The Relationship of Binder Delta Tc (ΔTc) to Mixture Fatigue

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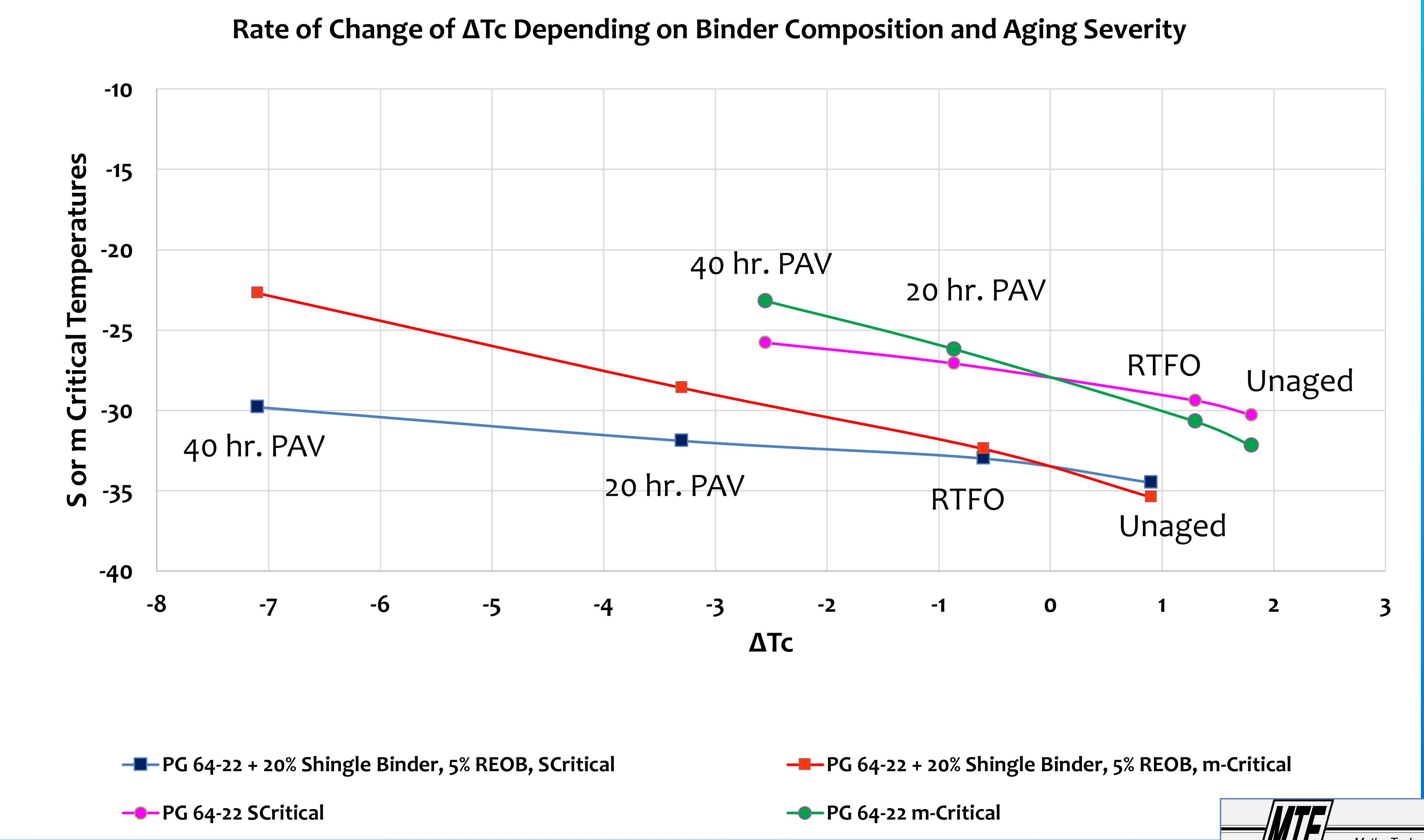
JUST WHAT IS ΔTc?

1. The very simple answer is ΔTc is the number you obtain when you subtract the BBR creep or m Critical Temperature from the BBR stiffness Critical Temperature ($T_{s\text{-critical}} – T_{m\text{-critical}}$)
   a. If the BBR S Temperature = -25.4°C and the BBR m-value Temperature = -24.6 °C then the ΔTc = (-25.4 - (-24.6)) which is -0.8°C ✓
2. To obtain an accurate value for ΔTc the BBR needs to be performed at enough temperatures so that
   a. BBR stiffness values < 300 MPa and > 300 MPa
   b. BBR m-values < 0.300 and > 0.300
   c. **Extended aging of binders , high levels of RAP and/or RAS, the use of high levels of additives such as REOB might require BBR testing at 3 or more temperatures** ✓
3. When BBR stiffness is less than ≈ 125 MPa and BBR m-value barely exceeds 0.300 then generally a 3rd BBR test temperature will be required to meet the requirements of 2.a and 2.b

When a binder exhibits a ΔTc of < -4 or -5 the S critical temperature increases at a substantially slower rate than does the m-critical temperature and this will necessitate the need for a 3rd BBR Test



JUST WHAT IS ΔTc ?

Now you've told me how to obtain the value of ΔTc,
But just why would I want or need to do that?

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   a. If the BBR S Temperature = -25.4°C and the BBR m-value Temperature = -24.6 °C then the ΔTc = (-25.4 - (-24.6)) which is -0.8°C

Now you've told me how to obtain the value of ΔTc,
But just why would I want or need to do that?

1. A more complete answer is ✓
   a. **As binders age they become more m-controlled** ✓
   b. **As binders become more m-controlled ΔTc becomes more negative** ✓
   c. **As pavements age they are more prone to cracking distress** ✓
   d. **As ΔTc becomes more negative pavements become more prone to top down fatigue cracking** ✓
   e. **It may not appear intuitively obvious that a value derived from low temperature testing should be associated with distresses that are associated with intermediate service temperatures** ✓
   f. **Based on research, some of which goes back 50+ years, I will show the connections between pavement surface distresses and several parameters the most recent of which is ΔTc** ✓

Simply Stated

ΔTc quantifies the aging propensity of a binder

IN THE FINAL ANALYSIS ΔTc COMES DOWN TO 1 THING

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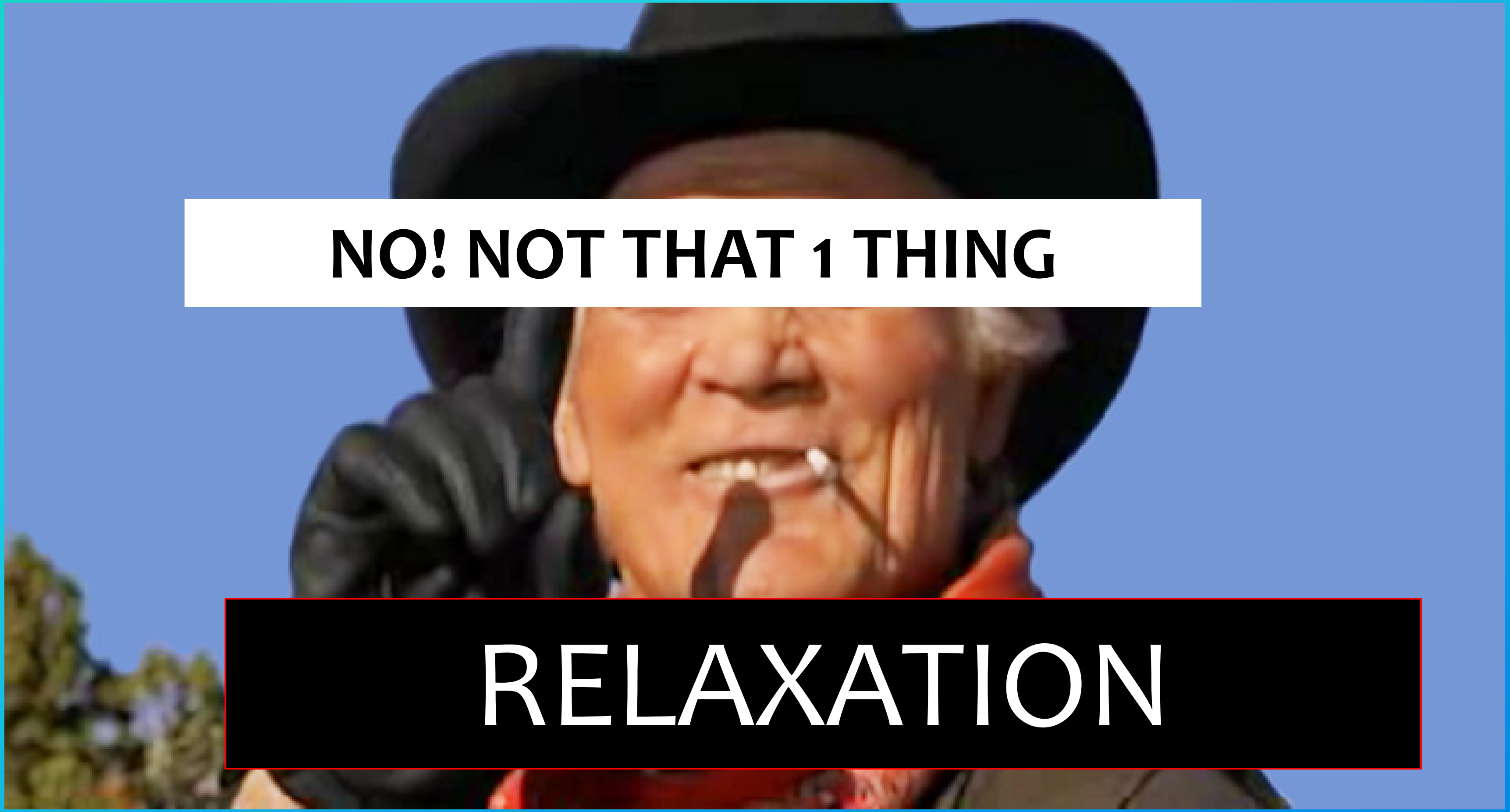
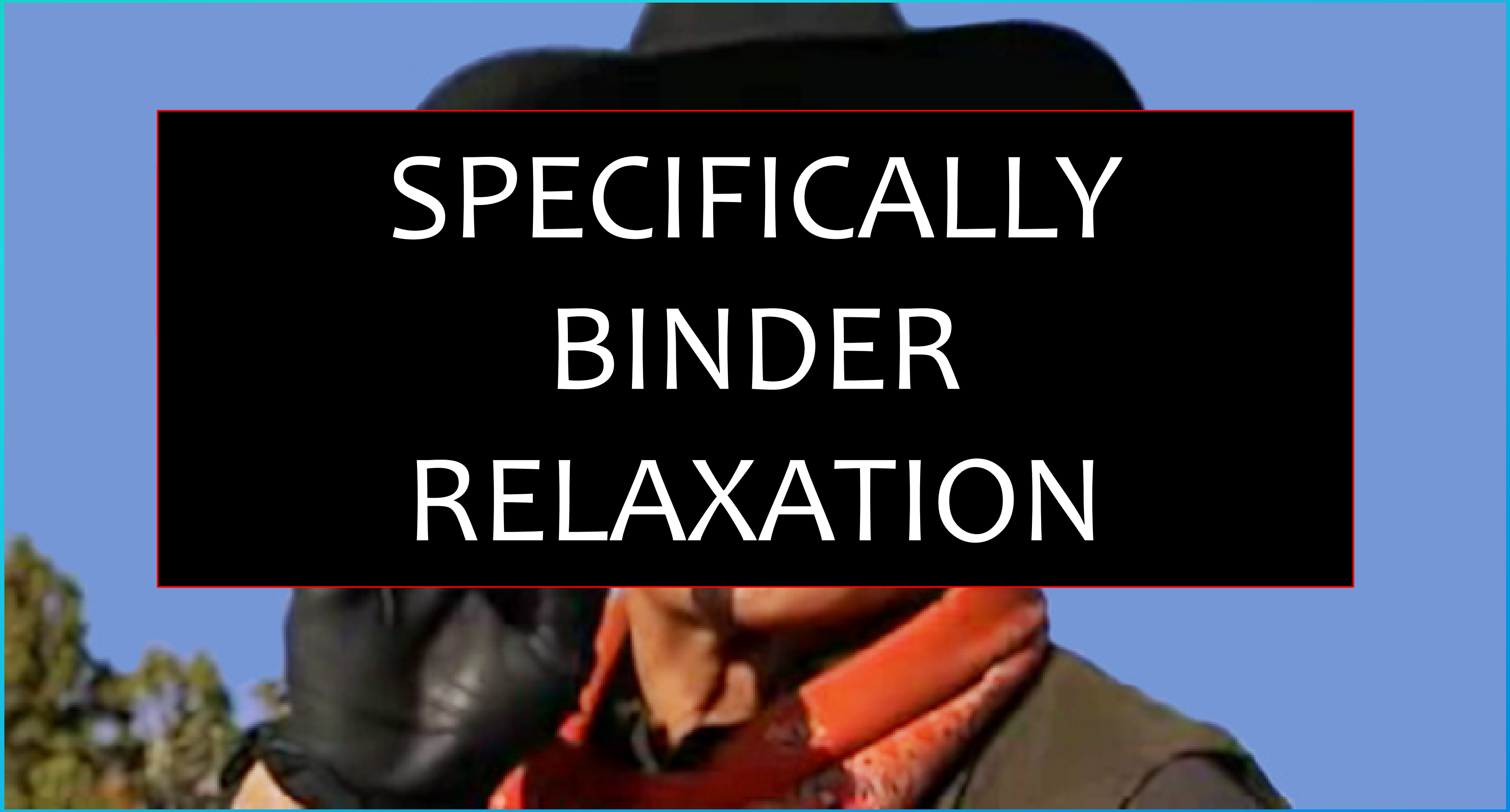


IN THE FINAL ANALYSIS ΔTc COMES DOWN TO 1 THING



TIME TO GET SERIOUS

- As with most advances in technical research developments are the result of cumulative increase in knowledge ✓
- I will focus on three individuals, but reading their research will show the many other contributors along the way
- Prithvi (Ken) Kandhal – Pennsylvania DOT Bituminous Engineer
- Dr. Charles Glover—Research Professor Texas Transportation Institute at Texas A&M
- Mike Anderson—Director of Research at the Asphalt Institute

KANDHAL'S WORK IN PENNSYLVANIA

- In 1961 and 1962 test pavements constructed in Pennsylvania
- Pavement performance tracked for more than 10 years and reported in 1977 ASTM symposium
  - Surface distress noted
  - Binder recovered at periodic intervals
    - Penetration at 77°F and ductility at 60°F & 5 cm/min tested ✓
- He found that when ductility dropped below 5 cm cracking became an issue ✓
- Provided additional references to other similar research
- Kandahl, Low Temperature Ductility in Relation to Pavement Performance, ASTM STP 628, Marek, Ed., 1977

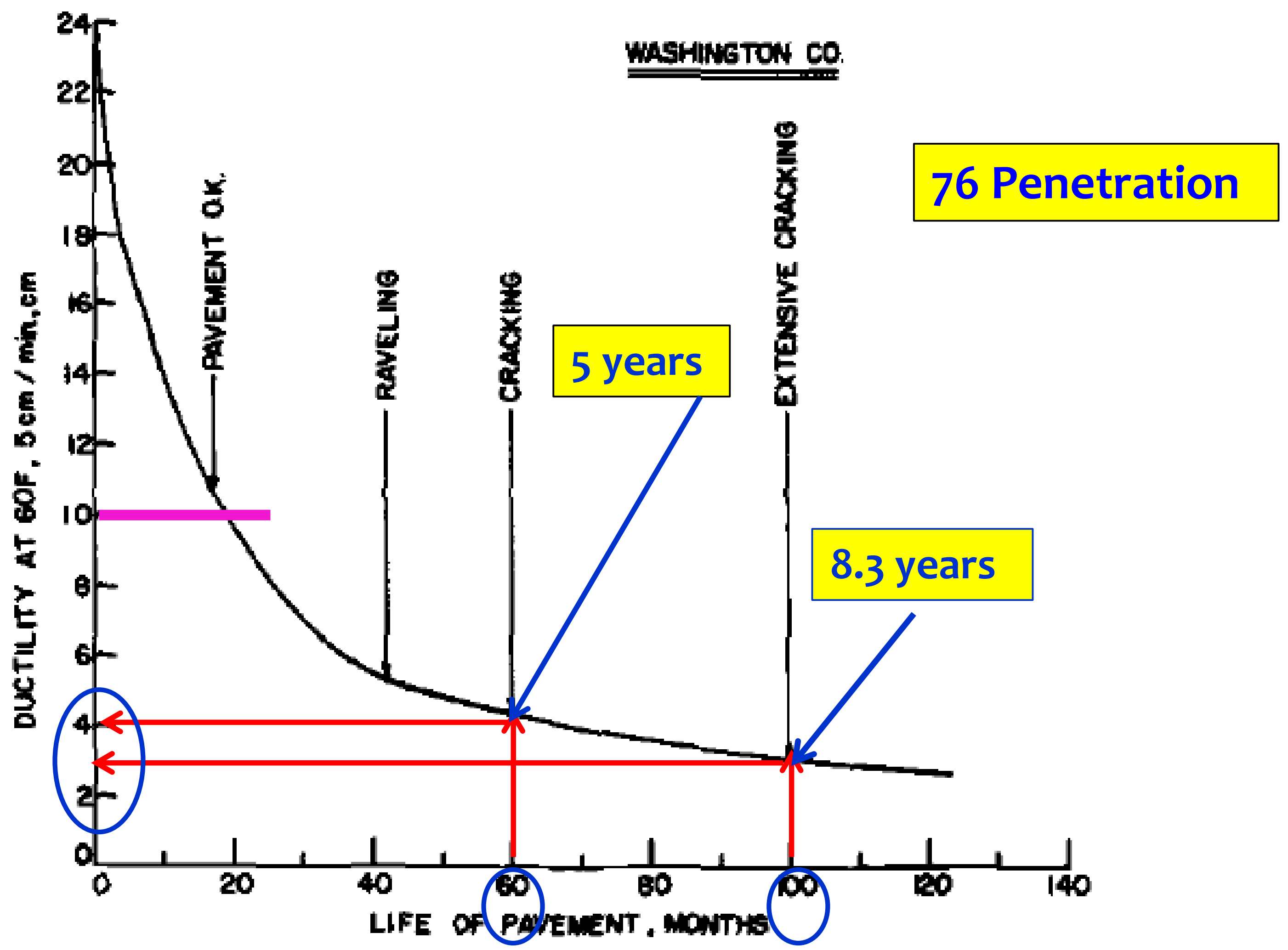


FIG. 7—*Ductility (60° F) versus time in months (Washington County).*

KEY POINTS

1. At 10 cm ductility pavement in good condition
2. At 5 years, when ductility reached 4 cm cracking had developed
3. At 8.3 years extensive cracking had developed and ductility had decreased to 3 cm
4. These ductility levels are important and will be referenced throughout this document

