set to overlap the first mat by a sufficient amount to allow the edge of the rolled over layer to be brought up to the correct level.

Coarse aggregates in the material overlapping the cold joint should be carefully removed.

The remaining fine materials will allow a satisfactory joint to be constructed.
SURFACE TREATMENTS

A surface treatment is a simple, highly effective and inexpensive road surfacing if adequate care is taken in the planning and execution of the work.

The process is used for surfacing both medium and lightly trafficked roads, and also as a maintenance treatment for roads of all kinds.

A surface treatment comprises a thin film of binder, generally bitumen or tar, which is sprayed onto the road surface and then covered with a layer of stone chippings.

The thin film of binder acts as a waterproofing seal preventing the entry of surface water into the road structure.

The stone chippings protect this film of binder from damage by vehicle tires, and form a durable, skid-resistant and dust-free wearing surface.

In some circumstances the process may be repeated to provide double or triple layers of chippings.
SURFACE TREATMENTS

- Roads carrying in excess of 1000 vehicles/lane/day, have been successfully surfaced with multiple surface treatments.
- If traffic growth over a period of several years necessitates a more substantial surfacing or increased pavement thickness, a bituminous overlay can be laid over the original surface treatment when the need arises.
- A surface treatment is also a very effective maintenance technique, which is capable of greatly extending the life of a structurally sound road pavement if the process is undertaken at the optimum time.
- Under certain circumstances a surface treatment may also retard the rate of failure of a structurally inadequate road pavement by preventing the ingress of water and preserving the inherent strength of the pavement layers and the subgrade.
- **SINGLE SURFACE TREATMENT**

- A single surface treatment would not normally be used on a new roadbase because of the risk that the film of bitumen will not give complete coverage.

- It is also particularly important to minimize the need for future maintenance and a double dressing should be considerably more durable than a single dressing.

- However, a ‘racked-in’ dressing may be suitable for use on a new roadbase which has a tightly knit surface because of the heavier applications of binder which is used with this type of single dressing.

- When applied as a maintenance operation to an existing bituminous road surface a single surface treatment can fulfill the functions required of a maintenance re-seal, namely waterproofing the road surface, arresting deterioration, and restoring skid resistance.
DOUBLE SURFACE TREATMENT

Double surface treatments should be used when:

- A new road base is surface treated.
- Extra ‘cover’ is required on an existing bituminous road surface because of its condition (e.g. slightly cracked or patched surface).
- There is a requirement to maximize durability and minimize the frequency of maintenance and resealing operations.

The quality of a double surface treatment will be enhanced if traffic is allowed to run on the first treatment for a minimum period of 2-3 weeks before the second treatment is applied.

This allows the chippings of the first treatment to adopt a stable interlocking mosaic, which provides a firm foundation for the second treatment.
**DOUBLE SURFACE TREATMENT**

- However, traffic and animals may cause contamination of the surface with mud or soil during this period and this must be thoroughly swept off before the second treatment is applied.
- Such cleaning is sometimes difficult to achieve and the early application of the second seal to prevent such contamination may give a better result.
- Sand may sometimes be used as an alternative to chippings for the second treatment.
- Although it cannot contribute to the overall all thickness of the surfacing, the combination of binder and sand provides a useful grouting medium for chipping of the first seal and helps to hold them in place firmly when they are poorly shaped.
- A slurry seal may also be used for the same purpose.
TRIPLE SURFACE TREATMENT

A triple surface treatment may be used to advantage where a new road is expected to carry high traffic volumes.

