New Method to Obtain Strength Properties of Asphalt Binder at Low Temperature using the BBR

Asphalt Binder ETG Meeting
Ames, IA
May 4, 2017

Mihai Marasteanu
University of Minnesota

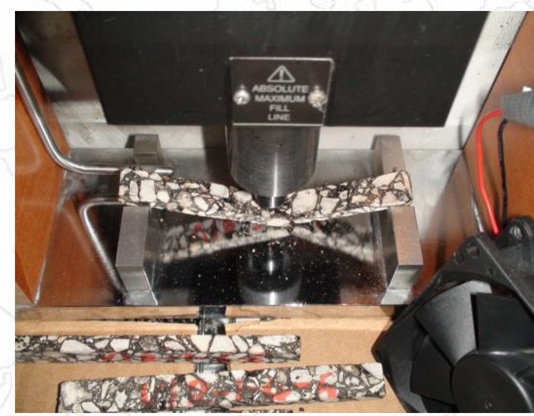
NCHRP Idea 151 (2010-2012)

- Testing asphalt binder and miniature asphalt mixture specimens at low temperatures to obtain bending strength
  - Material selection
  - Pavement design – MEPDG
  - Replace IDT and DTT?

Upgraded Testing Device: BBR Pro

- Modified BBR frame, with proportional valve that offers
  - ✓ Complex control of the pressure in the air bearing system (including cycles of loading/unloading)
  - ✓ Capable of applying loads at different loading rates
  - ✓ Bigger load cell for asphalt mixture three point bending strength.

Asphalt Binder Strength Test



Asphalt Mixture Strength Test

DTT vs. BBR Strength

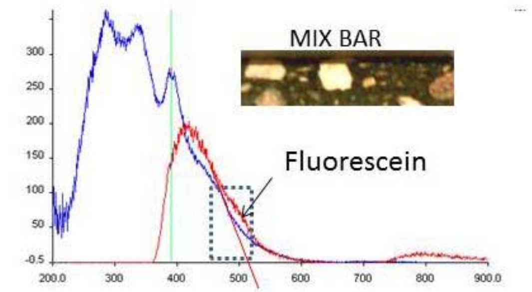
- Previous investigation concluded that
  - Only potassium acetate and air are appropriate cooling media for failure tests
  - DTT and BBR strength methods provide similar information about the failure properties of asphalt binders at low temperature
    - ✓ Different volumes of material tested in the two different methods need to be accounted for

Diffusion of Cooling Medium in BBR Samples

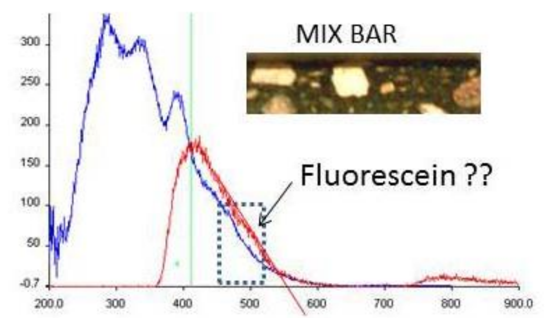
- Fluorescence spectra were thereafter obtained for THF solutions of BBR samples after washing off the cooling solvent containing FL on the surface
- Only the THF solution of the asphalt extracted from the BBR mix bar immersed in **EIM** has an emission shoulder at about λ_{em}=515 nm characteristic to FL solution
- The absence of a shoulder in the fluorescence spectrum for **PA** samples indicates **no FL diffusion**

- **The cooling agent affects strength values**

MIX [soaked at -12°C for 75 min in a solution of ***ethyl alcohol/IPA/Methyl alcohol(90/5/5)***]
THF solution of extracted asphalt(0.002 wt.%)
Excited at 284 emission at 417 nm.



