New methods for assessing rheology data such as ΔT_c and G-R Parameter and their relationship to performance of REOB in asphalt binders and other materials

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Asphalt Mix and Binder ETG Meetings

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Objectives

- Update on document development
- Information on ΔT_c from CA model
- Thoughts on “point” vs. “shape” parameters

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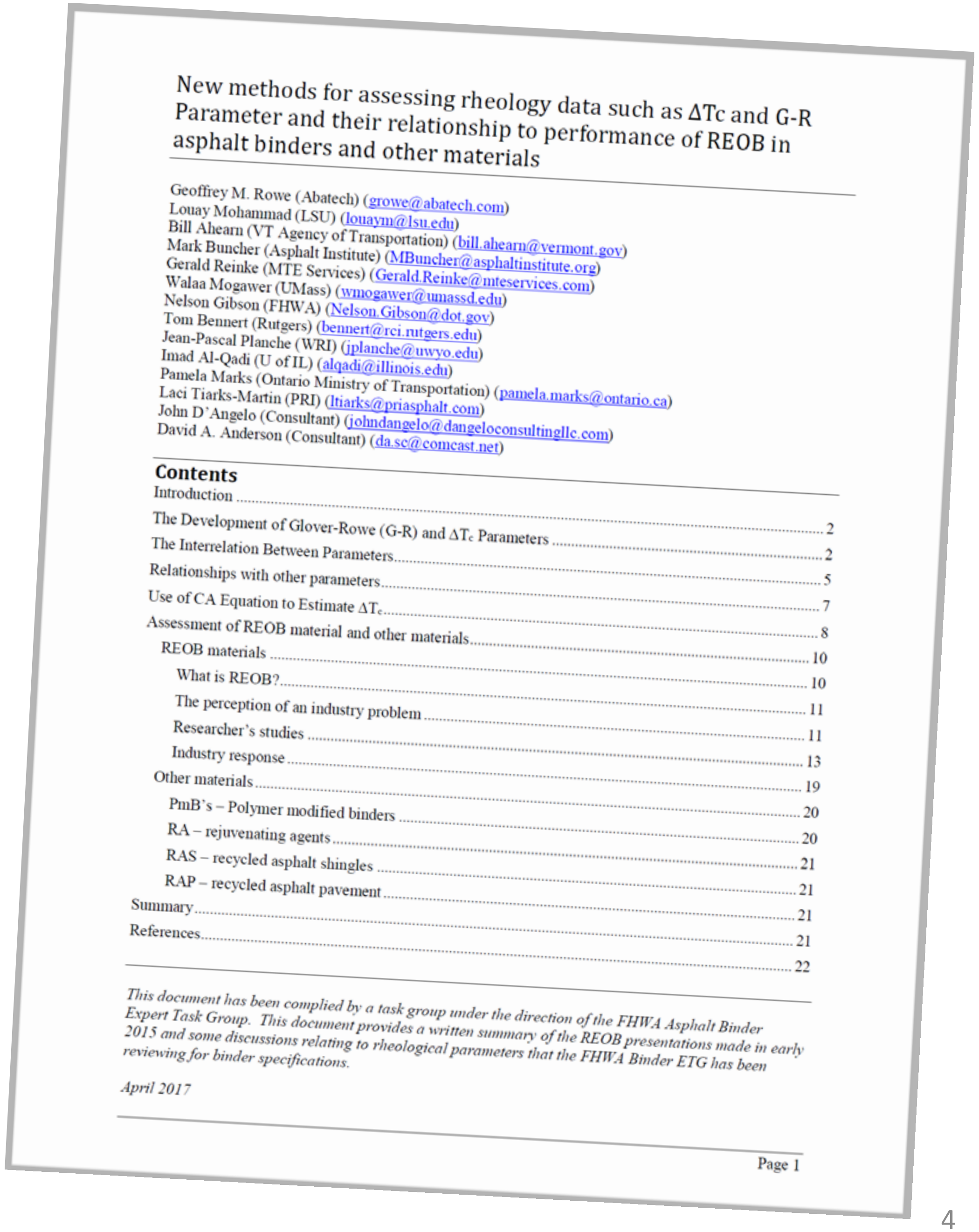
Document status

