ΔT_c – Some thoughts on the historical development

GM Rowe

Binder ETG Meeting
April 28th, 2016

ΔT_c

- Concept is linked to ductility, viscosity function, Black space parameter and shape of BBR master curve
  - In the development of the idea that has become know as ΔT_c all of the above ideas have contributed and/or can be used to assist with any validation of an approach
  - Each method is interrelated in some manner!
    - *Some thoughts go back to SHRP – but will go to more recent work*

What is ΔT_c

- Defined as the difference between S and m criteria with BBR
- $\Delta T_c = T_{S(300MPa)} - T_{m(0.300)}$
  - T is grade temperature for either S or m
  - Definitions in standards AASHTO PP78-16 and ASTM D 7643 are in same format

AASHTO Draft for RAS

Standard Practice for

Design Considerations When Using Reclaimed Asphalt Shingles (RAS) in Asphalt Mixtures

AASHTO Designation: PP 78-16[1]

For stiffness (S):

$$T_c = T_1 + \left[\frac{Log(300) - Log(S_1)}{Log(S_1) - Log(S_2)}\, x\, (T_1 - T_2)\right] - 10$$

For relaxation (m-value):

$$T_c = T_1 + \left[\frac{0.300 - m_1}{m_1 - m_2}\, x\, (T_1 - T_2)\right] - 10$$

From these two values the critical temperature difference (ΔT_c) can be determined as follows:

ΔT_c = Stiffness critical temperature (S) – the Relaxation critical temperature (m-value)

ASTM D7643 (revision)

INTERNATIONAL Designation: D7643 – 10

Standard Practice for
Determining the Continuous Grading Temperatures and Continuous Grades for PG Graded Asphalt Binders[11]

6.3.3. ΔT_c— determine ΔT_c as the difference between continuous grading temperature for S from the continuous grading temperature for the m-value. Report ΔT_c as a negative value if the continuous grading temperature for the in-value is lower than the continuous

7.3 ΔT_C—When required, report ΔT_C to the nearest 0.1°C.

What is ΔT_c

- Defined as the difference between S and m criteria with BBR
  - Some earlier work define as $T_m - T_S$ (so beware – in some publications sign is other way around

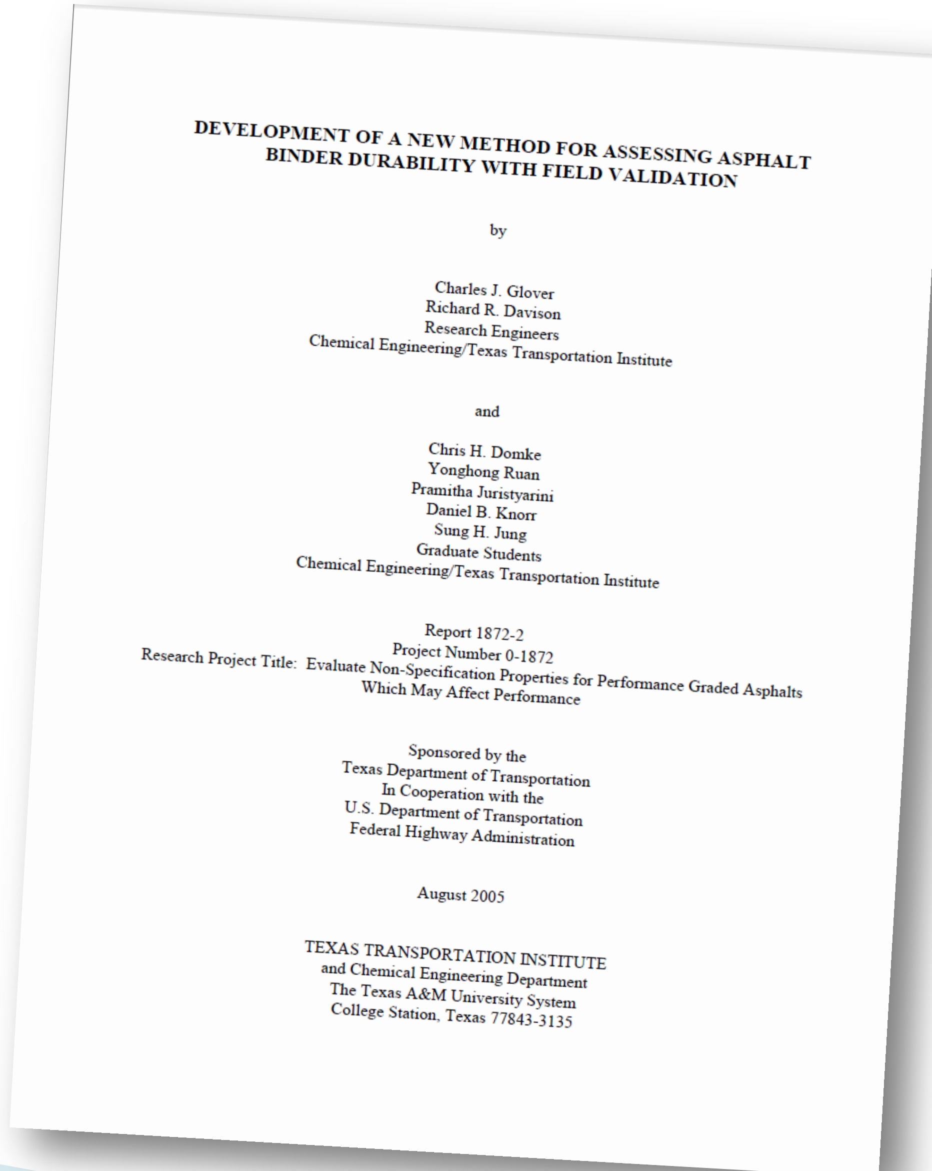
  - Ok – so this is just a temperature – so what does it tell us and why are we interested???

ΔTc – historical

- Main declaration of recent idea
  - 2011 AAPT (Anderson et al.)
    - Mike Anderson, Gayle King, Douglas Hanson, Phillip Blankenship
  - Related to airport pavements durability with surface cracking/raveling
    - Discussion provided by Rowe – showing rheological linkage
- Anderson et al. – relied heavily on concepts developed by Glover et al.

Glover et al.

- Report looks at various aspects of asphalt binder durability
- http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-1872-2.pdf



DEVELOPMENT OF A NEW METHOD FOR ASSESSING ASPHALT BINDER DURABILITY WITH FIELD VALIDATION

by

Charles J. Glover
Richard R. Davison
Research Engineers
Chemical Engineering/Texas Transportation Institute

and

Chris H. Domke
Yonghong Ruan
Pramitha Juristyarini
Daniel B. Knorr
Sung H. Jung
Graduate Students
Chemical Engineering/Texas Transportation Institute

Report 1872-2
Project Number 0-1872
Research Project Title: Evaluate Non-Specification Properties for Performance Graded Asphalts Which May Affect Performance

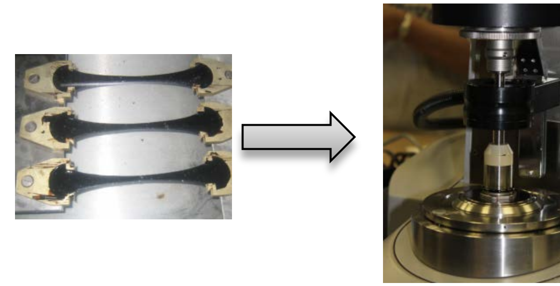
Sponsored by the
Texas Department of Transportation
In Cooperation with the
U.S. Department of Transportation
Federal Highway Administration

August 2005

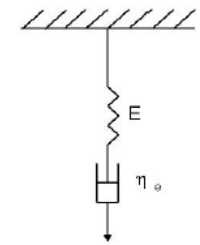
TEXAS TRANSPORTATION INSTITUTE
and Chemical Engineering Department
The Texas A&M University System
College Station, Texas 77843-3135

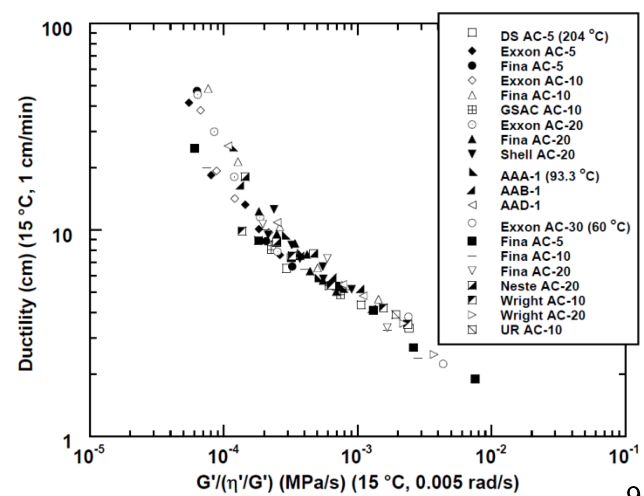
Glover et al. 2004 – some key statements

- Literature reports indicate that the ductility of binders recovered from asphalt pavements correlate with cracking failure. However, ductility measurement is a time and material consuming process and is subject to reproducibility difficulties, as are all failure tests.
- From this elongation model using a Maxwell element … it is seen that two rheological parameters are suggested to represent the extensional behavior of asphalt binders: the ratio of the dynamic viscosity to the storage modulus (η′/G′) and the value of the storage modulus G′
- As an alternate way of viewing these same data, ductility is plotted versus the ratio of G′ to (η′/G′)
- For conventional asphalts the function G′/(η′/G′) can serve as a surrogate for ductility, is easier to measure, and requires less material



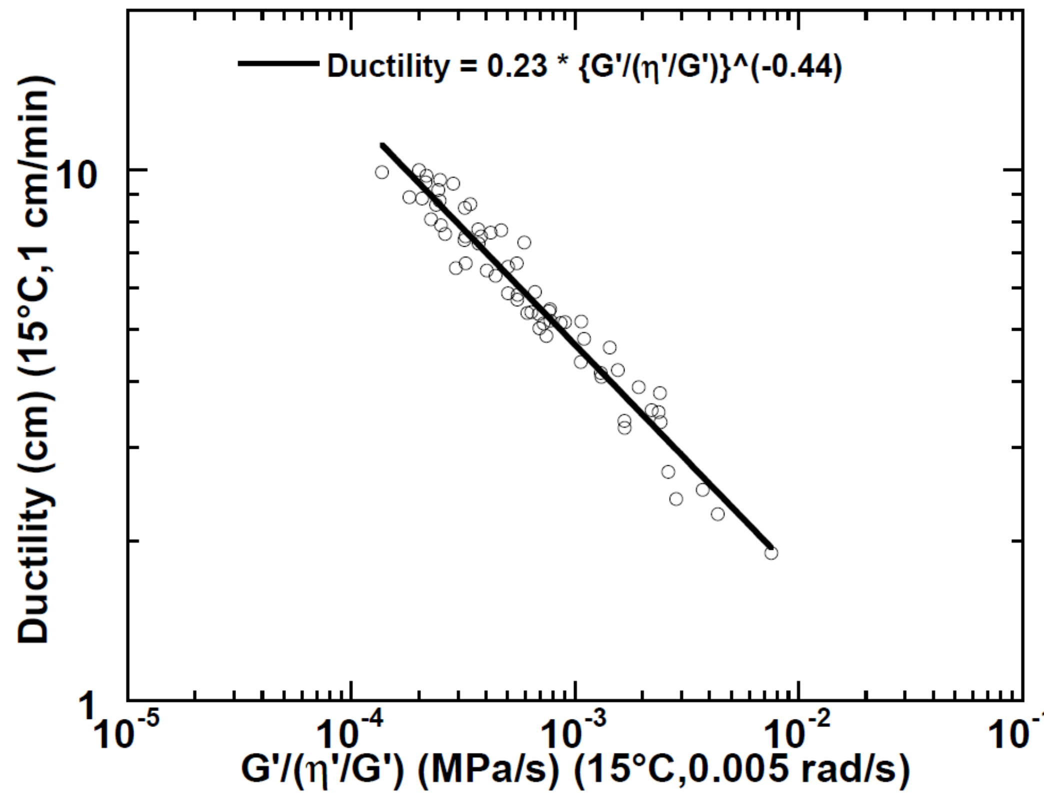
$$\tau + \frac{\eta_e}{E}\frac{d\tau}{dt} = \eta_e \frac{d\varepsilon}{dt}$$