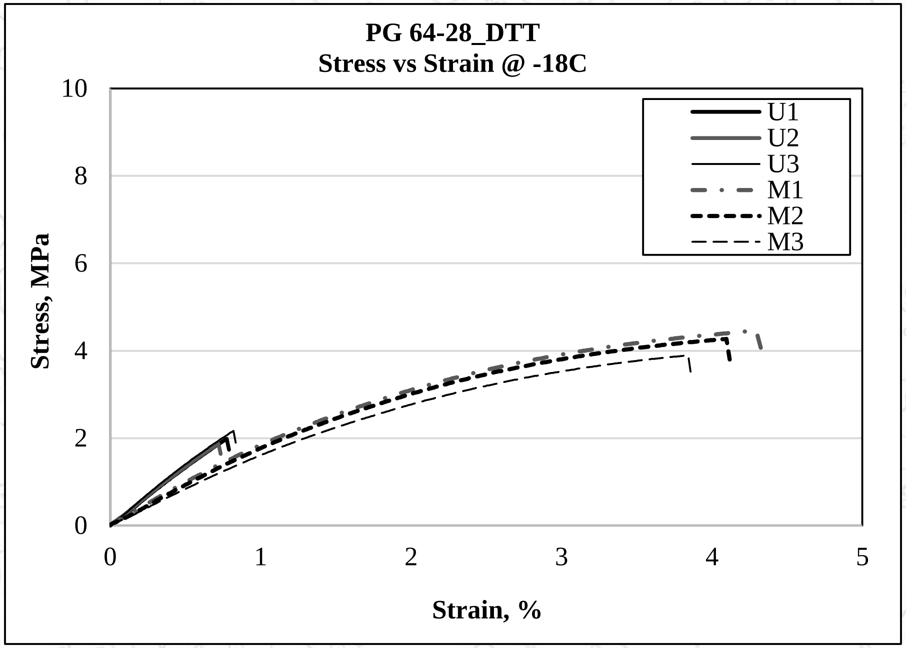
MIX (soaked at -12°C for 75 min in **42% Potassium acetate in water**). THF solution of extracted asphalt(0.002 wt.%)
Excited at 280 emission at 422 nm.