Reproduced from Kandahl 1977

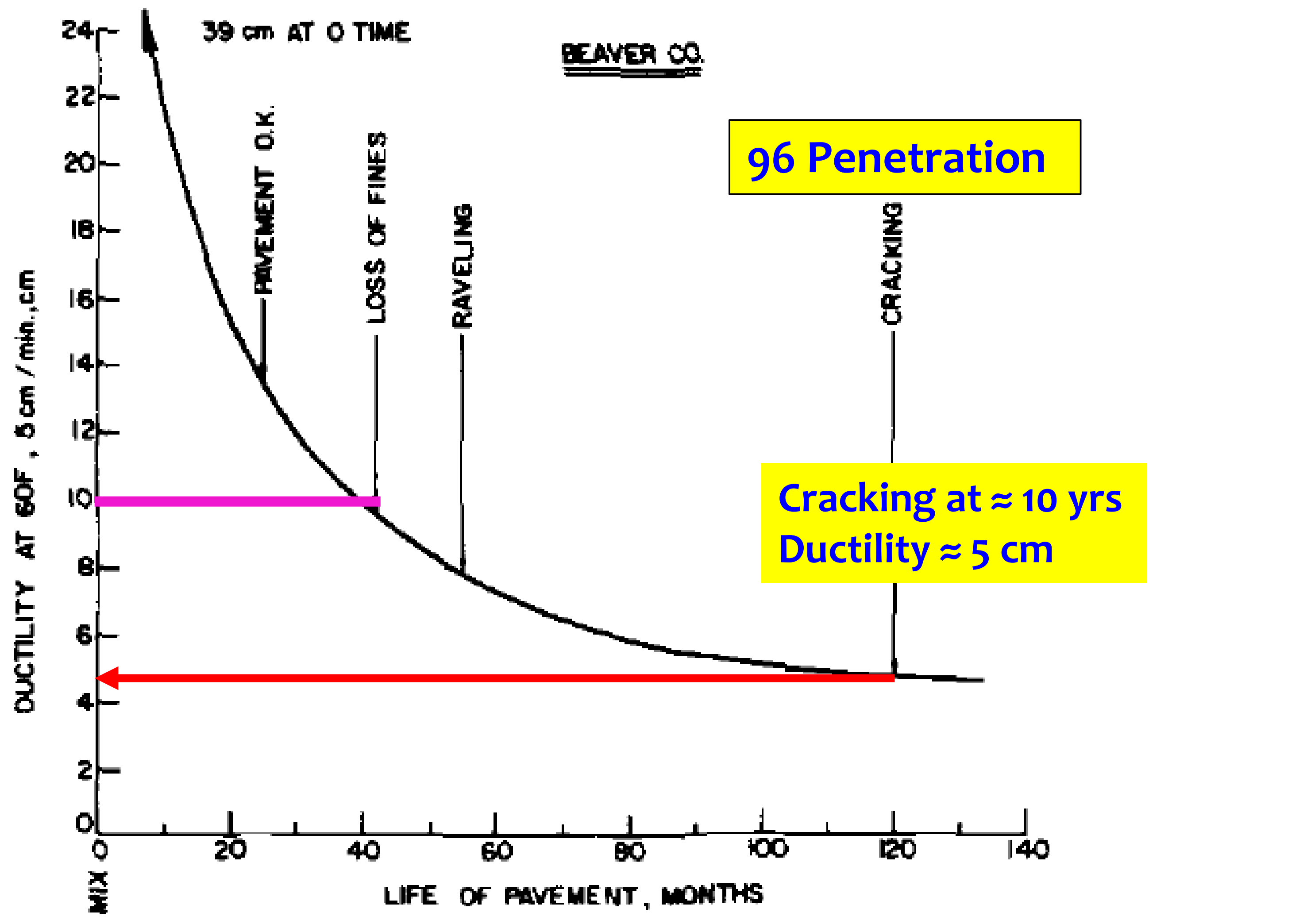


FIG. 5—*Ductility (60° F) versus time in months (Beaver County).*

KEY POINTS

1. At 10 cm ductility pavement in showed loss of fines but no cracking, at ≈ 42 months (3.5 years)
2. Cracking was not noted until ≈ 10 years at which point ductility was <5 cm

Reproduced from Kandhal 1977

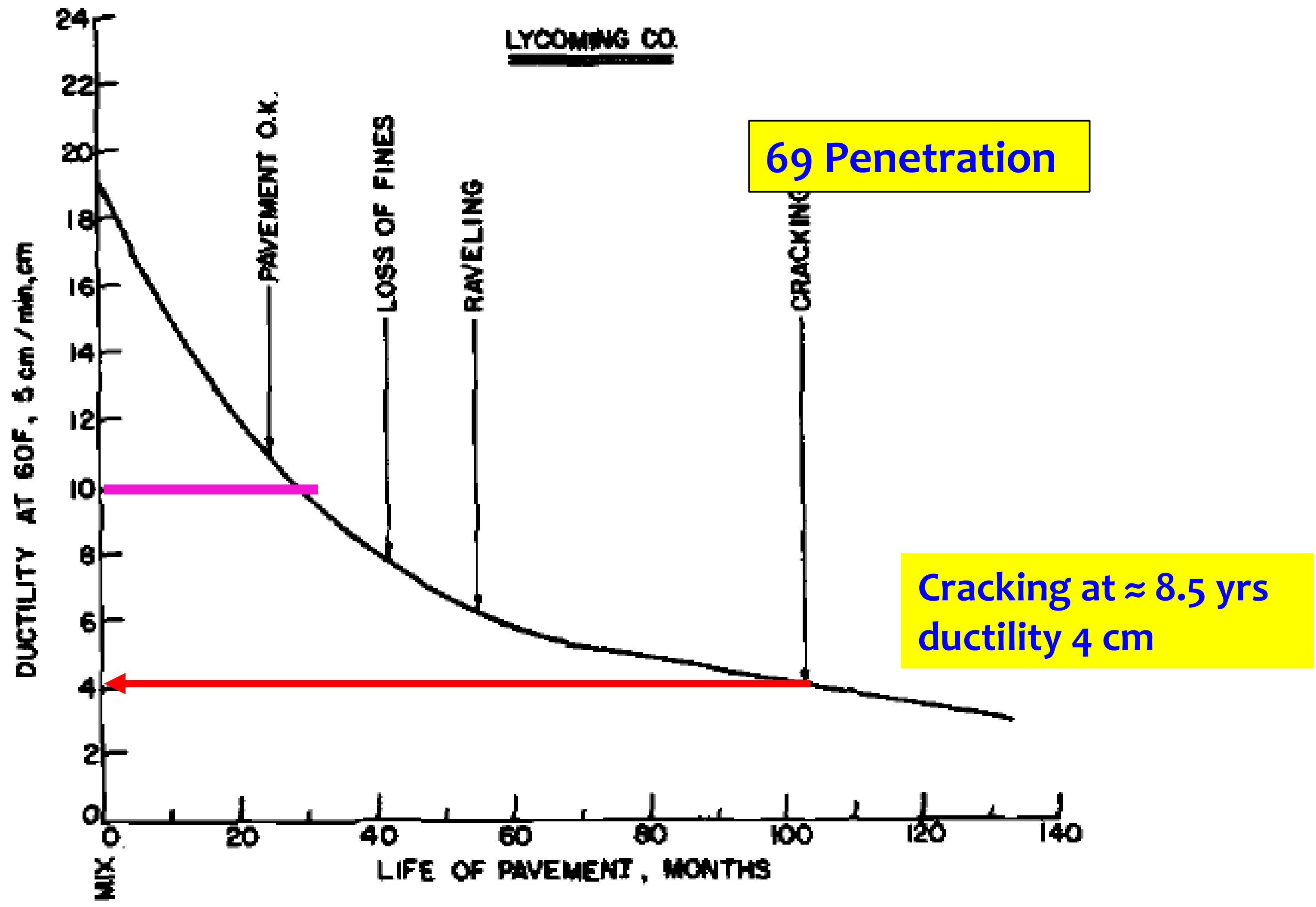


FIG. 6—*Ductility (60° F) versus time in months (Lycoming County).*

KEY POINTS

1. At 10 cm ductility (≈29 months/2.4 years) pavement in good condition, no cracking
2. Cracking was not noted until ≈ 8.5 years at which point ductility was 4 cm

Reproduced from Kandhal 1977

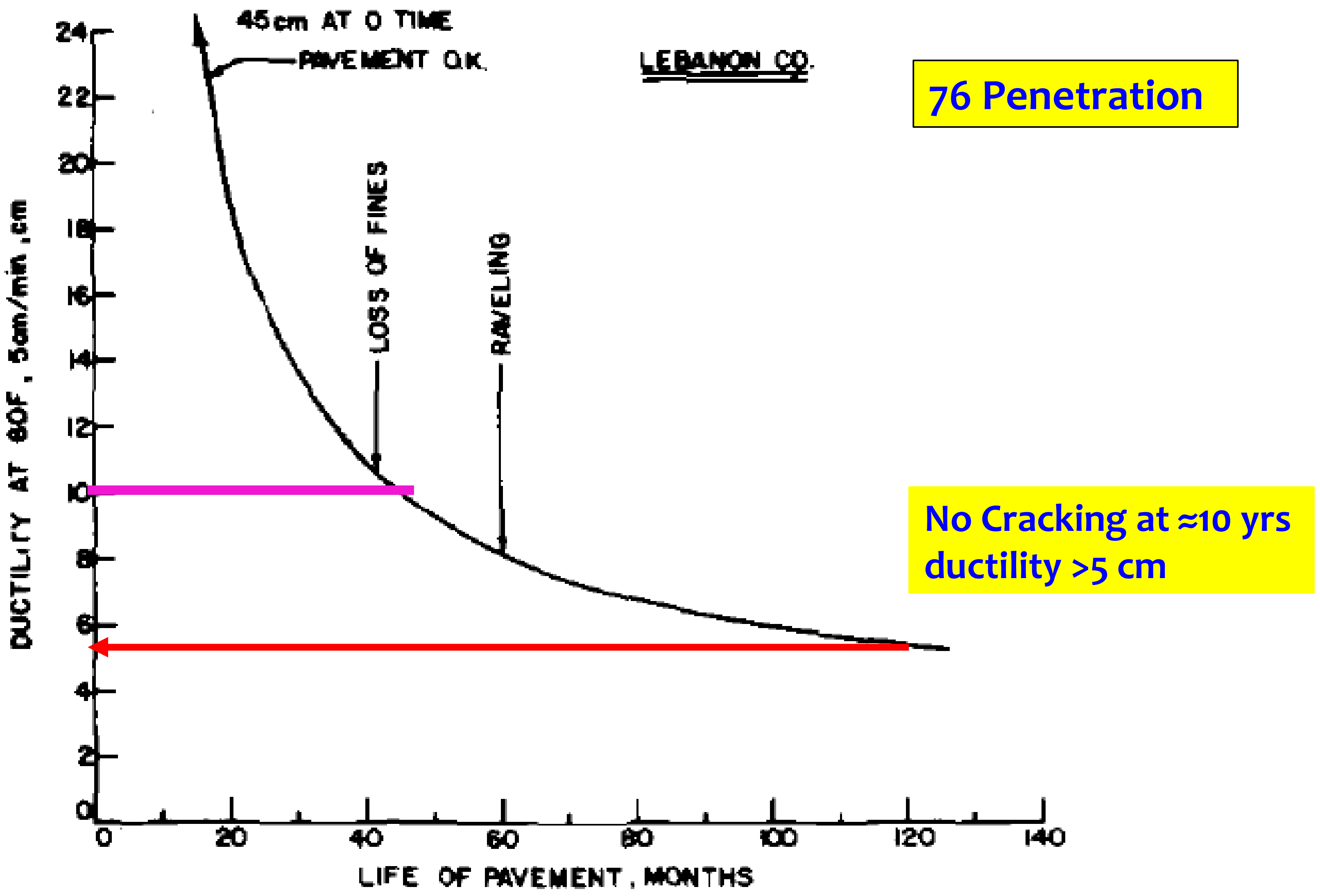


FIG. 8—*Ductility (60° F) versus time in months (Lebanon County).*

KEY POINTS

1. At 10 cm ductility pavement in showed loss of fines but no cracking, at ≈ 45 months (3.75 years)
2. Cracking was not noted at 10 years at which point ductility was still >5 cm

Reproduced from Kandhal 1977

Ductility and Pavement Condition of 1961 and 1962 Pennsylvania Pavements Reported by Kandhal (**Kandhal 1977**)

Ductility value at 60°F (15.5°C), 5 cm/min, cm	Pavement Condition Observed
More than 10	Satisfactory
8 to 10	Loss of fines (matrix)
5 to 8	Raveling
3 to 5	Cracking, needs resurfacing
Less than 3	Very poor, extensive cracking

SOME COMMENTS REGARDING KANDHAL'S WORK

1. At 10 cm ductility there is no cracking reported, however when it takes longer than 3 years to reach 10 cm loss of fines and some raveling is noted
2. Regardless of the time it takes to reach less than 5 cm of ductility that ductility value is associated with the onset of cracking
3. Extent of binder aging is the key factor and not the time of binder aging

What Can We Infer From This Data?

- There is a point in the aging of binder when cracking begins to develop
- Binder aging is not the same for every binder *(crude source impacts performance)* or perhaps it is not the same time point for the same binder depending on the conditions of the job construction
  - Time of year constructed
  - % bitumen in the mix
  - Air voids
  - Aggregate type and/or gradation
  - Other factors ???
- Extent of Binder Aging is the Key Driver
- How can we age binders and mixtures sufficiently in the lab to tell us something useful about long term performance?

