Asphalt Modification

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Presentation to the

WAPA

WISCONSIN ASPHALT PAVEMENT ASSOCIATION

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Todays 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!

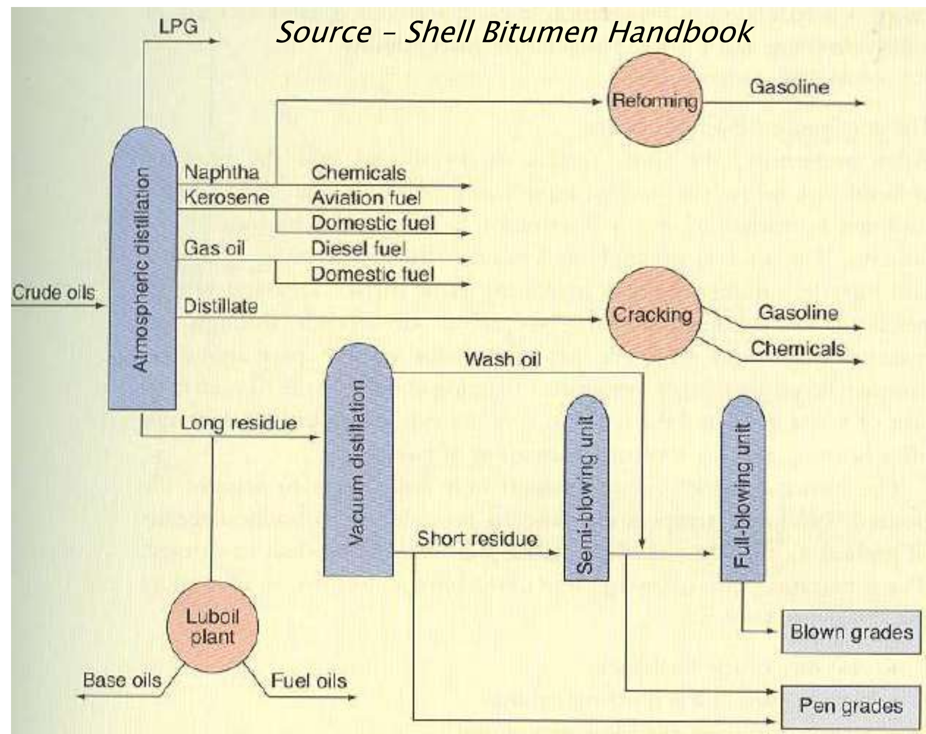
Asphalt modification

- 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

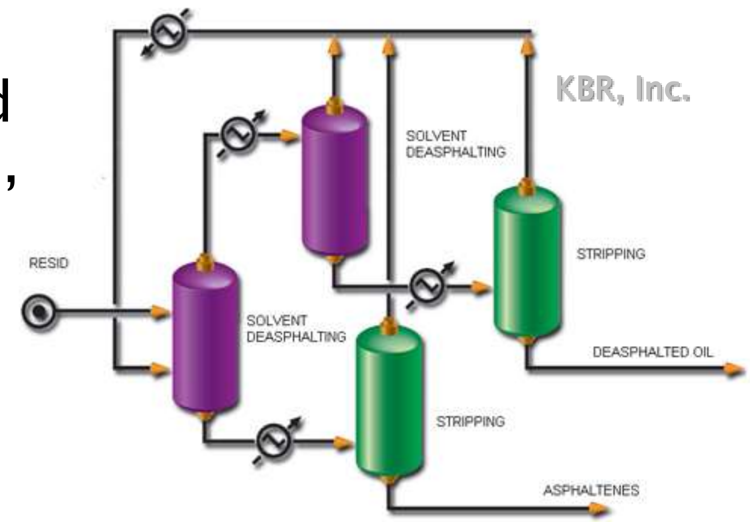


Why we modify

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

Types of asphalt modification

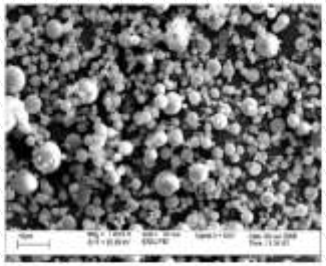
- Refining Process
  - Examples – Propane-Precipitated Asphalt (PPA), Oxidation Process, Residuum Oil Supercritical Extraction (ROSE) process, etc.
  - Examples
    - Production of oxidized grades, BND grades, etc.
- Material additions
  - Polymers (rubbers, plastics), Waxes, Resins, Hard/Natural Asphalts, Oils (various types), Powders (Carbon Black, dusts, fillers, etc.), Anti-strip additives, extenders (Sulphur), etc.

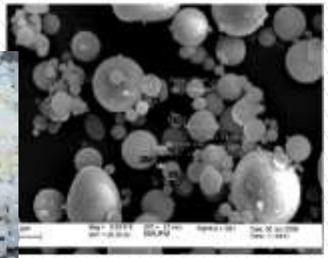


A partial list .....

- Chemical modifiers
  - Organo-metallic compounds
  - Sulphur
  - Lignin
  - Poly-phosphoric acid
- Fibers
  - Cellulose
  - Alumina-magnesium silicate
  - Glass fiber
  - Asbestos
  - Polyester
  - Polypropylene
- Adhesion improvers
  - Organic amines
  - Amides
  - Organo-Silanes
- 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
- 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 butyl acrylate (EBA)
  - 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
- Oils
  - Naphthenic
  - Aromatic
  - Paraffinic
  - VTAE/REOBs
- Nano modifiers
  - Various

Too many to consider in detail – we will talk with view to general requirements!





Sources – Shell Bitumen Handbook and Abatech

Some resources

- Recent issues
  - PPA
    - http://www.asphaltinstitute.org/wp-content/uploads/public/engineering/pdfs/materials/IS_220_4_09.pdf
  - REOB
    - http://www.asphaltinstitute.org/wp-content/uploads/IS235_REOB_VTAE_ASPHALTINSTITUTE.pdf
  - 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

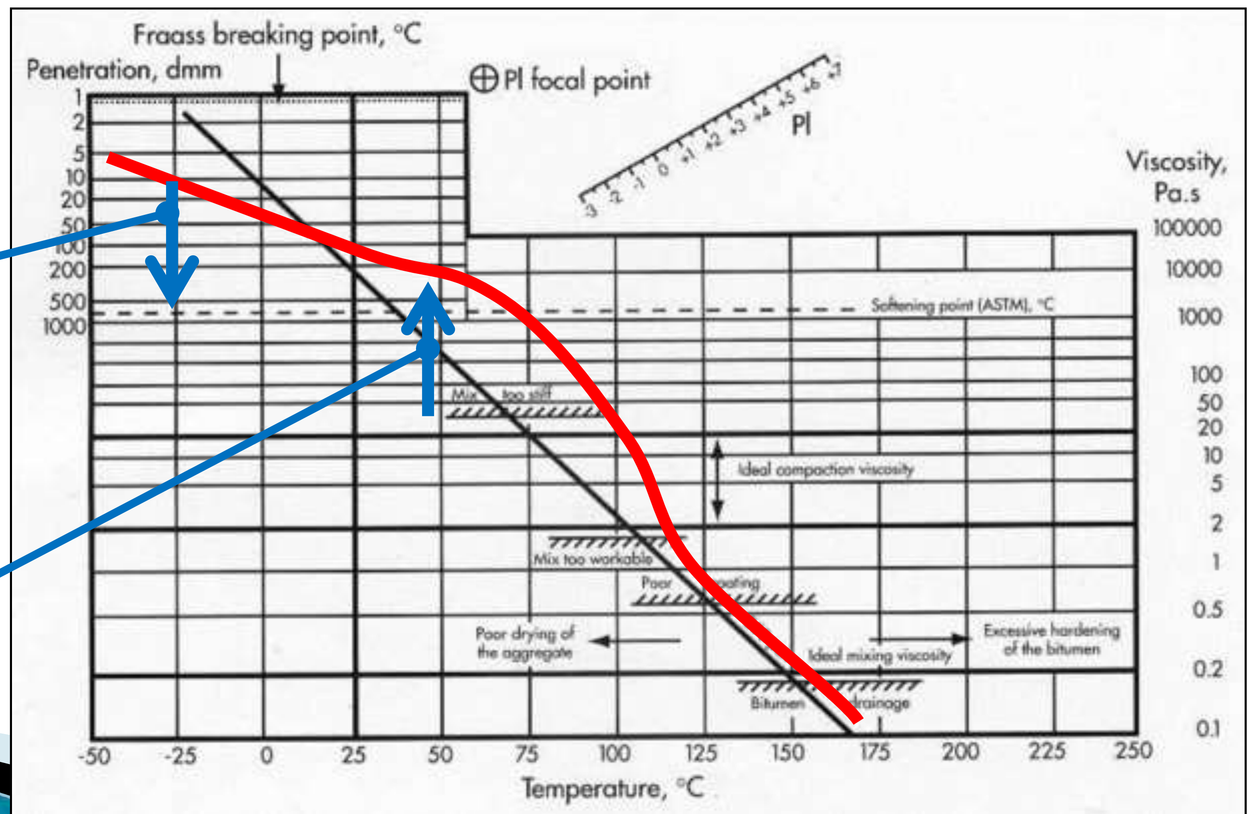
And a product that maintains these properties with time (low aging propensity)

How is this represented

- Typically consideration of viscosity, stiffness properties of a wide range of temperatures
  - Pre rheology – example Bitumen Test Data Chart (BTDC)

