Asphalt 101: An Introduction to Hot Mix Asphalt Materials

-Part I-

Asphalt and Modified Asphalts
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An Introduction to Hot Mix Asphalt Materials

-Part I-

Asphalt and Modified Asphalts

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Glue: Scott Shuler

Sticky Glue: Marshall Shackelford
Why Study Asphalt?
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of all the ROADS IN THE U. S. A.
(miles)
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of all the ROADS IN THE U. S. A. (miles)

Concrete  Earth  Gravel  Asphalt

100,000
Why Study Asphalt?

of all the ROADS IN THE U. S. A. (miles)

Concrete: 100,000
Earth: 400,000
Gravel
Asphalt
Why Study Asphalt?

of all the ROADS IN THE U. S. A.
(miles)

Concrete  Earth  Gravel  Asphalt
100,000  400,000  1,300,000
### Why Study Asphalt?

Of all the roads in the U. S. A.:

- **Concrete**: 100,000 miles (5%)
- **Earth**: 400,000 miles
- **Gravel**: 1,300,000 miles
- **Asphalt**: 2,200,000 miles (95%)
Why Study Asphalt?
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- Highway Expenditures in 2008
  - $140 Billion
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  - $140 Billion
- Hot Mix Asphalt Placed Annually
  - 500 Million Tons
  - $10.5 Billion
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- Employment
  - 300,000 directly
  - 600,000 additionally
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- Hot Mix Asphalt Placed Annually
  - 500 Million Tons
  - $10.5 Billion

- Employment
  - 300,000 directly
  - 600,000 additionally

- Asphalt is Largely Empirical
  - “Old Timers” Retiring
What Are Asphalt Pavements?
What Are Asphalt Pavements?

- Rocks Glued Together With Asphalt
What Are Asphalt Pavements?

- Rocks Glued Together With Asphalt
What Are Asphalt Pavements?

- Rocks Glued Together With Asphalt

\[ n \text{ Rocks} \rightarrow \text{Volume About 86\%} \]
What Are Asphalt Pavements?

- Rocks Glued Together With Asphalt

- Rocks
  - Volume
  - About 86%

- Asphalt
  - About 10%
What Are Asphalt Pavements?

- Rocks Glued Together With Asphalt

- **Rocks**:
  - Volume: About 86%

- **Asphalt**:
  - Volume: About 10%

- **Air**:
  - Volume: 4%
Let’s Consider the Glue
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- Among the Oldest Engineering Materials
  - Waterproofing of Ships
    - Sumeria-6000 BC
Let’s Consider the Glue

- Among the Oldest Engineering Materials
  - Waterproofing of Ships
    - Sumeria-6000 BC
  - Waterproofing of Baths and Tanks “Earth Butter”
    - Mohenjo-Daro Indus Valley-3000 BC
Let’s Consider the Glue

• Among the Oldest Engineering Materials
  – Waterproofing of Ships
    • Sumeria-6000 BC
  – Waterproofing of Baths and Tanks “Earth Butter”
    • Mohenjo-Daro Indus Valley-3000 BC
  – Mummies
    • Egypt-2600 BC
Let’s Consider the Glue

- **Among the Oldest Engineering Materials**
  - **Waterproofing of Ships**
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  - **Bible References**
    - Noah’s Arc Waterproofed with “Pitch” Genesis 6:14.20
    - Moses’ Basket Coated with “Bitumen” and “Pitch” Exodus 2:3.24
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- Among the Oldest Engineering Materials
  - Waterproofing of Ships
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  - Bible References
    - Noah’s Arc Waterproofed with “Pitch” Genesis 6:14.20
    - Moses’ Basket Coated with “Bitumen” and “Pitch” Exodus 2:3.24
  - Roman Buildings Waterproofed and Cemented
    - Romans called the source *Lacus Asphaltites*
So It Will Work!
So It Will Work!
So It Will Work!
So It Will Work!
Reed Boat, aka *Gufa*
Bitumen
Bitumen