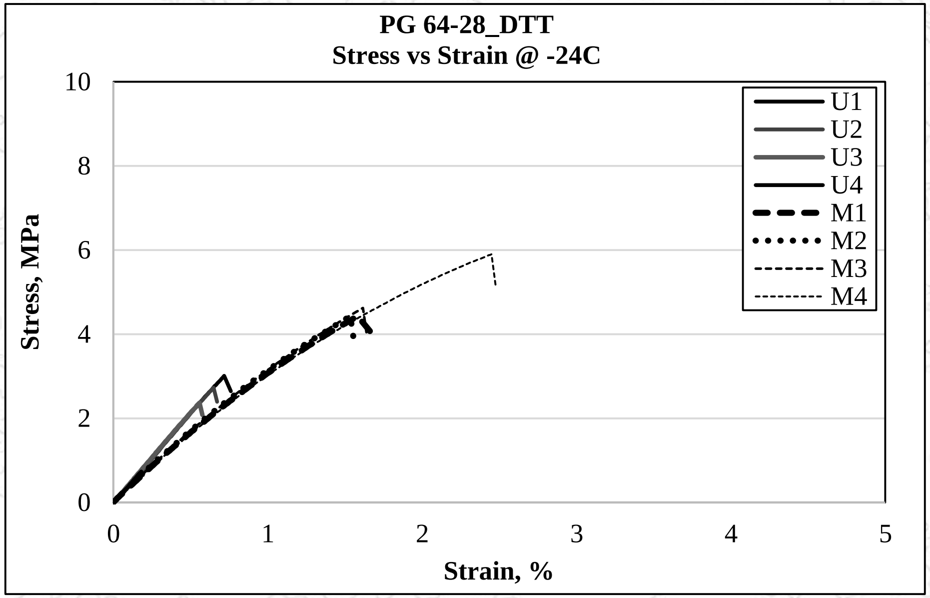


DTT vs. BBR Strength

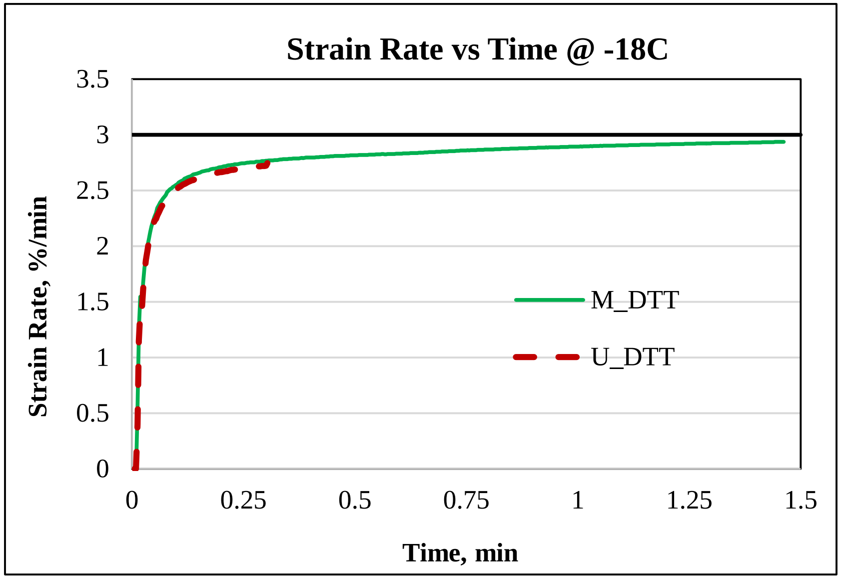
- To better understand the limitations and benefits of the two methods, linear viscoelasticity concepts are used to analyze the experimental data obtained on two binders:
  - Plain PG64-28 (U)
  - SBS-modified PG64-28 (M).
- The binders have similar creep properties, as indicated by the similar performance grade, however, the DTT responses are quite different

