Construction Materials

Topic: BITUMINOUS MATERIAL

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Bitumen Materials
What is Bitumen Materials?

- **Bitumen is defined as:**
  - an amorphous, black or dark-colored, (solid, semi-solid, or viscous) cementitious substance, composed principally of high molecular weight hydrocarbons, and soluble in carbon disulfide.

- **Bituminous materials are:**
  - extensively used for roadway construction, primarily because of their excellent binding characteristics and water proofing properties and relatively low cost.

Pavement Construction
A typical pavement structure consists of the surface course and the underlying base and subbase courses. Each of these layers contributes to structural support and drainage.

Basic Structural Elements: Pavement
Each of these pavement types distributes load over the subgrade in a different fashion.

- Rigid pavement, because of PCC's high elastic modulus (stiffness), tends to distribute the load over a relatively wide area of subgrade (see Figure). The concrete slab itself supplies most of a rigid pavement's structural capacity.
- Flexible pavement uses more flexible surface course and distributes loads over a smaller area. It relies on a combination of layers for transmitting load to the subgrade (see Figure).
Bituminous Mixtures

Cross Section - Concrete
History

- Prehistoric: Skeletons of prehistoric animals preserved intact to present day in surface deposits of asphalt. An example would be the La Brea Tar Pit, Los Angeles, CA, USA.
- 3200 - 540 BC: Recent archaeological excavations show extensive use of natural asphalt in Mesopotamia and Indus Valley, as cement for masonry and street construction and a waterproofing layer for temple baths and water tanks. These early asphalt materials were native asphalt. These native asphalts were found in pools and asphalt lakes.
- 300 BC: Asphalt extensively used for mummification in Egypt.
- 1802 AD: Rock asphalt used in France for floor, bridge and sidewalk surfacing.

Cont.

- 1838 AD: Rock asphalt imported and used in sidewalk construction in Philadelphia.
- 1870 (circa) AD: First asphalt pavement laid in Newark, New Jersey.
- 1902 AD: Approximately 20,000 tons of asphalt refined from petroleum in the United States. Since
- 1926 AD: The petroleum asphalt and road oil tonnage produced annually has increased steadily - from 3,000,000 tons in 1926 to 11,000,000 in 1950. Then to more than 30,000,000 tons in 1985. Total worldwide production in 1998 was over 50,000,000 tons.
Bitumen Materials:
Asphalt cement and tar are considered bituminous materials. Quite often, these two terms are used interchangeably due to misconception resulting from their similarity in appearance.
Asphalt cement and tar are two distinctly different materials with different origins and different chemical and physical characteristic.
Asphalt cement is a dark brown to black cementitious materials either its naturally occurred or produced by petroleum distillation.

Tar however, is primarily manufactured from the destructive distillation of bituminous coal and has a very distinct odor.

Tar is hardly used in paving. Why?
1. Some undesirable physical characteristic such as very high temperature susceptibility.
2. Significant health hazards such as severe eye and skin irritation when exposed to its fume.

Asphalt can be classified into two categories:
1. Natural asphalt
2. Petroleum asphalt

Natural asphalt – laid down in geologic strata and occur relatively as soft asphalt material and also as a hard, friable, black material in veins of rock formation. Hundred of thousands of tons of asphalt have been removed from the Trinidad Lake without it showing any appreciable sign of loss.
Petroleum asphalt – these are colloidally dispersed hydrocarbons in crude petroleum and are obtained by refining petroleum crudes. Gradually, these refined asphalt became plentiful and good quality. This forced the natural asphalt into position of relative unimportance.

Basic Refining Process

- Asphalt is simply the residue left over from petroleum refining.
- Crude oil is heated in a large furnace to about 340° C (650° F) and partially vaporized. It is then fed into a distillation tower where the lighter components vaporize and are drawn off for further processing.
- The residue from this process (the asphalt) is usually fed into a vacuum distillation unit where heavier gas oils are drawn off. Asphalt cement grade is controlled by the amount of heavy gas oil remaining. Other techniques can then extract additional oils from the asphalt.
Boiling and Distillation of Crude Oils

Products Made from a Barrel of Crude Oil

Typical Products Made from a 42-Gallon Barrel of Refined Crude Oil

- 3% Asphalt
- 4% Liquefied Petroleum
- 10% Jet Fuel
- 18% Other Products
- 23% Diesel Fuel & Heating Oil
- 47% Gasoline

Depending upon the exact process and the crude oil source, different asphalt cements of different properties can be produced. Additional desirable properties can be obtained by blending crude oils before distillation or asphalt cements after distillation.
Water is removed from the crude oil via a desalting process in vessels.