Asphalts

Tars
Asphalts
Asphalts

- Natural
- Petroleum
Asphalts

- Natural
  - Lake
- Petroleum
Asphalts

Natural

Petroleum

Trinidad

Lake
Asphalts

Natural

- Trinidad
- La Brea

Petroleum

Lake
Asphalts

Natural
- Trinidad
- La Brea
- KY

Petroleum
- Lake
- Rock
Asphalts

Natural
- Trinidad
- La Brea
- KY
- TX

Petroleum
- Lake
- Rock
Asphalts

Natural

- Trinidad
- La Brea
- KY
- TX
- AB

Lake

Rock

Petroleum

Asphaltites
Asphalts

- Natural
  - Trinidad
  - La Brea
  - KY
  - TX
  - AB
  - UT-Gilsonite

- Petroleum
  - Lake
  - Rock
  - Asphaltites
Asphalts

- Natural
  - Trinidad
  - La Brea
  - KY
  - TX
  - AB
  - UT-Gilsonite

- Petroleum
  - Cements
  - Liquids
    - Emulsions
    - Cutbacks

- Rock
- Asphaltites
Crude Oil Variations
Crude Oil Variations

Venezuelan Nigerian Light
Crude Oil Variations

Venezuelan
- Gasoline 3%

Nigerian Light
- Gasoline 33%
Crude Oil Variations

Venezuelan

- Gasoline 3%
- Kerosene 6%

Nigerian Light

- Gasoline 33%
- Kerosene 20%
Crude Oil Variations

Venezuelan
- Gasoline 3%
- Kerosene 6%
- Gas Oil 33%

Nigerian Light
- Gasoline 33%
- Kerosene 20%
- Gas Oil 46%
Crude Oil Variations

Venezuelan
- Gasoline 3%
- Kerosene 6%
- Gas Oil 33%
- Residuum 58%

Nigerian Light
- Gasoline 33%
- Kerosene 20%
- Gas Oil 46%
- Residuum 1%
Refining Methods
Refining Methods

- Distillation
  - Atmospheric
  - Vacuum
Refining Methods

- **Distillation**
  - Atmospheric
  - Vacuum

- **Solvent Deasphalting**
  - Propane and Butane Extraction of Lube Oils
  - Result is Very Hard Precipitate AC
Refining Methods

- Distillation
  - Atmospheric
  - Vacuum

- Solvent Deasphalting
  - Propane and Butane Extraction of Lube Oils
  - Result is Very Hard Precipitate AC

- Solvent Extraction (ROSE)
  - Separates AC into Asphaltenes/Resins/Oils
  - Result is Blended to Produce Spec AC
Petroleum Asphalts
Petroleum Asphalts
Petroleum Asphalts

油田
原油储罐

Oil Well
Crude Storage
Petroleum Asphalts

Oil Well

Crude Storage

Atmos Still

60-700F
Petroleum Asphalts

Oil Well

Crude Storage

Atmos Still

Condenser

60-700F
Petroleum Asphalts

- Oil Well
- Crude Storage
- Atmos Still
- Condenser
- 60-700F
- 60-325F
- 325-500F
- Gasoline
- Kerosene
Petroleum Asphalts

Oil Well

Crude Storage

Atmos Still

Condenser

Gasoline

Kerosene

60-700F

60-325F

325-500F

60-700F
Petroleum Asphalts

- Oil Well
- Crude Storage
- Atmos Still
- Condenser
- Vacuum Still

- 60-700°F
- 60-325°F
- 325-500°F
- Gasoline
- Kerosene
Petroleum Asphalts

- Oil Well
- Crude Storage
- Atmos Still
- Condenser
- Vacuum Still

- 60-700°F
- 650-1050°F
- 60-325°F
- 325-500°F
- 650-850°F

- Gasoline
- Kerosene
- Gas Oil

Temperature Ranges:
- 650-1050°F for Gas Oil
- 60-325°F for Gasoline
- 325-500°F for Kerosene
Petroleum Asphalts