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Follow On From Kandhal

- In 2005 Dr. Charles Glover, et al published a study detailing more than 4 years of research ✓
  a) Objective—Determine asphalt binder properties related to pavement performance
  b) Objective—Develop test methods to measure the properties
  c) Objective—Develop criteria for the measured properties ✓
  d) Glover's work originally based on ductility at 15°C & 1 cm/min and correlated ductility to a DSR function (G'/ η'/G') tested at 15°C & 0.005 radians/sec
  e) This was an effort to move beyond the mostly empirical ductility test to a more fundamental rheology based test

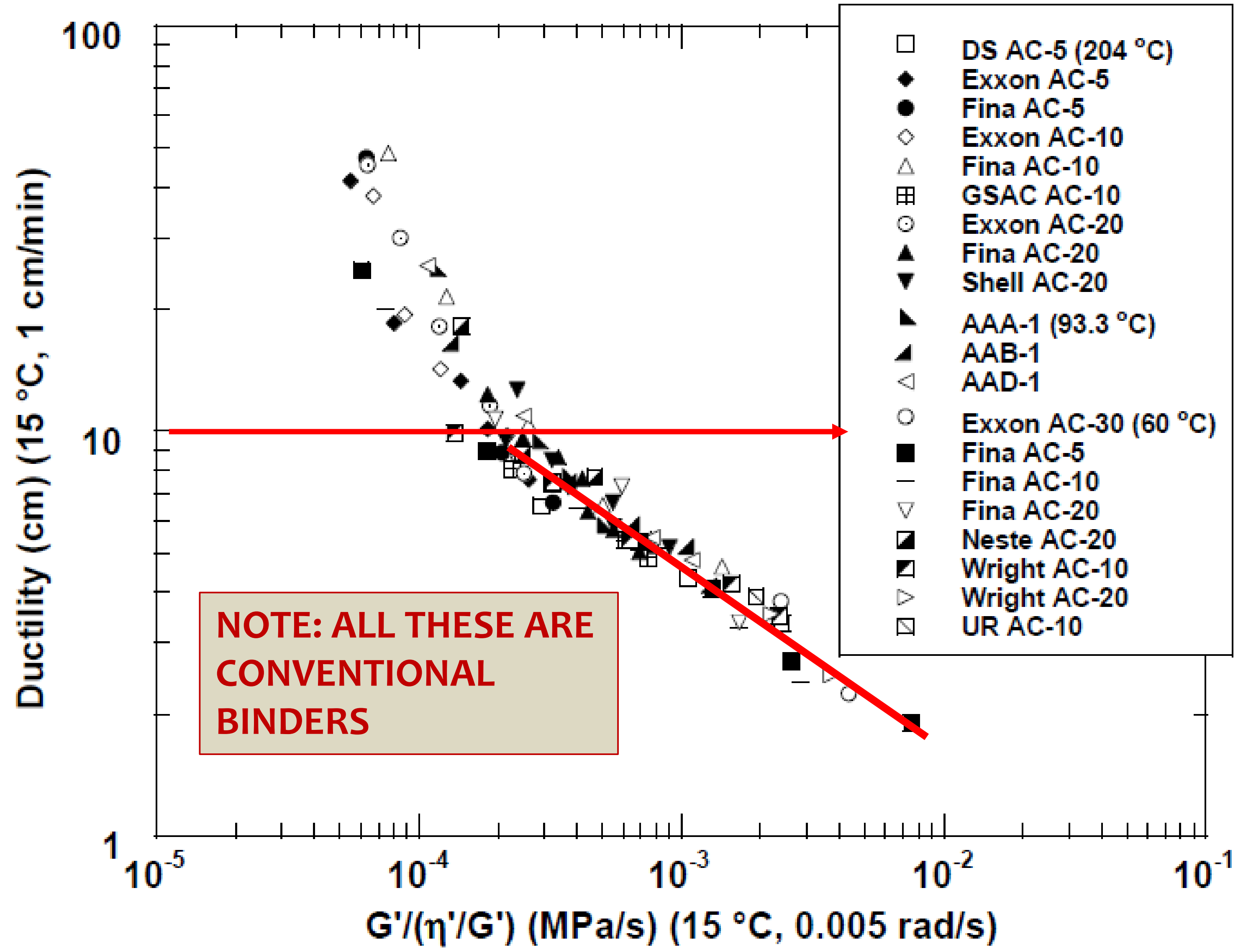


Figure 4-11. Ductility versus DSR Parameter G′/(η′/G′), All Ductilities.

Taken from Glover, et al 2005, plot shows

1. Linear correlation between G'/ η'/G' and 15°C ductility for ✓ ductility values < 10 cm
2. Based on Kandhal's data when ductility drops below 10 pavement distress begins ✓
3. The time required to perform a rheological test at a frequency of 0.005 rad/sec is excessive ✓
4. Glover used time temperature superposition principles to adjust the DSR test to 44.7°C and 10 rad/sec ✓

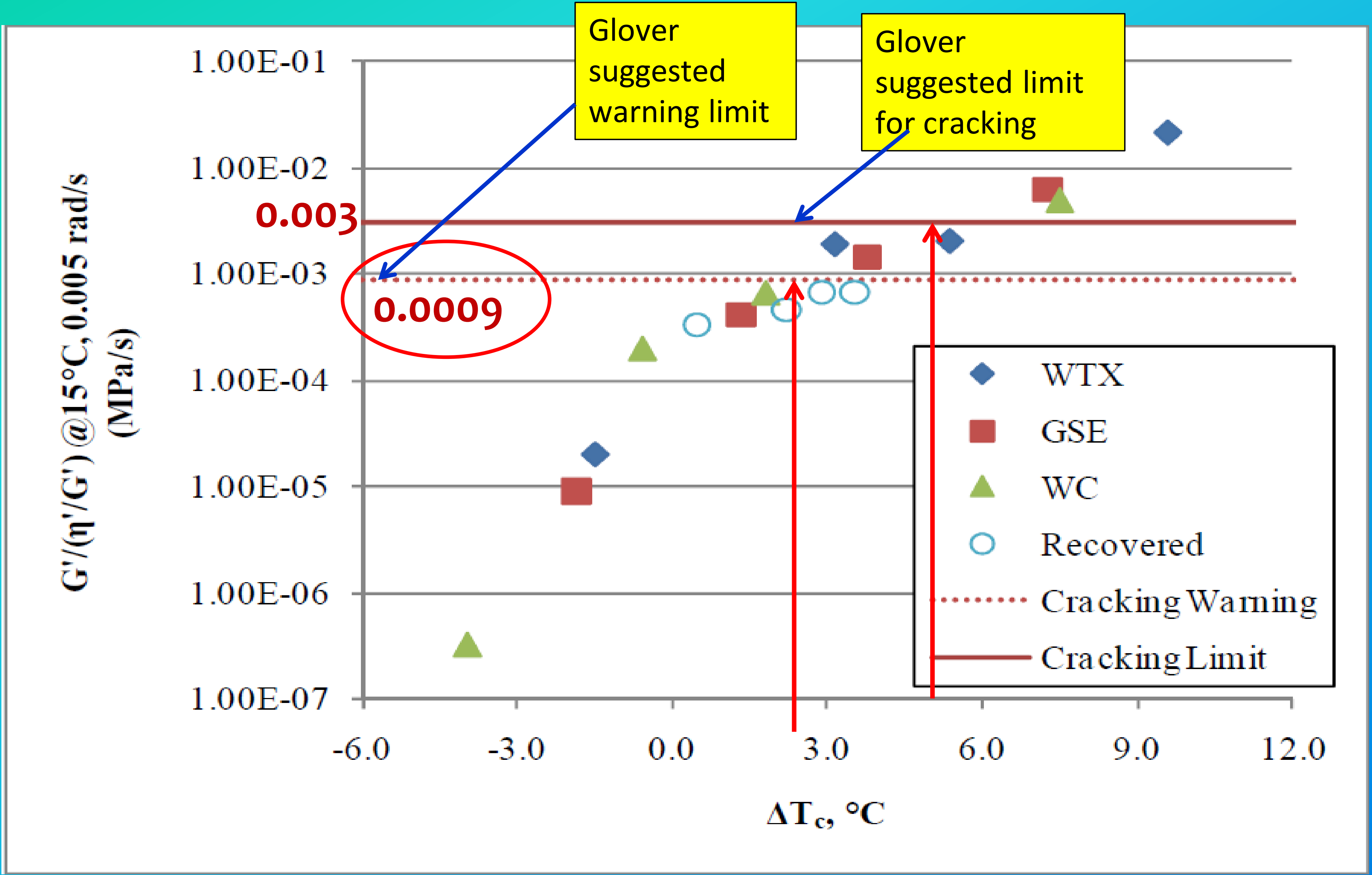
Moving from Ductility to ΔTc—Glover Recommendations

1. Glover recommended harsher aging criteria than current PAV for binder aging specification testing ✓
   a) Film thickness of 0.857 mm (≈1/3 PAV thickness), 32 hrs. @ 90°C and 20 atmospheres air pressure ✓
2. G'/ η'/G' less than 0.003 MPa stiffness (≈3 cm ductility @ 15°C) ✓
3. G'/ η'/G' of 0.0009 MPa stiffness (≈5 cm ductility @ 15°C) border line for pavement cracking ✓
4. You will note that current binder spec's do not following these recommendations
5. This does not mean they are without merit

Moving from Ductility to ΔTc

- Anderson, et al AAPT 2011—**introduced ΔTc concept** ✓
- Rheological & ductility of PAV binders and binders recovered from aged airfield mixtures
- Established Relationship of ΔTc to non-load associated distress
- Key findings ✓
  1) Glover @ Texas A&M had shown ductility @ 15°C & 1 mm/min correlated to long term pavement distress ✓
  2) G'/(η'/G') correlated to ductility @ 15°C & 1 mm/min ✓
  3) Also G'/(η'/G') correlated to ΔTc (difference between the BBR $T_{m\text{-critical}}$ – BBR $T_{s\text{-critical}}$ ✓
  4) ΔTc of 2.5°C = cracking warning limit, ΔTc = 5°C point where binder durability lost ✓

Relationship between (G'/(η'/G') and ΔTc taken from (Anderson, 2011)



1. **Glover Crack warning limit of 0.0009 MPa was equivalent to ΔTc ≈ 2.5°C**
2. **Glover Cracking limit of 0.003 MPa was equivalent to ΔTc ≈ of 5°C**

Some Necessary Explanation to Avoid Confusion

1. In their 2011 paper Anderson, et al used the concept of BBR $T_{m\text{-critical}}$ – BBR $T_{S\text{-critical}}$ to determine ΔT_c ✓
   a) **∴ ΔT_c had positive values when the binder was m-controlled** ✓
2. The convention has now been switched to ΔT_c= BBR $T_{\mathbf{S\text{-critical}}}$– BBR $T_{\mathbf{m\text{-critical}}}$ which results in negative values of ΔTc for m-controlled binders ✓
3. ***Therefore the more negative the value of ΔTc the more likely the binder and mix will have performance problems*** ✓

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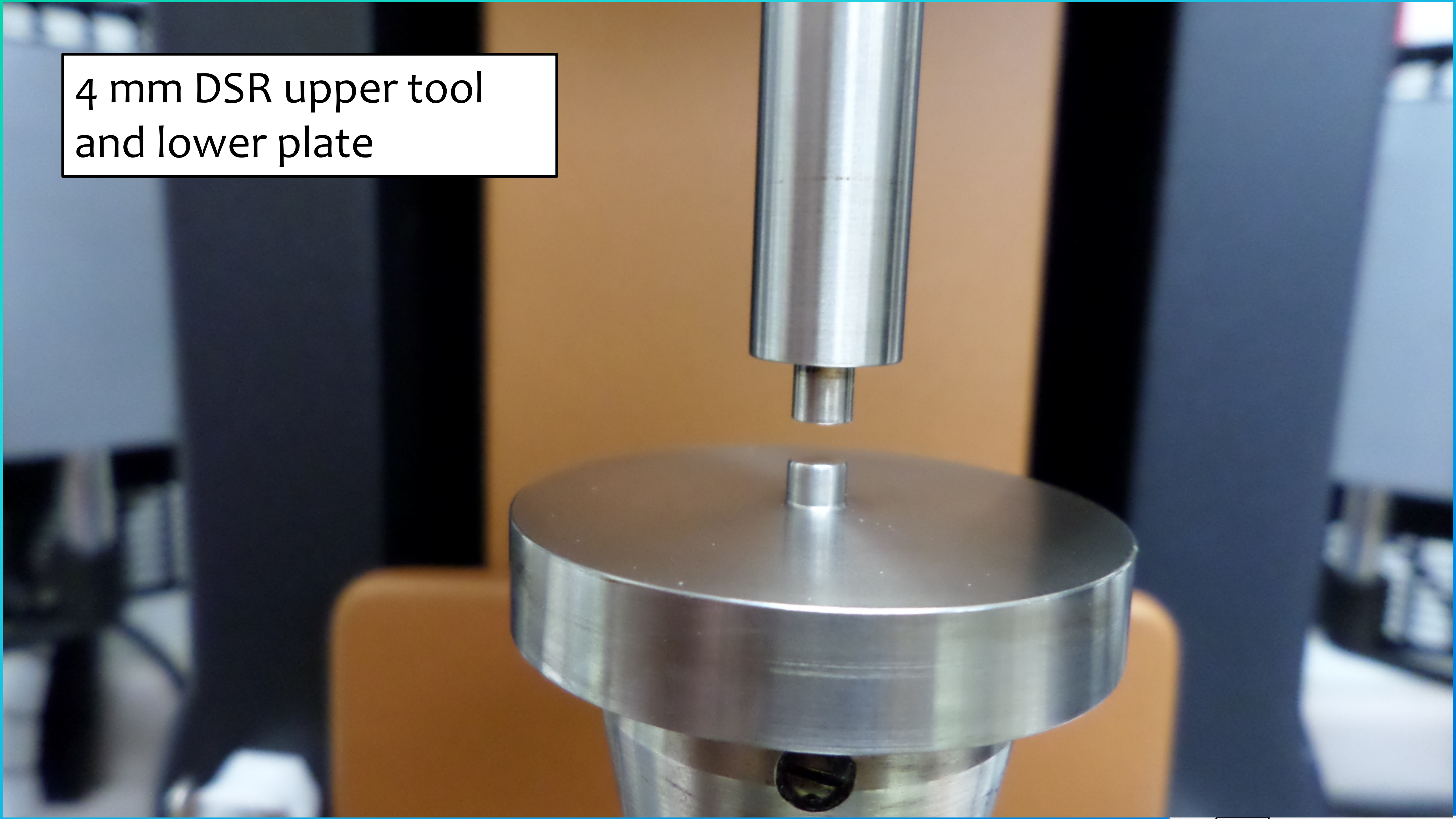
ΔTc and 4 mm DSR Testing

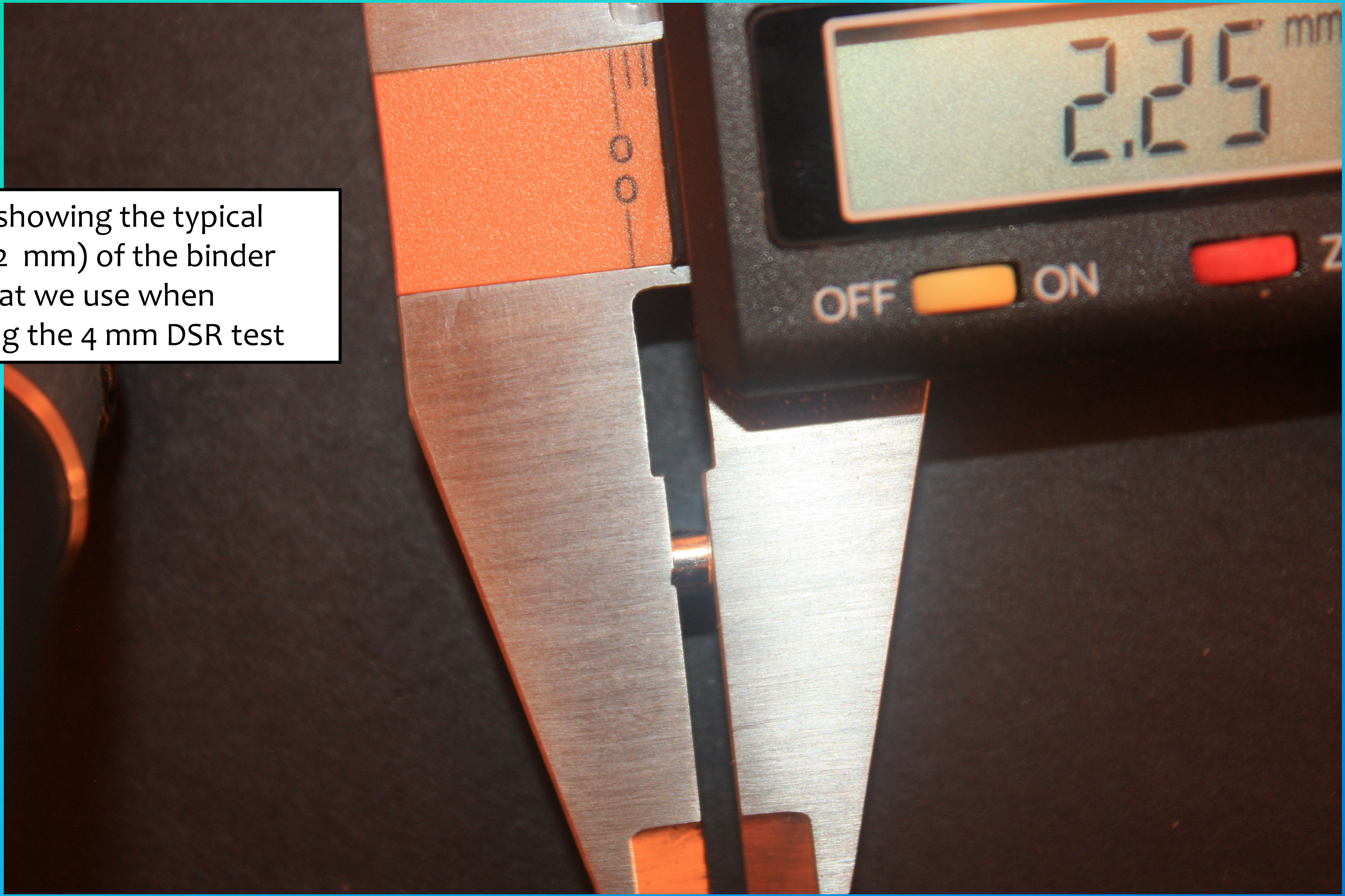
- Much of the data to be discussed next was generated at MTE using a 4 mm DSR test developed at Western Research Institute (see reference list)
- Requires very little material to perform test ✓
- Requires research grade DSR and environmental chamber
  - Peltier controlled DSR's have proven problematic ✓
- Results correlate well to BBR, but there is a learning curve ✓
- Provides a broader temperature range (-36°C to +30°C or +40°C) of data collection in the time it would take perform the BBR test at 3 temperatures ✓