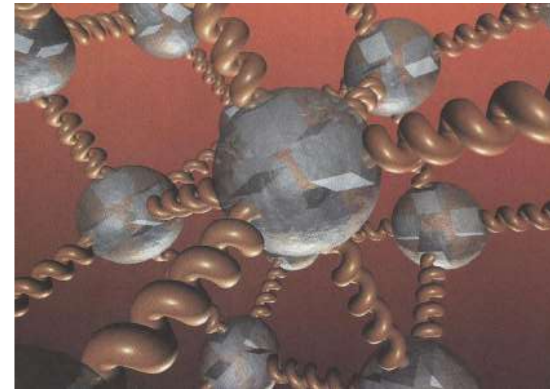
Higher PEN
Lower Fraass
Better low temperature properties

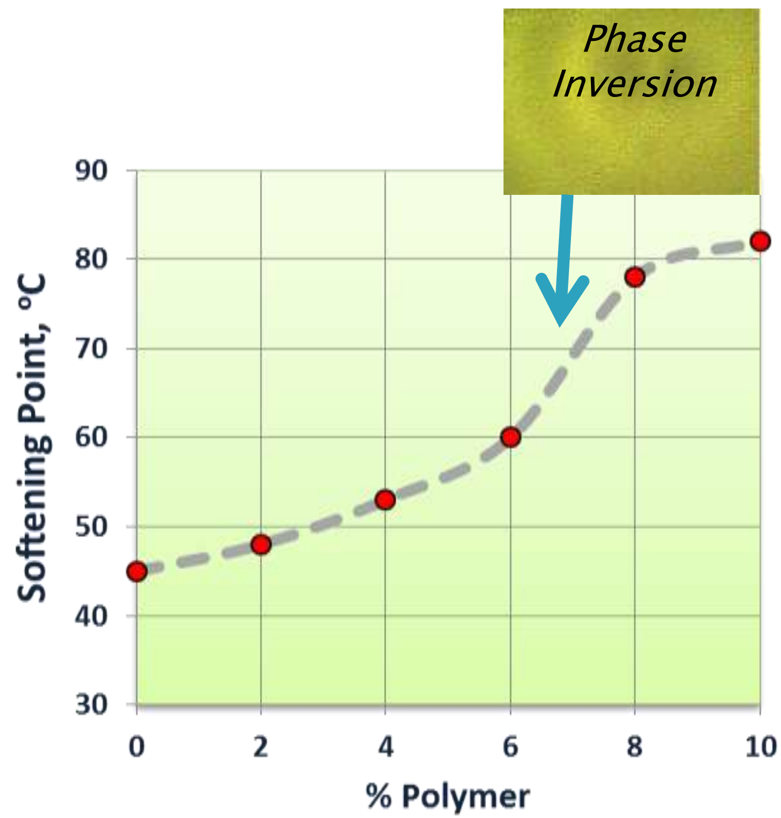
Lower PEN
Higher SP
Better high temperature properties



Quantity of modifier

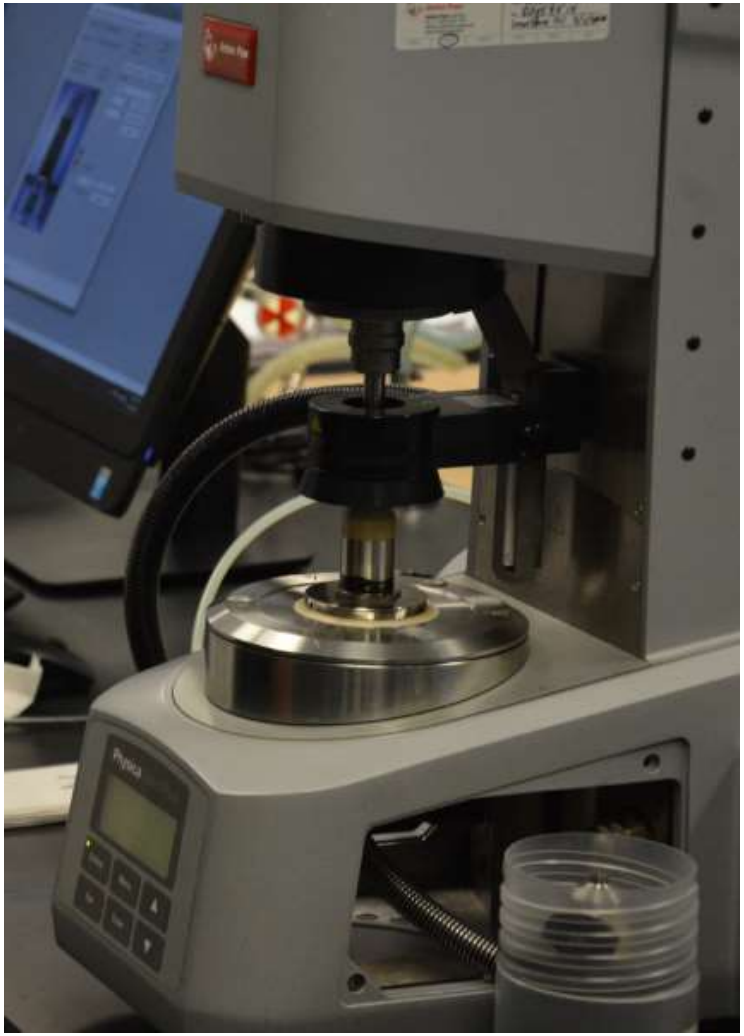
- A linear relationship does not exist!
- Some additives have an optimum amount!
- Some additives can result in poor performance if too much is added!
    - Need stability in blend!