- Redrafted with input from task-group members
- Forwarded for circulation to wider ETG for final review
- Some additional background provided
- Details on ΔT_c calculation from CA model added with a worked example using data from Anderson et al. (2011) paper



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Contents

This document has been complied by a task group under the direction of the FHWA Asphalt Binder Expert Task Group. This document provides a written summary of the REOB presentations made in early 2015 and some discussions relating to rheological parameters that the FHWA Binder ETG has been reviewing for binder specifications.

April 2017

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Interconversions

- CA model defines rheology in region of 10^5 to 10^9 Pascals to a good accuracy
- From this possible to calculate G-R and ΔT_c
  - Calculation of ΔT_c more complex
  - Can calculate from BBR or DSR data
  - Example using BBR data

- Method on next few slides

CA equation

- Form of CA within RHEA

  S = Stiffness modulus

  S_g = Glassy stiffness modulus

  t = Time of interest

  λ, β = Fitting parameters in the CA equation

  R = log2 $/\beta$

$$S(t) = S_g \left[1 + \left(\frac{t}{\lambda}\right)^{\beta}\right]^{-1/\beta}$$

- Time at a given stiffness is given by

$$t(S) = \lambda \left[\left(\frac{S}{S_g}\right)^{-\beta} - 1\right]^{1/\beta}$$

Determination of ΔT_c from the CA equation

- Further rearrangement provides for the determination:
  - The slope, m(t), were the time is set
  - The time, t(m) at when the slope is set

$$m(t) = \frac{1}{\left[1+\left(\frac{t}{\lambda}\right)^{-\beta}\right]}$$

$$t(m) = \lambda\left[\left(\frac{1}{m}\right) - 1\right]^{-1/\beta}$$

- In this formulation we have assumed an Arrhenius function – ok for BBR data in stiffer region of master curve (could consider linearized form or Kealble – in further development)

  a_T = Time – temperature shift function,
  c = Constant determined via regression analysis
  T = Temperature, °K
  T_r = reference temperature, °K

$$ln\, a_T = c\left(\frac{1}{T} - \frac{1}{T_r}\right)$$

The CA and Arrhenius equation result

- Combining the two equations we can develop two further equations
  - Stiffness at a temperature, T, which corresponds to a loading time of 60 seconds
  - Temperature (T) that corresponds to a stiffness at defined at 60 seconds

$$S(T,60) = S_g\left[1+\left(\frac{60}{\lambda\, exp\left[c\left(\frac{1}{T}-\frac{1}{T_r}\right)\right]}\right)^{\beta}\right]^{-1/\beta}$$

$$T(S,60) = \left[ln\left(\frac{60}{\lambda\left[\left(\frac{S_g}{S}\right)^{\beta}-1\right]^{1/\beta}}\right)/C\ +\frac{1}{T_r}\right]^{-1}$$

- Now we can do the steps to calculate ΔT_c using a stepwise process

Example

- Data from Anderson et al. (2011)
  - Computed values for S_g =2,638.1MPa, $\lambda = 4{,}787.93$ seconds, $\beta = 0.183734$, T_r = -18°C and Arrhenius constant = 29,680.4 ("0" aging condition)