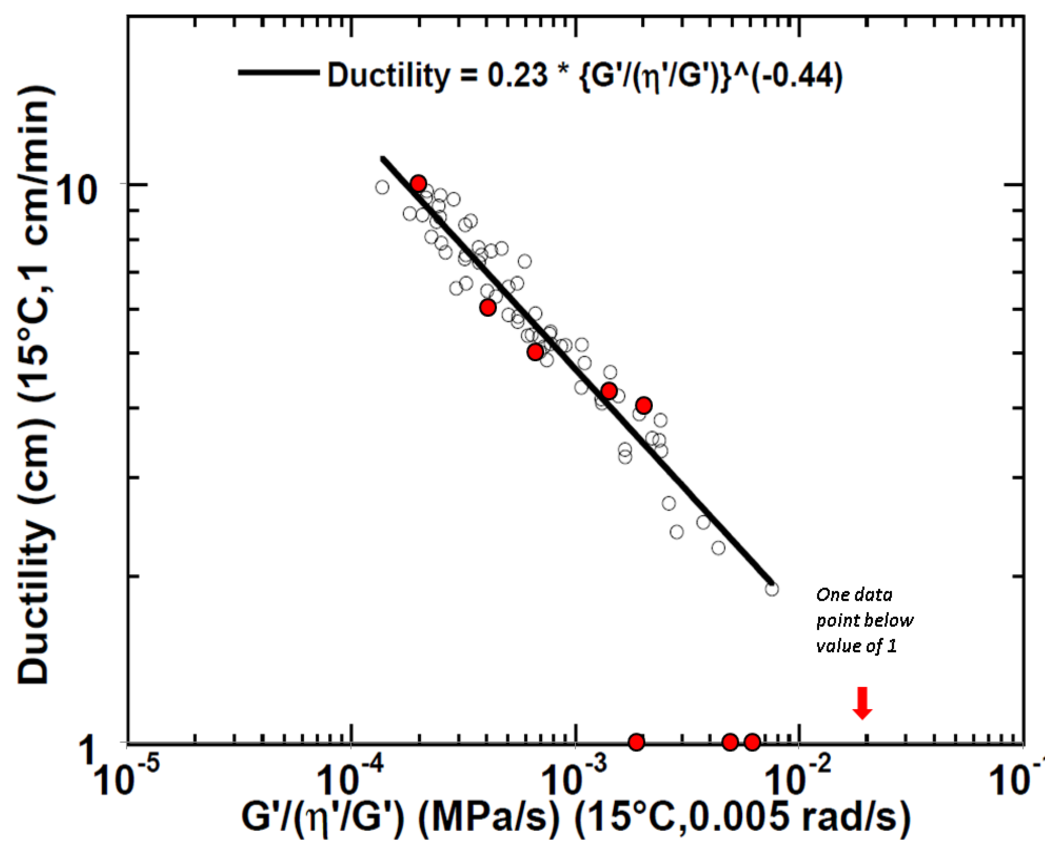
Ductility vs. rheology parameter

- Glover et concluded that the rheology parameter was a good match to ductility for conventional asphalts



Ductility vs. rheology parameter

- Data from Anderson et al. added to same plot – fit not quite as good – but similar trend



Limits

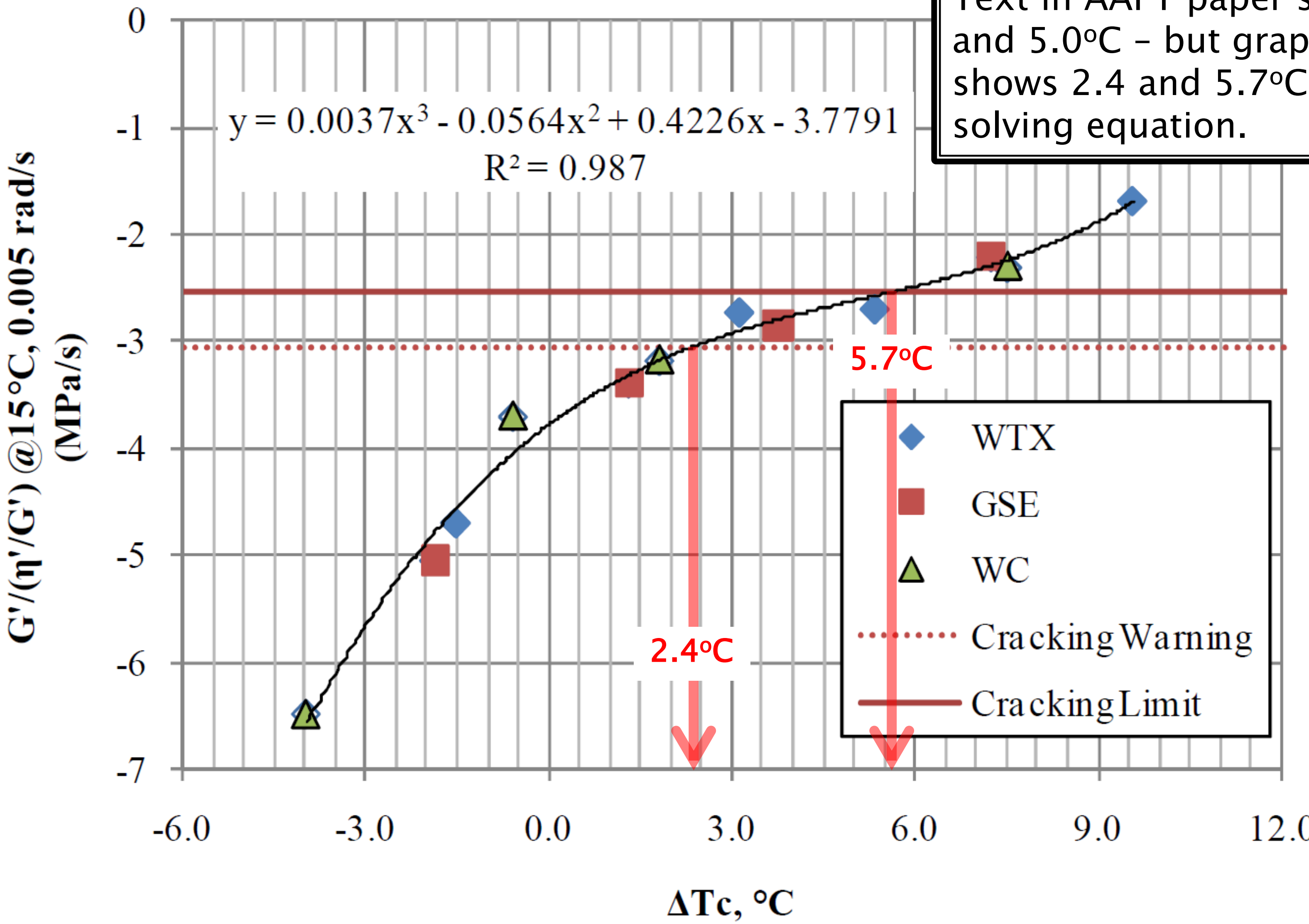
- Glover proposed two limits
  - Cracking warning, 3.0E-03 MPa/sec
  - Cracking limit, 9.0E-04MPa/sec
- Adopted in Anderson et al. 2011 paper
  - Also used to determine ΔT_c values in this paper

Anderson et al. 2011

- Study with asphalts made from three crude types
- Consideration of airport pavements
- Considered concepts developed by Glover et al.
- Developed data sets that included extended aging in PAV (0, 20, 40 and 80 hours)
- Looked at how the properties changed with aging
- Compared to binders taken from four asphalt mixes laid in airport construction

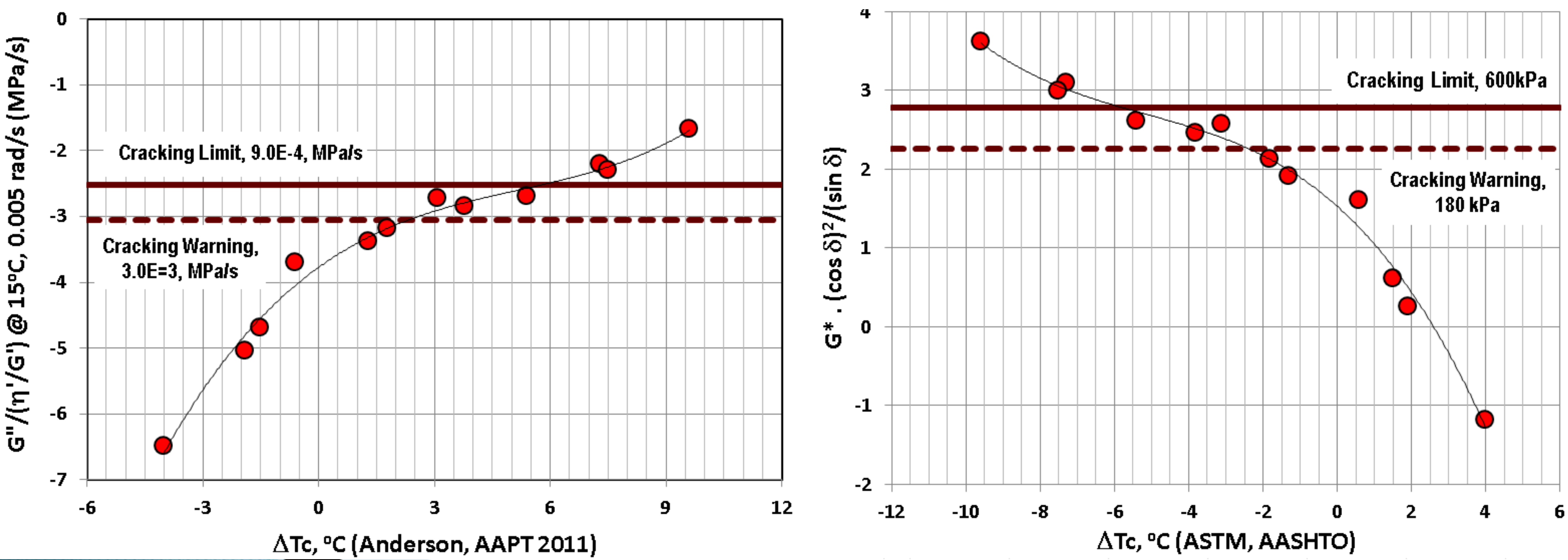
ΔTc vs. Glover's analysis

Text in AAPT paper says 2.5 and 5.0°C – but graph shows 2.4 and 5.7°C by solving equation.