These distillation (or fractionation) towers begin to take off the lighter components of the crude oil with the processing moving from left to right in this image. The towers shown operate at atmospheric pressure. The tower with the windsock produces diesel and jet fuels (at least partially processed).

The light and heavy vacuum gas oils, or flasher tops and bottoms, are removed at the cut points annotated in this image.
Asphalt Storage and Emulsion

Colloid mill used in manufacturing asphalt emulsion.
It is a hydrocarbon product of Petroleum crude which is semi solid material.

- Bitumen by definition is soluble in carbon disulphide.
- Asphaltenes
- Resins
- Oils
Asphaltenes and resins separated from crude oils
(Goual and Firoozabadi, 2002)
Asphaltenes are present in most petroleum materials, and in all heavy oils and bitumens from oilsands. Asphaltenes constitute the body of the asphalt.
Asphaltenes are large, high molecular weight hydrocarbon fractions precipitated from asphalt by a designated paraffinic naphtha solvent; and also having a carbon to hydrogen ratio of 0.8.

Asphaltenes is defined by solubility:

- the components that dissolve in toluene and precipitate in n-alkane solvents are the asphaltenes.
- For analytical purposes, the concentration of asphaltene in a crude oil is defined by precipitation with either n-pentane (C5) or n-heptane (C7).
The concentration of C7-asphaltene in a very low density crude oil may be only a fraction of 1%, while the concentration in a dense bitumen can be over 20% of the total mass.

The low solubility of the asphaltene fraction makes it very important in production and processing of petroleum.

In comparison to a whole petroleum or bitumen, the asphaltenes have lower hydrogen content (4.8 - 8 %), and a higher content of sulfur, nitrogen, nickel, vanadium, and oxygen.

The low concentration of hydrogen gives a high density of 1100-1200 kg/m³, compared to circa 1000 kg/m³ for bitumen and <1000 kg/m³ for heavy oil and other petroleum.
Resins are hydrocarbon molecules with a carbon to hydrogen ratio of more than 0.6 but less than 0.8. It provides ductility and adhesiveness to asphalt. Resins are soluble in higher molecular weight normal alkanes, but are insoluble in lower molecular weight alkanes.

The material that precipitates with addition of propane, but not with n-heptane, is considered to constitute the resins.
Oils

- Oils are hydrocarbon molecules with a carbon to hydrogen ratio of less than 0.6. Oils influence the viscosity and flow of the asphalt.

Constitutes of Bitumen

- Complex chemical mixture of molecules that are predominantly hydrocarbons with a small amount structurally analogous species (sulphur, nitrogen, oxygen atoms).
- Some trace quantities of metal such as vanadium, nickel, iron, mg, calcium.
  - Carbon : 82-88 %
  - Hydrogen : 5 - 11 %
  - Sulphur : 0-6 %
  - Oxygen : 0-1.5 %
  - Nitrogen : 0-1 %
Asphalt commonly used in flexible pavement construction and can be divided into three (3) types:

1. Asphalt cement
2. Emulsified asphalt
3. Cutback asphalt

As discussed earlier, asphalt cement obtained by distillation process from crude petroleum using different refining process.

Ambient temperature – asphalt cement is black, sticky and semisolid and highly viscous material. Its also strong and durable with excellent adhesive and water proofing characteristic, highly resistant to the action of most acids, alkalies and salt.
How do we grade asphalt cement?
- Two method: based on penetration and viscosity.
  - Penetration: As specified in ASTM D946, there are five (5) standard penetration graded of asphalt cement, 40-50, 60-70, 85-100, 120-150 and 200-300. The penetration grade is based from the penetration test.
  - Penetration test involve measurements of penetration of standard penetration needle into a sample of asphalt cement under standard temperature, time and load.