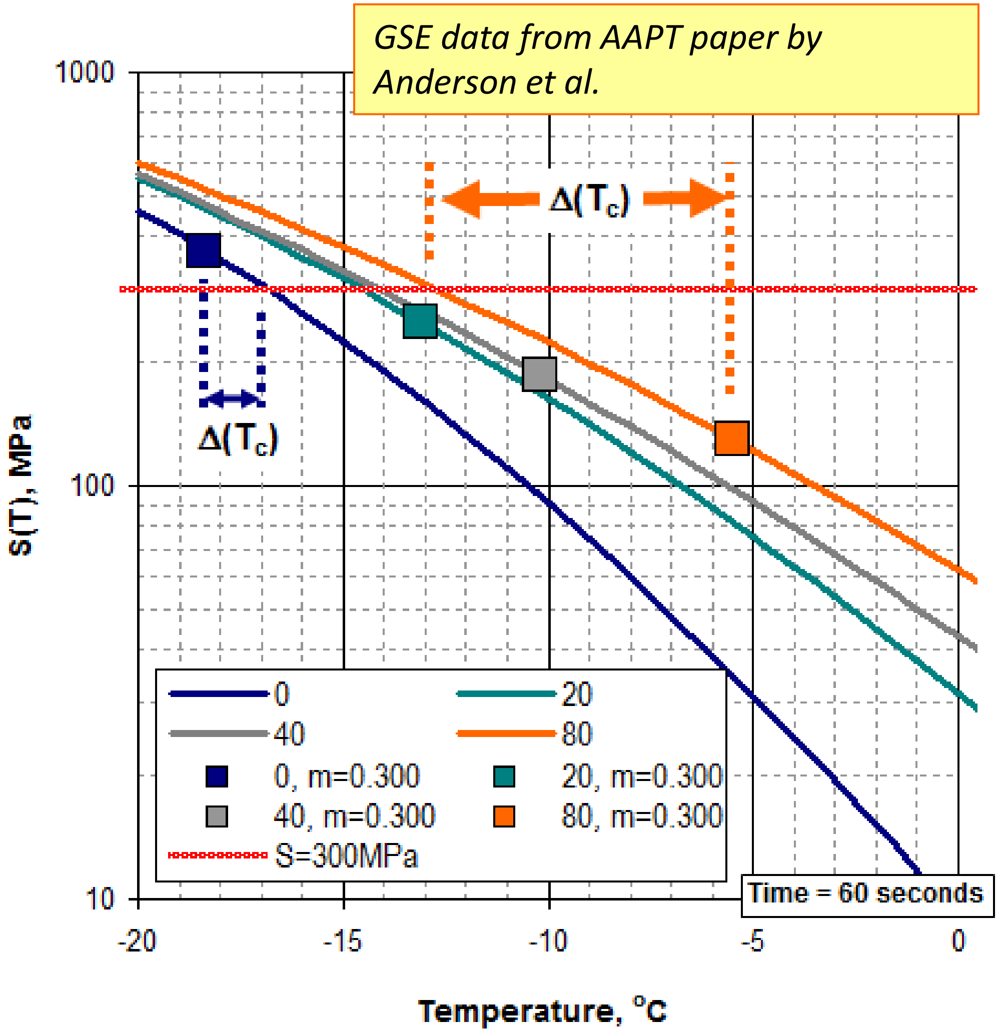
1. Obtain parameters as noted above
2. Use T(S) to get Temperature for S=300 when loading time is fixed as 60 seconds [= -16.9 C]
3. Use t(m) to obtain the loading time when m=0.300 at the reference temperature [= 47.6 sec]
4. Use S(t) to obtain the stiffness value when the loading time is associated with m=0.300 at the reference temperature [for t=47.6 sec, S(t)= 378.6 MPa at T_{ref}]
5. Use T(S) to obtain the temperature for the condition at which S(t) at the reference temperature corresponds to m=0.300 [S=378.6 which results in T(m) = -18.5°C]
6. Subtract T(S) - T(m) to get ΔT_c. [-16.9 - (-18.5) = +1.4]

Point vs. shape

- Need to consider what is defined as a point property versus a parameter that defines a shape of the master curve or part of the master curve