The application of a small chipping in the third seal will
- reduce noise generated by traffic and
- the additional binder will ensure a longer maintenance-free service life
• **RACKED-IN SURFACE TREATMENT**
• This treatment is recommended for use where traffic is particularly heavy or fast.
• A heavy single application of binder is made and a layer of large chippings is spread to give approximately 90 per cent coverage.
• This is followed immediately by the application of smaller chippings which should ‘lock-in’ the larger aggregate and form a stable mosaic.
• The amount of bitumen used is more than would be used with a single seal but less than for a double seal.
• The main advantages of the racked-in surface treatment are:
  ○ Less risk of dislodged large chippings.
  ○ Early stability through good mechanical interlock.
  ○ Good surface texture.
**OTHER TYPES OF SURFACE TREATMENT**

‘Pad coats’ are used where the hardness of the existing road surface allows very little embedment of the first layer of chippings, such as on a newly constructed cement stabilized roadbase or a dense crushed rock base.

A first layer of nominal 6mm chippings will adhere well to the hard surface and will provide a ‘key’ for larger 10mm or 14mm chippings in the second layer of the treatment.

‘Sandwich’ surface treatments are principally used on existing binder rich surfaces and sometimes on gradients to reduce the tendency for the binder to flow down the slope.
• **Chippings for Surface Treatments**

  The selection of chipping sizes is based on the volume of commercial vehicles having weight of more than 1.5 tones and the hardness of the existing pavement.

  Ideally, chippings used for surface treatment should be single sized, cubical in shape, clean and free from dust, strong, durable, and not susceptible to polishing under the action of traffic.

  It is recommended that chippings used of surface treatment should comply with the requirements of Table 7-12 for higher levels of traffic, and to the requirements of Table 7-13 for lightly trafficked roads of up to 250 vehicles per day:
**Table 7-12: Grading Limits, Specified Size and Maximum Flakiness Index for Surface Treatment Aggregates**

<table>
<thead>
<tr>
<th>Grading Limits Test Sieve</th>
<th>Nominal Size of Aggregates (mm)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20</td>
<td>14</td>
<td>10</td>
<td>6.3</td>
</tr>
<tr>
<td>28</td>
<td>100</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>20</td>
<td>85-100</td>
<td>100</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>14</td>
<td>0-35</td>
<td>85-100</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>0-7</td>
<td>0-35</td>
<td>85-100</td>
<td>100</td>
</tr>
<tr>
<td>6.3</td>
<td>-</td>
<td>0-7</td>
<td>0-35</td>
<td>85-100</td>
</tr>
<tr>
<td>5.0</td>
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<td>-</td>
<td>0-10</td>
<td>-</td>
</tr>
<tr>
<td>3.35</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0-35</td>
</tr>
<tr>
<td>2.36</td>
<td>0-2</td>
<td>0-2</td>
<td>0-2</td>
<td>0-10</td>
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<tr>
<td>0.600</td>
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<td>0.075</td>
<td>0-1</td>
<td>0-1</td>
<td>0-1</td>
<td>0-1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Specified Size</th>
<th>Minimum Percentage by Mass Retained on Test Sieve</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>65</td>
<td>65</td>
<td>65</td>
<td>65</td>
</tr>
<tr>
<td><strong>Maximum Flakiness Index</strong></td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>-</td>
</tr>
</tbody>
</table>
Table 7-13: Grading Limits, Specified Size and Maximum Flakiness Index for Surface Treatment Aggregates for Lightly Trafficked Roads

<table>
<thead>
<tr>
<th>Grading Limits Test Sieve</th>
<th>Nominal Size of Aggregates (mm)</th>
<th>20</th>
<th>14</th>
<th>10</th>
<th>6.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td></td>
<td>100</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>20</td>
<td></td>
<td>85-100</td>
<td>100</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>14</td>
<td></td>
<td>0-40</td>
<td>85-100</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>0-7</td>
<td>0-40</td>
<td>85-100</td>
<td>100</td>
</tr>
<tr>
<td>6.3</td>
<td></td>
<td>-</td>
<td>0-7</td>
<td>0-35</td>
<td>85-100</td>
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<td>5.0</td>
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<td>-</td>
<td>0-10</td>
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</tr>
<tr>
<td>3.35</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>0-35</td>
</tr>
<tr>
<td>2.36</td>
<td></td>
<td>0-3</td>
<td>0-3</td>
<td>0-3</td>
<td>0-10</td>
</tr>
<tr>
<td>0.600</td>
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<td>0-2</td>
<td>0-2</td>
<td>0-2</td>
<td>0-2</td>
</tr>
<tr>
<td>0.075</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Specified Size</th>
<th>Minimum Percentage by Mass Retained On Test Sieve</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>60</td>
</tr>
</tbody>
</table>