Viscosity: As specified in ASTM D3381, this grading is based on the viscosity test. The viscosity grading system is based from original asphalt cement include AC-2.5, AC-5, AC-10, AC-20, AC-30 and AC-40.
Emulsified asphalt (emulsion) is a mixture of asphalt cement, water and emulsified agent. This emulsified asphalt is usually used for prime coat (binder and road-base) and tack coat (binder and wearing).

Because the asphalt cement will not dissolve in water, asphalt cement and water exist in separate phases as shown in the figure.
What are emulsions?

- An emulsion is a dispersion of small droplets of one liquid in another liquid.
- Emulsions can be formed by any two immiscible liquids, but in most emulsions one of the phases is water.
- Oil-in-water (O/W) emulsions are those in which the continuous phase is water and the disperse (Droplet) phase is an “oily” liquid.
- Water-in-oil (W/O) “inverted” emulsions are those in which the continuous phase is an oil and the disperse phase is water.

Types of emulsions:

1. O/W emulsion
2. W/O emulsion
3. Multiple W/O/W
Bitumen Emulsion is a 2-phase system consisting of:
• Bitumen
• Water
• Other Additives

1. The bitumen is dispersed throughout the water phase in form of discrete globules, held in suspension by electrostatic charges stabilized by emulsifier.
2. The Emulsion contains 40-75% of bitumen, 0.1-2.5% emulsifier, 25-60% water and other ingredients.
3. Typically of 0.1 – 50 µm in diameter.
4. It is mainly dark brown in color after breaking changes to black.

• Primary objective is to use for road surfacing without much heating.
• As main advantages this improves the handling of bitumen at room temperature.
• Promotes surface interactions.
• Its mixture with the aggregate attains full strength.
• Economical and saves energy.
• Reduced atmosphere pollution.
• Water can also added before use to dilute as per requirement.
• Rains can not effect it at the time of use and after use.
Bitumen emulsions can be divided into four classes:

1) **Cationic emulsions.**
2) **Anionic emulsions.**
3) **Non-ionic emulsions.**
4) **Clay-stabilized emulsions.**

- The first two are most widely used

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**Cationic emulsions**

- If an electric potential is supplied between two electrodes immersed in an emulsion containing positively charged particles of bitumen, they will migrate to the cathode.
- This emulsion is said to be cationic.
Anionic emulsions

- If an electric potential is supplied between two electrodes immersed in an emulsion containing negatively charged particles of bitumen, they will migrate to the anode.
- This emulsion is said to be anionic.

Non-ionic emulsions

- If the bitumen particles in the emulsion are neutral, then they will not migrate to any of the pole.
- These type of emulsions are NON-IONIC.
Clay-stabilized Emulsions

- These are mainly used for industrial applications.
- In these materials, emulsifiers are fine powders, often natural or processed clays and bentonites.
- Particle size is very much less when compared with the bitumen particles in emulsions.

Manufacture of Bitumen Emulsions

- Bitumen emulsions can be manufactured using batch process or continuous process.
- Bitumen emulsions are made in continuous inline processes involving dispersing technologies like rotor stators, colloidal mills and static mixers.
- High shearing forces are required for producing emulsions.
- Colloidal mills contain high speed rotors.
- Hot bitumen and emulsifier are fed simultaneously into colloidal mill.
The speed of rotors is in the range of 1000-6000 revs/min.

Bitumen is generally heated to temperature of 100-140 degree celsius.

The viscosity of the bitumen is kept less than 2 poise.
FIGURE 18.2 Schematic diagram of charges on bitumen droplets (The Shell Bitumen Handbook, 1993).
Emulsifier functions

- It performs various functions within bitumen emulsion.
- Makes emulsification easier by reducing the interfacial tension between bitumen and water.
- Stabilize the emulsion by preventing coalescence of droplets.
- Dictates its performance characteristics such as setting and adhesion.
- Emulsifier also decreases rate of flocculation.

Properties of bitumen emulsion

- It is stable under transportation, storage & application condition. But it may break soon after application.
- It may have low viscosity
- It may flow due to irregular spraying but not due to road irregularities
- Important properties of Bitumen emulsion:
  - Stability
  - Viscosity
  - Breaking
  - Adhesivity
Crack Filling: To stop entering water in structural layer of pavement, Bitumen emulsions preferably containing rubber are used as they are inexpensive and effective.