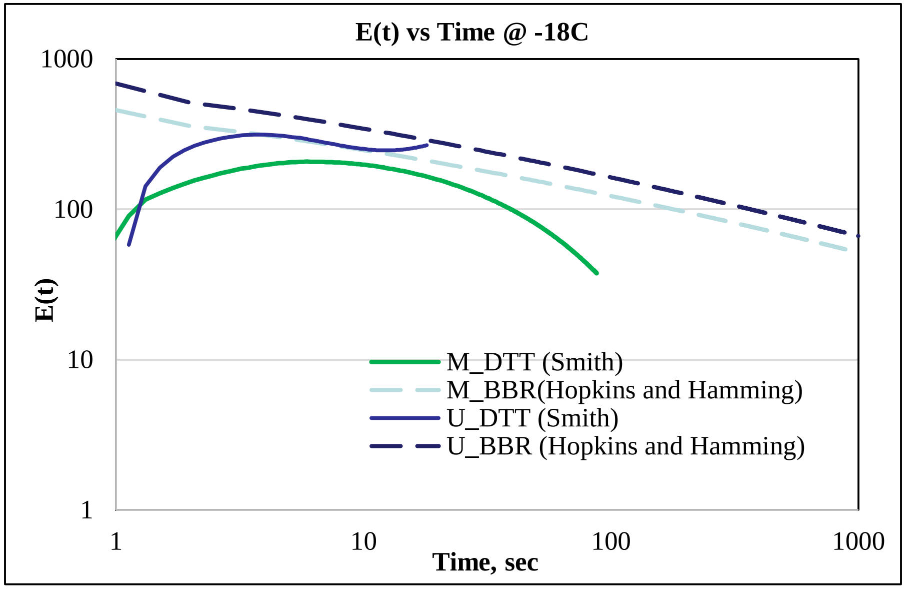
DTT Stress-Strain Curves

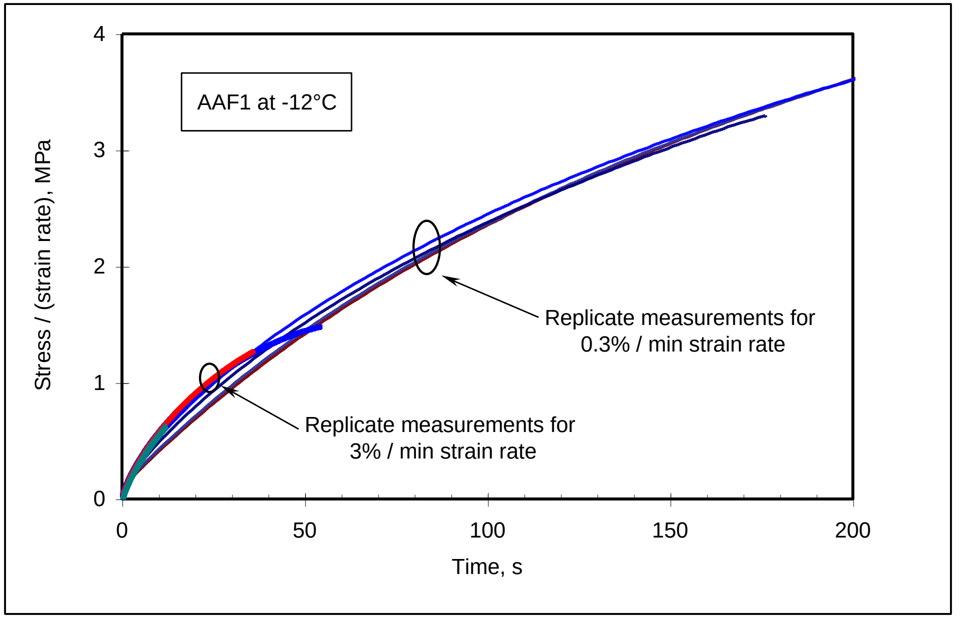




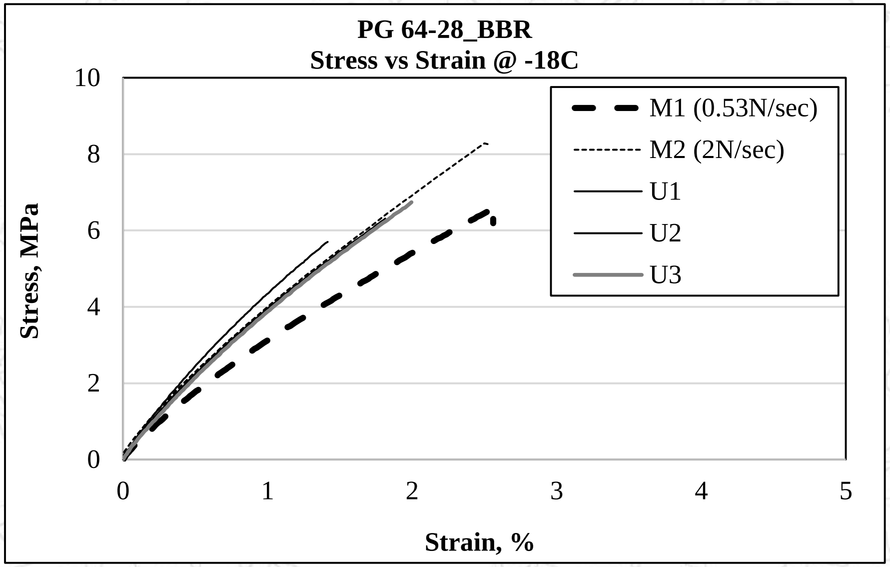
DTT Limitations

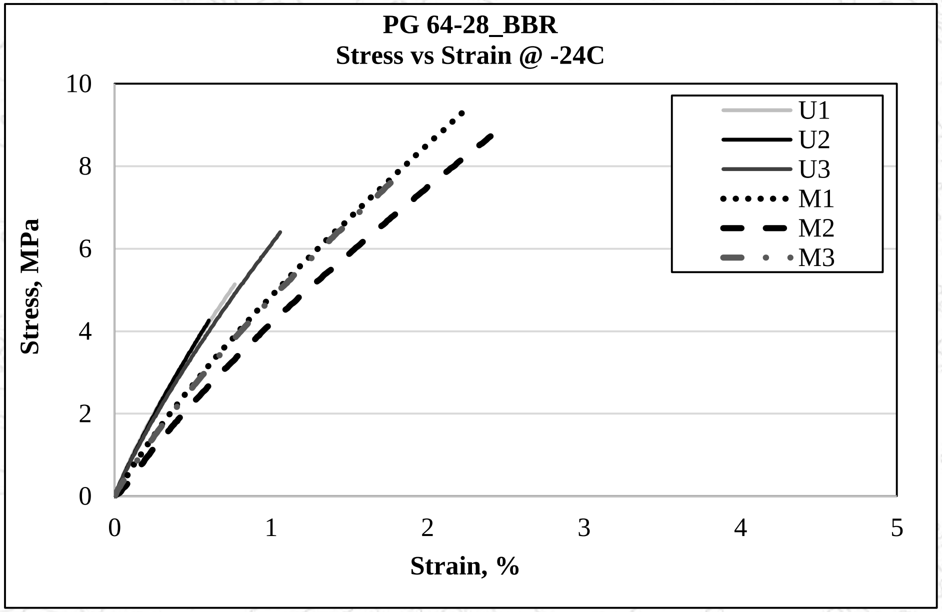






BBR Stress-Strain Curves





What Loading Rate for BBR Strength?