| Maximum Flakiness Index | 35 | 35 | 35 | - |
• Samples of the chippings should be tested for grading, flakiness index, aggregate crushing value and, when appropriate, the polished stone value and aggregate abrasion value.
• Specifications for maximum aggregate crushing value (ACV) for surface treatment chippings typically lie in the range 20 to 35. For lightly trafficked roads the higher value is likely to be adequate but on more heavily trafficked roads a maximum ACV of 20 is recommended.
• The polished stone value (PSV) of the chippings is important if the primary purpose of the surface treatment is to restore or enhance the skid resistance of the road surface.
• The PSV required in a particular situation is related to the nature of the road site and the speed and intensity of the traffic.
• The resistance to skidding is also dependent upon the macro texture of the surface which, in turn, is affected by the durability of the exposed aggregate.
### Table 7-14: Recommended Polished Stone Values of Chippings

<table>
<thead>
<tr>
<th>Site Definition</th>
<th>Traffic (cv/d) at Design Life</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 to 100</td>
</tr>
<tr>
<td>1 Dual carriageway non-event sections and minor junctions</td>
<td></td>
</tr>
<tr>
<td>2 Single carriageway non-event sections and minor junctions</td>
<td>55</td>
</tr>
<tr>
<td>3 Approaches to and across major junctions(all limbs)</td>
<td>45</td>
</tr>
<tr>
<td>Gradient 5%-10%, Longer than 50m</td>
<td>50</td>
</tr>
<tr>
<td>Bend, radius 100-250m.</td>
<td></td>
</tr>
<tr>
<td>Roundabout</td>
<td></td>
</tr>
<tr>
<td>4 Gradient &gt; 10%, longer than 50m</td>
<td>55</td>
</tr>
<tr>
<td>Bend, radius &lt; 100m</td>
<td></td>
</tr>
<tr>
<td>5 Approach to roundabout, traffic signals, pedestrian crossing, railway level crossing, etc.</td>
<td>63</td>
</tr>
</tbody>
</table>
The nominal sizes of chippings normally used for surface treatment are 6, 10, 14 and 20 mm.

Flaky chippings are those with a thickness (smallest dimension) less than 0.6 of their nominal size.

The proportion of flaky chippings clearly affects the average thickness of a single layer of the chippings, and it is for this reason that the concept of the ‘average least dimension’ (ALD) of chippings was introduced.

In effect, the ALD is the average thickness of a single layer of chippings when they have bedded down into their final interlocked positions.

The amount of binder required to retain a layer of chippings is thus related to the ALD of the chippings rather than to their nominal size.

The most critical period for a surface treatment occurs immediately after the chippings have been spread on the binder film.
Dusty chippings can seriously impede adhesion and can cause immediate failure of the dressing.

The effect of dust can sometimes be mitigated by dampening them prior to spreading them on the road.

The chippings dry out quickly in contact with the binder and when a cutback bitumen or emulsion is used, good adhesion develops more rapidly than when the coating of dust is dry.

Most aggregates have a preferential attraction for water rather than for bitumen.

Hence if heavy rain occurs within the first few hours when adhesion has not fully developed, loss of chippings under the action of traffic is possible.

Where wet weather damage is considered to be a severe risk, an adhesion agent should be used.

An adhesion agent can be added to the binder or, used in a dilute solution to precoat the chippings.
Improved adhesion of chippings to the binder film can also be obtained by pre-treating the chippings before spreading. This is likely to be most beneficial if the available chippings are very dusty or poorly shaped, or if traffic conditions are severe.