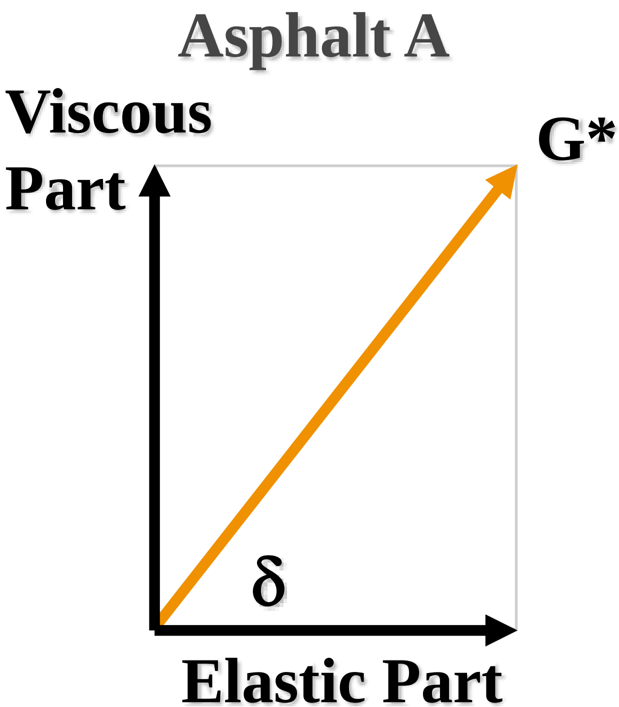


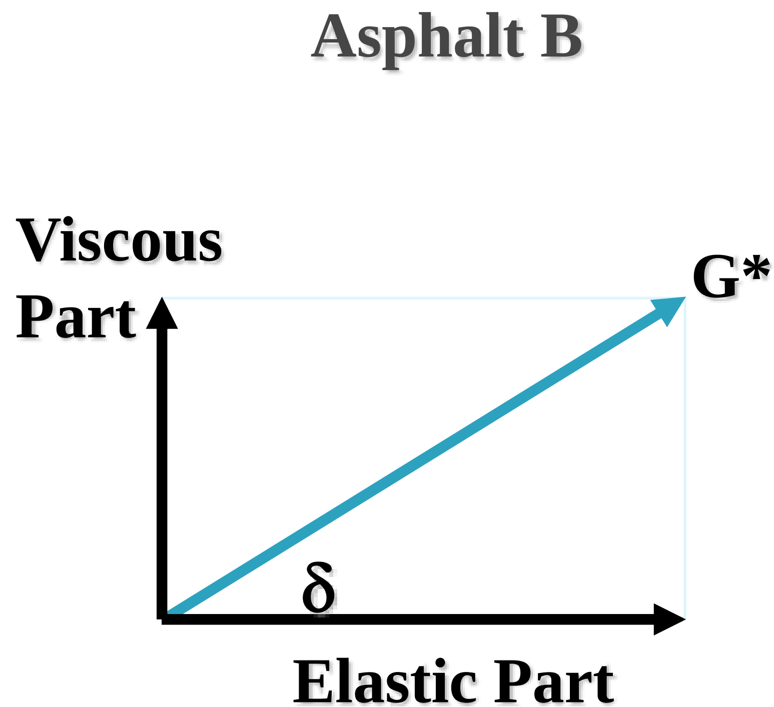
Use of dynamic shear rheometer

- 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*, δ

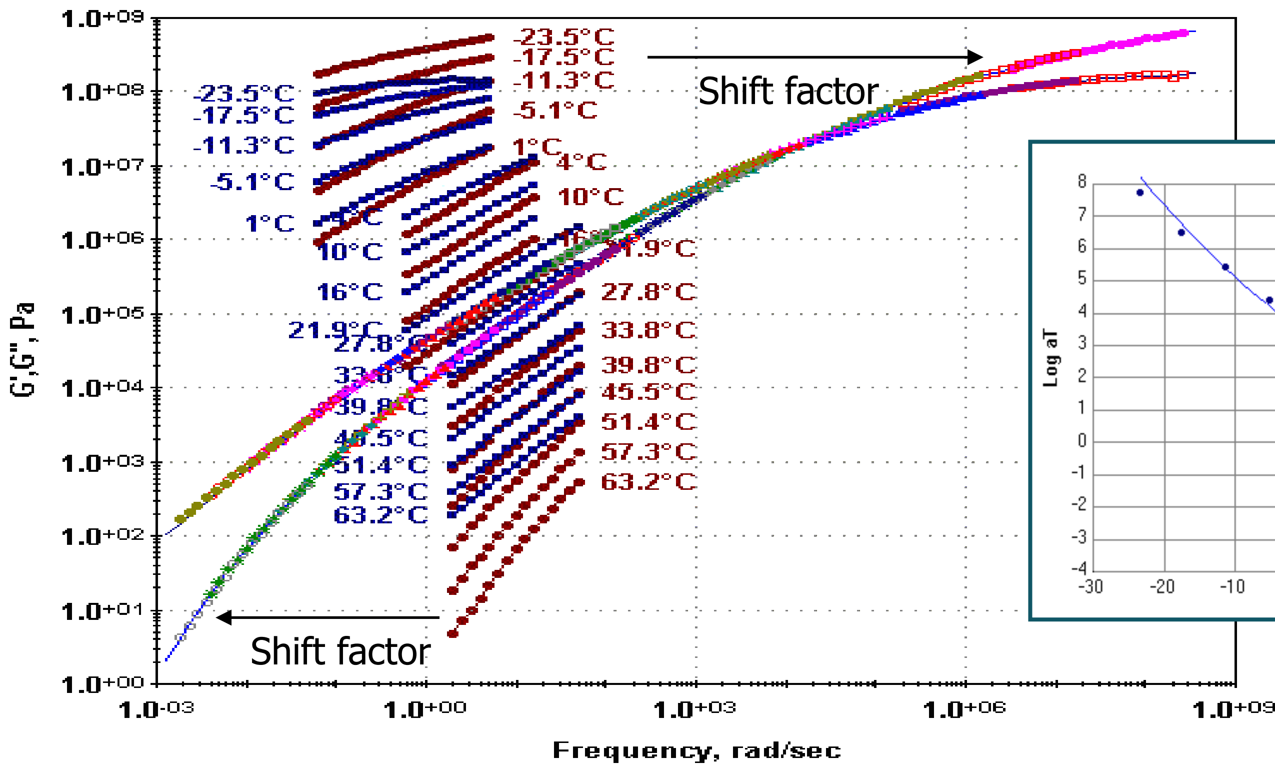


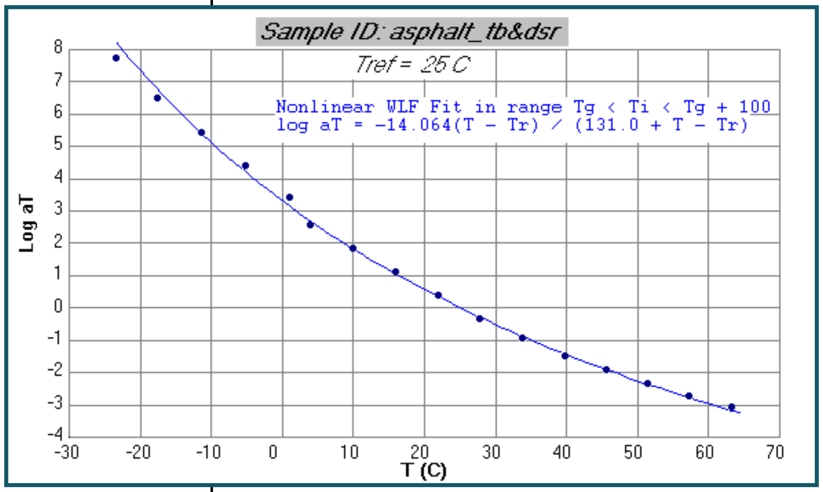


$$\sin \delta = \frac{\text{Viscous Part } (G'')}{G^*} \qquad \cos \delta = \frac{\text{Elastic Part } (G')}{G^*}$$

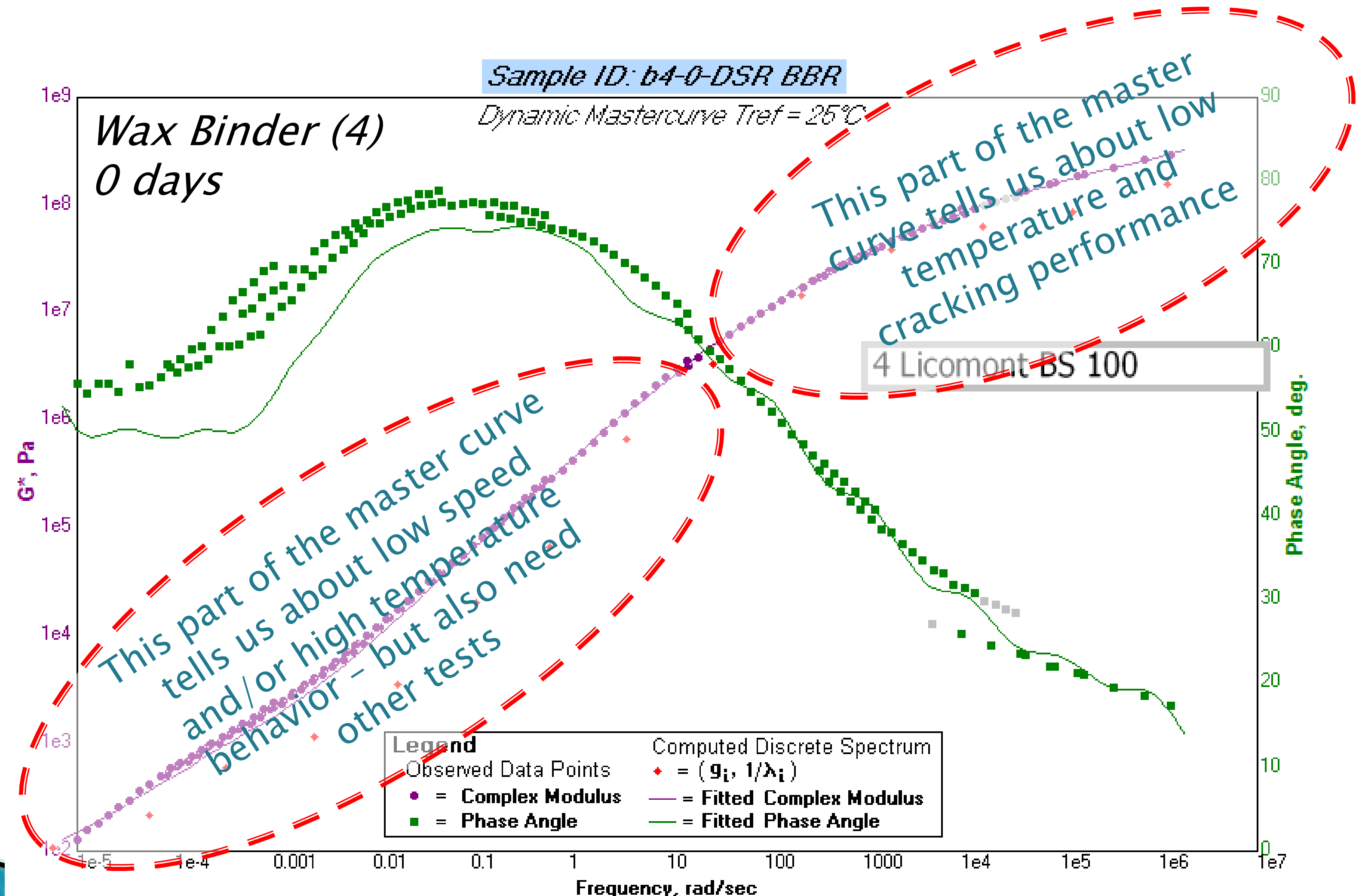
Data from DSR

- Shift factors used to slide data along horizontal axis to make smooth curve.