Grouting: It is the method of construction or stabilizing of road surfaces and footpath. Emulsion is applied to compacted dry aggregate and due to its low viscosity, it penetrates through void structure of the aggregate.
- **Soil Stabilization**: For agricultural land where fresh top soil is susceptible to surface erosion, bitumen emulsion can be used as binding agent also helps in retaining soil moisture & improving thermal insulation.

- **Slip layer & concrete curing**: Bitumen emulsions are used to create a membrane between layers of concrete to retain strength of upper layer by preventing water seepage into lower layers by avoiding rigid adhesion. Also it is sprayed on top surface to avoid evaporation of water.

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**Cutback Asphalt**

- Cutback asphalts are liquid asphalts which are manufactured by adding (cutting back) petroleum solvents to asphalt cements.
- They are made to reduce the asphalt viscosity for lower application temperature.
- Application to aggregate or pavement causes the solvent to escape by evaporation and leave the asphalt cement residue on the surface.
- Based on the rate of evaporation, cutback asphalt are divided to three types – rapid curing (RC), medium curing (MC) and slow curing (SC).
- **RC** – produce by adding a light diluent of high volatility (gasoline or naphtha) to asphalt cement. These are used primarily for tack coat and surface treatment.
- **MC** – produce by adding a medium diluent of intermediate volatility (kerosene) to asphalt cement. These are generally used for prime coat and road mixing operation.
- **SC** – produce by adding oils of low volatility (diesel or other gas oil) to asphalt cement. They are generally used for prime coat and dust palliatives.

<table>
<thead>
<tr>
<th>GRADE</th>
<th>RC-30</th>
<th>RC-70</th>
<th>RC-250</th>
<th>RC-800</th>
<th>RC-3000</th>
<th>Test Method</th>
</tr>
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<tbody>
<tr>
<td>Flash Point (Open Tag),°C</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>27</td>
<td>-</td>
<td>27</td>
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<tr>
<td>Kinematic Viscosity at 60° C, (mm²/s)</td>
<td>70</td>
<td>140</td>
<td>250</td>
<td>500</td>
<td>800</td>
<td>1 600</td>
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<tr>
<td>Distillation Test, (% of Total Distillate to 360° C)</td>
<td>ASTM 402</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>to 190° C</td>
<td>15</td>
<td>-</td>
<td>10</td>
<td>-</td>
<td>15</td>
<td>-</td>
</tr>
<tr>
<td>to 225° C</td>
<td>55</td>
<td>-</td>
<td>50</td>
<td>-</td>
<td>35</td>
<td>-</td>
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<tr>
<td>to 260° C</td>
<td>75</td>
<td>-</td>
<td>70</td>
<td>-</td>
<td>60</td>
<td>-</td>
</tr>
<tr>
<td>to 315° C</td>
<td>90</td>
<td>-</td>
<td>85</td>
<td>-</td>
<td>80</td>
<td>-</td>
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<tr>
<td>Residue from Distillation to 360° C, Volume % by difference</td>
<td>50</td>
<td>-</td>
<td>55</td>
<td>-</td>
<td>65</td>
<td>-</td>
</tr>
<tr>
<td>Tests on Residue from distillation</td>
<td>ASTM D5</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Penetration @ 25° C, 100 g, 5 s, (0.1 mm)</td>
<td>80</td>
<td>120</td>
<td>80</td>
<td>120</td>
<td>80</td>
<td>120</td>
</tr>
<tr>
<td>Ductility @ 25° C, (cm)</td>
<td>ASTM D113</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>100</td>
<td>-</td>
<td>100</td>
<td>-</td>
<td>100</td>
<td>-</td>
<td>100</td>
</tr>
<tr>
<td>Solubility in Trichloroethylene (% by mass)</td>
<td>ASTM D2042</td>
<td></td>
<td></td>
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<tr>
<td>Water, % by volume</td>
<td>ASTM D95</td>
<td></td>
<td></td>
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<tr>
<td>- 0.2</td>
<td>- 0.2</td>
<td>- 0.2</td>
<td>- 0.2</td>
<td>- 0.2</td>
<td>- 0.2</td>
<td>- 0.2</td>
</tr>
</tbody>
</table>

* If the ductility at 25° C is less than 100, the material will be acceptable if its ductility at 15° C is more than 100.
Penetration Test

- The depth of penetration is measured in unit of 0.1 mm and is reported as penetration units (i.e., Needle penetrate 8mm, the penetration of asphalt is 80).