There are basically two ways of pre-treating chippings:

- Spraying the chippings with a light application of creosote, diesel oil, or kerosene at ambient temperature.
- Pre-coating the chippings with a thin coating of hard bitumen such that the chippings do not stick together and can flow freely.
Chippings which are pre-coated with bitumen enable the use of a harder grade of binder for construction which can provide early strong adhesion and thus help to obtain high quality dressings.

The binder used for pre-coating need not necessarily be the same kind as that used for the surface treatment; for example, tar-coated chippings adhere well to a sprayed bitumen film.

Pre-coating is usually undertaken in a hot-mix plant and the hardness of the coating, and thus the tendency for the chippings to adhere to each other, can be controlled by the mixing temperature and/or the duration of mixing; typical coating temperatures are about 140°C for bitumen binders and 120°C for tar binders.
Pre-coated chippings should not be used with emulsions because the breaking of the emulsion will be adversely affected.

Adhesion agents or pre-treatment chippings are often used in an attempt to counteract the adverse effect of some fundamental fault in the surface treatment operation.

If loss of chippings has occurred, it is advisable to check whether the viscosity of the binder was appropriate for the ambient road temperature at the time to spraying.
• **Bitumens**

• It is essential that good bonding is achieved between the surface treatment and the existing road surface.

• This means that non-bituminous materials must be primed before surface treatment is carried out.
**PRIME COATS**

Where a surface treatment is to be applied to a previously untreated road surface it is essential that the surface should be dry, clean and as dust-free as possible.

The functions of a prime coat is summarized as follows:

- maintain adhesion between the roadbase and a surface treatment by pre-coating the roadbase and penetrating surface voids.
- seal the surface pores in the roadbase thus reducing the absorption of the first spray of binder of the surface treatment.
- strengthen the roadbase near its surface by binding the finer particles of aggregate together.
- If the application of the surface treatment is delayed for some reason it provides the roadbase with a temporary protection against rainfall and light traffic until the surfacing can be laid.
The depth of penetration of the prime should be between 3-10mm and the quantity sprayed should be such that the surface is dry within a few hours.

The correct viscosity and application rate are dependent primarily on the texture and density of the surface being primed.

The application rate is, however, likely to lie within the range 0.3-1.1kg/m².

Low viscosity cutbacks are necessary for dense cement or lime-stabilized surfaces, and higher viscosity cutbacks for untreated coarse-textured surfaces.

It is usually beneficial to spray the surface lightly with water before applying the prime coat as this helps to suppress dust and allows the primer to spread more easily over the surface and to penetrate.
• Bitumen emulsions are not suitable for priming as they tend to form a skin on the surface.
• Low viscosity, medium curing cutback bitumens such as MC-30, MC-70, or in rare circumstances MC-250, can be used for prime coats.
• Table 9-5: Kinematic Viscosities of Current Cutback Binders
BITUMENS FOR SURFACE TREATMENTS

The bitumen must fulfill a number of important requirements. It must:

- be capable of being sprayed;
- ‘wet’ the surface of the road in a continuous film;
- not run off a cambered road or form pools of binder in local depressions;
- ‘wet’ and adhere to the chipping at road temperature;
- be strong enough to resist traffic forces and hold the chippings at the highest prevailing ambient temperatures;
- remain flexible at the lowest ambient temperature, neither cracking nor becoming brittle enough to allow traffic to ‘pick-off’ the chippings; and
- resist premature weathering and hardening.
• At the lower road temperatures cutback grades of bitumen are most appropriate, whilst at higher road temperatures penetration grade bitumens can be used.
• The temperature/viscosity relationships shown in Figure 7-2 do not apply to bitumen emulsions.
• These have a relatively low viscosity and ‘wet’ the chippings readily, after which the emulsion ‘breaks,’ the water evaporates and particles of high viscosity bitumen adhere to the chippings and the road surface.
• Depending upon availability and local conditions at the time of construction, the following types of bitumen are commonly used:
  o Penetration grade
  o Emulsion
  o Cutback
  o Modified bitumens
In Ethiopia, daytime road temperatures lie between 25°C and 50°C, normally being in the upper half of this range.