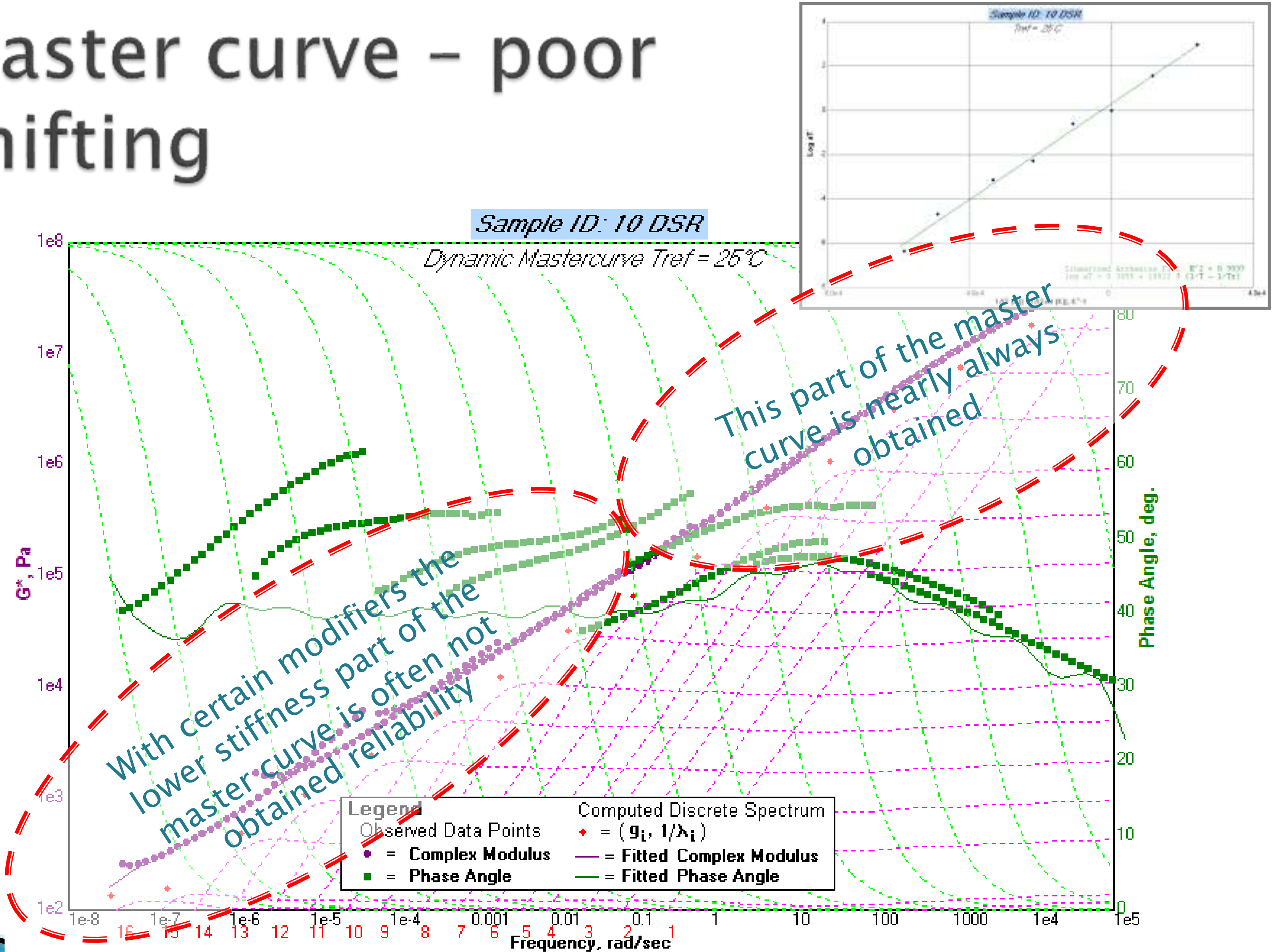




Master curve from rheology testing

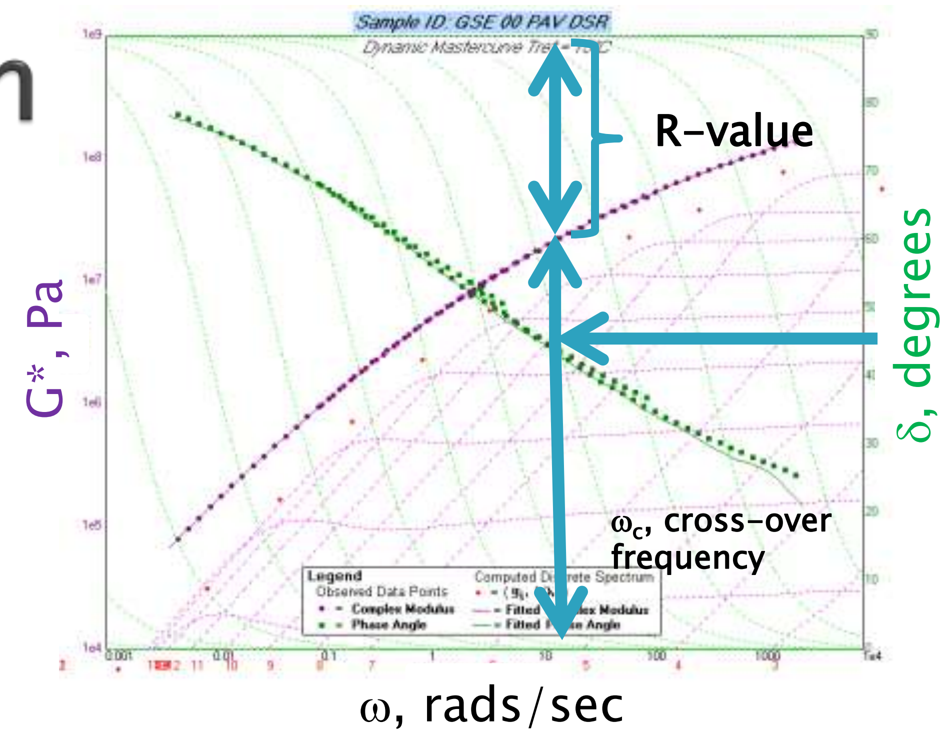


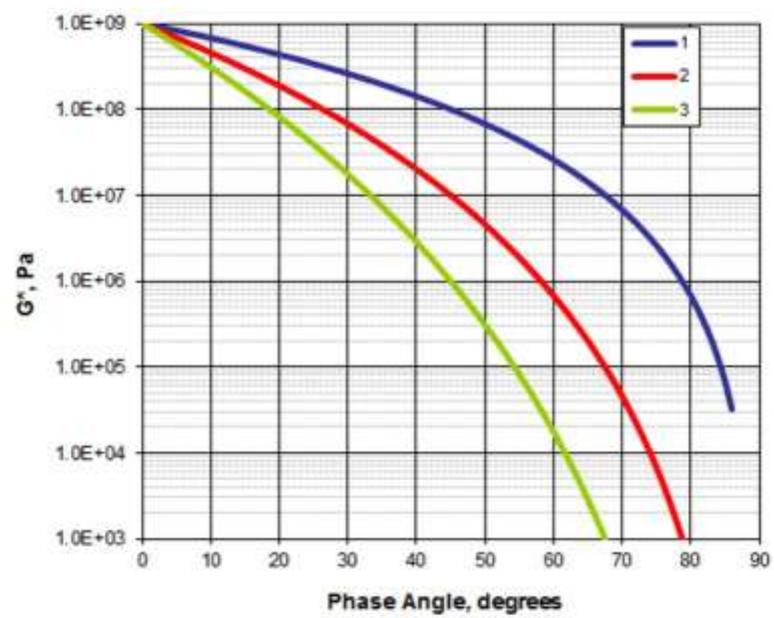
Master curve – poor shifting



Characterization

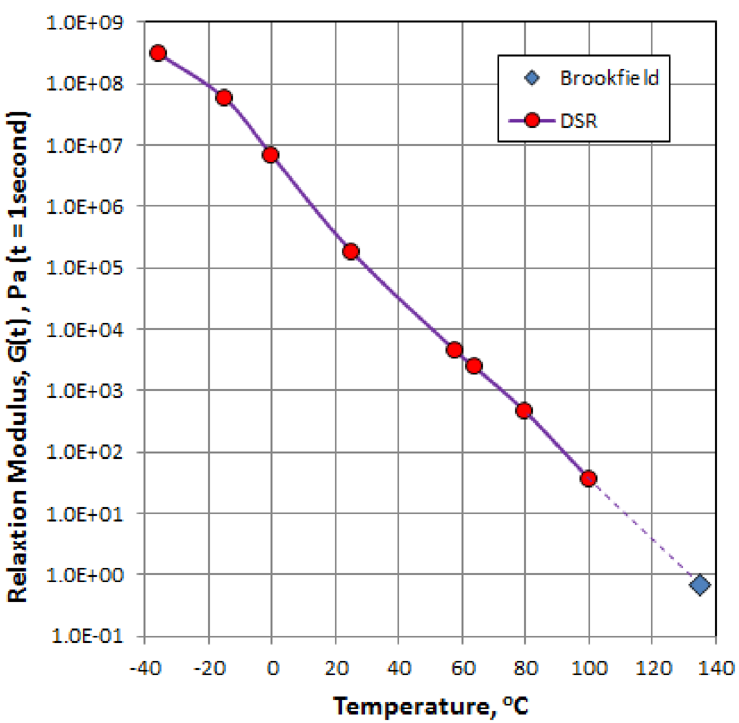
- Linear and non-linear effects
  - Linear – parameters from MC
    - ω_c, R, C1, C2, T_d, etc.
    - From parameters can calculated various other parameters, $G^*.\sin\delta$, S(t), m(t), ΔT_c Glover-Rowe, etc. + anything new that is developed
- Non-linear – torture tests such as MSCR

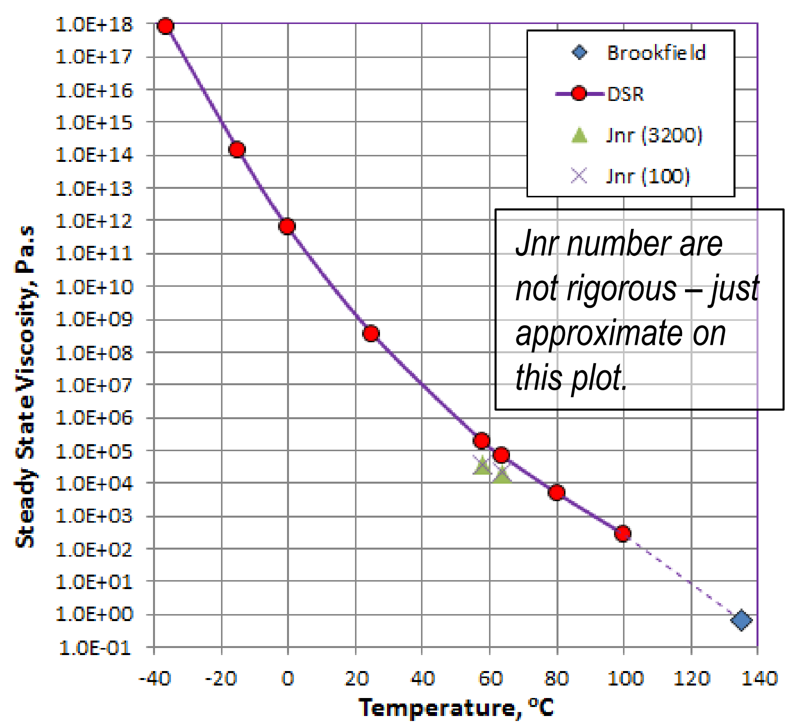




With today's equipment!

