Asphalt Modification
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Today's objectives

- Give you immediate tools to assess the quality of modified binders
  - Items you should implement today
  - Items to consider for the future
- To describe to you various options for modification
  - So many – we will hit on a few examples
- To discuss issues that I have personally encountered in the past 40–years working with modified asphalt!
Asphalt modification

- Historical
  - Asphalt modification dates to 100+ years – depending on definitions!
    - Oils and refinery processes early 1900’s
    - Asphalt rubber – 1950’s
    - Many others since

- Why do it?
What is asphalt

- Asphalt (or bitumen)
  - Residual from refinery process (or natural)
  - Process has become more complex with advent of better refinery processes

Natural Asphalt – 2009

Source – Shell Bitumen Handbook

2003 – Refinery, Beaumont, TX
Why we modify

- Address deficiency in specification compliance
- Addresses deficiency in performance
- Enable use of products that may otherwise not be suitable
- Value added to extend margins

For high performance asphalt roads
Types of asphalt modification

- Refining Process
  - Examples – Propane–Precipitated Asphalt (PPA), Oxidation Process, Residuum Oil Supercritical Extraction (ROSE) process, etc.
  - Examples
    - Production of oxidized grades, BND grades, etc.

- Material additions
  - Polymers (rubbers, plastics), Waxes, Resins, Hard/Natural Asphalts, Oils (various types), Powders (Carbon Black, dusts, fillers, etc.), Anti–strip additives, extenders (Sulphur), etc.
A partial list ...

- **Chemical modifiers**
  - Organo-metallic compounds
  - Sulphur
  - Lignin
  - Poly-phosphoric acid

- **Thermoplastic elastomers**
  - Styrene–butadiene–styrene (SBS)
  - Styrene–butadiene–rubber (SBR)
  - Styrene–isoprene–styrene (SIS)
  - Styrene–ethylene–butadiene–styrene (SEBS)
  - Ethylene–propylene–diene terpolymer (EPDM)
  - Isobutene–isoprene copolymer (IIR)
  - Natural rubber
  - Crumb tire rubber
  - Polybutadiene (PBD)
  - Polyisoprene

- **Thermoplastic polymers**
  - Ethylene vinyl acetate (EVA)
  - Ethylene methyl acrylate (EMA)
  - Ethylene hexyl acrylate (EHA)
  - Atactic polypropylene (APP)
  - Polyethylene (PE)
  - Polyvinyl chloride (PVC)
  - Polystyrene (PS)

- **Thermosetting polymers**
  - Epoxy resin
  - Polyurethane resin
  - Acrylic resin
  - Phenolic resin

- **Fillers**
  - Carbon black
  - Coal dust
  - Hydrated lime
  - Lime
  - Fly ash
  - Cement

- **Adhesion improvers**
  - Organic amines
  - Amides
  - Organosilanes

- **Antioxidants**
  - Amines
  - Phenols
  - Organo-zinc
  - Organo-lead compounds

- **Natural asphalts**
  - Trinidad Lake Asphalt
  - Gilsonite
  - Rock asphalt

- **Warm mix modifiers**
  - Chemical amines, oils, etc.
  - Waxes
  - Zeolites

- **Adhesions improvers**
  - Organocottene
  - Organosilanes

- **Nano modifiers**
  - Various

- **Sources**
  - Shell Bitumen Handbook and Abatech

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**Too many to consider in detail - we will talk with view to general requirements!**
Some resources

- Recent issues
  - PPA
  - REOB
  - Various Journals and online sources
    - Association of Asphalt Paving Technologists
    - Petersen Asphalt Conference
    - Etc.
What is an ideal binder?

- For a given climate
  - **Low pavement temperature** – Adequate flexibility at low temperatures, low stiffness and good relaxation properties to resist cracking
  - **High pavement temperature** – Sufficient stiffness and elastic properties that permanent flow will not occur
  - **Compaction temperatures** – Sufficient mobility to allow compaction to occur
  - **Mixing temperatures** – Adequate flow and coating properties to obtain wetting of aggregate with binder and to ensure good coating is maintained

*And a product that maintains these properties with time (low aging propensity)*
Typically consideration of viscosity, stiffness properties of a wide range of temperatures

- Pre rheology – example Bitumen Test Data Chart (BTDC)

- Higher PEN: Better low temperature properties
- Lower Fraass: Better low temperature properties
- Lower PEN: Better high temperature properties
- Higher SP: Better high temperature properties
Quantity of modifier