- The BBR strength results for all binders varied between 2 and 10MPa and never go above 12 Mpa
  - Can be set as upper limit to be reached within a reasonable period of time.
  - Similar to the approach used for DTT, one can set a loading rate such that 12MPa is reached in 60 seconds (0.53N/sec)
- In some cases, beams do not break, which means higher loading rate (or lower test temperature must be used).
  - To be able to calculate a loading rate that would result in less than the maximum deflection of 7mm (equivalent to a strain of 2.6%), prior information related to the strain evolution with time is needed.

What Loading Rate for BBR Strength?

- Use linear viscoelasticity: in a test in which the stress is increased linearly starting from zero, the resulting strain will reflect the superposition of a series of retarded compliances. If $\dot{\sigma} = \mathrm{d}\sigma/\mathrm{d}t$, then:

$$\gamma = \dot{\sigma} t J_g + \dot{\sigma} \int_0^t \int_{-\infty}^{\infty} L(1 - e^{-u/\tau}) d \ln \tau \, du + \frac{\dot{\sigma} t^2}{2\eta_o}$$

$$\gamma = \dot{\sigma} t J_g + \dot{\sigma} \int_{-\infty}^{\infty} L\left[t - \tau\left(1 - e^{-t/\tau}\right)\right] d \ln \tau + \frac{\dot{\sigma} t^2}{2\eta_o}$$

- When the stress-strain curve under this condition is differentiated, the result is the creep compliance:

$$\frac{d\gamma}{d\sigma} = (1/\dot{\sigma}) \frac{d\gamma}{dt} = J_g + \int_{-\infty}^{\infty} L\left(1 - e^{-t/\tau}\right) d \ln \tau + t/\eta_o = J(t)$$

What Loading Rate for BBR Strength?

- This also means that if creep compliance is known, the variation of strain with stress is known for a constant loading rate test. If the loading rate is known, then the entire stress-strain curve can be determined for a given stress rate. An example is shown next.

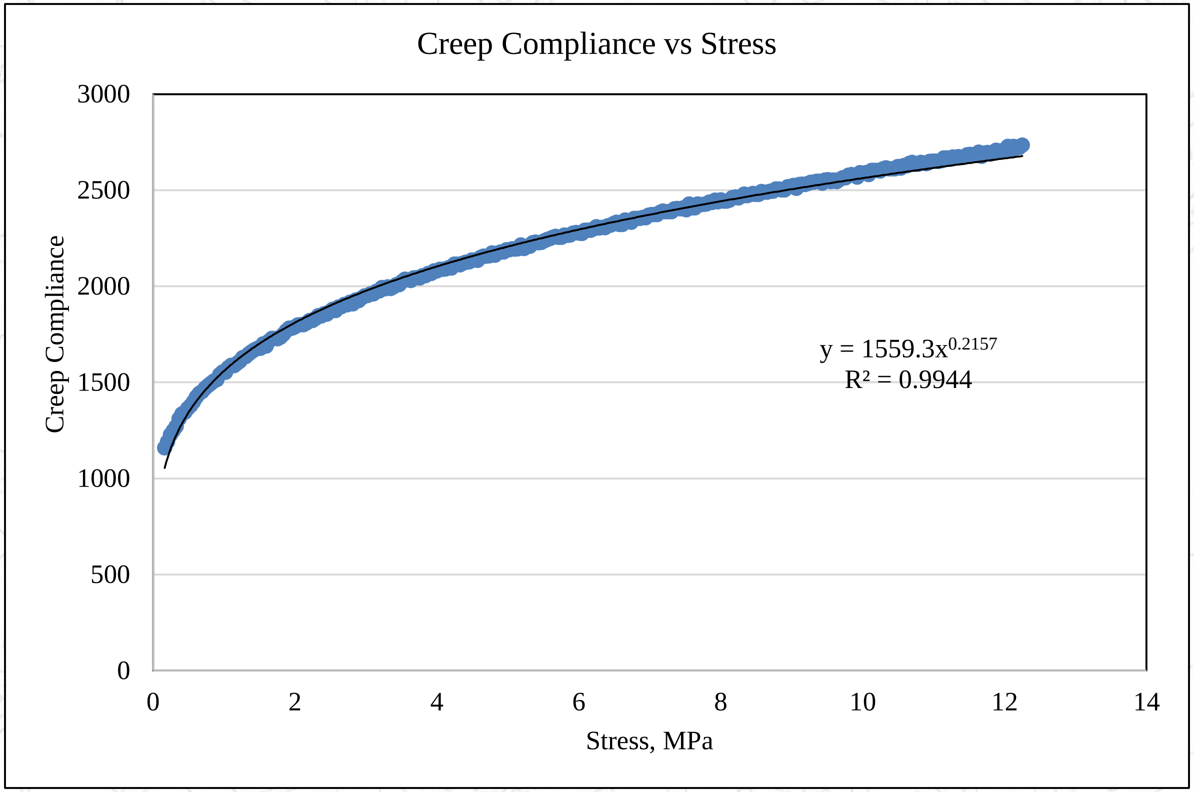
What Loading Rate for BBR Strength?