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





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

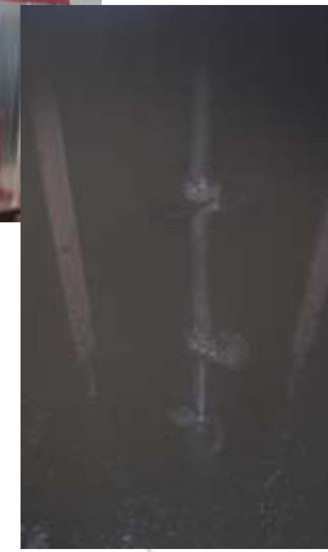
- Are these specifications adequate for understanding our modified asphalt and impact on performance?

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)

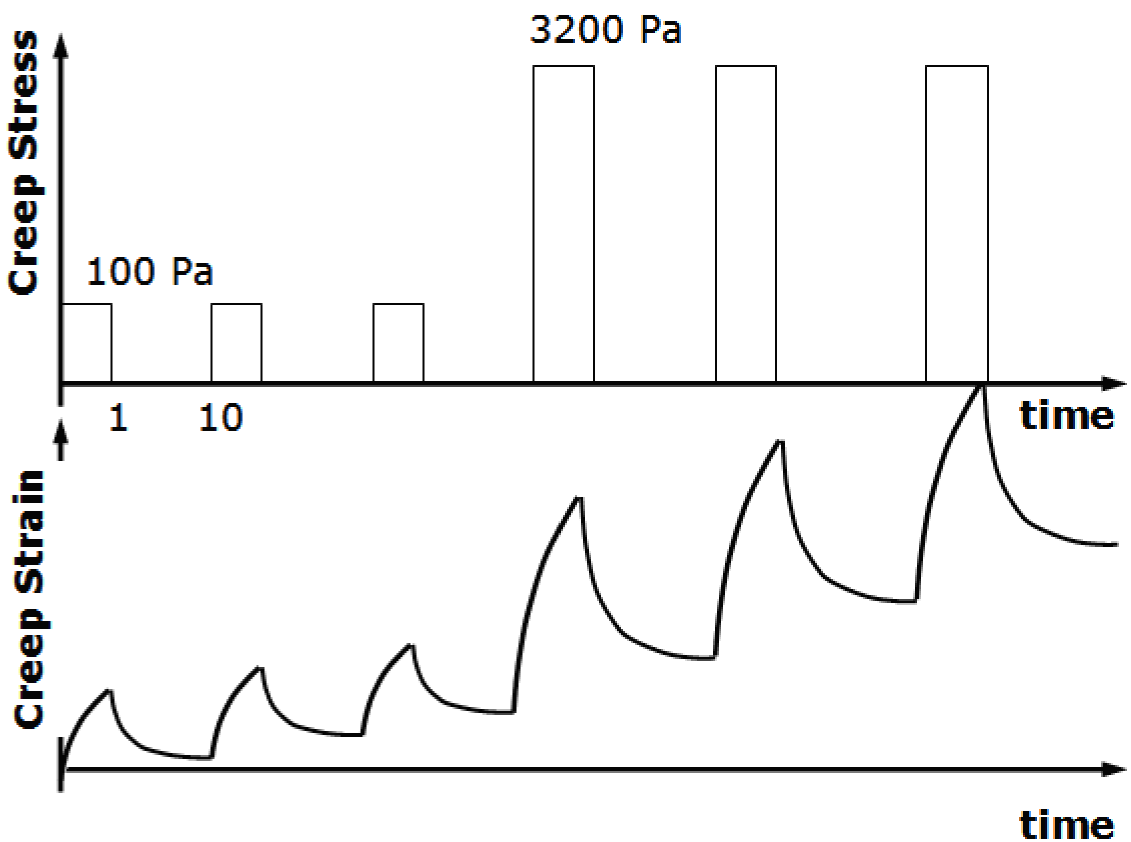
Improvements we should use!

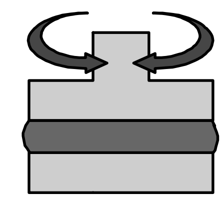
- High temperature performance
  - MSCR

  - 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?

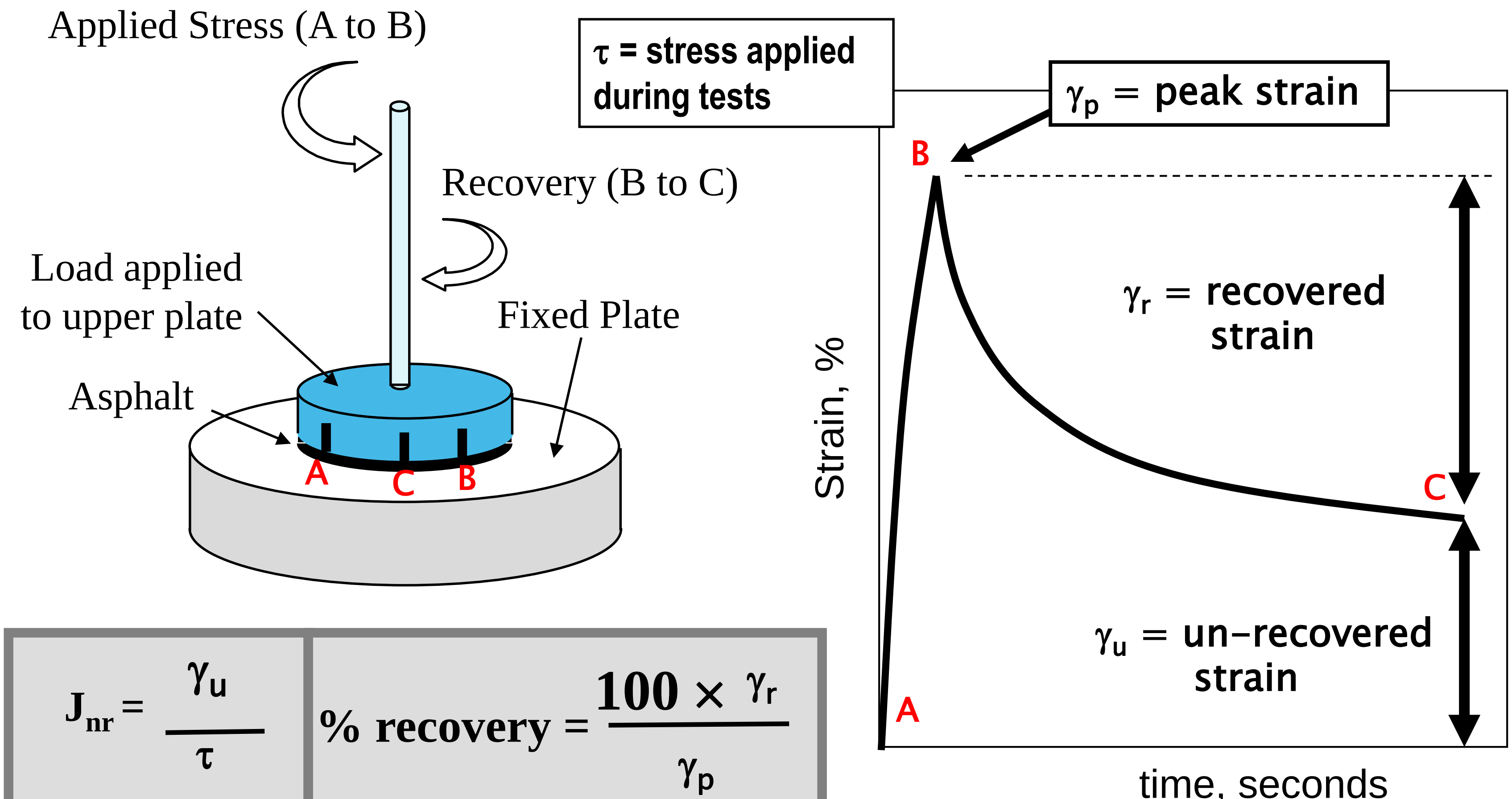
Multi Step Creep and Recovery





Test using the DSR applying a 1 sec creep stress followed by 9 sec recovery.

MSCR test performed in DSR



$J_{nr} = \dfrac{\gamma_u}{\tau}$	$\%\ \text{recovery} = \dfrac{100 \times \gamma_r}{\gamma_p}$

Higher Strains in MSCR!!