Oil Well

Crude Storage

Atmos Still

Condenser

Vacuum Still

Asphalt Cements

60-700F

60-325F

650-1050F

325-500F

650-850F

Gasoline

Kerosene

Gas Oil
Petroleum Asphalts

Petroleum operations involve multiple stages, including the extraction of crude oil from an oil well, storage, and processing through different stills. The temperature ranges for these processes are as follows:

- **Oil Well**: 60-700°F
- **Crude Storage**
- **Atmos Still**: 60-325°F
- **Condenser**: 325-500°F
- **Vacuum Still**: 650-850°F

- **Gasoline**
- **Kerosene**
- **Gas Oil**

- **Asphalt Cements**: 650-1050°F
- **Emulsions**: 650-850°F

Water (H₂O) is also a byproduct in some processes.
Petroleum Asphalts

Oil Well -> Crude Storage

Atmos Still

Condenser

Vacuum Still

Asphalt Cements

Emulsions

H₂O

Gas/ Kero

Cutbacks

Gasoline Kerosene

Gas Oil

60-325°F

325-500°F

650-850°F

60-700°F

650-1050°F
Petroleum Asphalts

Oil Well → Crude Storage

Atmos Still

Condenser

Vacuum Still

60-700°F

650-1050°F

60-325°F

325-500°F

650-850°F

Gasoline

Kerosene

Gas Oil

Emulsions

H₂O

Gas/Kero

Cutbacks

Roofing Asphalts

Asphalt Cements

Air
Asphalt Types
Asphalt Types

- Asphalt Cement
Asphalt Types

- Asphalt Cement
- Liquid Asphalts
  - Emulsified Asphalts
  - Cutback Asphalts
Behavior of Asphalt Cements
Behavior of Asphalt Cements

- Asphalt is Viscoelastic
  - Viscous (Flows) at High Temperatures
Behavior of Asphalt Cements

- Asphalt is Viscoelastic
  - Viscous (Flows) at High Temperatures
  - Elastic at Low Temperatures
Behavior of Asphalt Cements

- Asphalt is Viscoelastic
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- Silly Putty is Viscoelastic
  - Pull it Slowly- It stretches – same as high temperature
Behavior of Asphalt Cements

- Asphalt is Viscoelastic
  - Viscous (Flows) at High Temperatures
  - Elastic at Low Temperatures

- Silly Putty is Viscoelastic
  - Pull it Slowly- It stretches – same as high temperature
  - Pull it Rapidly – It breaks – same as low temperature
Asphalt Performance depends on Environment and Traffic
Asphalt Performance depends on Environment and Traffic
Hot Behavior
Weak Behavior

Hot Behavior
Temperature Effects
Temperature Effects

100°F

1 Hour
Temperature Effects

100°F

30°F

1 Hour
Temperature Effects

1 Hour

100°F

30°F

10 Hours
Temperature Effects

100°F

30°F

1 Hour

10 Hours
Material Effects
Material Effects

30°F

1 Hour
Material Effects

30°F

1 Hour

Hard Asphalt

Softer Asphalt
Achieving
SUPERPAVE

To The Rescue!
SUPERPAVE

To The Rescue!
SPECIFYING PERFORMANCE

Based on Climate
SPECIFYING PERFORMANCE

Based on Climate

PG 64 - 22
SPECIFYING PERFORMANCE

Based on Climate

PG 64 - 22

Performance Grade
SPECIFYING PERFORMANCE

Based on Climate

Performance Grade

PG 64 - 22

Average 7-day max pavement temperature, C
SPECIFYING PERFORMANCE

Based on Climate

PG 64 - 22

Performance Grade

Min pavement temperature, °C

Average 7-day max pavement temperature, °C
Tests in PG Specifications

Dynamic Shear Rheometer

Bending Beam Rheometer

Rotational Viscometer
Caused by Warm Weather, Traffic and Wrong Mixture

Permanent Deformation (Rutting)
High Temperature or, Slow Loading Behavior, aka Rutting