4 mm DSR upper tool and lower plate

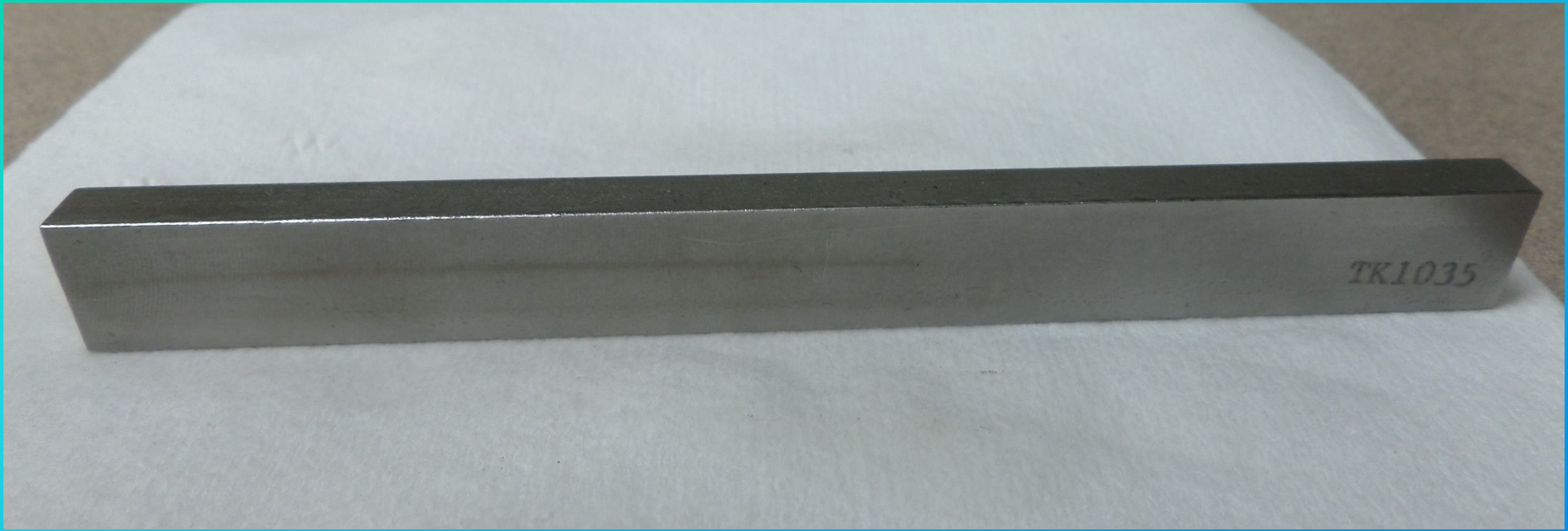


A picture showing a 4 mm diameter cylinder of metal to provide an image of the sample size of binder used in the test

A picture showing the typical height (2.2 mm) of the binder sample that we use when performing the 4 mm DSR test



A picture comparing images corresponding (roughly) to the typical 25 mm diameter sample for unaged and RTFO samples, the 8 mm sample for PAV DSR tests and the 4 mm diameter sample for the low temperature DSR test.



The size advantages are obvious for performing tests on field samples and other forensic work

When the main mixture layer that needs testing is binder recovered from the top ½ inch of a 6 inch diameter core very little binder is obtained and the 4 mm test requires only one core to provide sufficient binder for a 25 mm and 4 mm test

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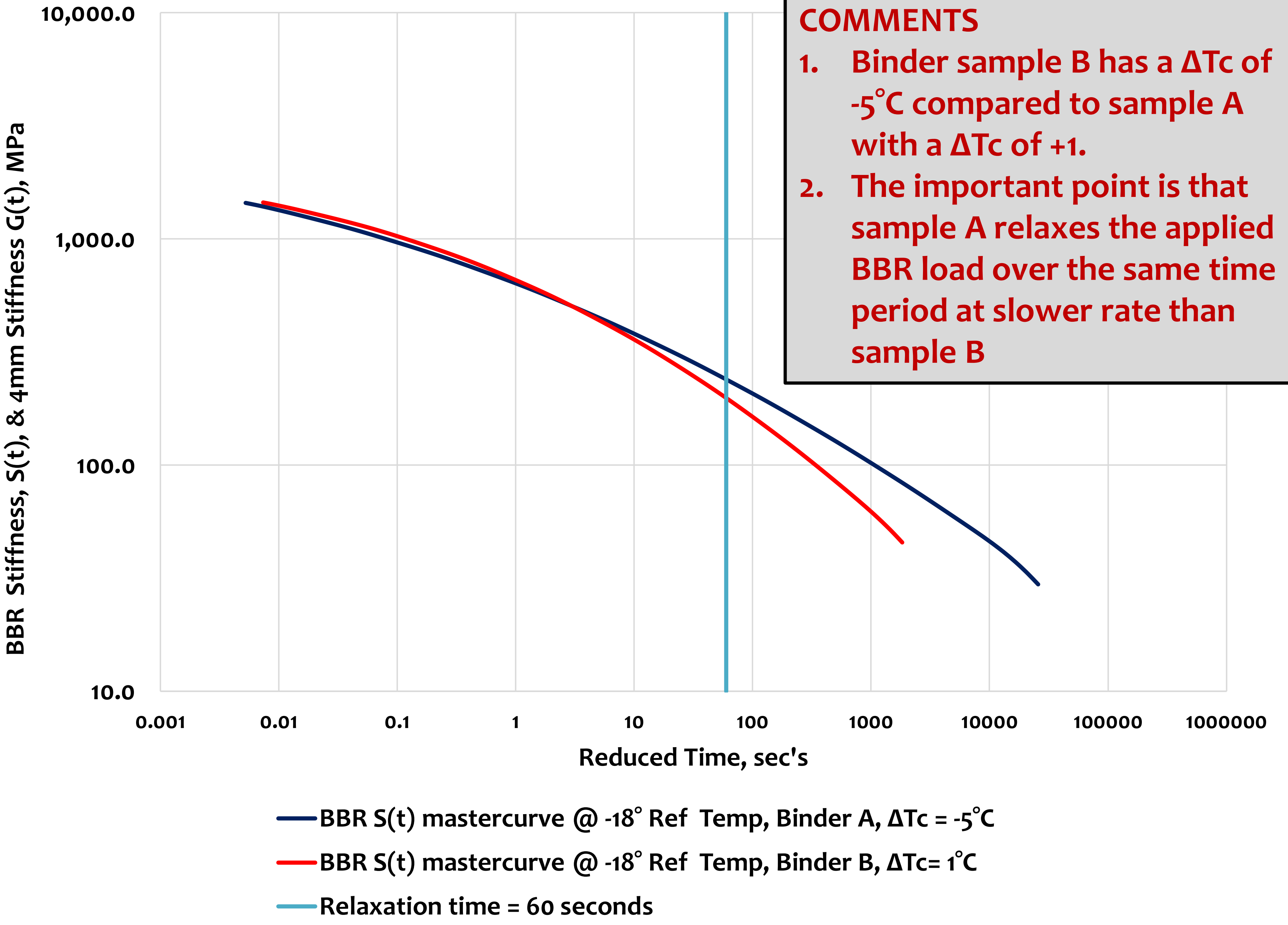
Just How Does ΔTc Relate to Mix Performance?

- Need to get back to RELAXATION
- As binders age their ability to relax stress diminishes ∴ BBR result becomes increasingly m-controlled (poor relaxation) ✓
- Some binders have inherently poor relaxation properties, BBR will show this and ΔTc will quantify ✓
- This is not just a low temperature (i.e. sub 0°C) problem
  - Ductility decreases when binder cannot relax fast enough to prevent the binder thread from breaking (Kandhal & Glover at 15°C)
  - The DSR data shows similar behavior (Glover's DSR vs Ductility Plot another test performed at 15°C)

Just How Does ΔTc Relate to Mix Performance?

- How many of you have really looked at or compared the BBR data plot for two different binders?
- BBR test is not just a single data point at 60 seconds
- In that plot is the story of how the binder relaxes (or doesn't) due to the imposition of load

COMPARISON OF BBR MASTERCURVES @ -18°C FOR TWO DIFFERENT BINDERS



COMMENTS

1. Binder sample B has a ΔTc of -5°C compared to sample A with a ΔTc of +1.
2. The important point is that sample A relaxes the applied BBR load over the same time period at slower rate than sample B

1. If you only focus on the slope at 60 seconds you will see a difference, but it is just a comparison of 2 numbers
2. When you look at the complete BBR mastercurve you see how much more readily the binder with a ΔTc of 1°C relaxes stress compared to the binder with a ΔTc of -5°C

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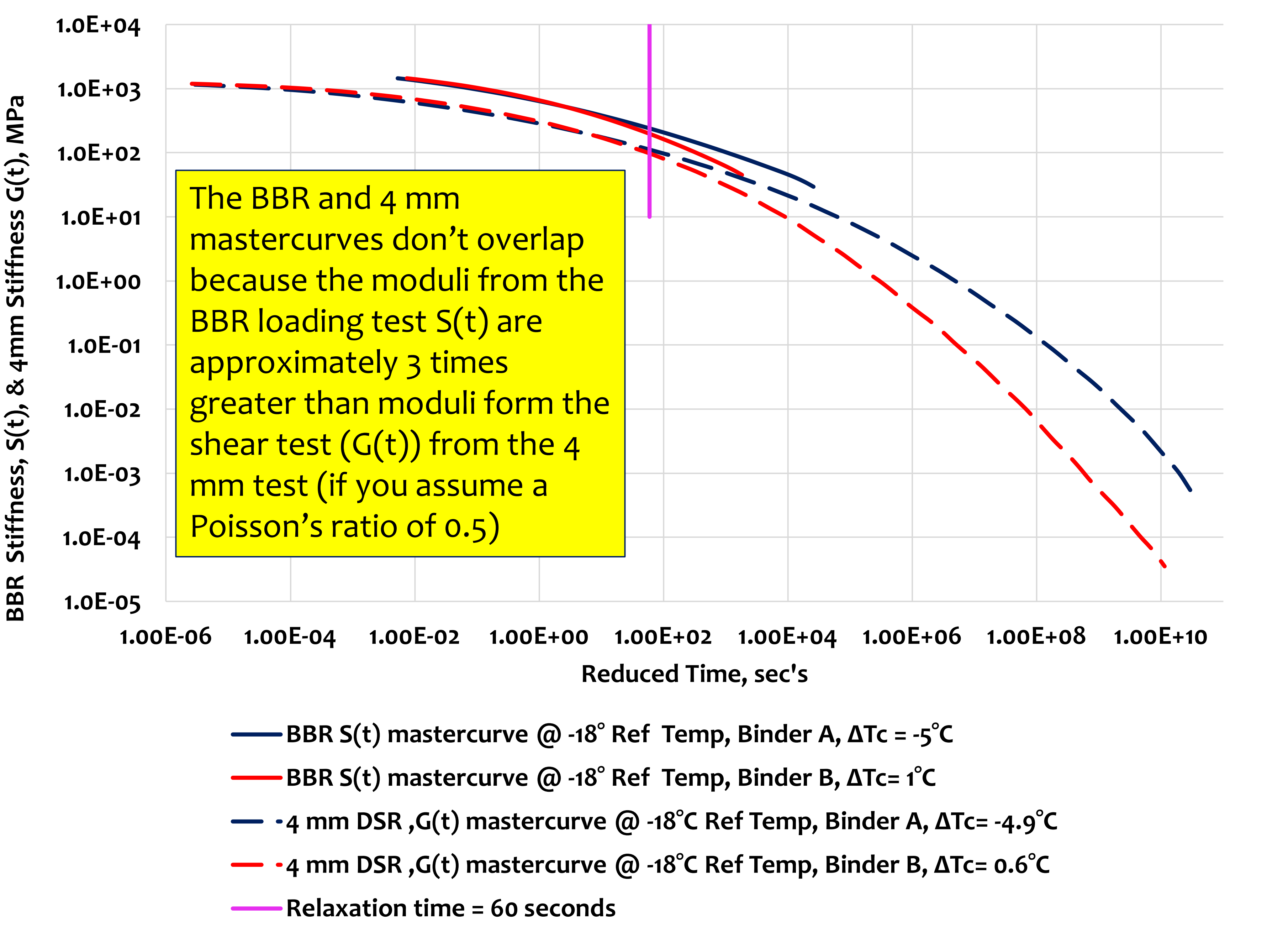
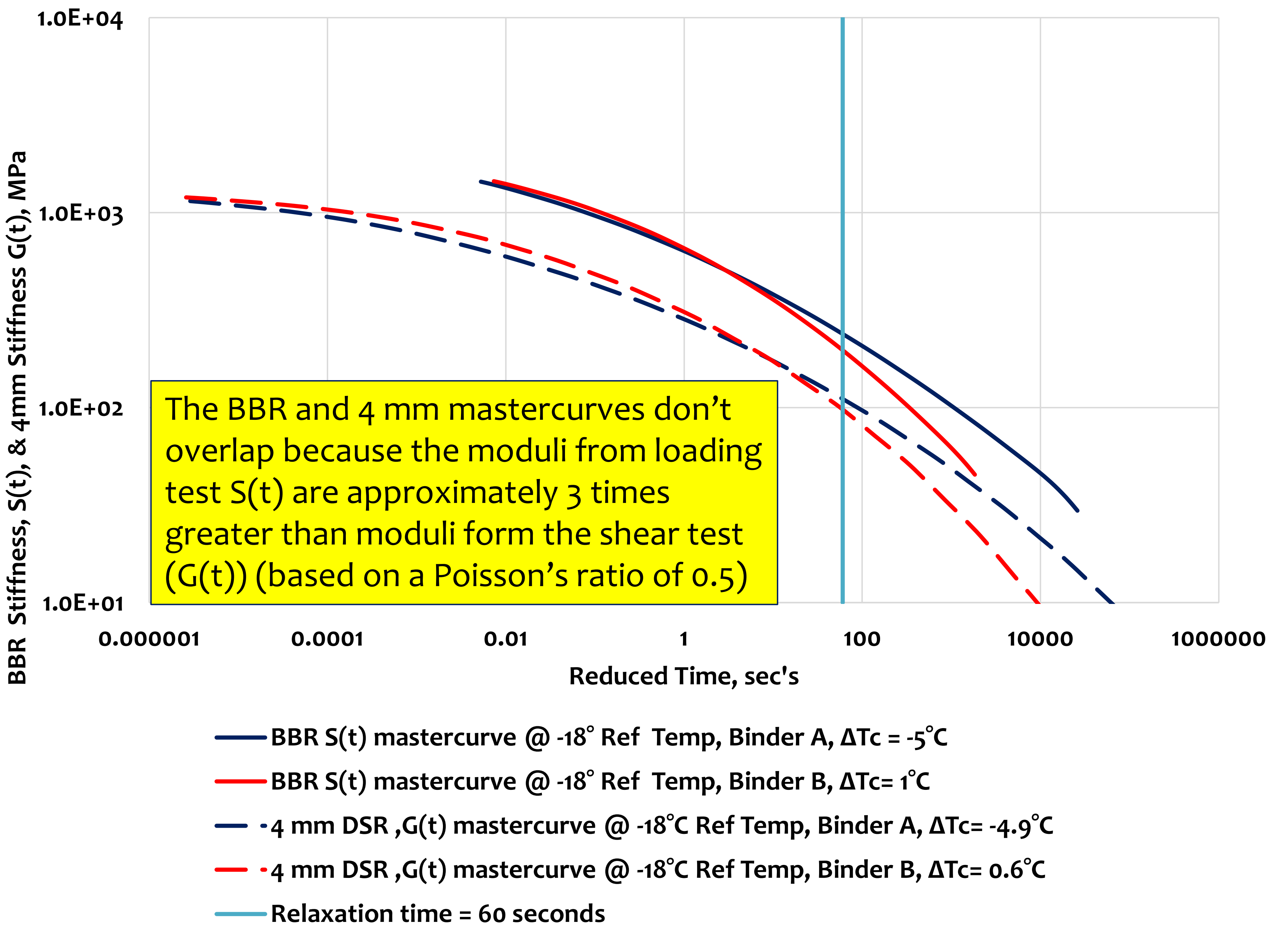
COMPARISON OF BBR & 4 mm MASTERCURVES @ -18°C FOR TWO DIFFERENT BINDERS



1. When you incorporate the 4 mm data for the same binders similar ΔTc results are obtained, but you also observe how the relaxation disparity carries over to longer relaxation times
2. Longer relaxation times are a surrogate for relaxation behavior at warmer temperatures

ZOOMED COMPARISON OF BBR & 4 mm MASTERCURVES @ -18°C FOR TWO DIFFERENT BINDERS



1. When you incorporate the 4 mm data for the same binders similar ΔTc results are obtained, but you also observe how the relaxation disparity carries over to longer relaxation times
2. Longer relaxation times are a surrogate for relaxation behavior at warmer temperatures
3. In the zoomed image the difference between the slopes of the 4 mm curves at 60 seconds are more apparent