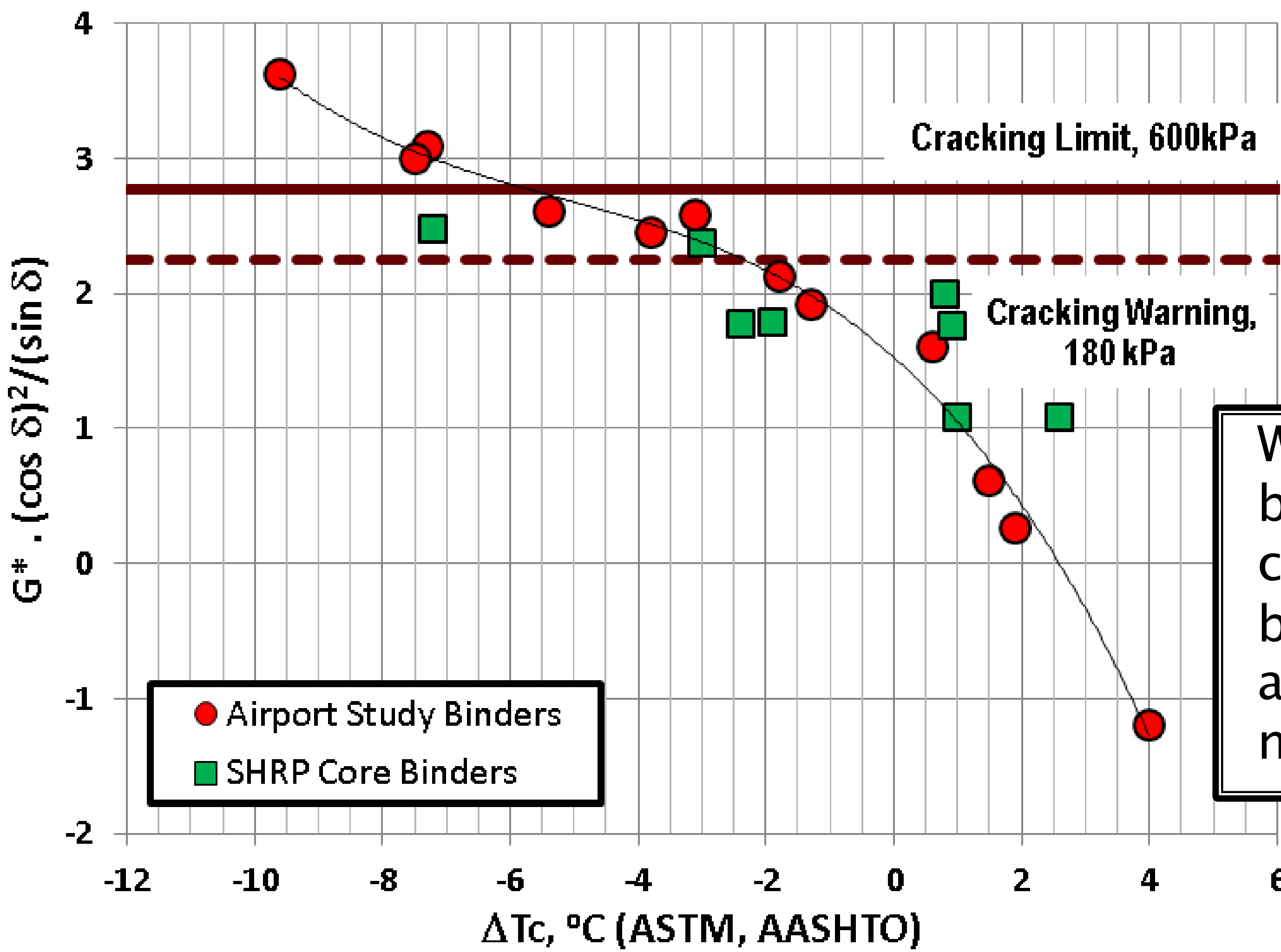


Expression as viscosity function or G-R parameter

- Data is from 2011 Anderson et al. paper
  - Left side as Glover viscosity function
  - Right side as G-R Black Space Parameter

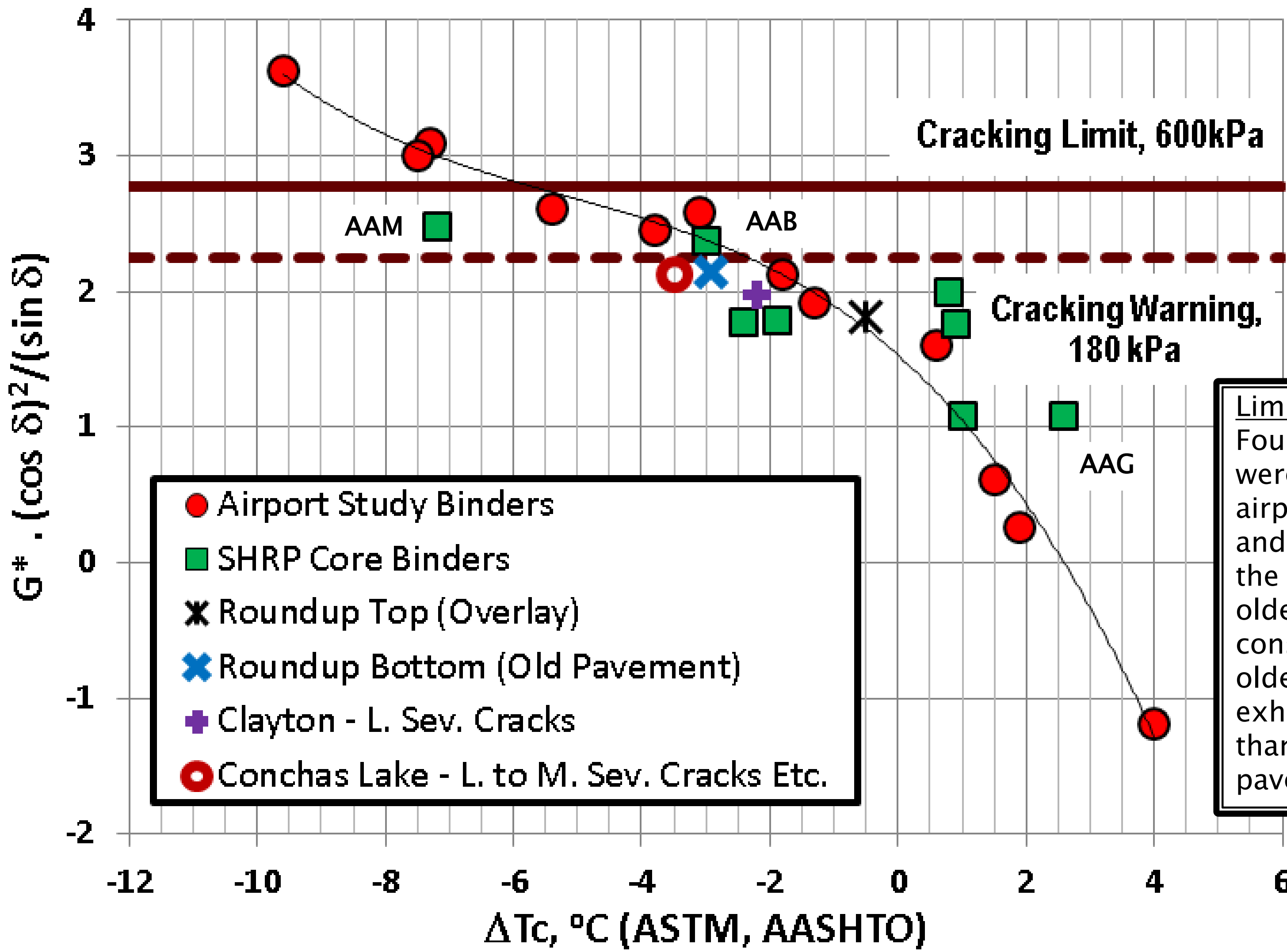


Parameters including SHRP core binders



With core binders the correlation between ΔTc and G-R is not as good!

Anderson et al. validation points – shown using G-R vs. ΔT_c



<u>Limited validation</u>
Four airfield pavements were cored from 3GA airports in New Mexico and Montana. Two of the pavements were older and two were considered newer. The older pavements exhibited more cracking than the newer pavements.