- A linear relationship does not exist!
- Some additives have an optimum amount!
- Some additives can result in poor performance if too much is added!
  - Need stability in blend!
Use of dynamic shear rheometer

- We can use the same test equipment as used for $G^*/\sin \delta$ and $G^*.\sin \delta$ testing – but at additional frequencies and temperatures
- This will enable us to understand the viscous and elastic response over a very wide range of conditions
Oscillatory experiments – $G^*$, $\delta$

$$\sin \delta = \frac{\text{Viscous Part} \ (G'')}{G^*} \quad \text{cos} \ \delta = \frac{\text{Elastic Part} \ (G')}{G^*}$$
Data from DSR

- Shift factors used to slide data along horizontal axis to make smooth curve.
Master curve from rheology testing

Wax Binder (4) 0 days

This part of the master curve tells us about low speed and/or high temperature behavior – but also need other tests.

Computed Discrete Spectrum
- $g_i$, $1/\lambda_i$
- Complex Modulus
- Phase Angle
- Fitted Complex Modulus
- Fitted Phase Angle

Legend

Sample ID: b4-0-DSR BBR
Dynamic Mastercurve Tref = 25°C

This part of the master curve tells us about low temperature and cracking performance.

4 Licomont BS 100
Master curve – poor shifting

With certain modifiers the lower stiffness part of the master curve is often not obtained reliability. This part of the master curve is nearly always obtained.
Characterization

- Linear and non-linear effects
  - Linear – parameters from MC
    - $\omega_c$, $R$, $C1$, $C2$, $T_d$, etc.
    - From parameters can calculated various other parameters, $G^*.\sin\delta$, $S(t)$, $m(t)$, $\Delta T_c$
    - Glover–Rowe, etc. + anything new that is developed
  - Non-linear – torture tests such as MSCR

- Graph showing $G^*$, $P_a$, $R$-value, $\omega_c$, $\omega$, $\delta$, degrees
With today’s equipment!

- Using BBR, DSR and Brookfield – we can represent data on single plots as either stiffness or viscosity
  - Many data representations exist!

![Graphs showing relaxation moduli and steady state viscosities vs temperature, with data points and trendlines for Brookfield, DSR, and Jnr numbers.

Jnr number are not rigorous – just approximate on this plot.
Typical PG grade specification representation

- PGXX–YY
  - Typically - when XX + YY > 90 then modified
  
  - Difficult for non-modified binder to have a temperature range >90°C - although several do exist
What tools do we have?

- In USA – PG graded binders
  - Two specifications
    - M320 – Based on high temperature $G^*/\sin\delta$
      - Table 1 and Table 2
    - M322 – Based on high temperature MSCR

- Are these specifications adequate for understanding our modified asphalt and impact on performance? **No – limited at best!**

Standards developed around materials in use at time of development!
The challenge

- How we define and characterize modified binders
  - SHRP program – did limited work on modified binders
  - Did leave some useful tools to further understand

- Consideration of distress areas
- Consideration of aging

- What improvements should we use?
- What other improvements should we make today?
- What work do we need to do?
Highway distresses

- Two main areas considered to be related to asphalt binder
  - Rutting
    - Deformation/rutting
    - Flow
  - Cracking
    - Fatigue Cracking
    - Durability
    - Low Temperature Cracking

(Could also consider adhesion – but both mix and binder)
Improvements we should use!

- High temperature performance
  - MSCR
    - MSCR captures to a reasonable degree the polymer network effect and the impact on permanent deformation
    - Requires more widespread adoption of M322 specification
  - What is MSCR?
Test using the DSR applying a 1 sec creep stress followed by 9 sec recovery.
**MSCR test performed in DSR**

- **Applied Stress (A to B)**
- **Fixed Plate**
- **Asphalt**
- **Load applied to upper plate**
- **Recovery (B to C)**

**Symbols and Equations:***

- $\tau = \text{stress applied during tests}$
- $\gamma_p = \text{peak strain}$
- $\gamma_r = \text{recovered strain}$
- $\gamma_u = \text{un-recovered strain}$

**Formulas:**

- $J_{nr} = \frac{\gamma_u}{\tau}$
- \[ \text{% recovery} = \frac{100 \times \gamma_r}{\gamma_p} \]

**Additional Text:**

- Higher Strains in MSCR!!
Viscosity and MSCR

- If the strain at the end of a MSCR load cycle has fully recovered – then the MSCR is a measure of the viscosity at that stress level (or strain level)
  - Otherwise need to model to get the viscosity!