- High Pavement Temperature
  - Desert climates
  - Summer temperatures
- Sustained loads
  - Slow moving trucks
  - Intersections
High Temperature or, Slow Loading Behavior, aka Rutting

- High Pavement Temperature
  - Desert climates
  - Summer temperatures
- Sustained loads
  - Slow moving trucks
  - Intersections
Thermal Cracking

Caused by Low Temperatures, Rapid Loads, Hard Binder

Courtesy of FHWA
Low Temperature, or Fast Loading Behavior-aka Cracking
Low Temperature, or Fast Loading Behavior-aka Cracking

- Low Temperature
  - Cold climates
  - Winter
Low Temperature, or Fast Loading Behavior-aka Cracking

- **Low Temperature**
  - Cold climates
  - Winter

- **Rapid Loads**
  - Fast moving trucks
Low Temperature, or Fast Loading Behavior-aka Cracking

- Low Temperature
  - Cold climates
  - Winter
- Rapid Loads
  - Fast moving trucks
Low Temperature, or Fast Loading Behavior-aka Cracking

- Low Temperature
  - Cold climates
  - Winter
- Rapid Loads
  - Fast moving trucks
Aging

- Asphalt reacts with oxygen
  - Becomes harder, more brittle
  - More Elastic, Less Viscous
- Short term
  - During Mixing with Aggregates (280F-330F)
- Long term
  - In Pavement
  - Air, Water, Sun
Asphalt Plant and Construction Aging

- Rolling Thin Film Oven (RTFO)
Pressure Aging Vessel
Pressure Aging Vessel

50 grams of Asphalt in Each Pan

Pressure Aging Vessel
Pressure Aging Vessel

Courtesy of FHWA
Rutting, Hardening and Fatigue

DSR

BBR

RV
1 cycle
Fixed Lower Plate
Oscillating Upper Plate

Fixed Lower Plate

1 cycle
1 cycle
Asphalt Glued In-Between

Oscillating Upper Plate

Fixed Lower Plate

1 cycle
Asphalt Glued In-Between

Oscillating Upper Plate

Fixed Lower Plate

Time

1 cycle
Asphalt Glued In-Between

Oscillating Upper Plate

Fixed Lower Plate

Time

A

B

C

1 cycle
Now, Measure the Force Required to Rotate the Upper Plate

And, Measure When Movement Occurs in the Binder
Elastic

Time
Elastic

Strain Occurs With Stress

\( \delta = 0^\circ \)
Strain Occurs With Stress
\[ \delta = 0^\circ \]
Elastic

Viscous

Strain Occurs With Stress
\( \delta = 0^\circ \)
Elastic

Strain Occurs With Stress
\[ \delta = 0^\circ \]

Viscous

Strain Lags Stress
\[ \delta = 90^\circ \]
Elastic, $G'$
Complex Modulus is the vector sum of Elastic and Viscous Components
Controlling Rutting

> Early part of pavement life

Heavy Trucks
Controlling Rutting

Addressed by:

\[ \frac{G^*}{\sin \delta} \text{ on Unaged binder} > 1.00 \text{ kPa} \]

\[ \frac{G^*}{\sin \delta} \text{ on Lab Aged binder} \geq 2.20 \text{ kPa} \]

> Early part of pavement life
Fatigue Cracking
Fatigue Cracking

Caused by repeated traffic loads in wheel paths
Fatigue Cracking

- Addressed by intermediate temperature stiffness
  - $G \times \sin \delta$ on RTFO & PAV aged binder $\leq 5000 \text{ kPa}$

> Later part of pavement service life
Thermal Cracking

RV

DSR

BBR
Bending Beam Rheometer

Computer

Deflection Transducer

Load Cell

Fluid Bath
BBR Measures Stiffness at Low Temperatures using Beam Theory
BBR Measures Stiffness at Low Temperatures using Beam Theory