For these temperatures the viscosity of the binder should lie between approximately $10^4$ and $7 \times 10^5$ centistokes.

At the lower road temperatures cutback grades of bitumen are most appropriate, whilst at higher road temperatures penetration grade bitumens can be used.
PENETRATION GRADE BITUMENS

Penetration grade bitumens vary between 80/100 to approximately 700 penetration.

The softer penetration grade binders are usually produced at the refinery but can be made in the field by blending appropriate amounts of kerosene, diesel, or a blend of kerosene and diesel.

With higher solvent contents the binder has too low a viscosity to be classed as being of penetration grade and is then referred to as a cutback bitumen which, for surface treatment work, is usually an MC or RC 3000 grade.

In very rare circumstances a less viscous grade such as MC or RC 800 may be used if the pavement temperature is below 15°C for long periods of the year.
**BITUMEN EMULSION**

- Cationic bitumen emulsion with a bitumen content of 70 to 75 per cent is recommended for most surface treatment work.
- This type of binder can be applied through rotating spray jets at a temperature between 70 and 85°C and, once applied, it will break rapidly on contact with chippings of most mineral types.
- The cationic emulsifier is normally an anti-stripping agent and this ensures good initial bonding between chippings and the bitumen.
- When high rates of spray are required, the road is on a gradient, or has considerable camber, the emulsion is likely to drain from the road or from high parts of the road surface before ‘break’ occurs.
- In these cases it may be possible to obtain a satisfactory result if the bitumen application is ‘split’, with a reduced initial rate of spray and a heavier application after the chippings have been applied.
• **BITUMEN EMULSION**

• If the intention was to construct a single seal then the second application of binder will have to be covered with sand or quarry fines to prevent the binder adhering to roller and vehicle wheels.

• If a double dressing is being constructed then it should be possible to apply sufficient binder in the second spray to give the required total rate of spray for the finished dressing.

• If split application of the binder is used care must be taken with the following:
  
  ○ The rate of application of chippings must be correct so that there is a minimum of excess chippings.

  ○ The second application of binder must be applied before traffic is allowed onto the dressing.

  ○ For a single seal it will be necessary to apply grit or sand after the second application of binder.
**CUTBACK BITUMENS**

- Except for very cold conditions, MC or RC 3000 grade cutback is normally the most fluid binder used for surface treatments.
- This grade of cutback is basically an 80/100 penetration grade bitumen blended with approximately 12 to 17 percent of cutter.
- It may be necessary to blend two grades together or to ‘cut-back’ a supplied grade with diesel oil or kerosene in order to obtain a binder with the required viscosity characteristics.
- Diesel oil, which is less volatile than kerosene and is generally more easily available, is preferable to kerosene for blending purposes.
- Only relatively small amounts of diesel oil or kerosene are required to modify a penetration grade bitumen such that its viscosity is suitable for surface treatment at road temperatures in Ethiopia.
- For example, Figure 7-3 shows that between 2 and 10 per cent of diesel oil was required to modify 80/100 pen bitumen to produce binders with viscosities within the range of road temperatures of between 40° – 60°.
- Figure 7-4 shows the temperature/viscosity relationships for five of the blends made for trials in Kenya.
• Figure 7-3: Blending Characteristics of 80/100 Pen Bitumen with Diesel Fuel
Figure 7-4: Viscosity/Temperature Relationships for Blends of 80/100 Pen Bitumen with Diesel Fuel
**Determining the average least dimension of chippings**

The ALD of chippings is a function of both the average size of the chippings, as determined by normal square mesh sieves, and the degree of flakiness.

The ALD may be determined in two ways.