Penetration Specification

- Five Grades
  - 40 - 50
  - 60 - 70
  - 85 - 100
  - 120 - 150
  - 200 - 300
Penetration Gradation Specification

- Uses penetration results to specify
- Adds
  - Flash point test
  - Ductility
  - Solubility
  - Thin film oven aging
    - Penetration
    - Ductility

Flash Point (Safety)

- Thermometer
- Cup filled with asphalt
- Wand attached to gas line
Ductility

![Diagram of a mold with labeled parts: Centimeter Scale, Mold, Asphalt Sample]

Solubility (Purity)

![Chemical equipment setup with a flask, a beaker, and a box of test tubes on a counter]
Thin Film Oven

Outside of Oven

Rotating Shelf

Pan

Typical Penetration Specifications

<table>
<thead>
<tr>
<th>Penetration</th>
<th>40 - 50</th>
<th>200 - 300</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flash Point, C</td>
<td>450+</td>
<td>350+</td>
</tr>
<tr>
<td>Ductility, cm</td>
<td>100+</td>
<td>100+</td>
</tr>
<tr>
<td>Solubility, %</td>
<td>99.0+</td>
<td>99.0+</td>
</tr>
<tr>
<td>Retained Pen., %</td>
<td>55+</td>
<td>37+</td>
</tr>
<tr>
<td>Ductility, cm</td>
<td>NA</td>
<td>100+</td>
</tr>
</tbody>
</table>
Penetration, 0.1 mm

25°C (77°F)

Temperature

Advantages

- Grades asphalt near average in-service temp.
- Fast
- Can be used in field labs
- Low capital costs
- Precision well established
- Temp. susceptibility can be determined
Disadvantages

- Empirical test
- Shear rate
  - High
  - Variable
- Mixing and compaction temp. information not available
- Similar penetrations at 25C (77F) do not reflect wide differences in asphalts

Definition

Viscosity: the ratio between the applied shear stress and the rate of shear.

\[ \eta = \frac{\tau}{\dot{\gamma}} \]
Testing

- Absolute viscosity
  - U-shaped tube with timing marks & filled with asphalt
  - Placed in 60°C bath
  - Vacuum used to pull asphalt through tube
  - Time to pass marks
  - Visc. in Pa s (Poise)

- Kinematic viscosity
  - Cross arm tube with timing marks & filled with asphalt
  - Placed in 135°C bath
  - Once started gravity moves asphalt through tube
  - Time to pass marks
  - Visc. in mm² / s (centistoke)
Mixing/Compaction Temps

Viscosity, Pa s

Compaction Range
Mixing Range

Temperature, C

Softening Point Test
Softening Point Test

- A steel ball of specified dimensions and weight is placed in the center of the sample. The bath is heated at a controlled rate of 5°C per minute.
- When the asphalt soften, the ball and the asphalt will sink to the bottom of the beaker. The temperature is recorded the minute when the soften asphalt sink the prescribes distances and touch the bottom plate.

Asphalt Mix Types

Asphallic Concrete
- well graded
- impermeable
- combination fine graded and coarse graded
- suits all pavement types
- uses bitumen PEN 80/100
Asphalt Mix Types

Stone Mastic Asphalt
- gap graded
- impermeable
- large stone to stone contact
- high in binder content
- uses bitumen Penetration Grade
- withstand higher loading and traffic
- improve rut resistance and pavement durability
Porous Asphalt
- open graded
- permeability
- high in binder content
- coarser stone and filler
- uses modified bitumen Penetration Grade
- specially designed to resist skid
Asphalt Mix Types

Fig. 3.4a Open-graded (Permeable Friction Course) mix cross section.

Fig. 3.4b Typical gradation curve for an open-graded mix.