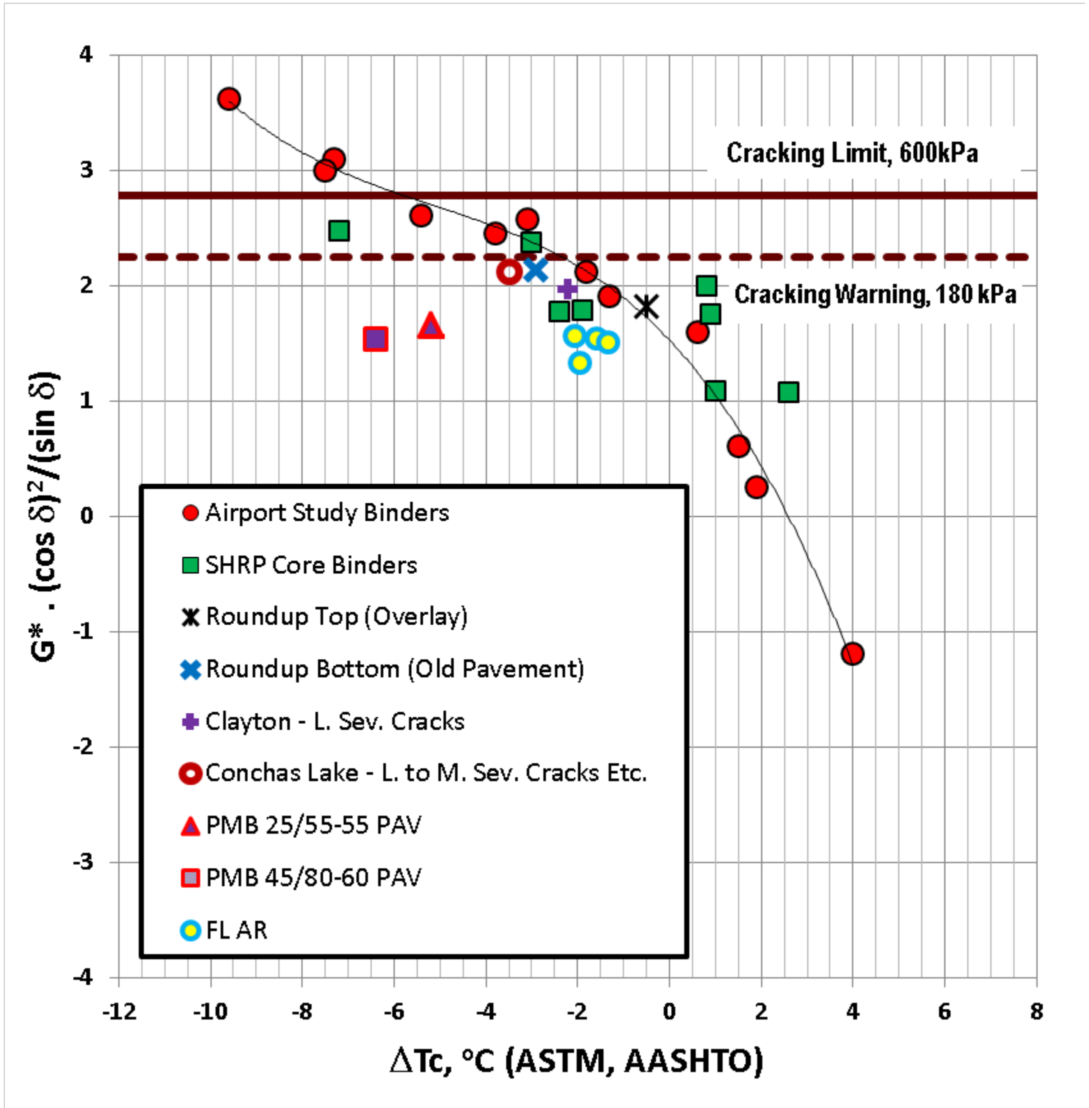
Limits

- Viscosity function
  - warning 3.0E-03 MPa/sec
  - limit 9.0E-04MPa/sec
- ΔT_c – Anderson poly fit
  - warning 2.4°C
  - limit 5.7°C
- ΔT_c – Anderson recomendation
  - warning 2.5°C
  - limit 5.0°C
- G-R parameter
  - warning 180 kPa
  - limit 600 kPa *(not 450 kPa as stated in some publications)*

Concept that all of these should be giving similar failure conditions in the field.

Adding a few more data points

- As more materials are added the correlation between these two approaches does not appear to be as good as originally suggested
  - Includes some PMB binders and Asphalt Rubber
- Concepts are measuring in different region

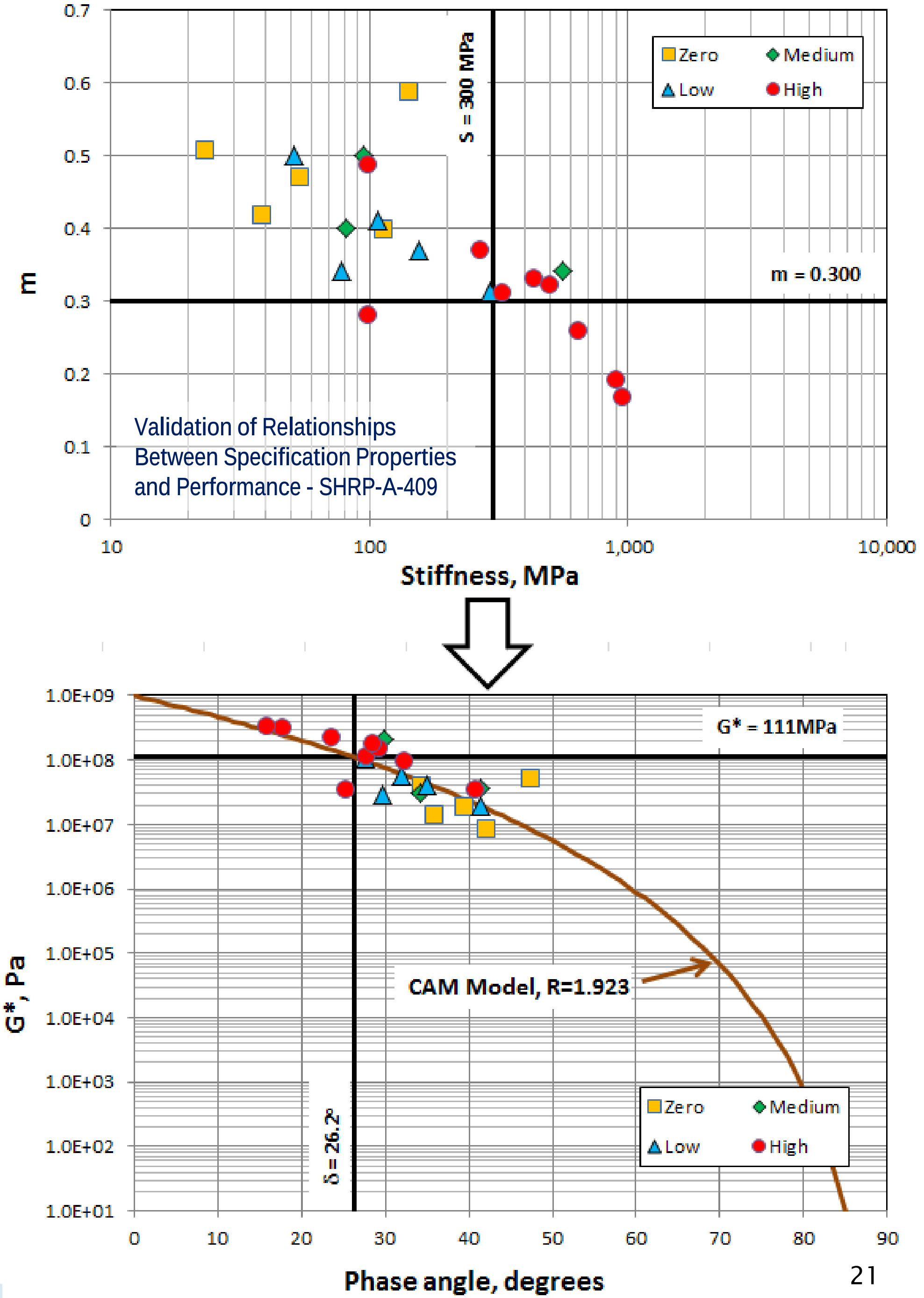


Aging

- The values expressed are in a manner that are independent of aging
- Binders are aging at different rates in the studies
- Use of one of the methods should be able to predict durability cracking/raveling
  - Concept originally that PAV would represent reasonable field aging
  - If this is correct then limits would apply to PAV
    - Do we need to consider longer aging?
    - What about climate?

BBR vs. DSR

- BBR parameters can be substituted with G* and δ with equivalent meaning
- S or m controlled is related to R-value
  - Low R = S controlled
  - High R = m controlled
  - R value Cut-off around ≈1.92 – depending on G_{glassy}

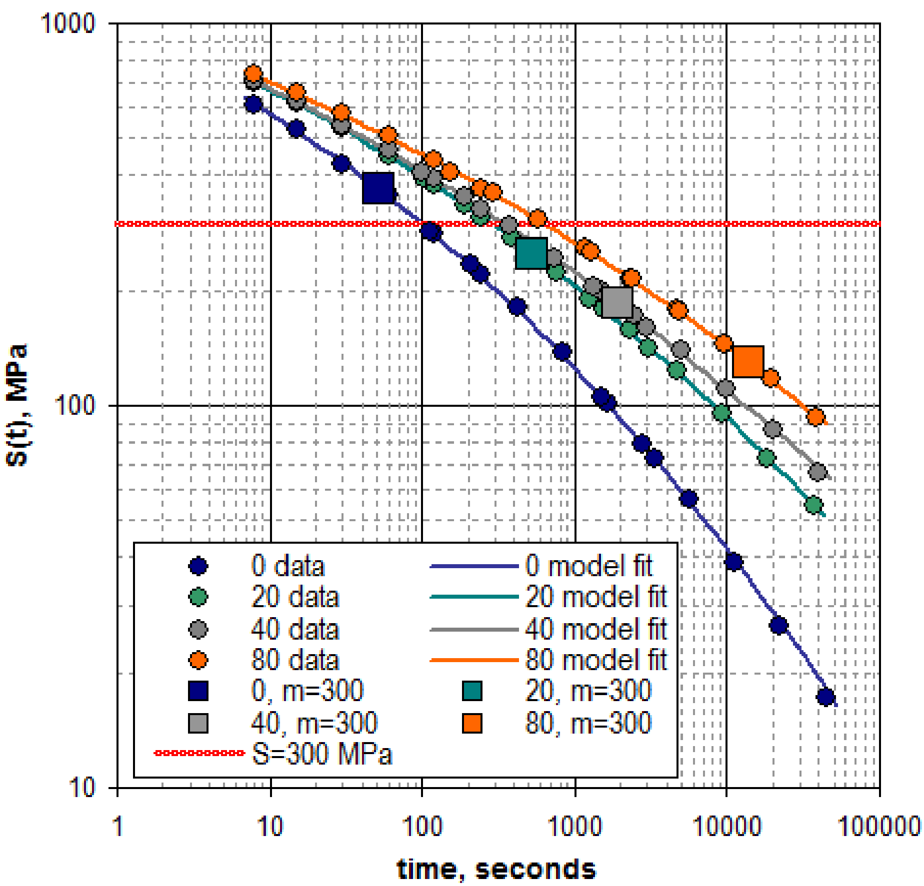


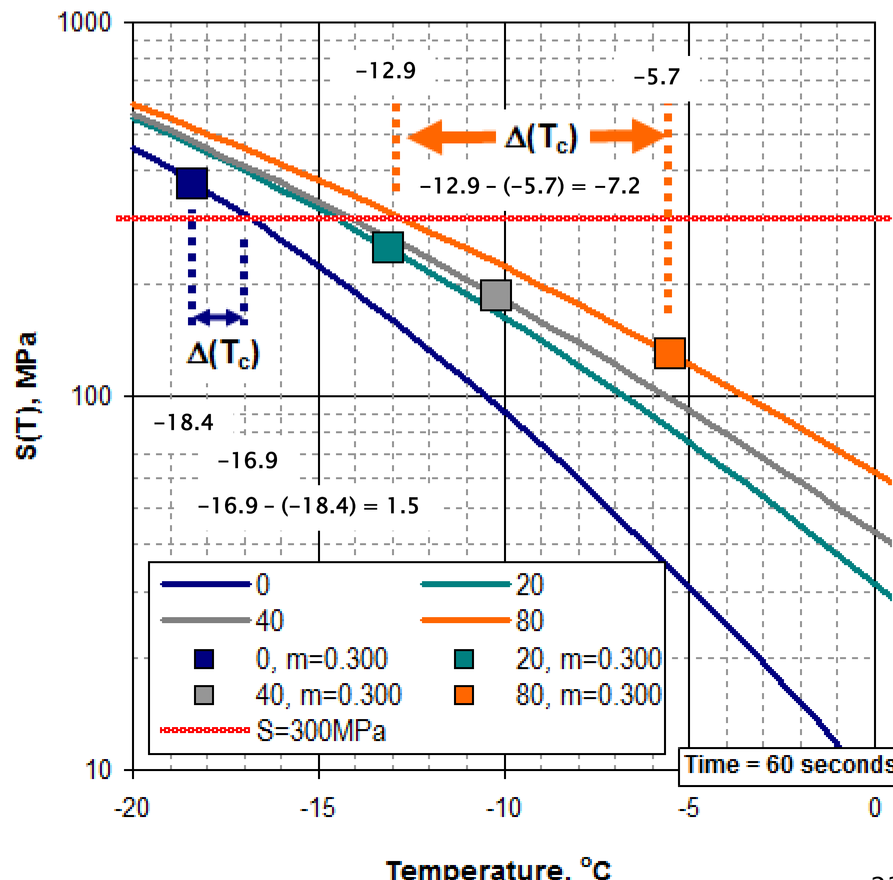
Rheology and ΔT_c

- ΔT_c developed as concept supported largely by ductility
  - How does this relate to rheology and models?