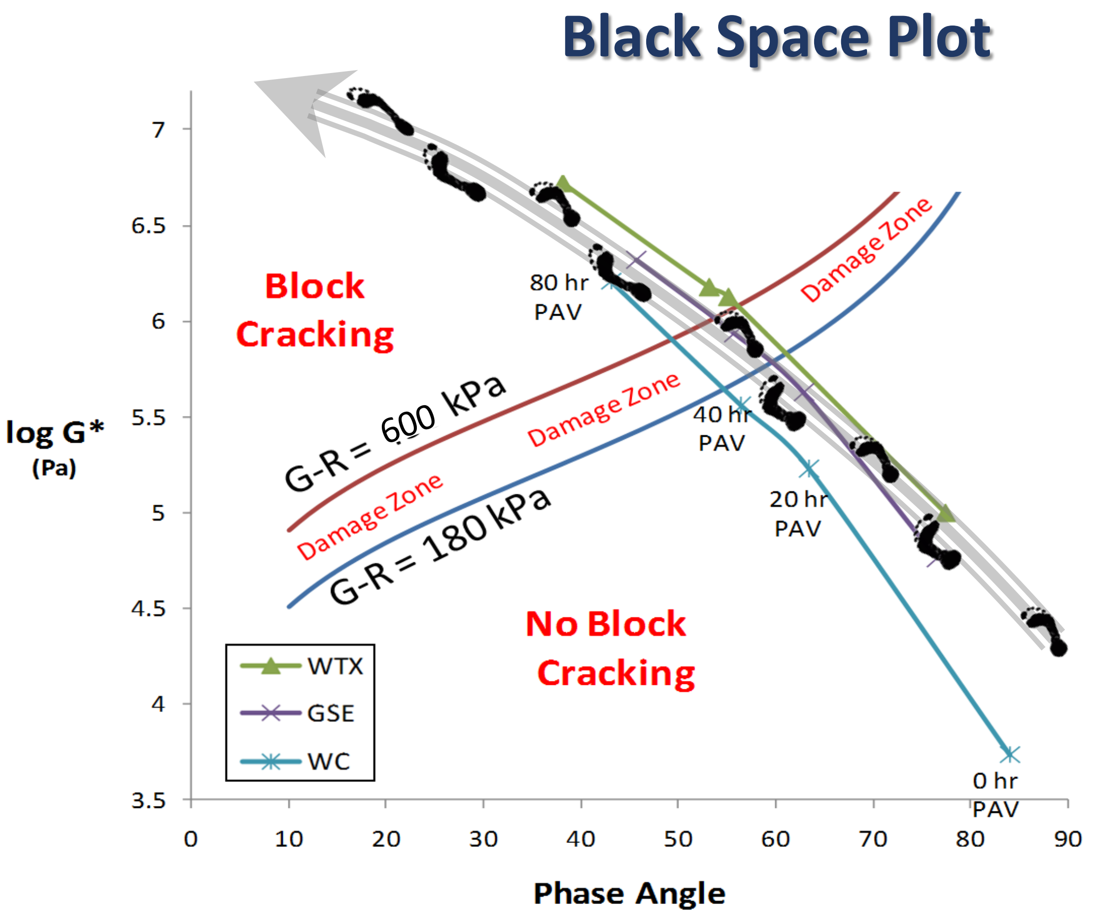
What is ΔT_c ?

- $T_{S(60s)}$ -$T_{m(60s)}$
- ΔT_c defines the slope of the stiffness curve in the temperature domain
- Is a shape parameter in the higher stiffness region – related to temperature susceptibility and the rheological index



What is Glover-Rowe (G-R) parameter ?