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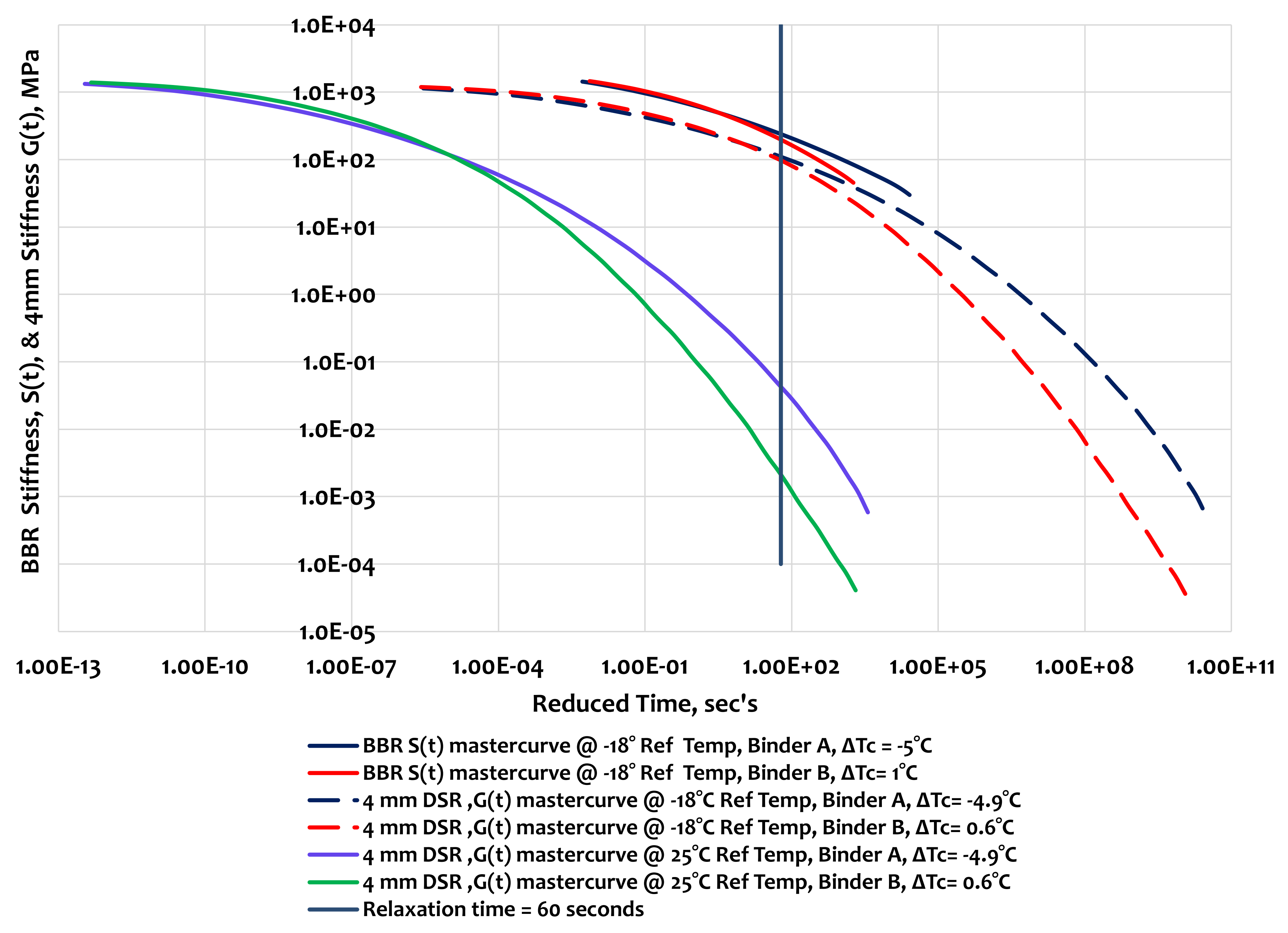
COMPARISON OF BBR & 4 mm MASTERCURVES @ -18°C & 25°C FOR TWO DIFFERENT BINDERS



If binders have a relaxation disparity at low temperatures they also have a relaxation disparity at warmer temperatures

An additional benefit of the 4 mm test is the ability to examine the binder's behavior at temperatures beyond those capable by the BBR

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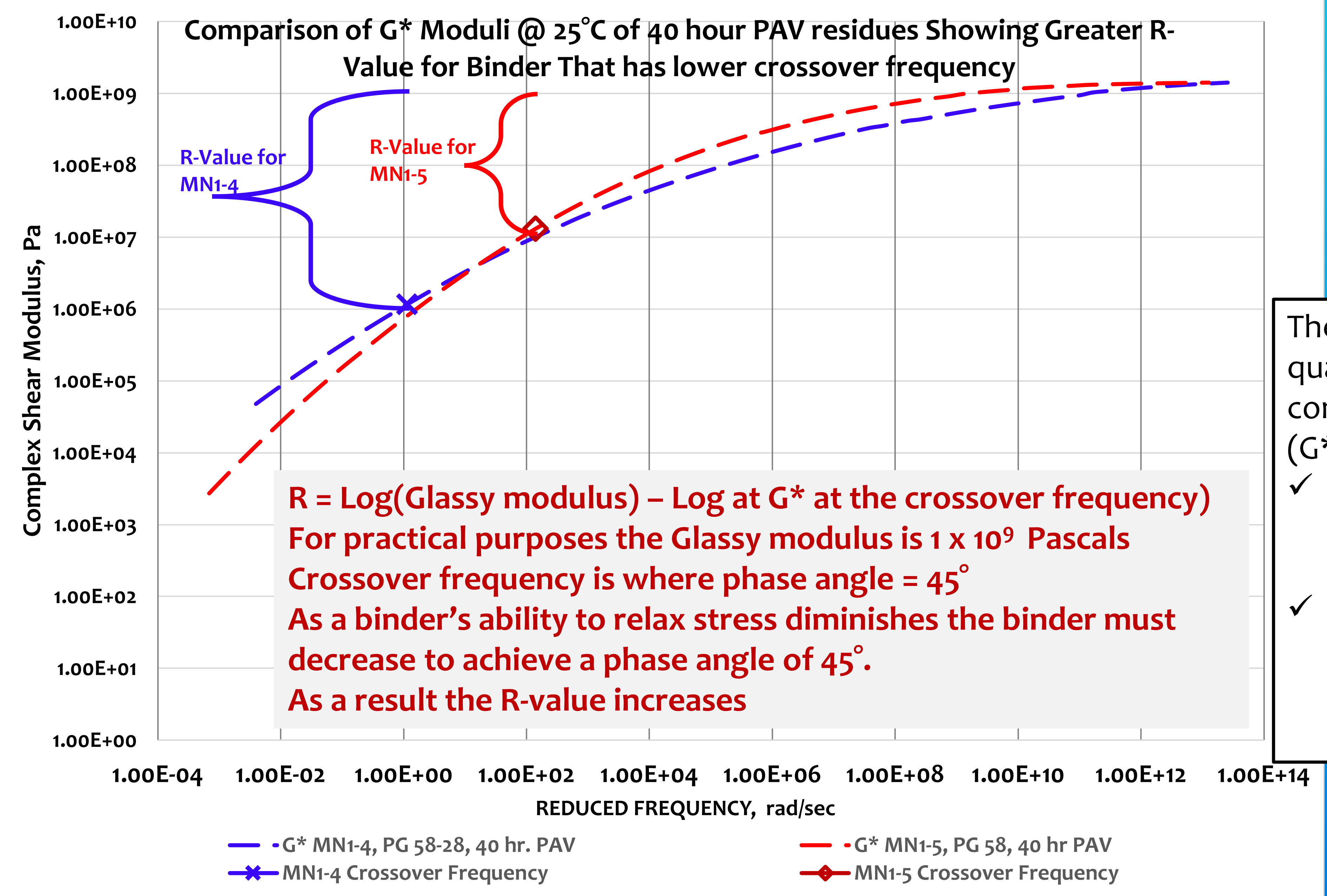
Illustration of Determination of R-Value (Rheological Index)



1. MN1-5 binder performed the best and has the lowest R-value
2. MN1-4 performed the worst and has the highest R-value

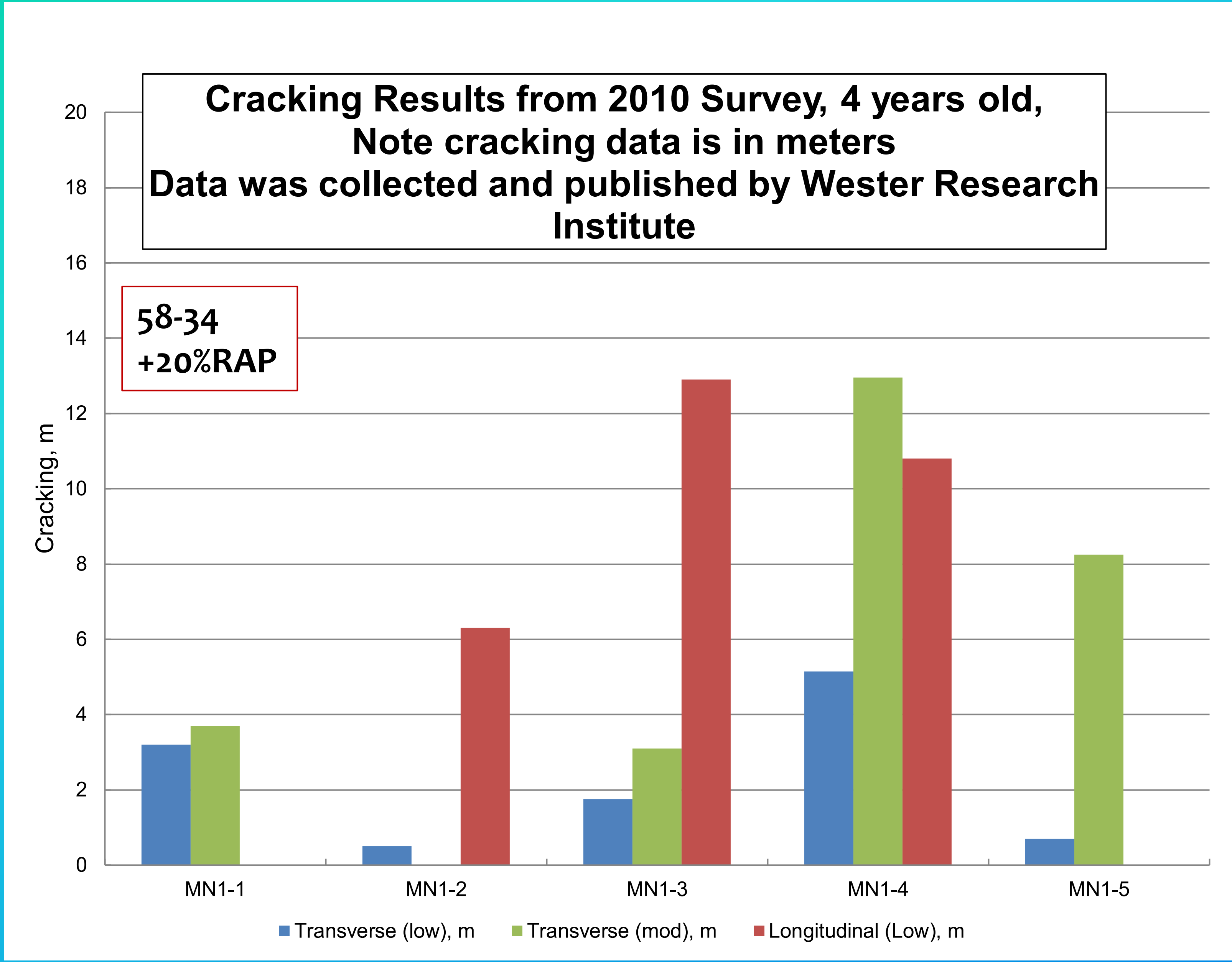
The R-Value is another way to quantify binder relaxation by comparing the shear modulus (G*) mastercurves

- ✓ The method of determining the R-value from rheological data is summarized at the left
- ✓ A graphical presentation of R-Value is shown in the difference in length for the 2 sets of brackets

SOME FIELD EXAMPLES

COMPARATIVE CRUDE SOURCE STUDY

- In August of 2006 Mathy constructed at the request of MNDOT and in cooperation with WRI 5 test sections on Olmsted CTH 112, North of Rochester, MN
- Three of these test sections were to be a performance comparison of 3 different crude sources of PG 58-28 binder and the other 2 were a virgin PG 58-34 PMA binder and the project specified mix of a PG 58-34 + 20% RAP



At 4 years there was not much total cracking in any test section , however sections MN1-3 and MN1-4 had the most cracking.

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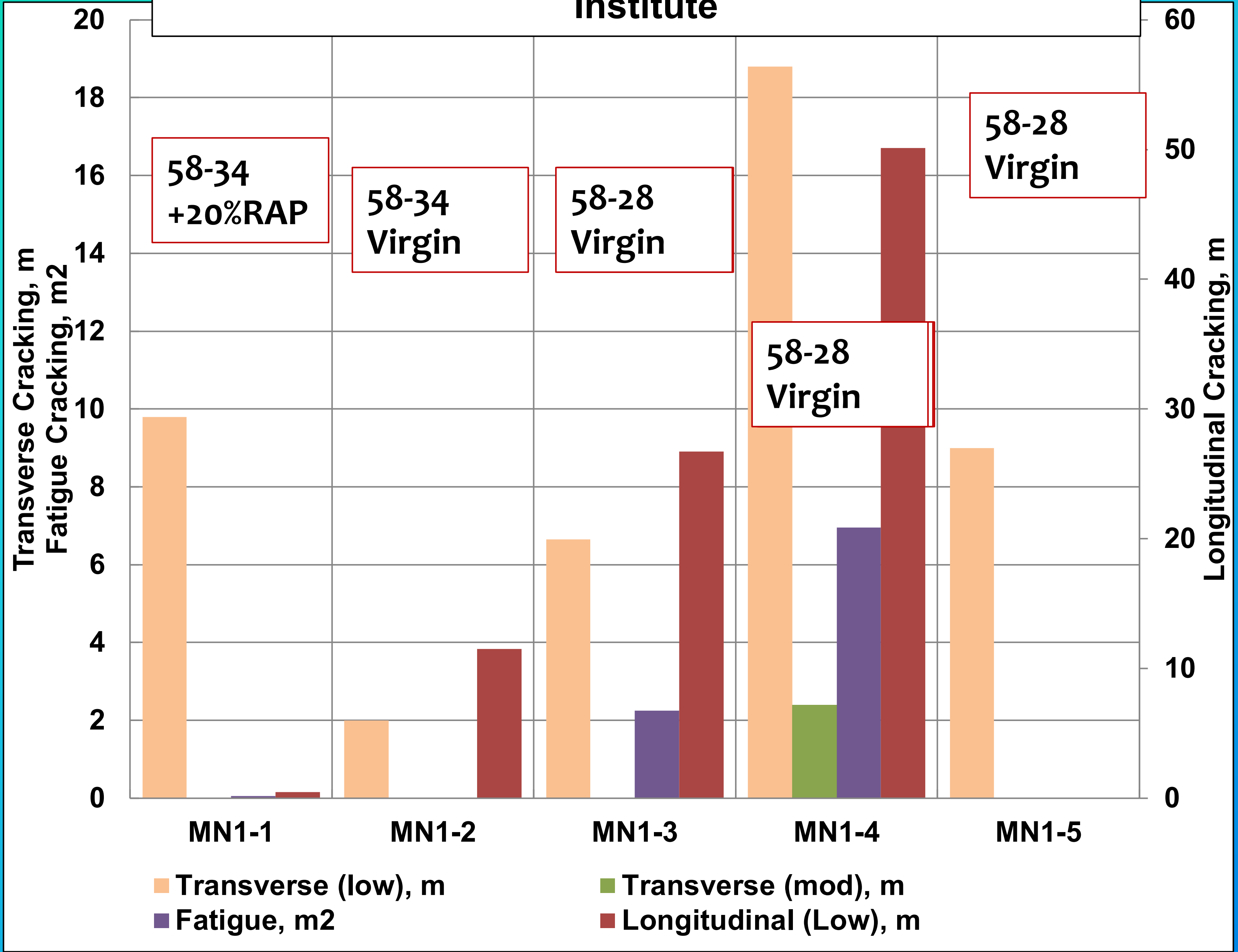
Cracking Results from 2011 Survey, 5 years old, Note cracking data is in meters Data was collected and published by Wester Research Institute



There was a substantial increase in cracking between years 4 and 5 especially for MN1-4