Creep stiffness at $t = 60$ secs

$$S(t) = \frac{PL^3}{4bh^3 \delta(t)}$$
BBR Measures Stiffness at Low Temperatures using Beam Theory

Creep stiffness at $t = 60$ secs

$$S(t) = \frac{PL^3}{4 \cdot bh^3 \cdot \delta(t)}$$

- 100 grams
BBr Measures Stiffness at Low Temperatures using Beam Theory

Creep stiffness at $t = 60$ secs

\[ S(t) = \frac{PL^3}{4bh^3 \delta(t)} \]

- 100 grams
- Clear Span of Beam, 102 mm
BBR Measures Stiffness at Low Temperatures using Beam Theory

Creep stiffness at $t = 60$ secs

$$S(t) = \frac{PL^3}{4bh^3 \delta(t)}$$

- 100 grams
- Clear Span of Beam, 102 mm
- Beam Width, 12.5 mm
- Beam Thickness, 6.25 mm
BBR Measures Stiffness at Low Temperatures using Beam Theory

Creep stiffness at $t = 60$ secs

$S(t) = \frac{PL^3}{4bh^3 \delta(t)}$

- 100 grams
- Clear Span of Beam, 102 mm
- Deflection at $t = 60$ secs
- Beam Width, 12.5 mm
- Beam Thickness, 6.25 mm
Bending Beam Rheometer
Bending Beam Rheometer

- Creep Stiffness
- Stiffness v. Time Slope
Bending Beam Rheometer

- Creep Stiffness
- Stiffness v. Time Slope
Bending Beam Rheometer

- Creep Stiffness
- Stiffness v. Time Slope

Log Creep Stiffness, $S(t)$ vs. Log Loading Time, $t$ (sec)
Bending Beam Rheometer

- Creep Stiffness
- Stiffness v. Time Slope
Bending Beam Rheometer

- Creep Stiffness
- Stiffness v. Time Slope
Bending Beam Rheometer

- Creep Stiffness
- Stiffness v. Time Slope

Log Creep Stiffness, $S(t)$

Log Loading Time, $t$ (sec)

$m$
Bending Beam Rheometer

- Creep Stiffness
- Stiffness v. Time Slope

Log Creep Stiffness, $S(t)$ vs. Log Loading Time, $t$ (sec)

Time (sec): 8, 15, 30, 60, 120, 240

Graph shows the relationship between log creep stiffness and log loading time.
Thermal Cracking

- **Question:** How Much Should the Asphalt Be Able to Stretch before Breaking?
Thermal Cracking

**Question:** How Much Should the Asphalt Be Able to Stretch before Breaking?

**Answer:** at least 1%

**How:** Find the Temperature Where the Asphalt Can Stretch 1% or More
Direct Tension Test

\[ \Delta L_e \]
Direct Tension Test

\[ \Delta L_e \]
Direct Tension Test

\[ \Delta L \]

Load

\[ \Delta L_e \]

\[ \Delta L \]
Direct Tension Test

Load

\[ \Delta L \]

\[ \Delta L_f \]

\[ \sigma_f \]

\[ \varepsilon_f \]
Direct Tension Test

\[ \Delta L \]

\[ \sigma_f \]

\[ \Delta L_c \]

Load

Strain

\[ \varepsilon_f \]
Direct Tension Test

\[ \text{Load} \]

\[ \Delta L \]

\[ \Delta L_e \]

Stress = \( \sigma = \frac{P}{A} \)

\( \sigma_f \)

\( \varepsilon_f \)

Strain

Load

\( \Delta L \)
But Will it Flow for Mixing?

Construction

Rotational Viscometer

Dynamic Shear Rheometer

Bending Beam Rheometer
Rotational Viscometer (Brookfield)

- Torque Motor
- Inner Cylinder
- Thermosel Environmental Chamber
- Digital Temperature Controller
Spec Requirements

- Make Sure It’s Not Too Thick
  - Keep Viscosity Below 3 Pa-sec at 275F (135C)
Questions...