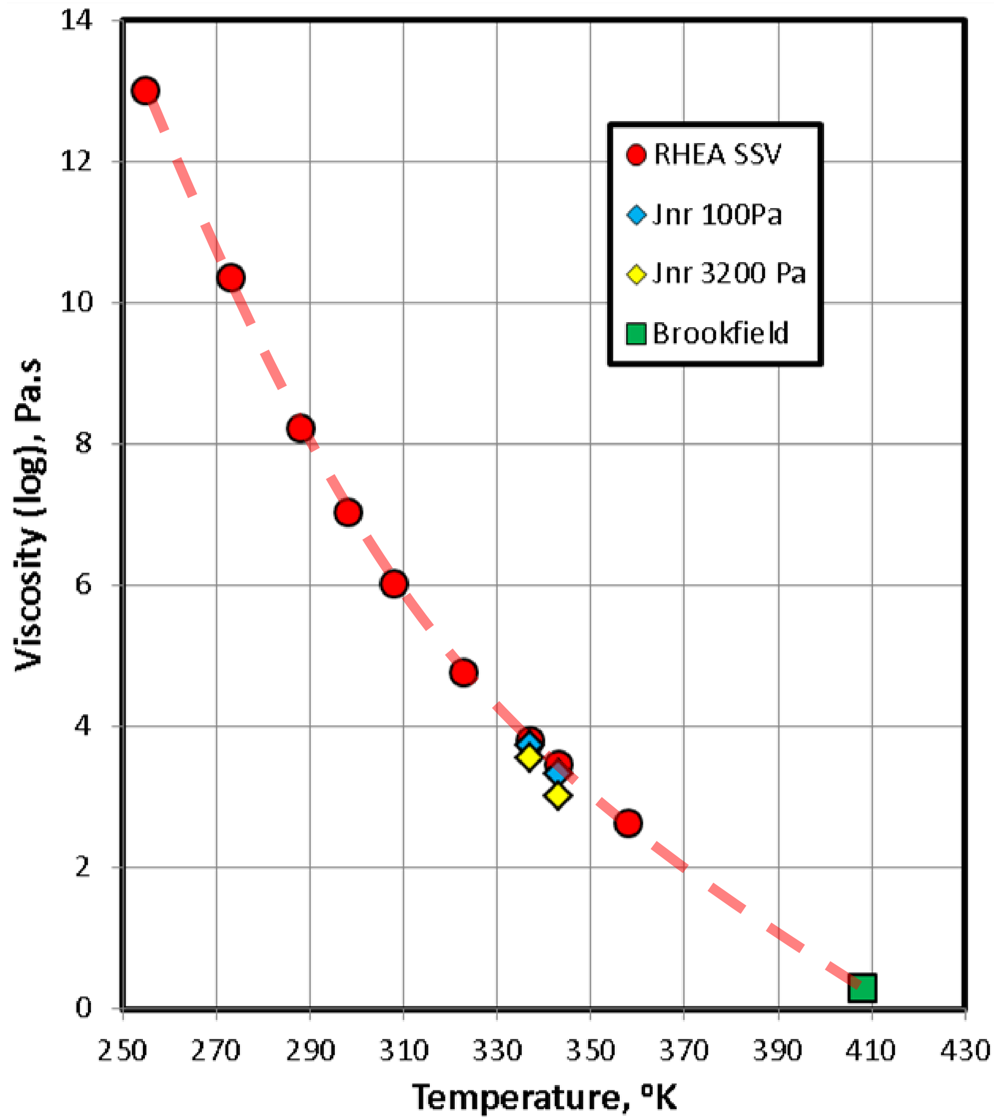
Viscosity and MSCR

- 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)

$$\eta = \left(\frac{1}{J_{nr}}\right)$$

MSCR and Viscosity

- Example from recent testing at AI, PG76-22
- Viscosity from three types of measurements
- Example
  - Jnr = 0.9741 (1/kPa)
  - 1000/0.9741 =1026.6 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 →

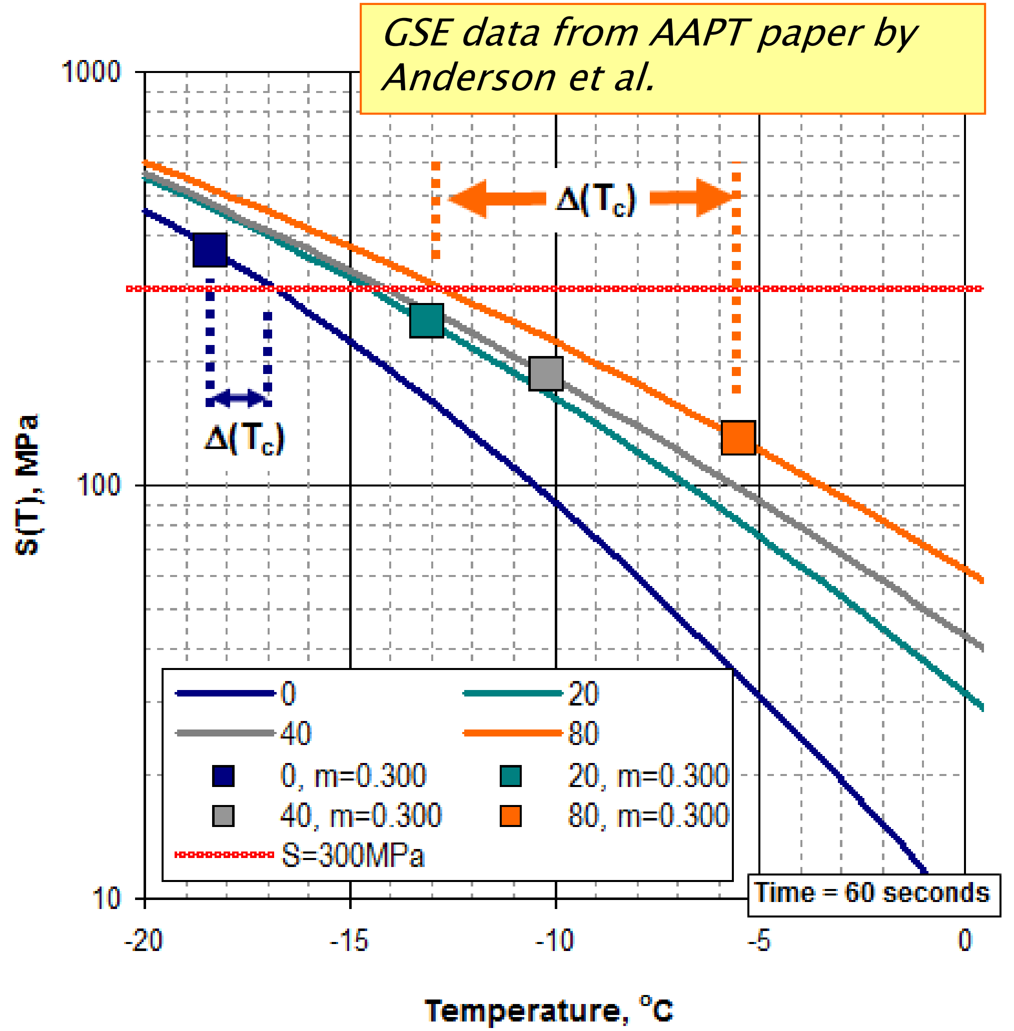
Implement MSCR!

What other improvements should we make today?

- Very strong evidence suggests that we should specify a limit for ΔT_c for surface course asphalt mixes
  - What is ΔT_c?
  - Why is this a good idea?

What is ΔT_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



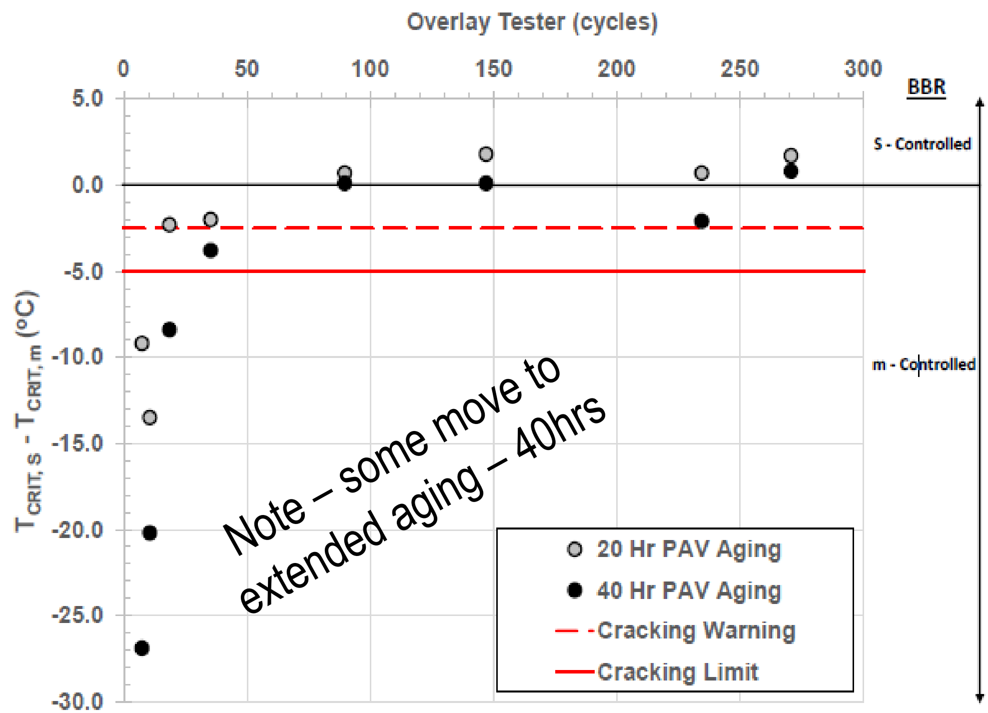
ASTM D7643

- ΔT_C— determine ΔT_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_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 ΔT_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.