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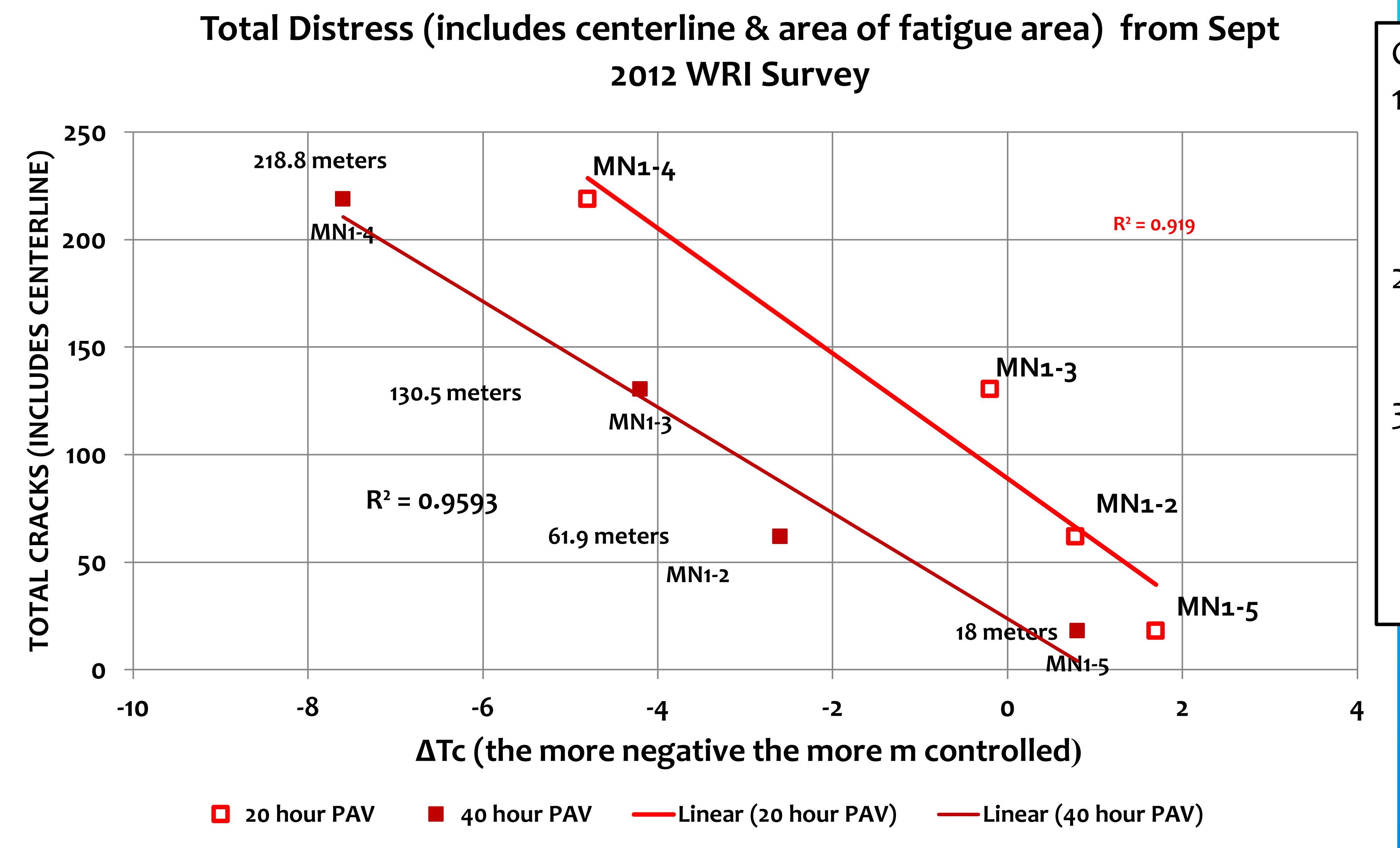
CORRELATION BETWEEN ΔTc OF 20 & 40 HOUR PAV AND CRACKS IN 2012 FOR OLMSTED CTH 112



COMMENTS

1. Plot of ΔTc for 20 and 40 hour PAV residues versus the amount of cracking after 6 years of service
2. The correlation is slightly better for the 40 hour PAV data than the 20 hour data
3. Regardless of the ΔTc values there is a strong correlation between worsening pavement performance and worsening ΔTc

MN1-4	PG 58-28 Arab heavy/Arab medium/Kirkuk blend
MN1-3	PG 58-28 Canadian blend
MN1-5	PG 58-28 Venezuelan blend
MN1-2	PG 58-34 PMA based on Canadian blend

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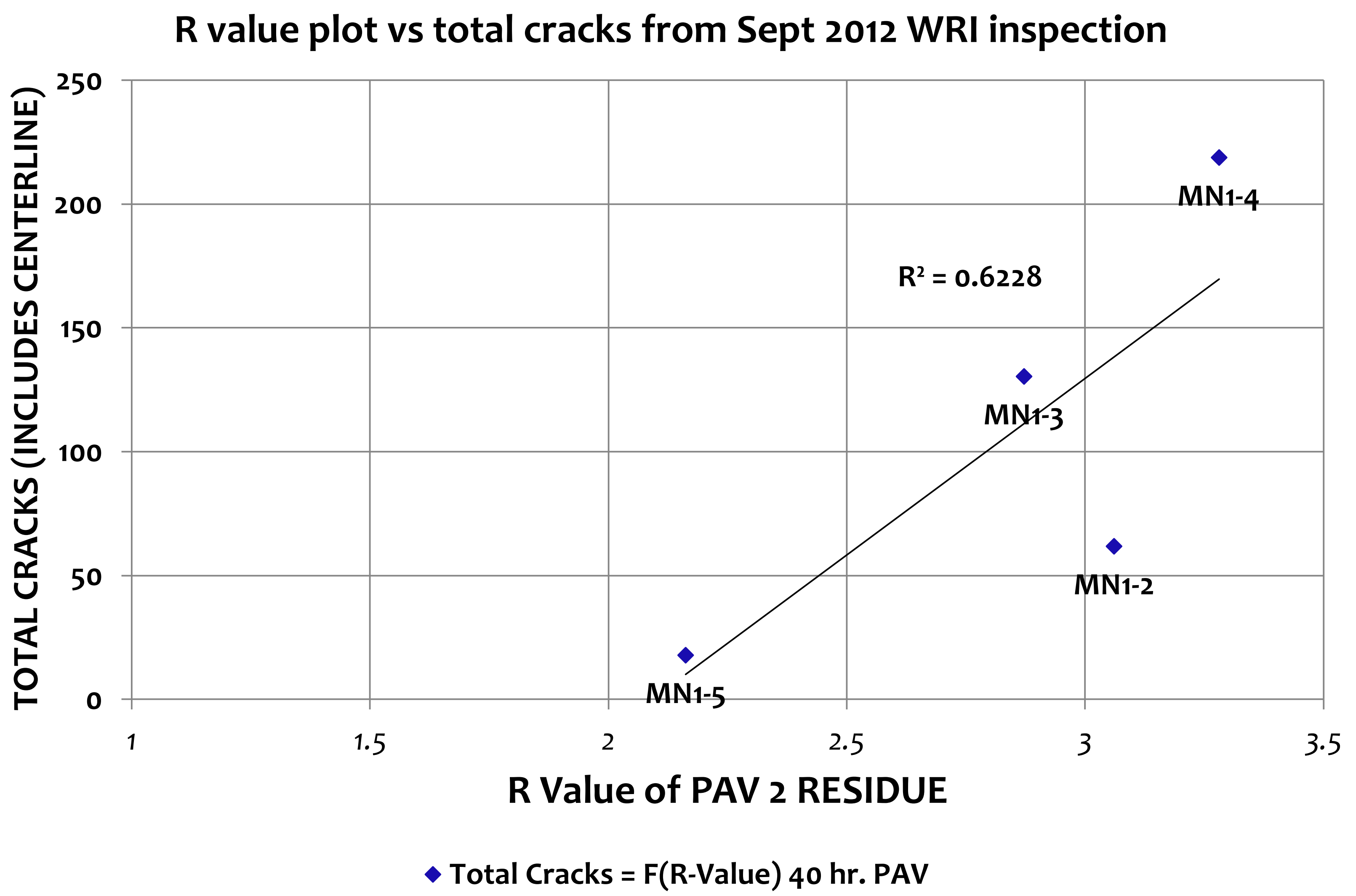
CORRELATION BETWEEN R-VALUE OF 40 HOUR PAV AND CRACKS IN 2012 FOR OLMSTED CTH 112



MN1-4	PG 58-28 Arab heavy/Arab medium/Kirkuk blend
MN1-3	PG 58-28 Canadian blend
MN1-5	PG 58-28 Venezuelan blend
MN1-2	PG 58-34 PMA based on Canadian blend

COMMENTS

1. The correlation between R-Value and total cracking for the 4 virgin test sections is not good
2. This is because the R-Value for the PMA section (MN1-2) does not follow the same trend line as the unmodified PG 58-28 binders
3. Visually one can see that the R-Value versus cracking for the 3 PG 58-28 binders is quite good
4. One of the strengths of comparing binders based on ΔTc is that it is little affected by differences in binder grade of formulation, whereas R-Value is

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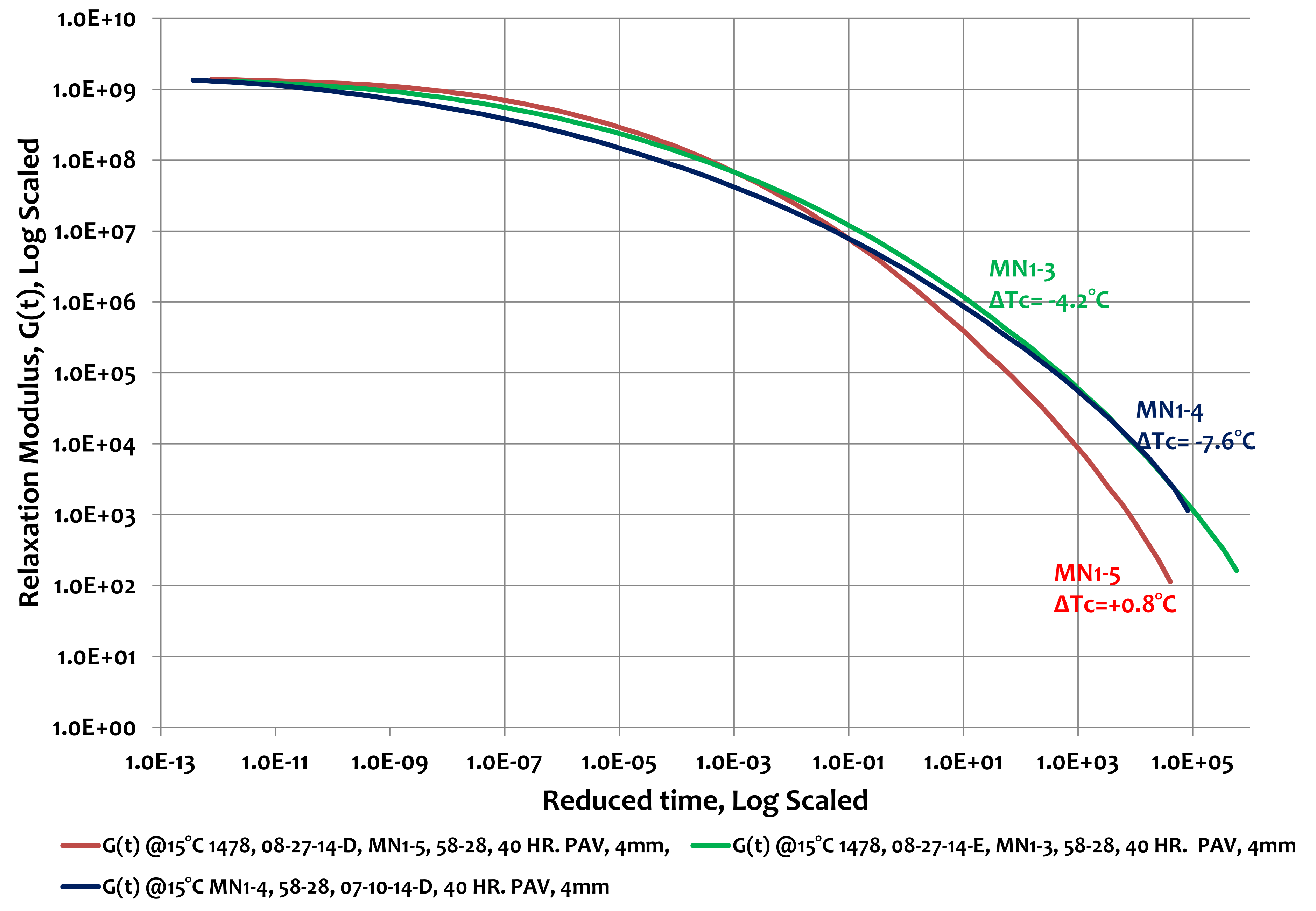
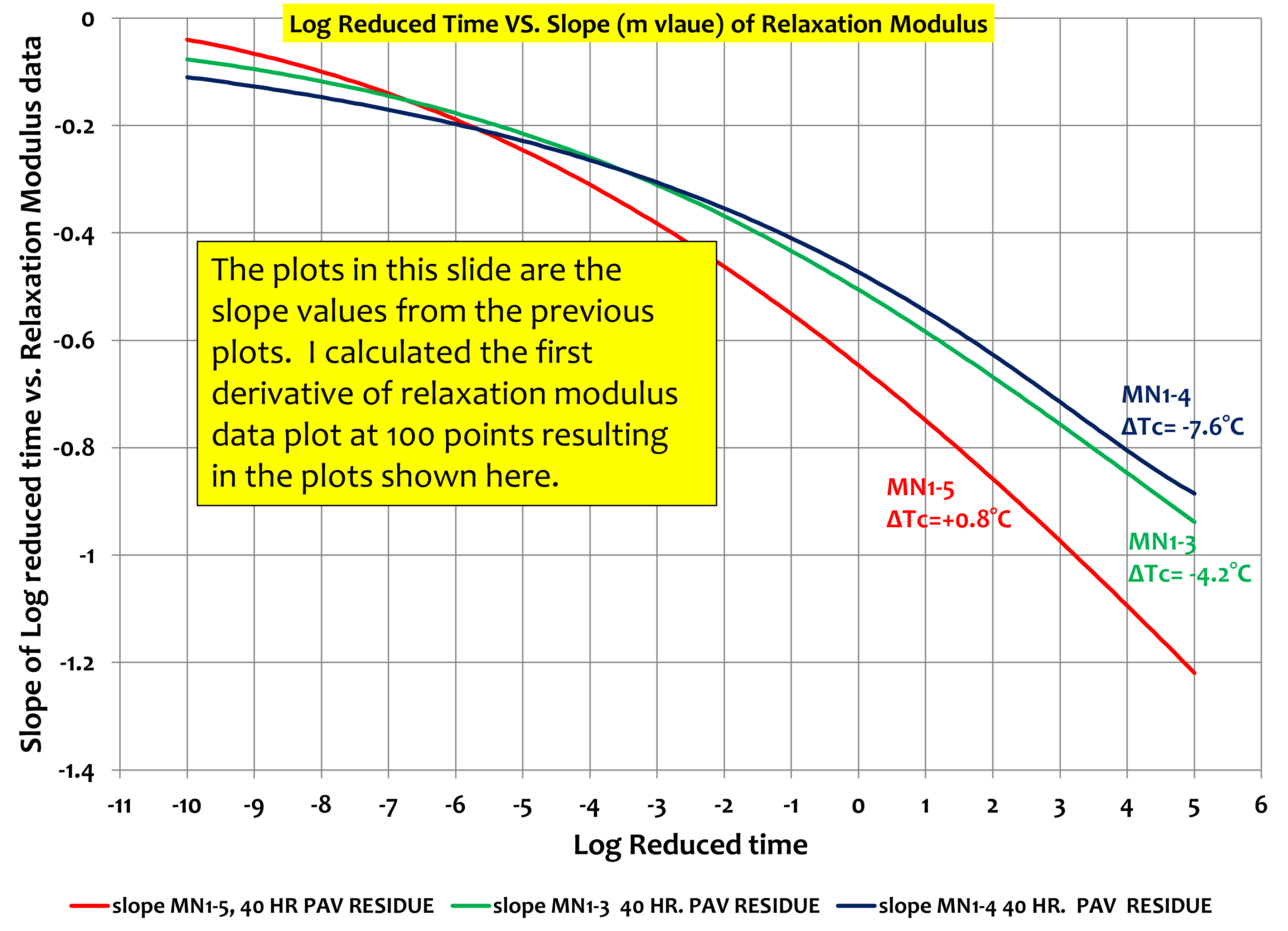
Reduced Time VS Relaxation Modulus @ 15°C for MN1-3, MN1-4, MN1-5 of 40 hour PAV Residue



COMMENTS

1. The plot shows relaxation moduli for the 40 hour PAV residue of 3 CTH 112 PG 58-28 binders
2. As the relaxation time increases the relaxation modulus of MN1-4 and MN1-3 begin to merge and yet MN1-3 has a ΔTc that is 3.4°C better than MN1-4.
3. MN1-3 has a higher stiffness than MN1-4 at short relaxation times but relaxes more rapidly than MN1-4
4. The plots show that MN1-4 relaxes at a slower rate than does MN1-3