- A grading analysis is performed on a representative sample of the chippings
- The sieve size through which 50 per cent of the chippings pass is determined (i.e. the ‘median size’).
- The flakiness index is then also determined.
- The ALD of the chippings is then derived from the nomograph shown in Figure 7-5.
Figure 7-5
Determination of average least dimension
• **Determining the overall weighting factor**
  
  The ALD of the chippings is used with an overall weighting factor to determine the basic rate of spray of bitumen.
  
  The overall weighting factor $F'$ is determined by adding together four factors that represent: the level of traffic, the condition of the existing road surface, the climate and the type of chippings that will be used.
  
  Factors appropriate to the site to be surface dressed are selected from Table 7-6.
### Table 7-6: Weighting factors for surface dressing design

<table>
<thead>
<tr>
<th>Description</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total traffic (all classes)</strong></td>
<td></td>
</tr>
<tr>
<td>Very light</td>
<td>+3</td>
</tr>
<tr>
<td>Light</td>
<td>+1</td>
</tr>
<tr>
<td>Medium</td>
<td>0</td>
</tr>
<tr>
<td>Medium-heavy</td>
<td>-1</td>
</tr>
<tr>
<td>Heavy</td>
<td>-3</td>
</tr>
<tr>
<td>Very heavy</td>
<td>-5</td>
</tr>
<tr>
<td><strong>Existing surface</strong></td>
<td></td>
</tr>
<tr>
<td>Untreated or primed base</td>
<td>+6</td>
</tr>
<tr>
<td>Very lean bituminous</td>
<td>+4</td>
</tr>
<tr>
<td>Lean bituminous</td>
<td>0</td>
</tr>
<tr>
<td>Average bituminous</td>
<td>-1</td>
</tr>
<tr>
<td>Very rich bituminous</td>
<td>-3</td>
</tr>
<tr>
<td><strong>Climatic conditions</strong></td>
<td></td>
</tr>
<tr>
<td>Wet and cold</td>
<td>+2</td>
</tr>
<tr>
<td>Tropical (wet and hot)</td>
<td>+1</td>
</tr>
<tr>
<td>Temperate</td>
<td>0</td>
</tr>
<tr>
<td>Semi-arid (hot and dry)</td>
<td>-1</td>
</tr>
<tr>
<td>Arid (very dry and very hot)</td>
<td>-2</td>
</tr>
<tr>
<td><strong>Type of chippings</strong></td>
<td></td>
</tr>
<tr>
<td>Round/dusty</td>
<td>+2</td>
</tr>
<tr>
<td>Cubical</td>
<td>0</td>
</tr>
<tr>
<td>Flaky (see Appendix A)</td>
<td>-2</td>
</tr>
<tr>
<td>Pre-coated</td>
<td>-2</td>
</tr>
</tbody>
</table>
For example, if flaky chippings (factor -2) are to be used at a road site carrying medium to heavy traffic (factor -1) and which has a very rich bituminous surface (factor -3) in a wet tropical climate (factor +1) the overall weighting factor 'F' is: $-2 - 1 - 3 + 1 = -5$

The rating for the existing surface allows for the amount of binder which is required to fill the surface voids and which is therefore not available to contribute to the binder film that retains the chippings.

If the existing surface of the road is rough, it should be rated as 'very lean bituminous' even if it’s overall color is dark with bitumen.

Similarly, when determining the rate of spread of binder for the second layer of a double surface dressing, the first layer should also be rated 'very lean bituminous'.
• **Determining the basic bitumen spray rate**

Using the ALD and 'F' values in the following equation will give the required basic rate of spread of binder.

\[ R = 0.625 + (F \times 0.023) + [0.0375 + (F \times 0.0011)] \times ALD \]

• Where
  - F = Overall weighting factor
  - ALD = the average least dimension of the chippings (mm)
  - R = Basic rate of spread of bitumen (kg/m²)
• Alternatively, the two values can be used in the design chart given in Figure 7-6.
• The intercept between the appropriate factor line and the ALD line is located and the rate of spread of the binder is then read off directly at the bottom of the chart.
• The basic rate of spread of bitumen (R) is the mass of MC3000 binder per unit area on the road surface immediately after spraying.
• The relative density of MC3000 can be assumed to be 1.0 and the spread rate can therefore also be expressed in 1/m², however, calibration of a distributor is easier to do by measuring spray rates in terms of mass.
Figure 7-6: Surface dressing design chart
The basic rate of spread of binder must also be modified to allow for the type of binder used. The following modifications are appropriate:

- *Penetration grade binders*: decrease the rate of spread by 10 per cent.