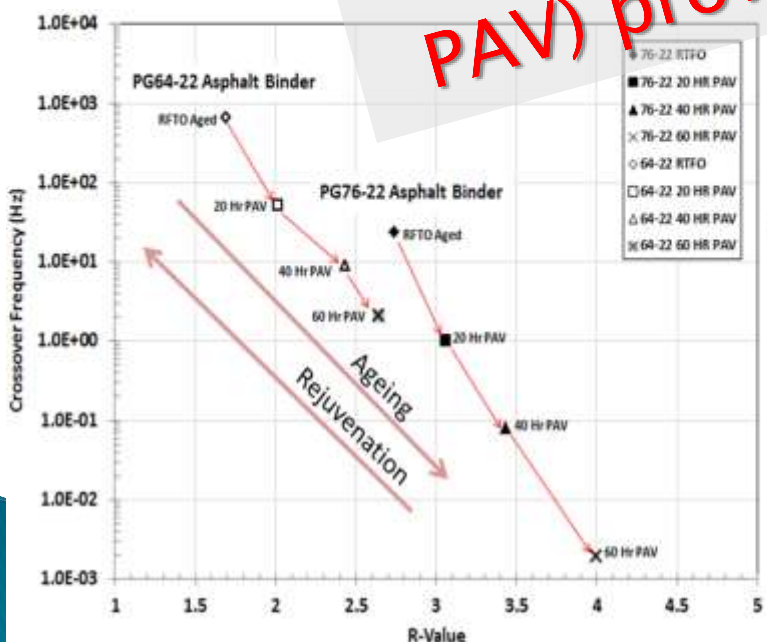
What work do we need to do?

- 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

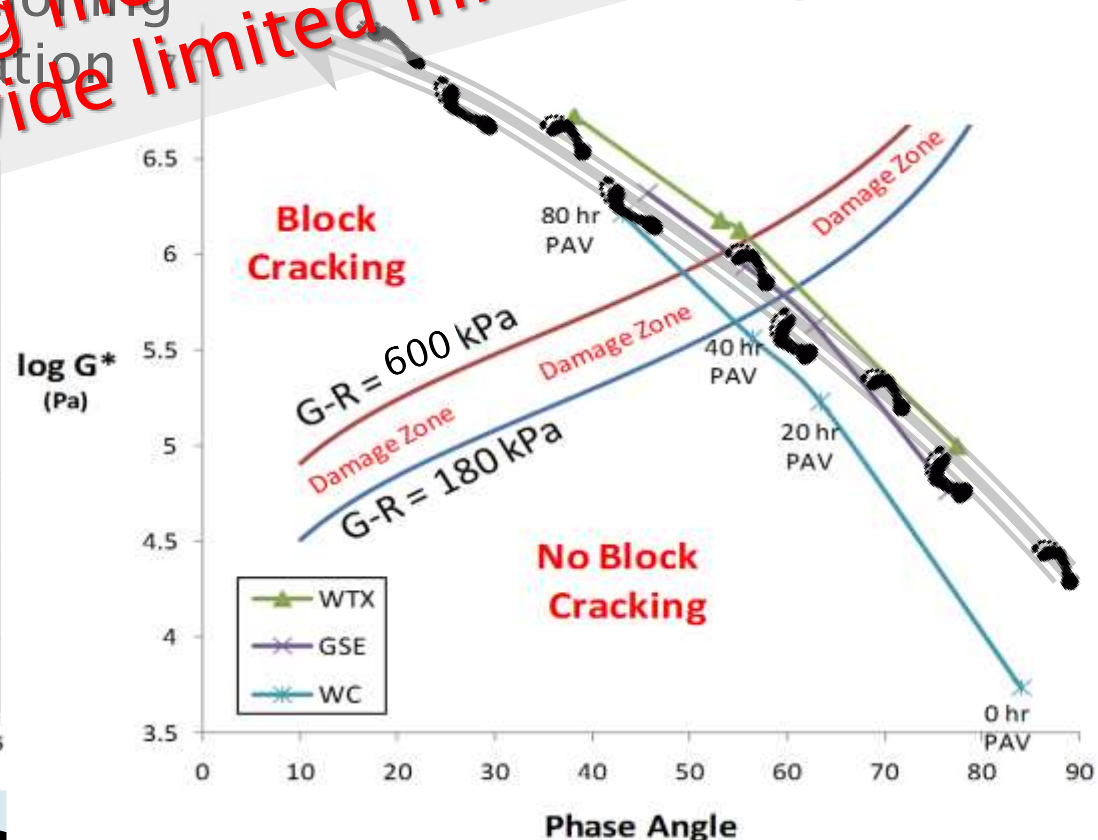
Aging

- 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!



Black Space Plot

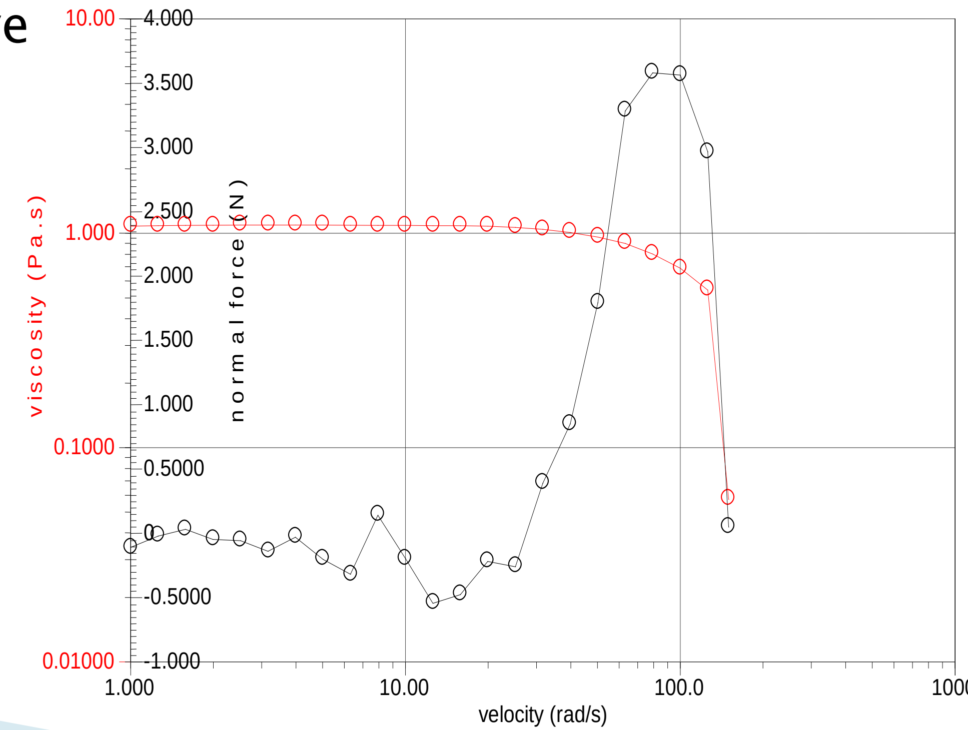


Linkage of cause and effects – aging and cracking

Which are best parameters – ΔTc, G-R, G*.sinδ, LAST, etc.?

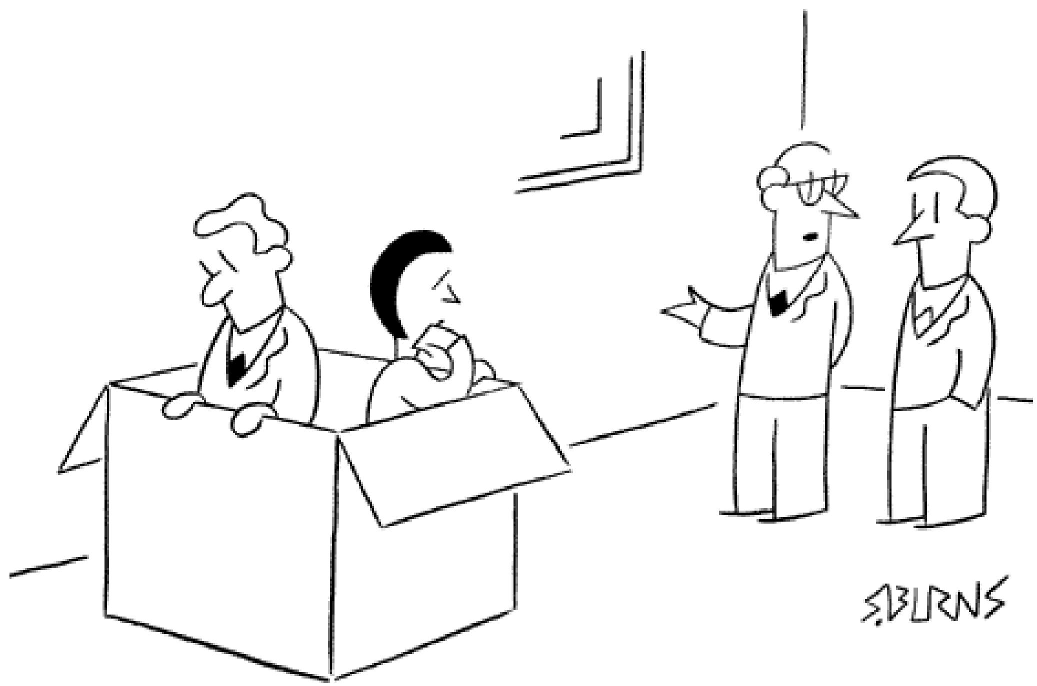
Understanding mixing and compaction

- 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.