Rheological aspects for ΔT_c

These two plots show the same data – one versus time – the other versus temperature. Simple interconversion through the use of CA model and use of t–T shift factor. As material ages the curve flattens and ΔT_c becomes more negative





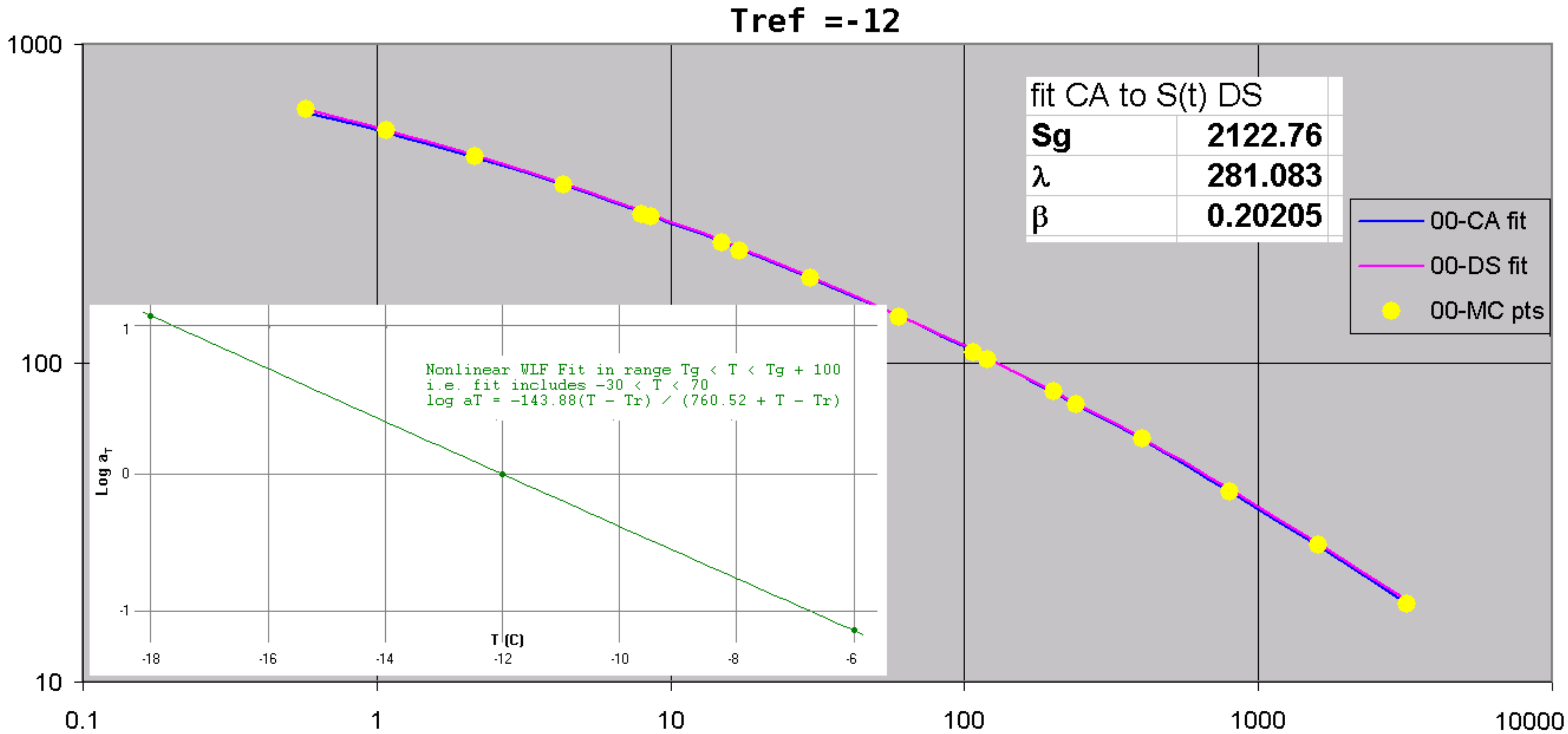
Lines become flatter

- What does this tell us?
  - Rheological index increases
  - Oxidation greater

- ΔT_c can be computed directly from CA relationship

Calculation of ΔT_c

- $\Delta T_c = f(\text{CA Model})$



Other aspects

- ΔT_c with REOB
  - Working group on this aspect to finalize work – some notes on this
- RAP – effects
  - Some work with G-R shows same basis
- RAS – what is being considered!
- Ties with other methods
  - Need to document aspects such as
    - Cold temperature cracking methods
    - Ties to VET and other methods

ΔT$_c$ with REOB

- Last meeting draft of REOB summary document was distributed
  - This document will be updated in next few weeks – too late for this meeting!
  - Some comments with REOB ….

DRAFT

FHWA Asphalt Binder ETG, REOB – Re-refined Engine Oil Bottoms Residue – Task Force

Report to the September 2015 FHWA Binder ETG
September 15, 2015

Introduction

Lubricating oils used by vehicle engines have to be replaced at least every 5000 to 10000 miles depending upon the type of vehicle being used. This oil used to be dumped, but now most of it is re-refined and reused. This is done in a multi-step process, in which items such as water, solids, lighter oils, dissolved metals, degraded additives, etc. are removed. The oil bottoms from this process – REOB have been used in the paving industry since the 1980s, typically at an addition rate of 3 to 10%.

In some areas concern has been expressed over the use of these materials. In some areas such as New England these have been banned from used and in certain areas of Canada they have been suspected by various researchers as contributing to cracking propensity of binders. However, much of the work conducted to date is of a very limited nature and concerns exist with regard to the validity of the research and how this impacts the industry.

As a consequence of the industry and agency concerns several initiatives have been started to address this issue. The Asphalt Institute has from a task force (http://www.asphaltinstitute.org/re-refined-engine-oil-bottom-residue/) and the Asphalt Modifiers Association has published a news bulletin on this (http://modifiedasphalt.org/news-bulletin-reob/). In addition AASHTO also has a REOB task force.

During the April 2015 Binder ETG several presentations were made on REOB or related issues such as the characterization of cracking with recycled materials. As a consequence of this the ETG decided to form a task force with the initial objective of summarizing the presentations and providing further input and advice on the REOB issues. This document sets out the summary of those presentations. This document will be updated as developments take place.

Task Force Members

1. Geoff Rowe (Abatech) – Lead (growe@abatech.com)
2. Louay Mohammad (LSU) (louaym@lsu.edu)
3. Bill Ahearn (VT Agency of Transportation) (bill.ahearn@vermont.gov)
4. Mark Buncher (Asphalt Institute) (MBuncher@asphaltinstitute.org)
5. Gerald Reinke (MTE Services) (Gerald.Reinke@mteservices.com)
6. Walaa Mogawer (UMass) (wmogawer@umassd.edu)
7. Nelson Gibson (FHWA) (Nelson.Gibson@dot.gov)
8. Tom Bennert (Rutgers) (bennert@rci.rutgers.edu)
9. Jean-Pascal Planche (WRI) (jplanche@uwyo.edu)
10. Imad Al-Qadi (U of IL) (alqadi@illinois.edu)
11. Pamela Marks (Ontario Ministry of Transportation) (pamela.marks@ontario.ca)
12. Laci Tiarks-Martin (PRI) (ltiarks@priasphalt.com)
13. John D'Angelo (Consultant) (johndangelo@dangeloconsultingllc.com)

Presentations at April 2015 ETG Meeting

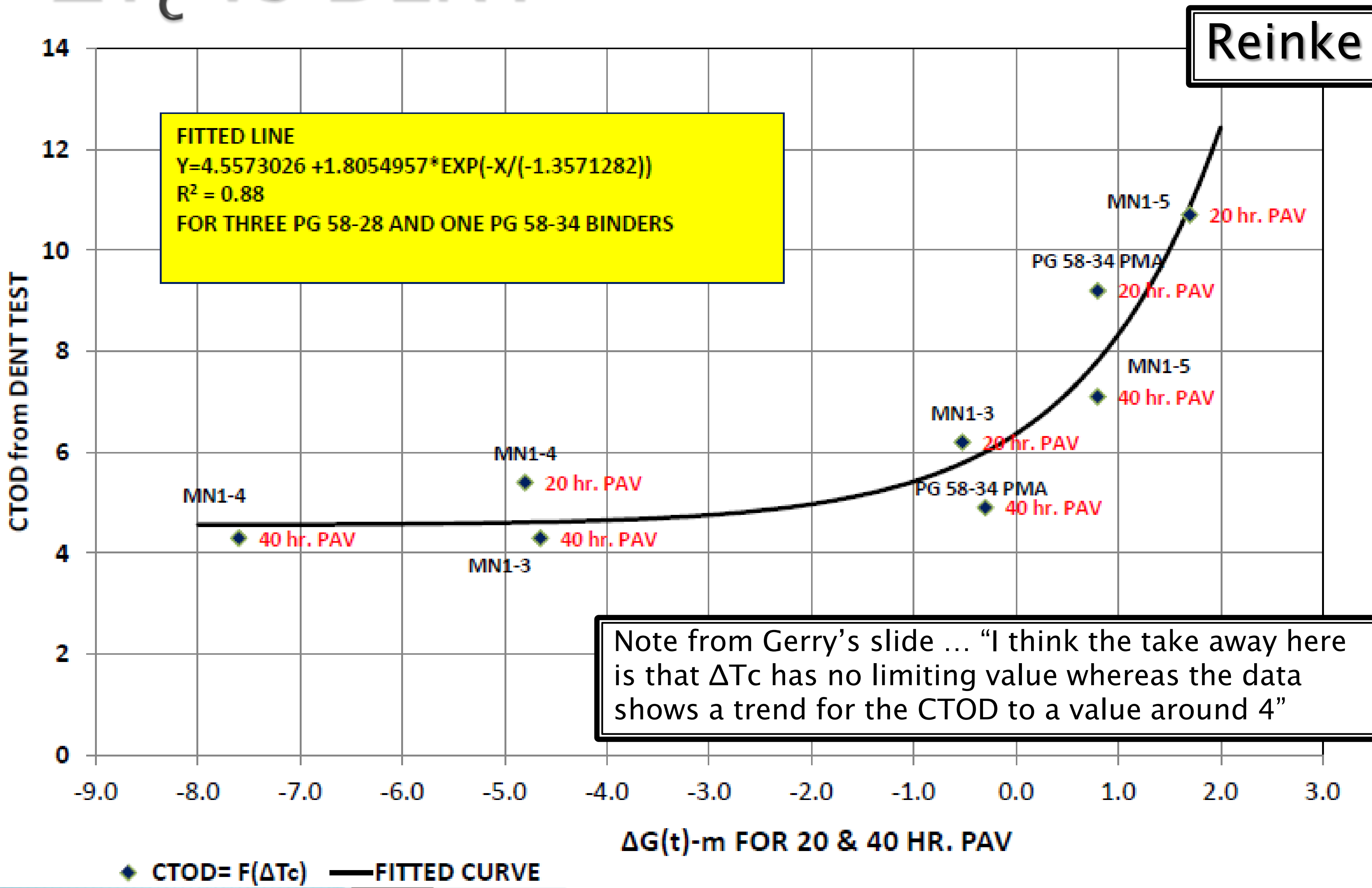
Seven presentations were given at the ETG. These are listed below and include a hyperlink to the downloadable version on the Asphalt Institute web site. A few comments is made on each of these papers has been made and the key findings summarized.