- *Cutback binders*: for MC/RC 3000 no modification is required. (In the rare cases when cutbacks with lower viscosity are used the rate of spread should be increased to allow for the additional percentage of cutter used).

- *Emulsion binders*: multiply the rate of spread given in the chart by 90/bitumen content of the emulsion (per cent). This calculation includes a reduction of ten per cent for the residual penetration grade bind
• **Spread rate of chippings**

An estimate of the rate of application of the chippings assuming that the chippings have a loose density of 1.35Mg/m³, can be obtained from the following equation:

Chipping application rate (kg/m²) = 1.364 * ALD

• **Table 8 Suggested maximum increases in bitumen spray rate for low volume roads**

<table>
<thead>
<tr>
<th>ALD of chippings (mm)</th>
<th>3</th>
<th>6</th>
<th>&gt;6</th>
</tr>
</thead>
<tbody>
<tr>
<td>All traffic (vehicles/lane/day)</td>
<td>&lt;20</td>
<td>20-100</td>
<td>&lt;20</td>
</tr>
<tr>
<td>Increase in bitumen spray rate (per cent)</td>
<td>15</td>
<td>10</td>
<td>20</td>
</tr>
</tbody>
</table>
The chipping application rate should be regarded as a rough guide only.

It is useful in estimating the quantity of chippings that is required for a surface dressing project before crushing and stockpiling of the chippings is carried out.

A better method of estimating the approximate application rate of the chippings is to spread a single layer of chippings taken from the stockpile on a tray of known area.

The chippings are then weighed, the process repeated ten times with fresh chippings, and the mean value calculated.

An additional ten per cent is allowed for whip off.

Storage and handling losses must also be allowed for when stockpiling chippings.
• The precise chipping application rate must be determined by observing on site whether any exposed binder remains after spreading the chippings, indicating too low a rate of application of chippings, or whether chippings are resting on top of each other, indicating too high an application rate.

• Best results are obtained when the chippings are tightly packed together, one layer thick.

• To achieve this, a slight excess of chippings must be applied.

• Some will be moved by the traffic and will tend to fill small areas where there are insufficient chippings.

• Too great an excess of chippings will increase the risk of whip-off and windscreen damage.
• The quantity of chippings must be sufficient to cover the entire surface of the binder film after rolling.

• The rate at which chippings should be spread depends on their size, shape and specific gravity, but rates can be estimated using Figure 7-7.
Table 9-9: Typical Bitumen Spray Rate Adjustment Factors

<table>
<thead>
<tr>
<th>Binder Grade</th>
<th>Basic Spray Rate from Figure 9-7 or Equation 1</th>
<th>Flat Terrain, Moderate Traffic Speed</th>
<th>High Speed Traffic, Down-Hill Grades &gt; 3%</th>
<th>Low Speed Traffic, Up-Hill Grades &gt; 3%</th>
</tr>
</thead>
<tbody>
<tr>
<td>MC 3000</td>
<td>R</td>
<td>R</td>
<td>R*1.1</td>
<td>R*0.9</td>
</tr>
<tr>
<td>300 pen</td>
<td>R</td>
<td>R*0.95</td>
<td>R*1.05</td>
<td>R*0.86</td>
</tr>
<tr>
<td>80/100 pen</td>
<td>R</td>
<td>R*0.9</td>
<td>R*0.99</td>
<td>R*0.81</td>
</tr>
<tr>
<td>Emulsion</td>
<td>R</td>
<td>R*(90/% binder)</td>
<td>R*(99/% binder)</td>
<td>R*(81/% binder)</td>
</tr>
</tbody>
</table>