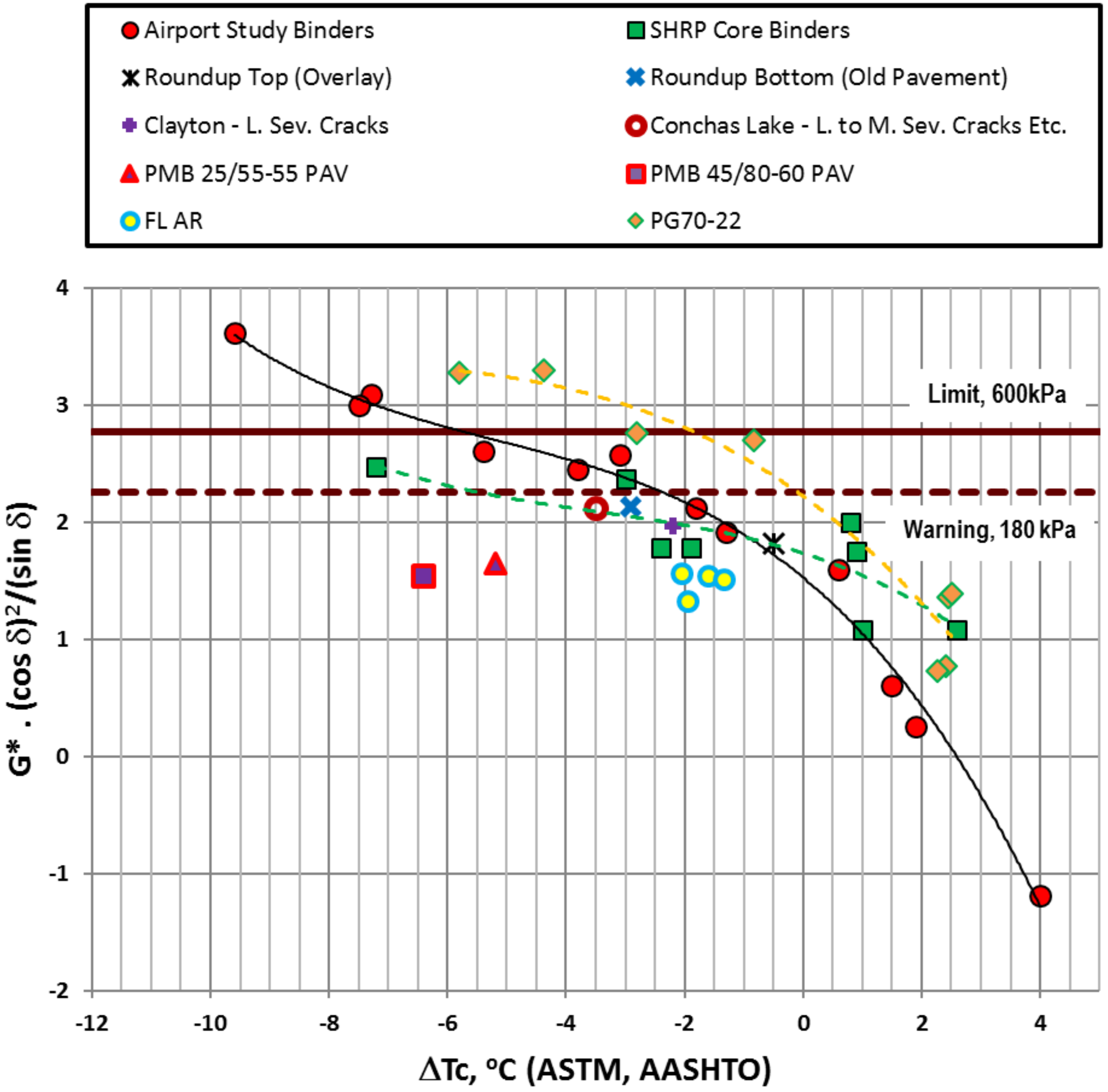
- G-R = G*.(cos δ)²/G*.sin δ
  - Defined at 15ºC and 0.005 rads/sec
- This defines a point within a Black space plot of G* vs. phase angle
- Is a point property in a similar manner to S, m, G*.sinδ, G*/sinδ, J_{nr}, etc.



Point versus shape

- Will not necessarily correlate since they are defining different parameters
- Initial relationship shown for ΔT_c versus G-R does not apply to many materials
  - Which is a more reliable indicator of performance?
  - In our existing specifications we have not used a shape parameter without a point parameter!

Point	Shape
Rheology S, m, $G^*.\sin\delta$, $G^*/\sin\delta$, J_{nr} *Empirical* Pen, R&B SP, Frass	*Rheology* R, WLF/Arrhenius, ΔT_c, A+VTS, etc. *Empirical* PI, PVN, etc.



Thanks for listening ...

Questions?
Comments!