1 | Page

REOB – notes from 2015 ETGs

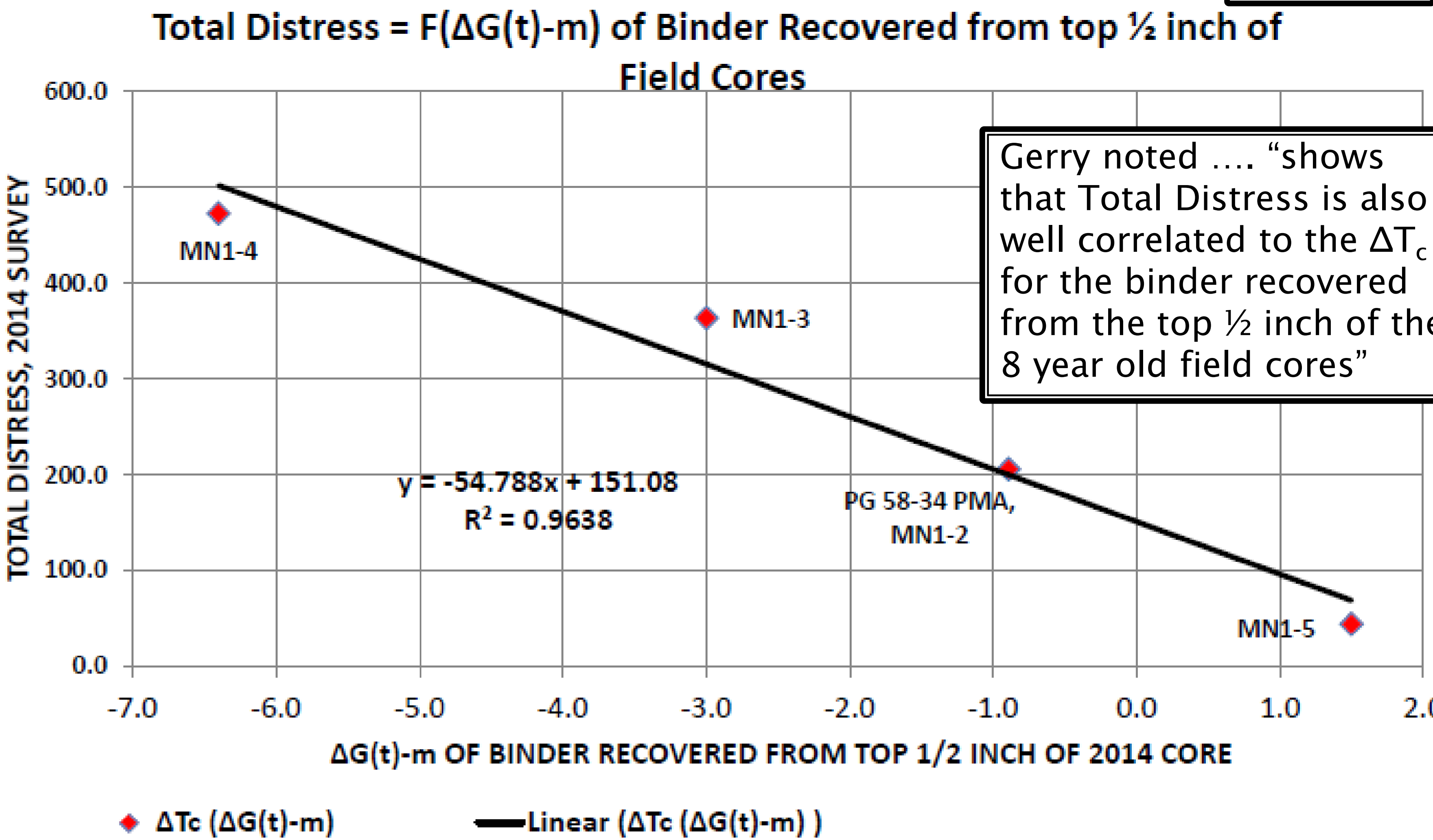
- Agreed …
  - A concern exists from the agency/DOT perspective on the durability of asphalt surfacing
  - ΔT_c and G-R could both be used to track performance
  - ΔTc is used by more of the researchers since it is readily available in the data
  - The amount of REOB generally effects the ΔT_c – but not all materials are created equal

ΔT_c vs DENT



ΔT_c vs Distress

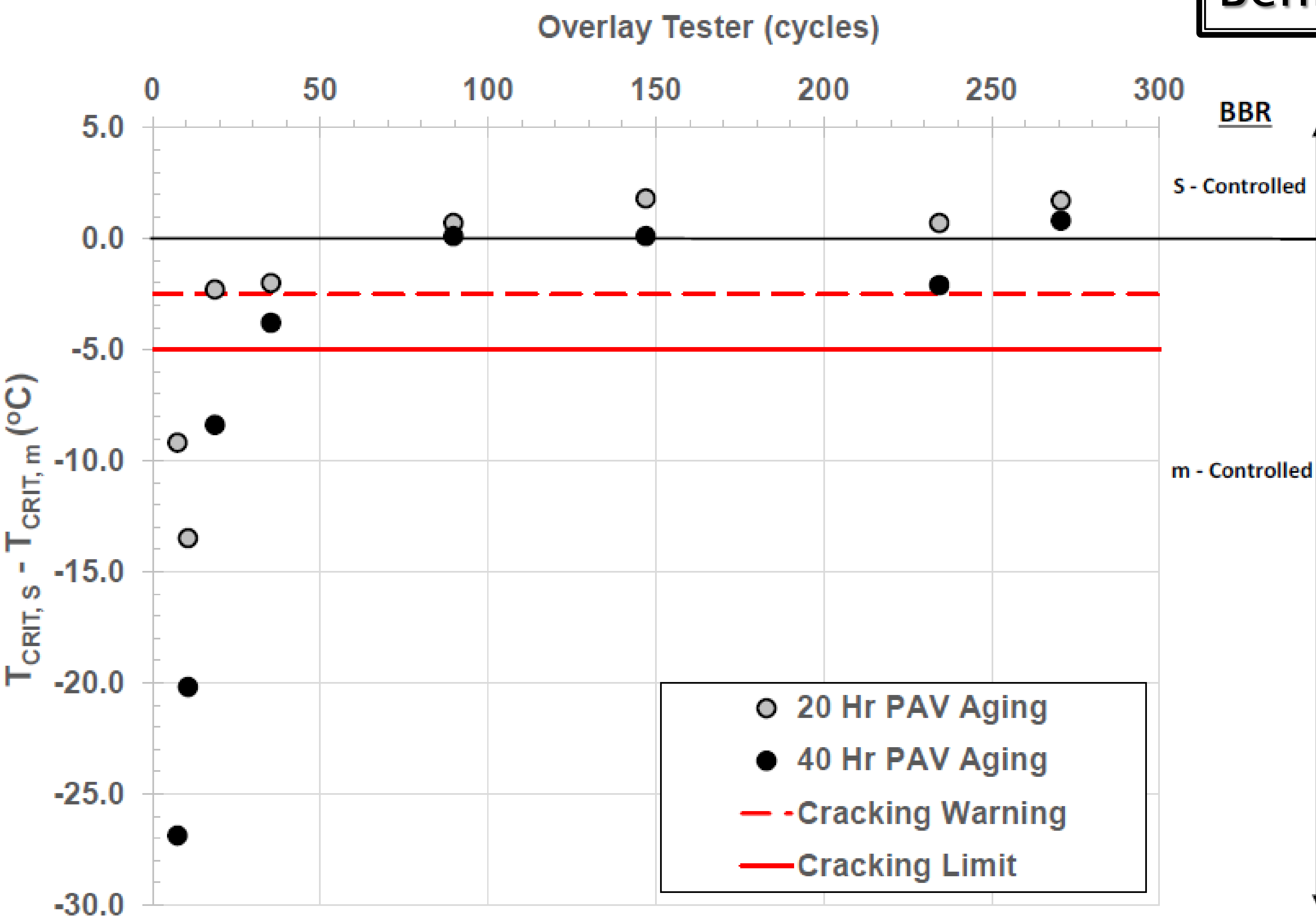
Reinke



Gerry noted …. "shows that Total Distress is also well correlated to the ΔT_c for the binder recovered from the top ½ inch of the 8 year old field cores"

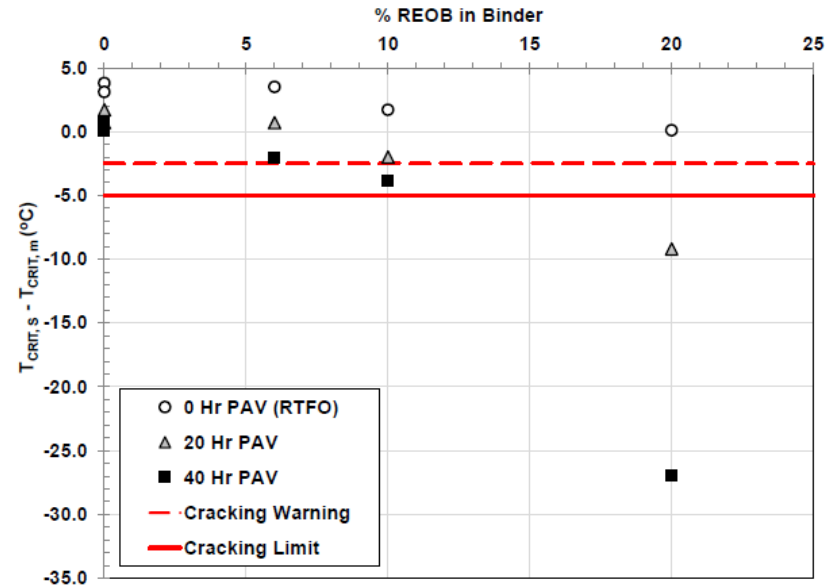
ΔT_c vs. Overlay Tester

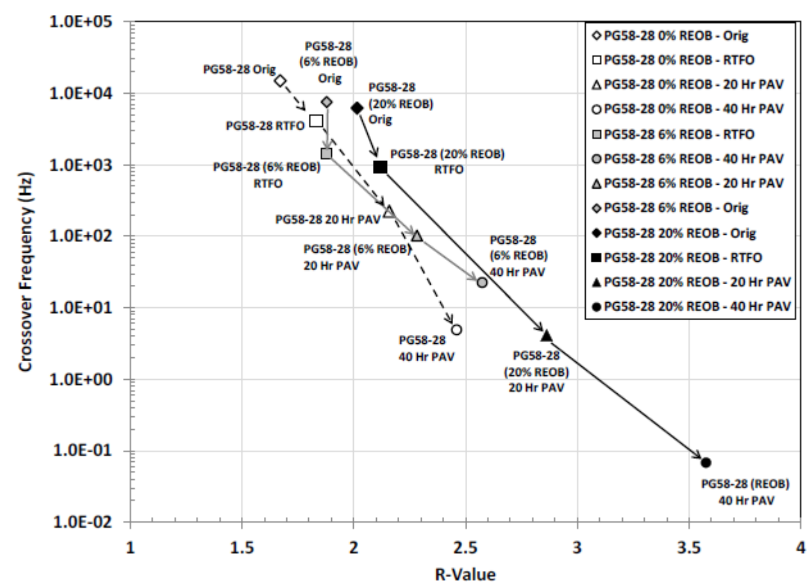
Bennert



Other comments from Bennert presentation

- The binder results show clearly the change in ΔTc with higher percentages of REOB
- A strong relationship is also shown clearly evident for the rheological index (R) versus the cross over frequency (ω_c)
- These two plots enable many of the other rheological parameters to be calculated such as the Glover-Rowe parameter.