1. ‘\% binder’ is the percentage of bitumen in the emulsion.
**Example**

In a two lane trunk road in temperate zone, the average vehicle is 3370 per day/lane (i.e. ‘Heavy’ rating). The same road is proposed to be designed with surface treatment using cutback grade bitumen and 19mm nominal size aggregate (Medium Size (i.e. 50 per cent passing) is 15mm and flakiness index of 15). Determine the chipping and binder application rate if cubical chipping is used and the existing surface is untreated or prime base.
• **POLYMERMODIFIED BITUMENS**

  Polymers can be used in surface treatment to modify penetration grade, cutback bitumens and emulsions.

  Usually these modified binders are used at locations where the road geometry, traffic characteristics or the environment dictate that the road surface experiences high stresses.

  Generally the purpose of the polymers is to reduce binder temperature susceptibility so that variation in viscosity over the ambient temperature range is as small as possible.

  Polymers can also improve the cohesive strength of the binder so that it is more able to retain chippings when under stress from the action of traffic.

  They also improve the early adhesive qualities of the binder allowing the road to be reopened to traffic earlier than may be the case with conventional unmodified binders.

  Other advantages claimed for modified binders are improved elasticity in bridging hairline cracks and overall improved durability.
POLYMER MODIFIED BITUMENS

Examples of polymers that may be used to modify bitumens are proprietary thermoplastic rubbers such as Styrene-Butadiene-Styrene (SBS), crumb rubber derived from waste car tires and also glove rubber from domestic gloves. Latex rubber may also be used to modify emulsions. Binders of this type are best applied by distributors fitted with slotted jets of a suitable size.

Rubber modified bitumen may consist, typically, of a blend of 80/100 penetration grade bitumen and three per cent powdered rubber. Blending and digestion of the rubber with the penetration grade bitumen should be carried out prior to loading into a distributor.

Cationic emulsion can be modified in specialized plant by the addition of three per cent latex rubber.

One of the advantages of using emulsions is that they can be sprayed at much lower temperatures than penetration grade bitumens, which reduces the risk of partial degradation of the rubber which can occur at high spraying temperatures.
**POLYMERMODIFIED BITUMENS**

- Bitumen modified with SBS exhibits thermoplastic qualities at high temperatures while having a rubbery nature at lower ambient temperatures.
- With three per cent of SBS, noticeable changes in binder viscosity and temperature susceptibility occur and good early adhesion of the chippings is achieved.
- SBS can be obtained in a carrier bitumen in blocks of approximately 20kg mass.
- The blocks can be blended, at a concentration recommended by the manufacturer, with 80/100 penetration binder in a distributor. In this procedure it is best to place half of the required polymer into the empty distributor, add hot bitumen from a main storage tank and then circulate the binder in the distributor tank.
- The remaining blocks are added after about 30 minutes and then about 2 hours is likely to be required to complete blending and heating of the modified binder.
- Every effort should be made to use the modified bitumen on the day it is blended.
ADHESION AGENTS

- Fresh hydrated lime can be used to enhance adhesion.
- It can be mixed with the binder in the distributor before spraying or the chippings can be pre-coated with the lime just before use, by spraying with lime slurry.
- The amount of lime to be blended with the bitumen should be determined in laboratory trials but approximately 12 per cent by mass of the bitumen will improve bitumen aggregate adhesion.
- Proprietary additives, known as adhesion agents, are also available for adding to binders to help to minimize the damage to surface treatments that may occur in wet weather with some types of stone.
- When correctly used in the right proportions, these agents can enhance adhesion between the binder film and the chippings even though they may be wet.
- Cationic emulsions inherently contain an adhesion agent and lime should not be used with this type of binder.
THANK YOU