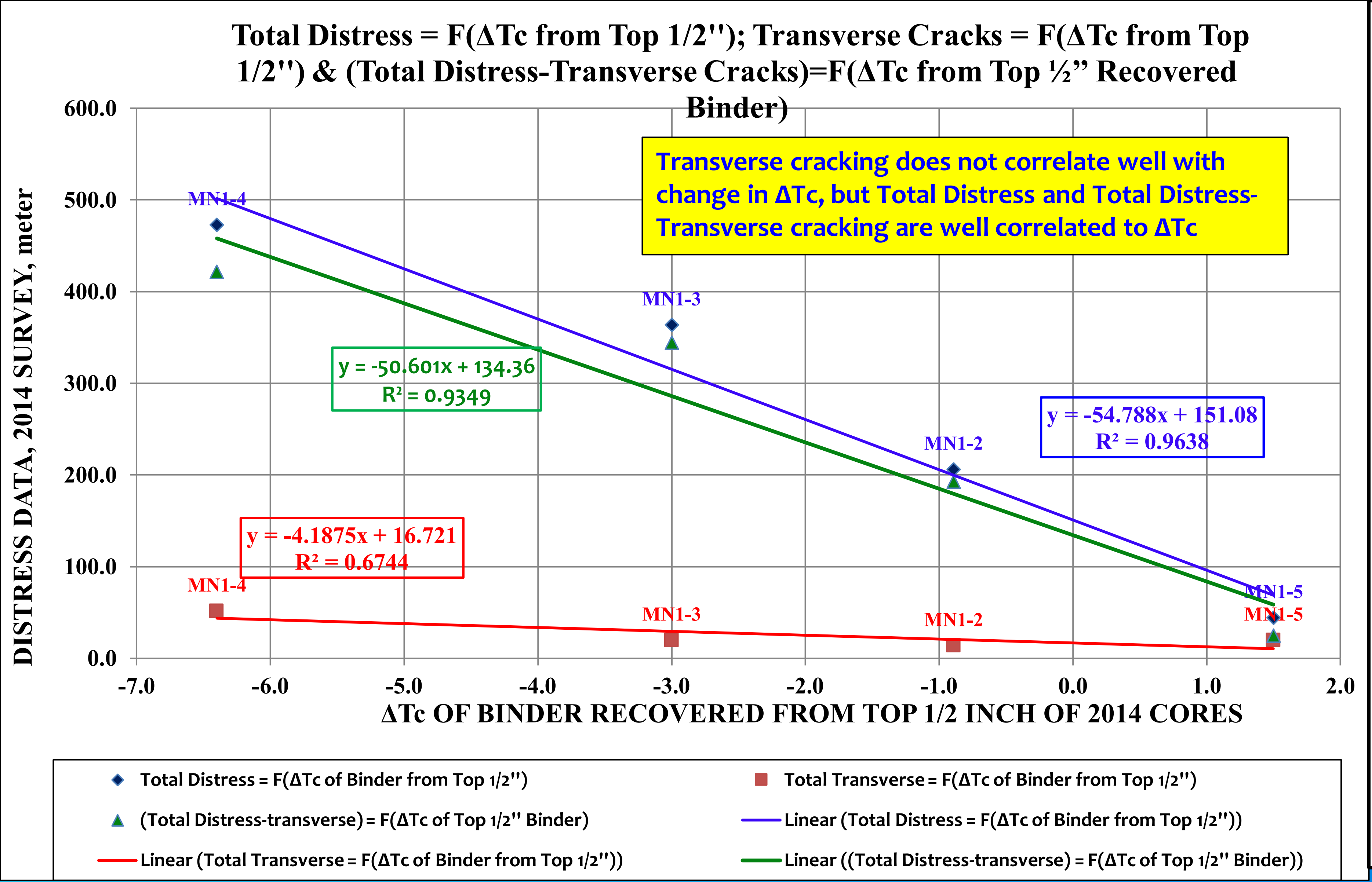
The plots in this slide are the slope values from the previous plots. I calculated the first derivative of relaxation modulus data plot at 100 points resulting in the plots shown here.



COMMENTS

1. To further clarify the results of the previous slide I show the plot of slope value of the relaxation modulus mastercurves for each binder. Think of this as determining the m-value at every point along the relaxation modulus curve
2. What you see is the slope of MN1-3 changes faster than does the slope of MN1-4 and the slope of MN1-5 decreases at the fastest rate of all.
3. This rate of relaxation emphasizes the interrelation of relaxation slope and level of ΔTc

Olmsted County, MN CTH 112, 2014 (8 yrs)



COMMENTS

1. This plot shows the relationship between ΔTc of binder recovered from the top ½ inch of 8 year old field cores for the 4 virgin mixes and amount of surface cracking after 8 years
2. The correlation of ΔTc with transverse cracking is not very good mainly because the transverse cracking level is similar for all mixes.
3. Even though there is a large variation in ΔTc and total cracking this is not reflected in the correlation of ΔTc with just transverse cracking.

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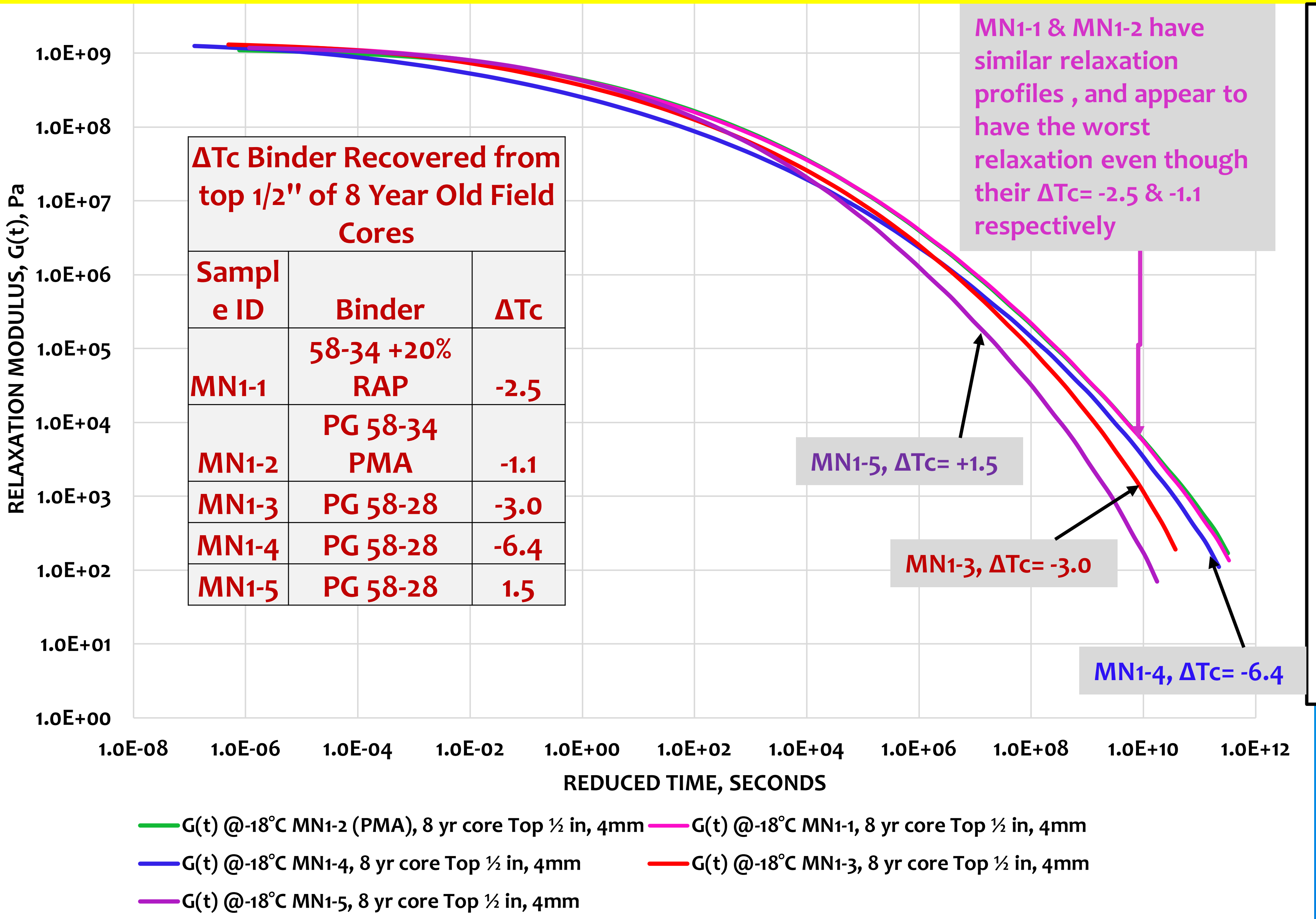
Reduced Time VS Relaxation Modulus @ -18°C of Recovered Binder from Top ½ inch of 8 year Field Cores of MN1-1, MN1-2, MN1-3, MN1-4, MN1-5



COMMENTS

1. Plot is of relaxation moduli of binder recovered from the top ½ inch of 8 year field cores
2. The 3 PG 58-28 binders have relaxation moduli plots that reflect their ΔTc values; the slopes of MN1-1 and MN1-2 (PMA binder) appear to have worse relaxation moduli slopes even though they have the 2nd & 3rd best ΔTc values
3. Next slide sheds some light on this data

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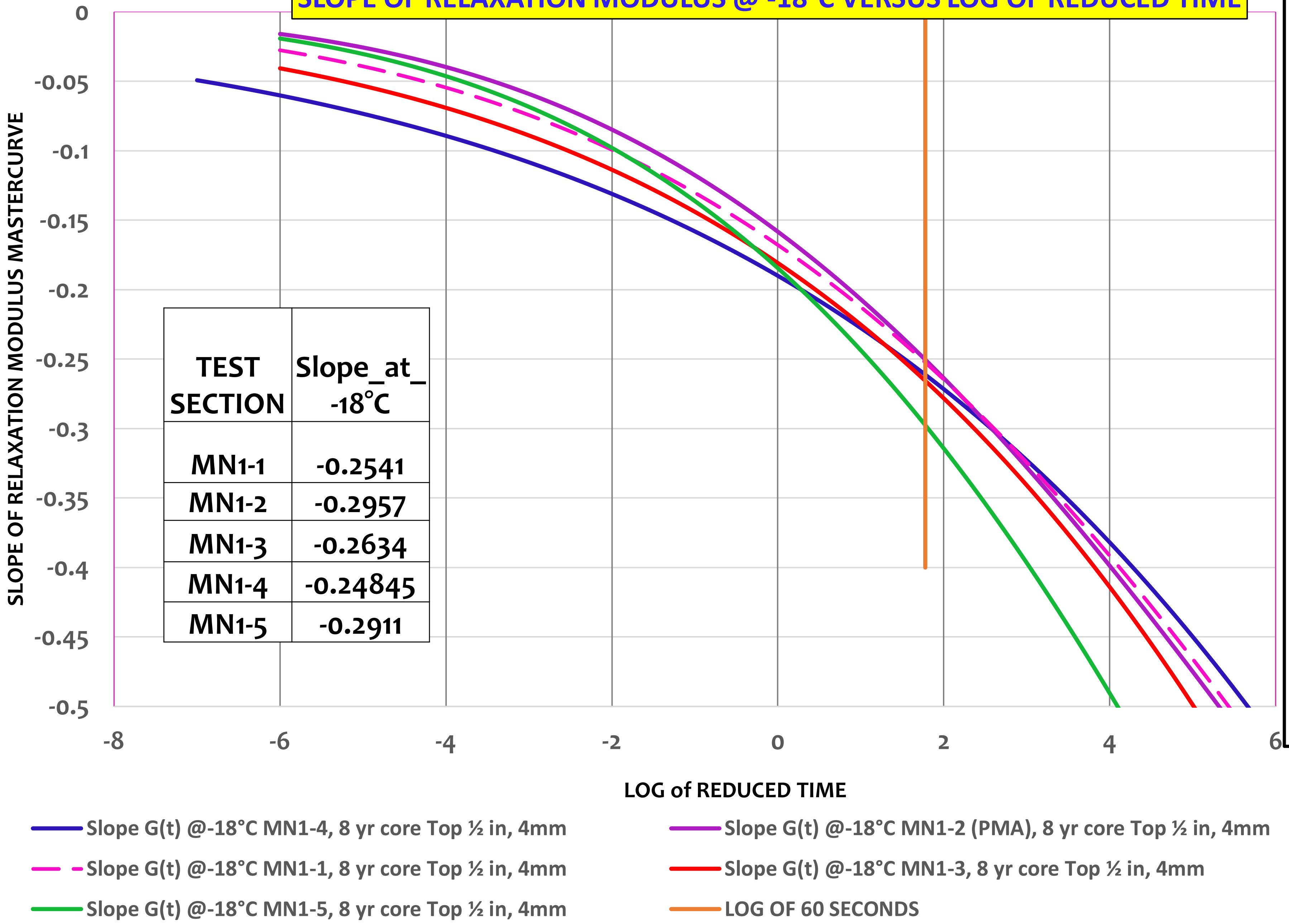
SLOPE OF RELAXATION MODULUS @ -18°C VERSUS LOG OF REDUCED TIME



TEST SECTION	Slope_at_ -18°C
MN1-1	-0.2541
MN1-2	-0.2957
MN1-3	-0.2634
MN1-4	-0.24845
MN1-5	-0.2911

COMMENTS

1. This is a zoomed plot of the slope of the relaxation modulus mastercurve vs log of reduced time for all 5 CTH 112 binders
2. MN1-1 starts out at a slightly lower relaxation modulus than MN1-5, but relaxes more slowly and by 60 seconds is relaxing at a slower rate than MN1-2
3. MN1-4 which has the lowest relaxation modulus at short times relaxes so slowly that it eventually crosses over all of the other binders and has the worst slope of all materials

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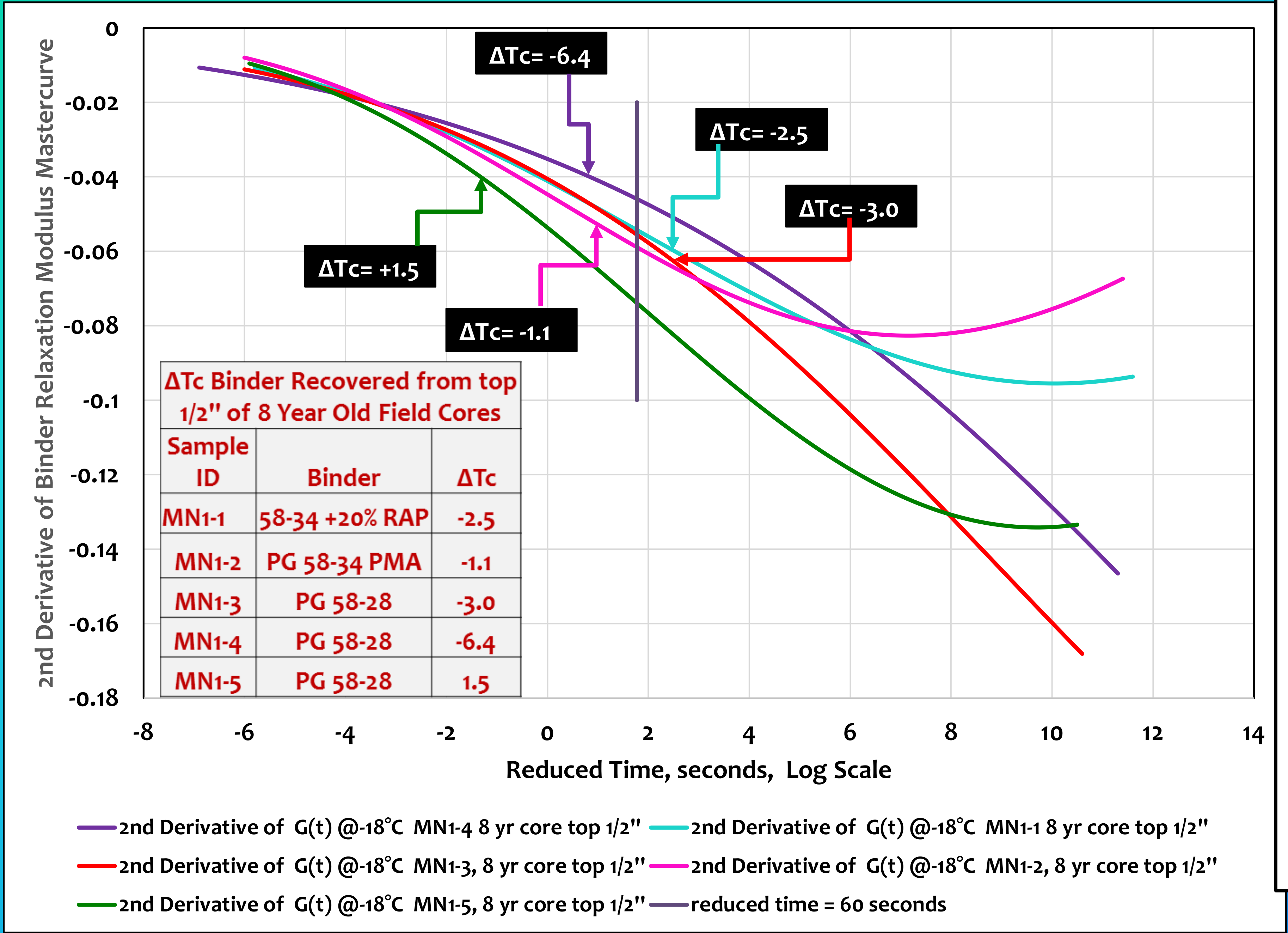
Plot of 2nd Derivative of Relaxation Modulus Mastercurve