Ensure full understanding

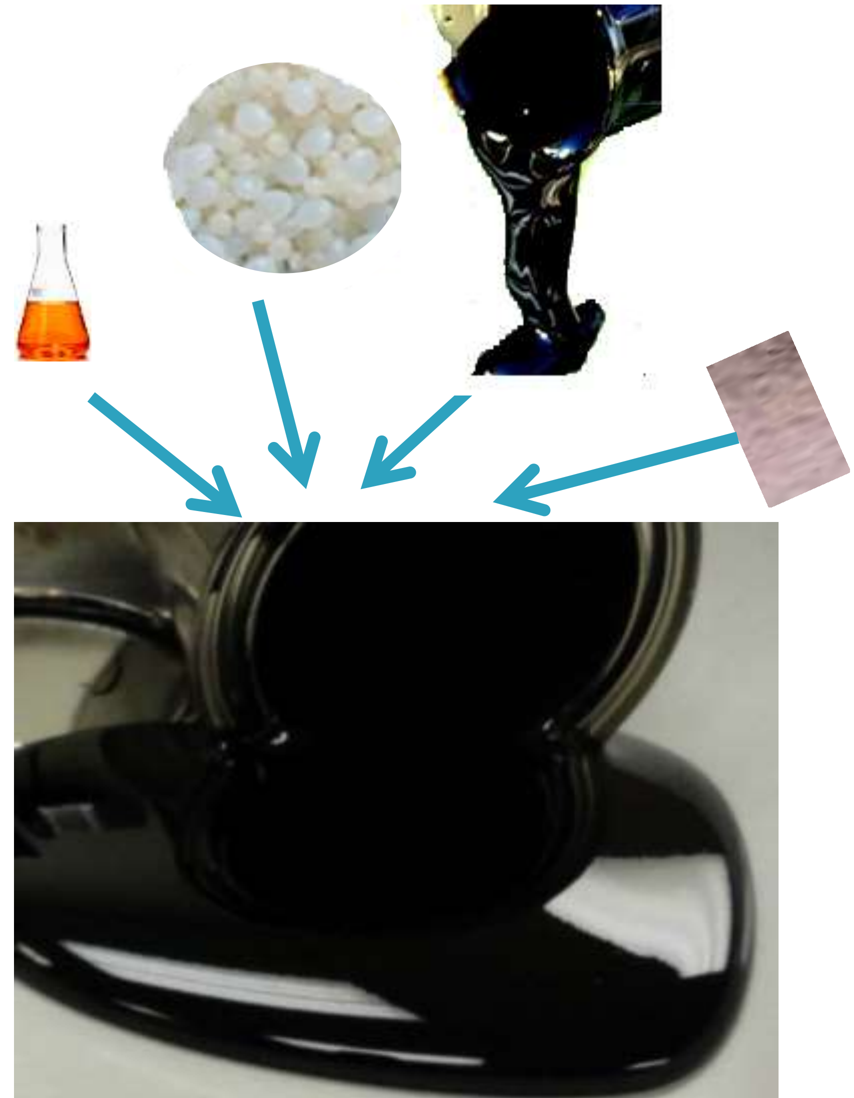
- What is coming next in our understanding of modification!
  - Be aware and consider all options that relate to performance!



"...and this is where we train our employees to think out of the box."

Modification concept

- Base binder
  - Make sure soft enough to resist cracking
  - May need to soften with oils
    - For this check ΔT_c
- Then modify high end with polymer to stiffen at high temperatures
  - Use cross linking
  - PPA in limited amount



Manufacture

- 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!*

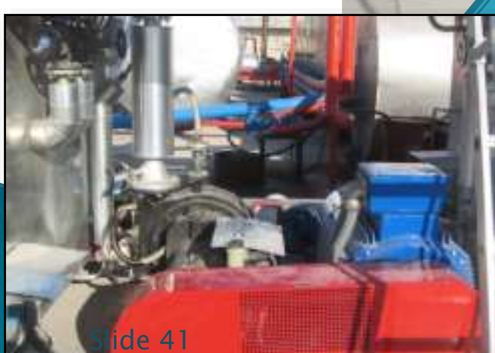
HMA plant – PmB asphalt modification

- 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



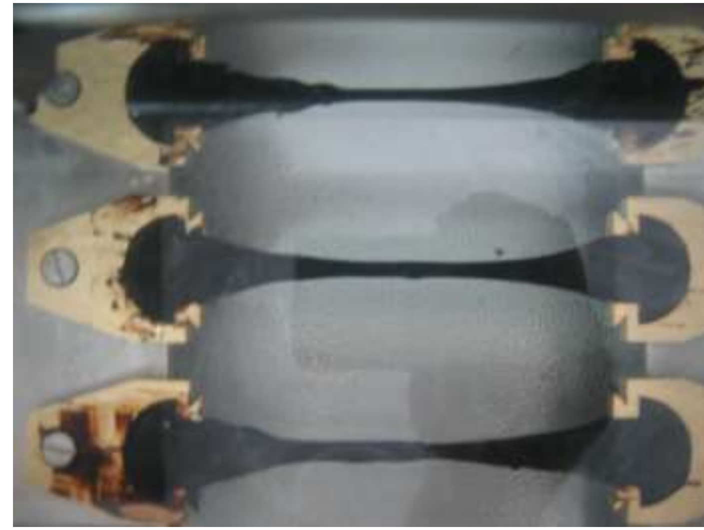
On site QC

- 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.



Ductility test of
lumpy Pmb!

Get the lab level!

Better performing roads

- With care and good setup we achieve the end result!

Binder is only part of process!

- 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

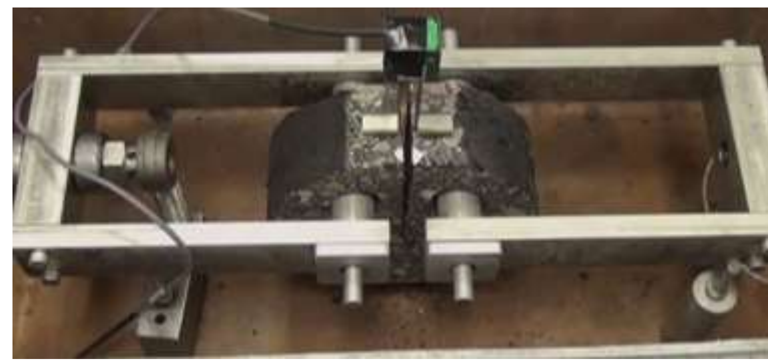
- SATS

- Bending beam fatigue test

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

- Fracture tests

Texas Overlay Tester



Direct compact tension test

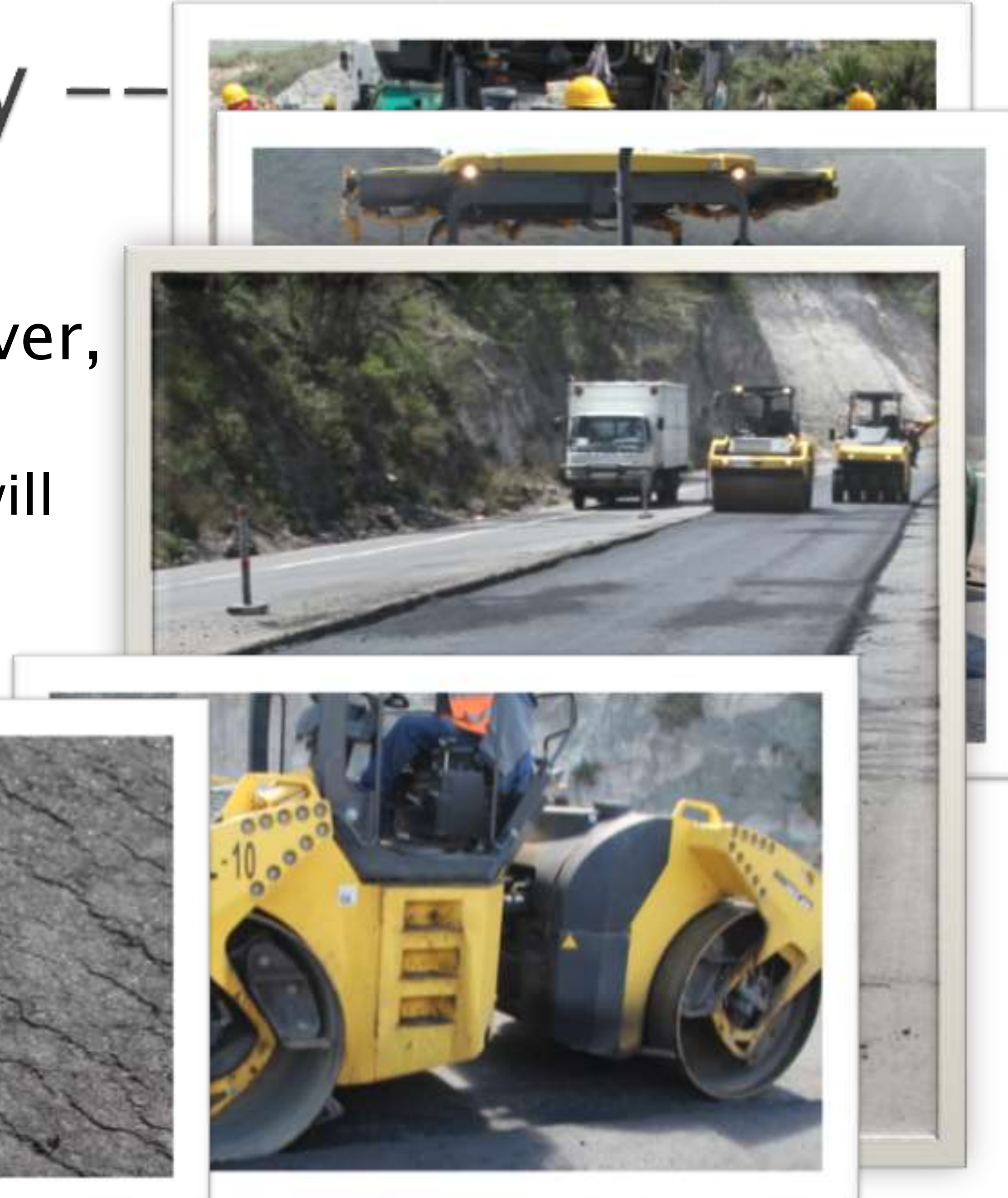
Semi-circular bend test

… 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 …
JAC
Questions?
Comments!