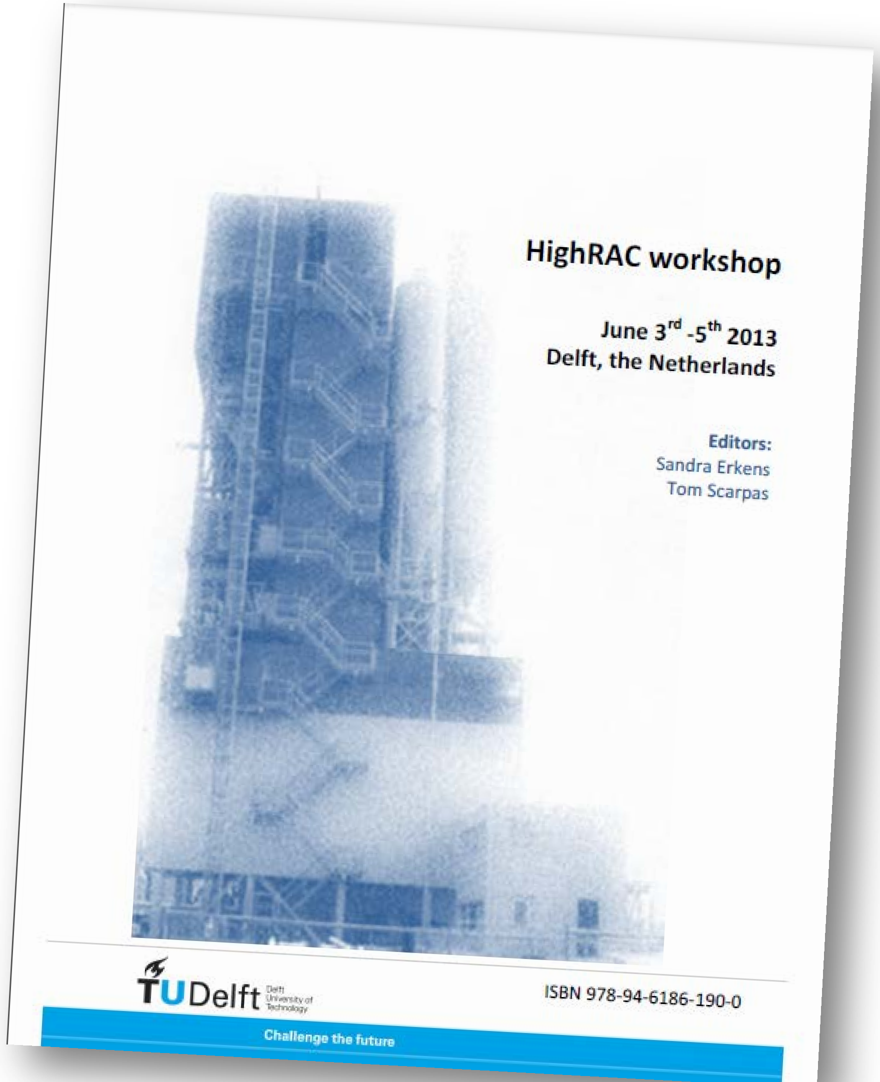




RAP

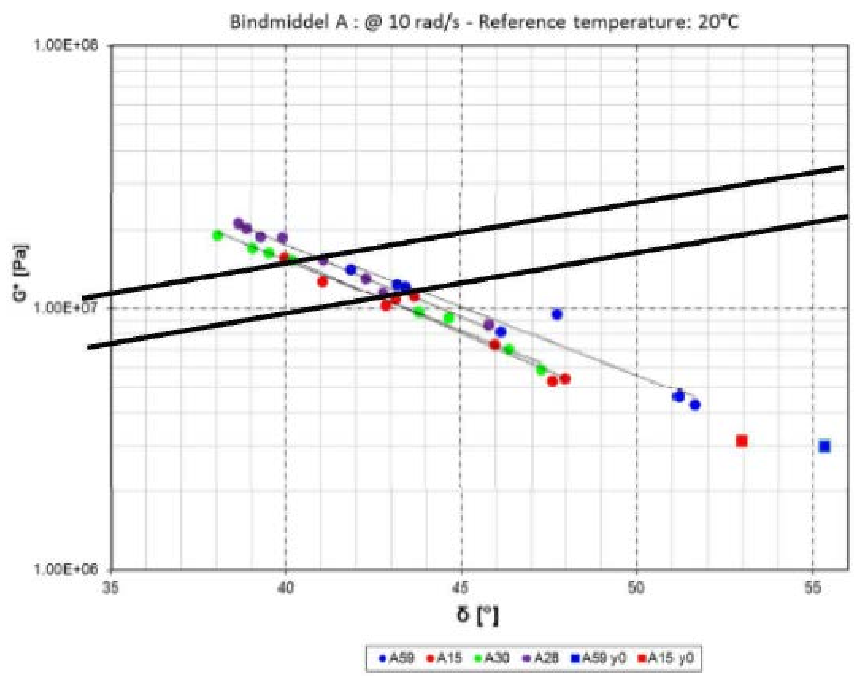
Steven Mookhoek, Field aging and damage and the relation to DSR stiffness – conclusions

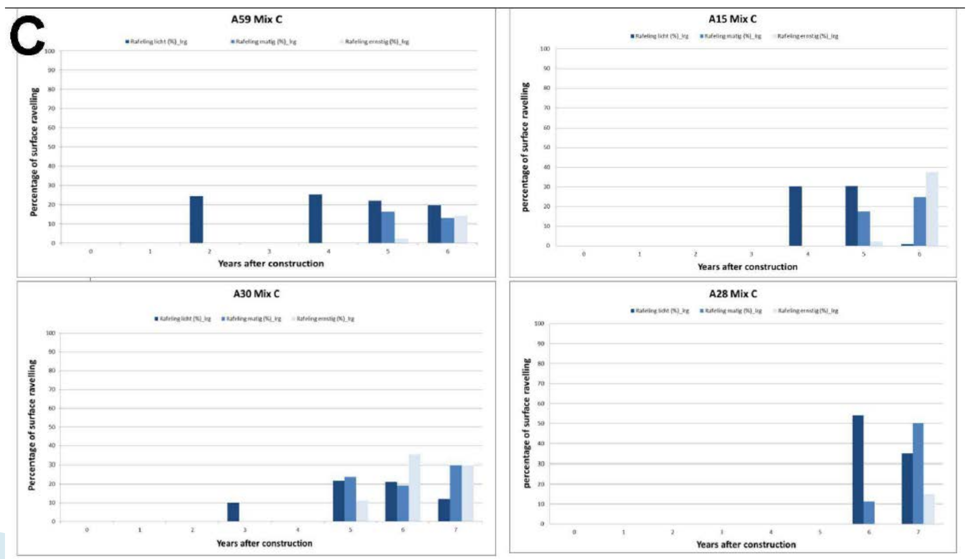
- Proof is found for establishing a correlation between binder rheological properties and 2LPA raveling resistance
- Damage levels can be described by function (G*, δ): Glover-Rowe
- Variety and fluctuations in binder properties may have significant effect on binder/asphalt performance
- Food for thought about making (binder specific) rheological criteria in contracts to fight early service life failures
- Current work can be used as benchmark…



RAP

- Most of work looking at G-R concept
- Example – http://repository.tudelft.nl/view/ir/uuid:4fd5151b-e192-4477-a78a-3bca4a808172/
- Consideration of raveling



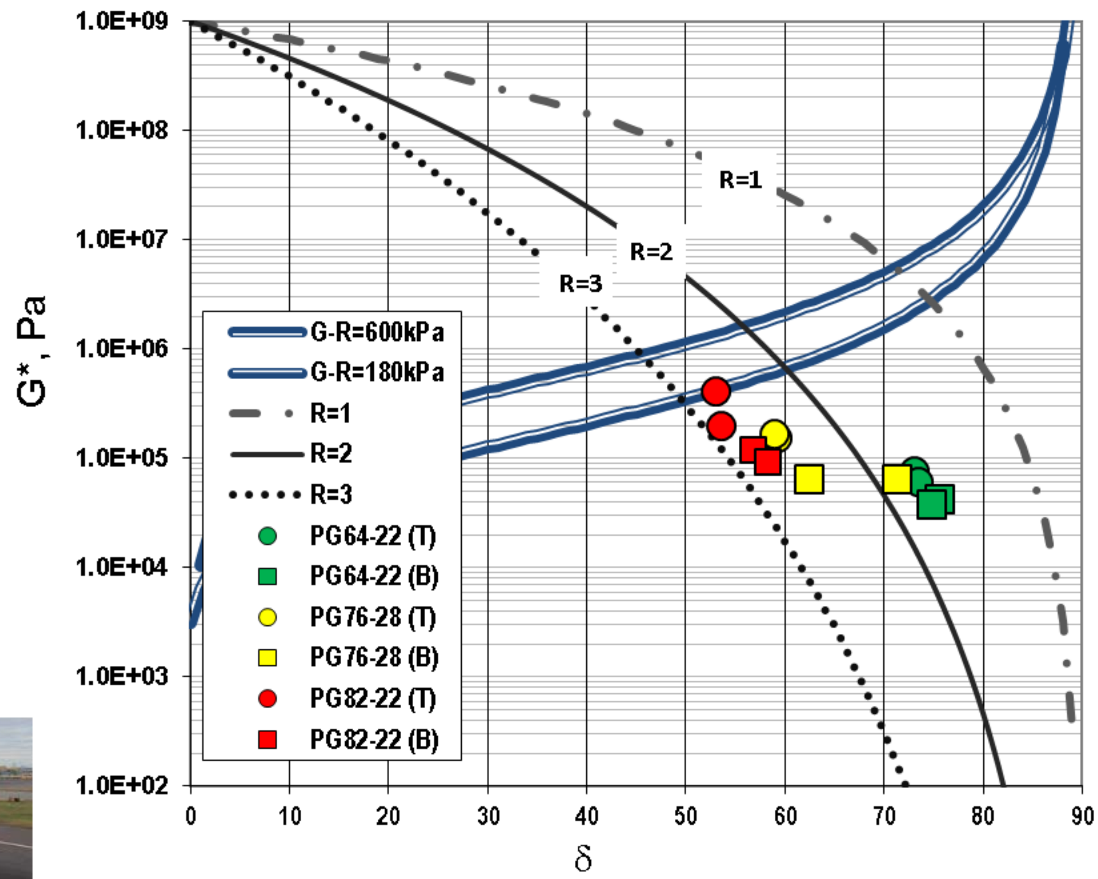


RAP

- Other work at UNH and other sources
  - Looking at the linkage between the binder properties and mix properties