- First, a BBR creep test is performed and the creep compliance is calculated as a function of time.
- Assumption creep compliance D(t) follows a power law.
- Consider hypothetical BBR strength test performed using constant stress rate $\dot{\sigma}$. The stress at any time can be simply calculated as $\sigma(t) = \dot{\sigma} * t$
- Relate creep compliance from BBR creep test to stress from BBR strength test using a power law:

$$D(t) = a * \{\dot{\sigma} * t\}^b = a * \{\sigma(t)\}^b \qquad (1)$$

- Coefficients *a* and *b* can be simply calculated from fitting equation to creep compliance vs stress plot, for an assumed loading rate. The loading rate is required to match the times for the creep compliance (vertical axis) and the stress data (horizontal axis).

What Loading Rate for BBR Strength?



What Loading Rate for BBR Strength?

- First derivative of strain-stress curve is creep compliance, *D*(*t*), and, therefore:

$$D(t) = \mathrm{d}\varepsilon(t)/\mathrm{d}\sigma(t) = a * \{\sigma(t)\}^{b} \qquad (1a)$$

- The strain can then be obtained as:

$$\varepsilon(t) = \frac{a * \{\sigma(t)\}^{b+1}}{b+1} + c \qquad (2)$$

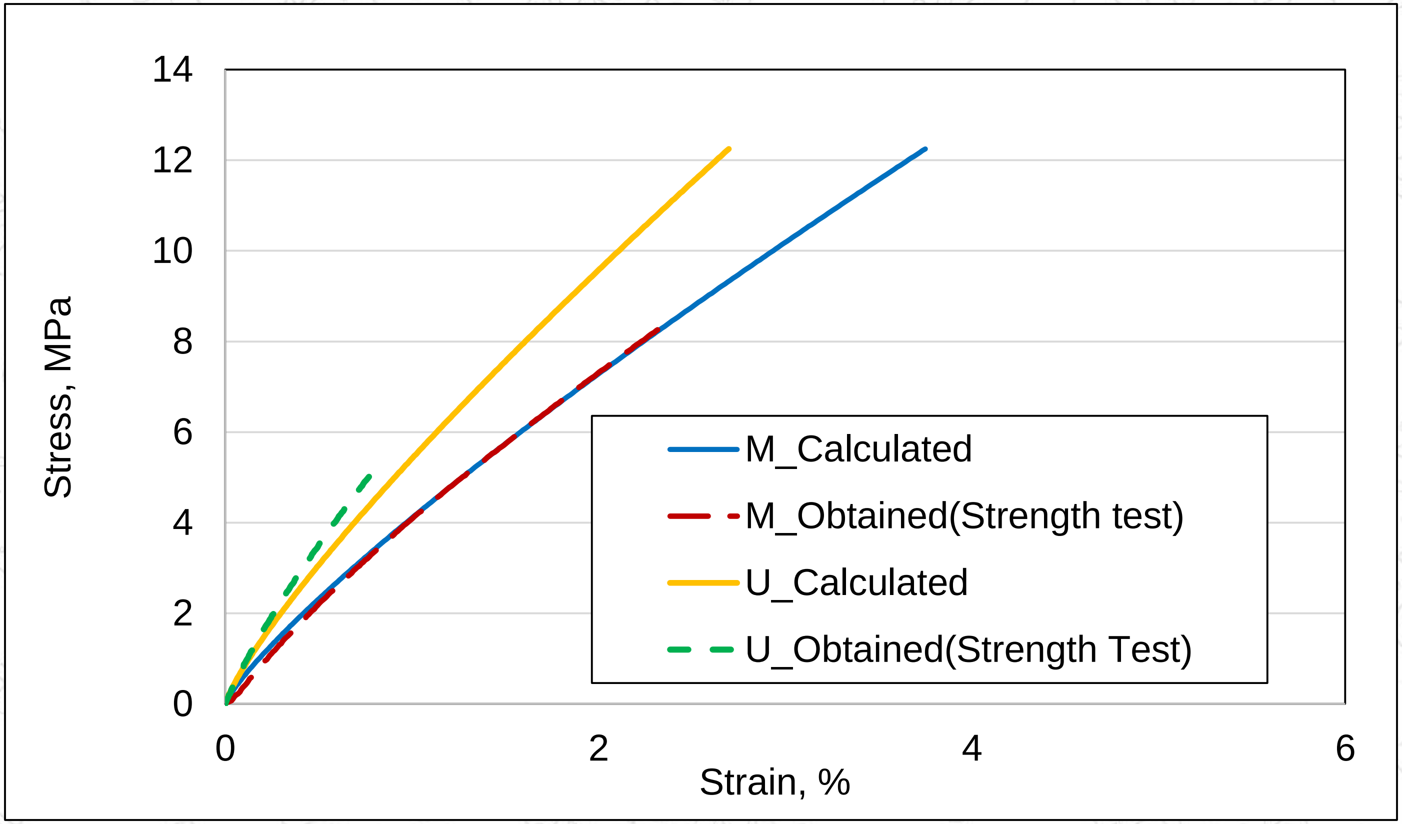
Constant *c* is zero, since the plot starts in the origin.