- Approximate viscosity
  - ($\times 1000$ to convert from kPa to Pa.s, Jnr is reported for 1 second – so reciprocal is strain/second – or viscosity)

$$\eta = \left( \frac{1}{J_{nr}} \right)$$
Example from recent testing at AI, PG76–22

Viscosity from three types of measurements

Example
  ◦ \( \text{Jnr} = 0.9741 \ (1/\text{kPa}) \)
  ◦ \( 1000/0.9741 = 1026.6 \ \text{Pa.s} \)

Difference between viscosities associated with stress levels, test time and strength of polymer network
  ◦ Multiple effects!
Rutting performance

- We need this ....

- Not this ➔

Implement MSCR!
Very strong evidence suggests that we should specify a limit for $\Delta T_c$ for surface course asphalt mixes.

- What is $\Delta T_c$?
- Why is this a good idea?
What is $\Delta T_c$?

- $S(60s)$ and $m(60s)$ plotted vs. temperature
  - For these we get a limiting temperature value when $S=300$ MPa and $m=0.300$

GSE data from AAPT paper by Anderson et al.
ΔT\text{C} — determine ΔT\text{C} as the difference between continuous grading temperature for S(60s) from the continuous grading temperature for the m-value (at 60 seconds).

Report ΔT\text{C} as a negative value if the continuous grading temperature for the m(60s)-value is lower than the continuous grading temperature for S(60s).

In final ballot process!
Why $\Delta T_c$?

- Large differences appear to be related to durability cracking and early life issues.
- Easy to calculate since all data already captured and is part of typical grade evaluation process.

Note – some move to extended aging – 40hrs
What work do we need to do?

- 4 main areas are of high importance
  - Better understand aging effects with new modification systems
  - Better understand interaction between aging and cracking
  - Better understand mixing and compaction temperature effects
  - Ensure specification development considers full range of issues
Aging

- Binders – as all organic materials – age
  - Oxidation changes behavior
  - Need to better understand aging and lab conditioning effects with modification

Our aging methods (RTFOT and PAV) provide limited information!
Linkage of cause and effects – aging and cracking

Which are best parameters – $\Delta T_c$, $G-R$, $G^*.\sin\delta$, LAST, etc.?
Understanding mixing and compaction

- Viscosity or lubricity!!!???
  - Historical work has focused on viscosity studies
  - More recent work points to lubricity
    - Several test methods have been developed – example shown!
    - Different researchers have various proposal for substrates, test configurations, etc.

![Graph showing viscosity and normal force](image-url)
Ensure full understanding

- What is coming next in our understanding of modification!
  - Be aware and consider all options that relate to performance!
Modification concept

- Base binder
  - Make sure soft enough to resist cracking
  - May need to soften with oils
    - For this check $\Delta T_c$
- Then modify high end with polymer to stiffen at high temperatures
  - Use cross linking
  - PPA in limited amount
What are options!

1. At refinery
2. At terminal
3. At mix plant

1 and 2 – more conventional – lets look a little at #3

Some personal reflections!
PmB – mobile manufacturing units
- Several designs exist
- Generally a batch type production
- Daily production to meet 1-day of HMA production
- Consists of mixing unit – skid mounted
- Additional PmB storage
Adding polymer at HMA plant

- Two tanks – separated by pump and high shear mill
- Tanks have agitation
- After mixing – material sent to tanks for overnight period
On site QC

- A mix of tests have been applied
  - European style
    - Ductility
    - Elastic recovery
    - Pen
    - Softening Point
    - Fraass
  - PG Graded binders
    - Full PG M320 lab implemented
    - BBR, DSR, etc. (sometime BBR not implemented)
  - Other
    - Fluorescence microscope
    - Other tests/methods

Training of technicians is key need!
Some examples

- What materials do we test
- Basic test methods
- DSR, etc.
Better performing roads

- With care and good setup we achieve the end result!
Must implement good mix design
  ◦ Careful attention to volumetrics !!!!!!
  ◦ Basic training needed →
  ◦ Understand your aggregates

Understand mix physical tests
  → see thoughts on next slide
  ◦ Binder goes part way to getting good physical properties!
…. and after all of this – don’t forget the mixture!

- Hamburg
- SATS

- Bending beam fatigue test

- Fracture tests
  - Texas Overlay Tester

- Tensile tests
  - Use of beam, direct or indirect tension

- Direct compact tension test

- Semi-circular bend test
... or the paving ....

End of truck load segregation
... and finally --

- Don’t forget the crew with the paver, rollers, etc…
  - A good binder – will not substitute for good site practice
Thanks for listening ...