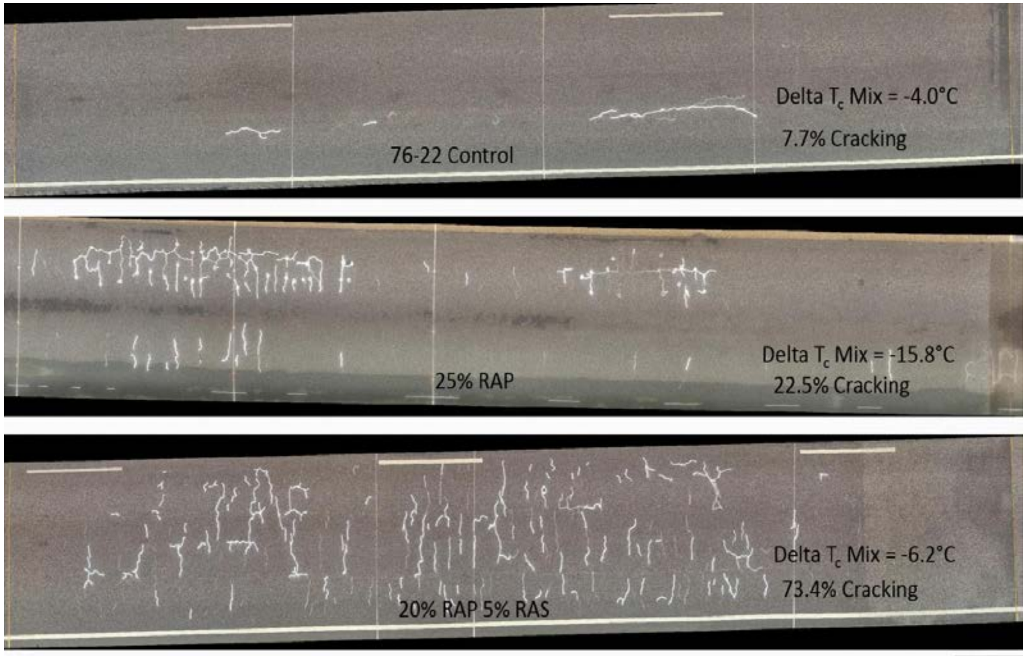
Airport – concept cont. (modified binders)

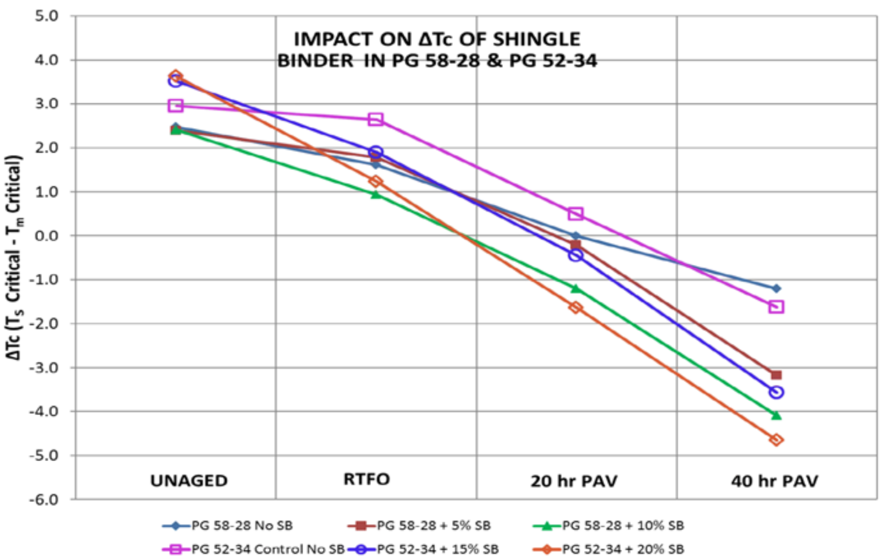
- Black space
  - updated with 600 kPa limit
- Top and bottom of cores
- Trend shows with modified binders



RAS

- Large amount of data being collected
- Data discussed at working group meeting – RAS Task Group – just a couple of examples..
  - NCAT 2012 section (Florida) – Laid in 2012 – 2-years old at time of photograph. On this photo ΔT_c was based on 20 hours.
  - Gerry Reinke – shows progression of ΔT_c for different binders aging



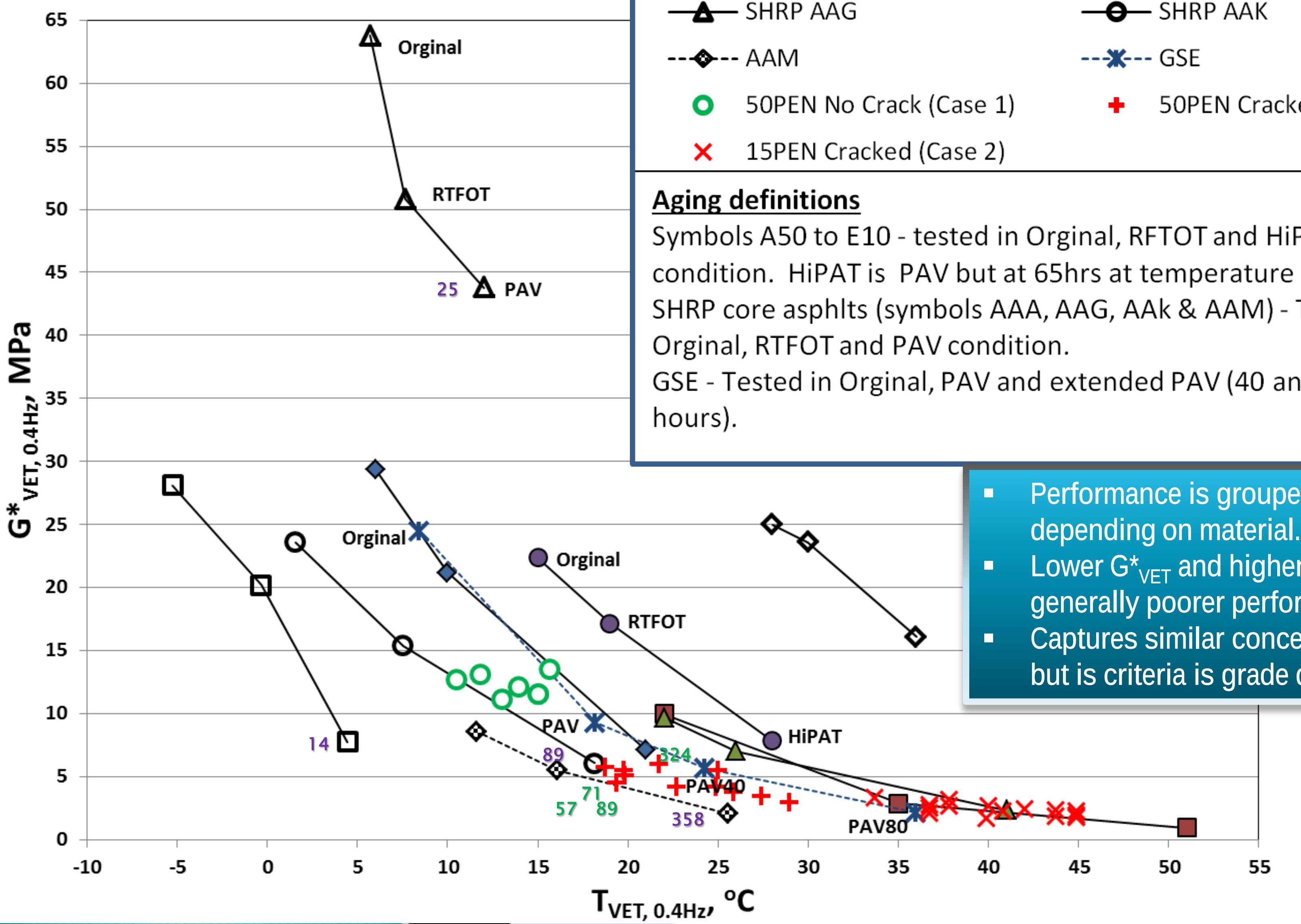


Other methods – VET

- Visco-elastic transition – based on concept of G’=G” when expressed as a function of temperature

  - G^*_{VET}
  - VET temperature

VET data



Aging definitions

Symbols A50 to E10 - tested in Orginal, RFTOT and HiPAT condition. HiPAT is PAV but at 65hrs at temperature of 85°C.

SHRP core asphlts (symbols AAA, AAG, AAk & AAM) - Tested in Orginal, RTFOT and PAV condition.

GSE - Tested in Orginal, PAV and extended PAV (40 and 80 hours).

- Performance is grouped depending on material.
- Lower G^*_{VET} and higher T_{VET} generally poorer performance.
- Captures similar concept to G-R but is criteria is grade dependent!

VET and G-R concept

- G-R and VET approaches can be interrelated
- G-R parameter can be plotted within VET space and explains VET cracking parameter
- VET cracking approach is related to R-value, stiffness and relaxation properties
  - Concept reversed with VET numbers
    - Lower E^*_{VET} = more blown and harder asphalt
    - Higher T_{VET} = harder material
  - VET criteria will be different for different binder grades
- Both methods describe stiffness and relaxation but in different ways

Also ΔT_c is related in similar manner

Summary and Action

- Summary
  - ΔT_c beginning to be used in specifications
  - Aspects include REOB, RAS, RAP, other binders, etc.
  - Concept between stiffness and relaxation important
  - Ties in with other concepts
    - G-R, VET, etc.
- Actions
  - Suggest that document on REOB be completed as is with that Task Group
  - Extend this document to include ΔT_c concept and this background written up as a support document

Thanks to …

REOB Task Group

Geoff Rowe (Abatech) (growe@abatech.com)

Louay Mohammad (LSU) (louaym@lsu.edu)

Bill Ahearn (VT Agency of Transportation) (bill.ahearn@vermont.gov)

Mark Buncher (Asphalt Institute) (MBuncher@asphaltinstitute.org)

Gerald Reinke (MTE Services) (Gerald.Reinke@mteservices.com)

Walaa Mogawer (UMass) (wmogawer@umassd.edu)

Nelson Gibson (FHWA) (Nelson.Gibson@dot.gov)

Tom Bennert (Rutgers) (bennert@rci.rutgers.edu)

Jean-Pascal Planche (WRI) (jplanche@uwyo.edu)

Imad Al-Qadi (U of IL) (alqadi@illinois.edu)

Pamela Marks (Ontario Ministry of Transportation) (pamela.marks@ontario.ca)

Laci Tiarks-Martin (PRI) (ltiarks@priasphalt.com)

John D'Angelo (Consultant) (johndangelo@dangeloconsultingllc.com)

Also inputs from RAS Mix Task Group, Mark Sharrock and others