- For the example shown in previous figure, using equation (2) and the values for *a* and *b*, the strain is calculated as

$$\varepsilon(t) = \frac{\left[1559.3 * \{\sigma(t)\}^{0.2157+1}\right]}{0.2157+1}$$

- Examples of predicted stress-strain curves for the two 64-28 binders at -24°C and a loading rate of 0.53N/s are shown in the next figure

Predicted vs Experimental



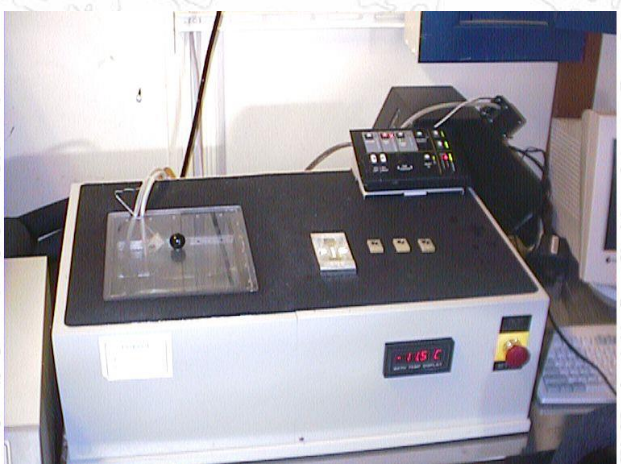
Procedure for BBR Strength

- Perform BBR creep tests at two temperatures, according to the current specifications, to determine the grade of the binder.
- Use experimental creep compliance to predict stress-strain curves for a stress rate of 0.53N/s, which will limit the duration of the test to 1 minute or less.
- Use stress-strain curves to determine if the 2.6% strain limit is reached within 1 minute. If the limit is reached, increase the stress rate accordingly. If the strain is less than 2.6%, perform strength test using the 0.53N/s rate.
- Perform BBR strength tests and obtain stress-strain curves and the stress and strain at failure.

Work in Progress

- This approach can only be used to select the best binder out of a group of binders that have similar PG lower limit based on creep data.
- Research is in progress to determine a limiting parameters and criteria that would allow selecting an asphalt binder based on a limiting criterion, similar to the current PG specification.
- Test new fluid: low-temperature polysiloxane (silicone oil) bath fluid with a viscosity of 2-5cSt at ambient temperature (used in low-temp kinematic viscometer baths down to -40 °C).

Thank You !




CANNON
THERMOELECTRIC BENDING - BEAM
RHEOMETER
LOCAL - REMOTE
CONTROL
ZERO - LOAD
CANNON
DC POWER HEAT COOL