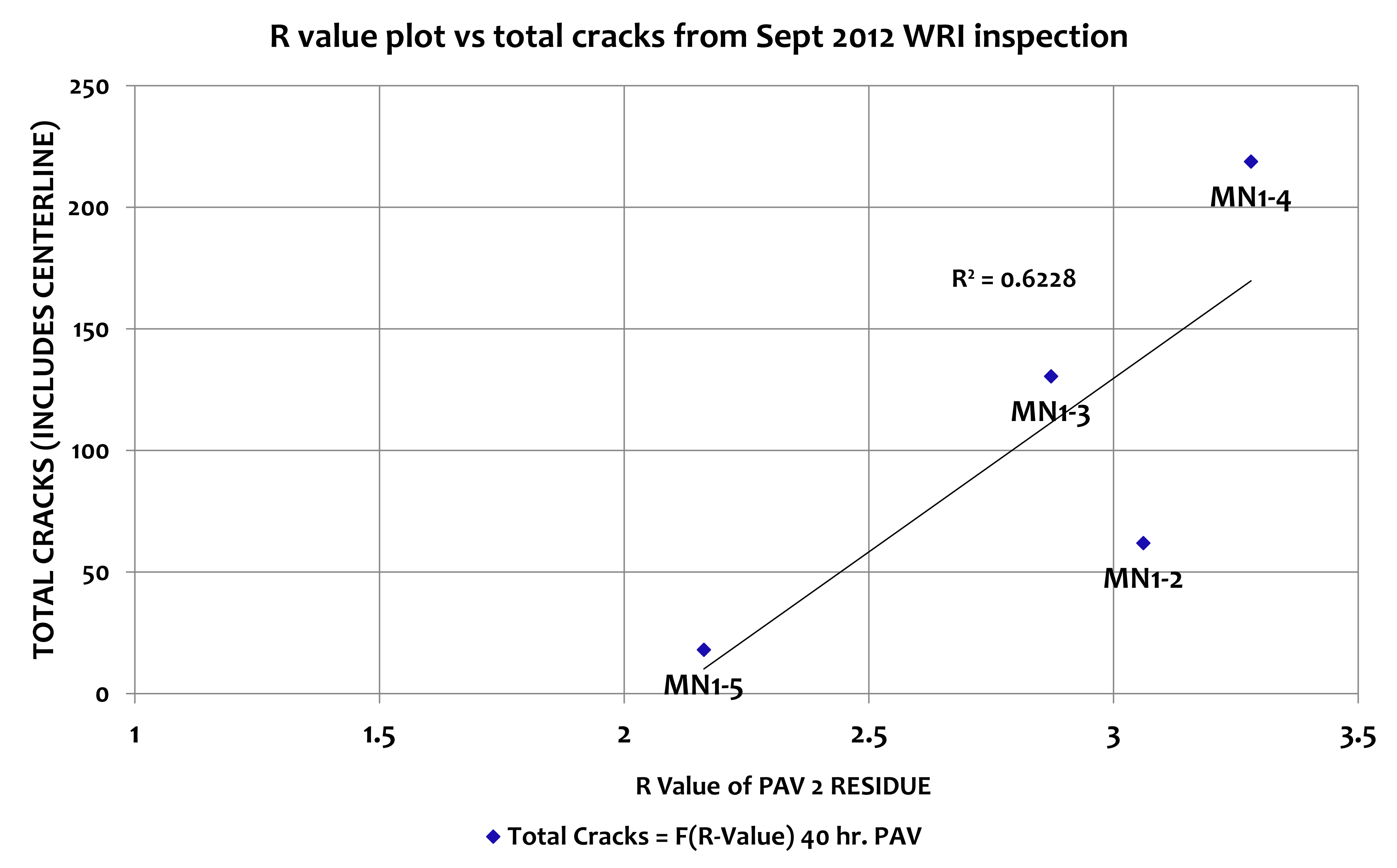


ΔTc Binder Recovered from top 1/2" of 8 Year Old Field Cores		
Sample ID	Binder	ΔTc
MN1-1	58-34 +20% RAP	-2.5
MN1-2	PG 58-34 PMA	-1.1
MN1-3	PG 58-28	-3.0
MN1-4	PG 58-28	-6.4
MN1-5	PG 58-28	1.5

COMMENTS

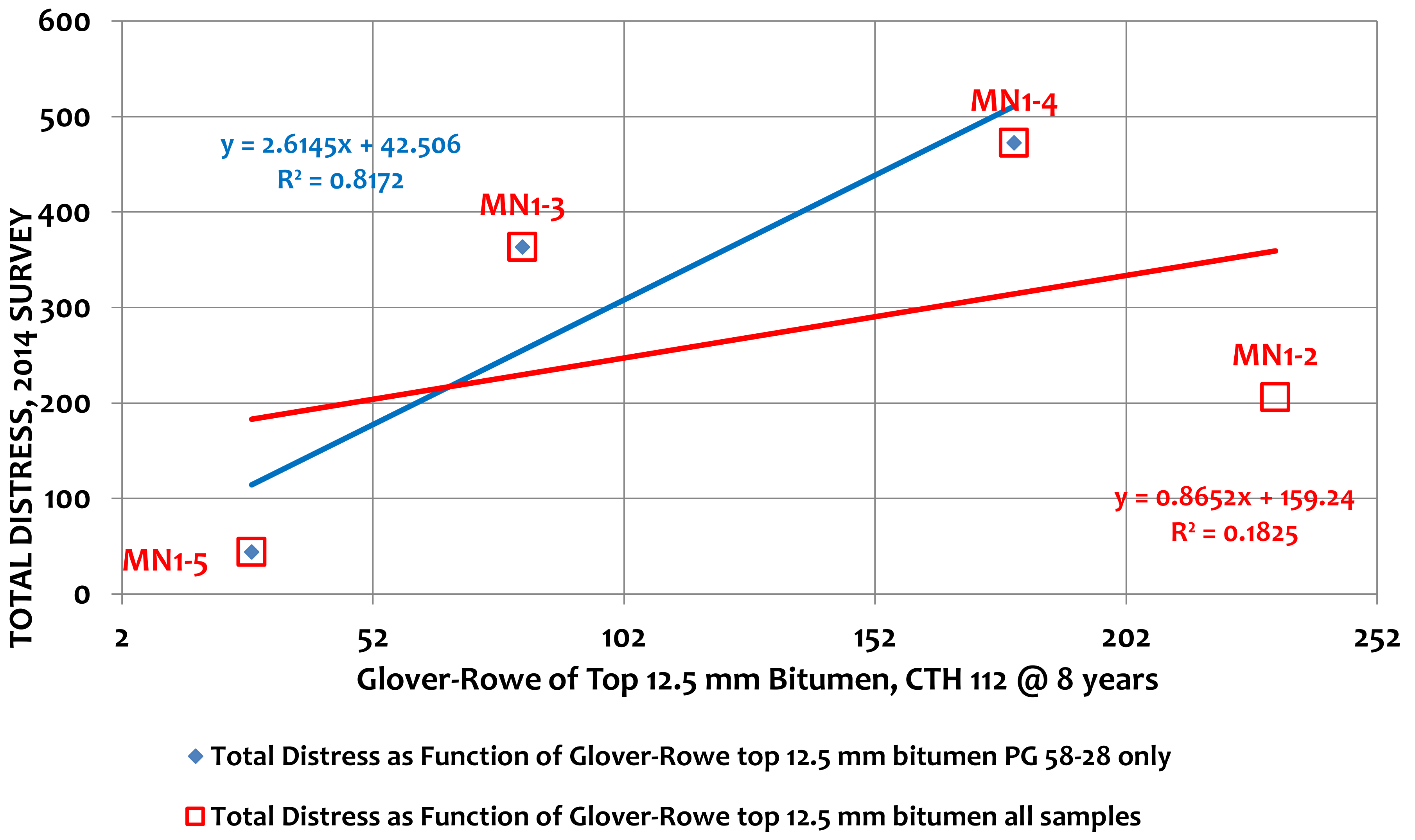
1. The 2nd derivative of the relaxation modulus mastercurve in effect provides the rate of change in the slope of the relaxation modulus
2. The data at 60 seconds shows MN1-4 (ΔTc = -6.4) has the slowest relaxation rate; the relaxation rates for MN1-1 (ΔTc = -2.5), MN 1-3 (ΔTc = -3.0), and MN1-2(ΔTc= -1.1) are grouped very closely together as are their ΔTc values.
3. MN1-5 (ΔTc = +1.5) exhibits a much greater relaxation rate and also has a substantially higher ΔTc
4. These results show quantitatively and qualitatively the interconnection between binder relaxation and ΔTc

Relationship between R-Value and Pavement performance



COMMENTS

1. This plot shows that the R-value parameter is not a good predictor for comparing performance of modified and non-modified binders
2. Because the PMA binder relaxes more slowly relative to the non-modified binders its crossover frequency is lower than the PG 58-28 binders and this inflates the R-value even though its overall performance is good



COMMENTS

1. This is a plot of the slope of the Glover-Rowe parameter vs total pavement distress on CTH 112.
2. Due to modification MN1-2 has the highest G* value at 15°C and a crossover frequency only slightly higher than MN1-4 and ultimately has the worst Glover-Rowe value even though its pavement distress is 2nd best of all binders
3. The correlation of Glover-Rowe for the non modified PG 58-28 mixtures is reasonable at R^2=0.82

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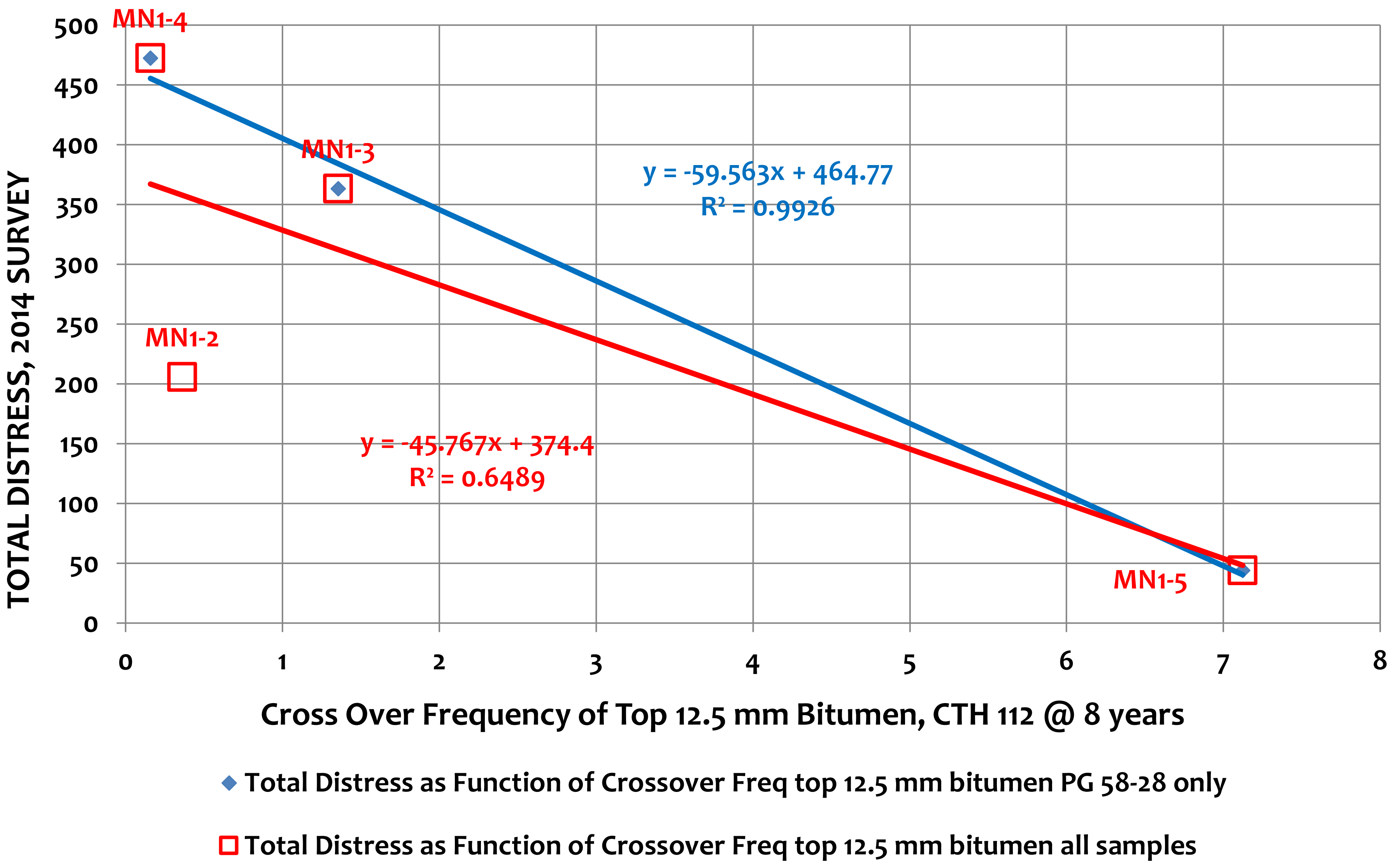
Total avement Distress plotted as a Function of Crossover Frequency



COMMENTS

1. It stands to reason that if R-Value is does not correlate well to pavement performance that crossover frequency would not given that one of the inputs for R-Value is crossover frequency.
2. MN1-2 has a crossover frequency slightly better than MN1-4, the worst performer.
3. Crossover frequency correlates strongly for the non-modified binders even though they are from 3 distinct crude sources.
4. Crossover frequency does not correlate across different binder formulations

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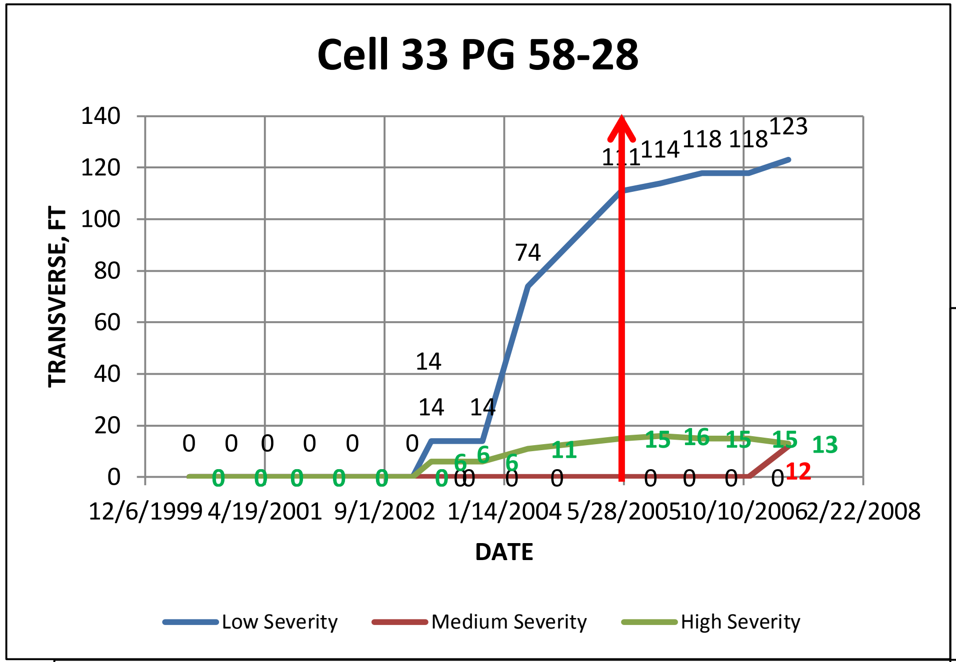
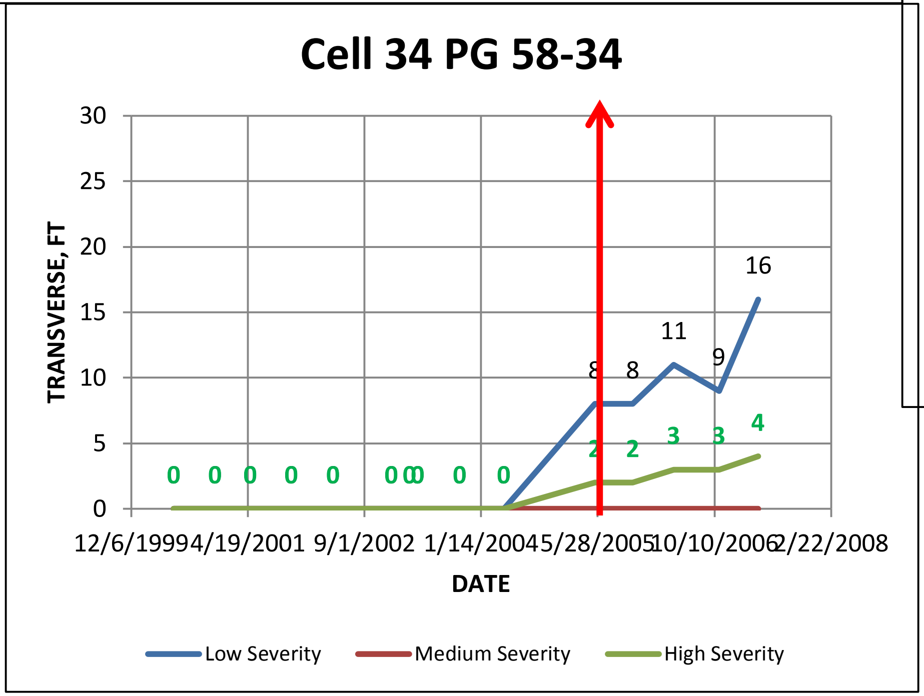
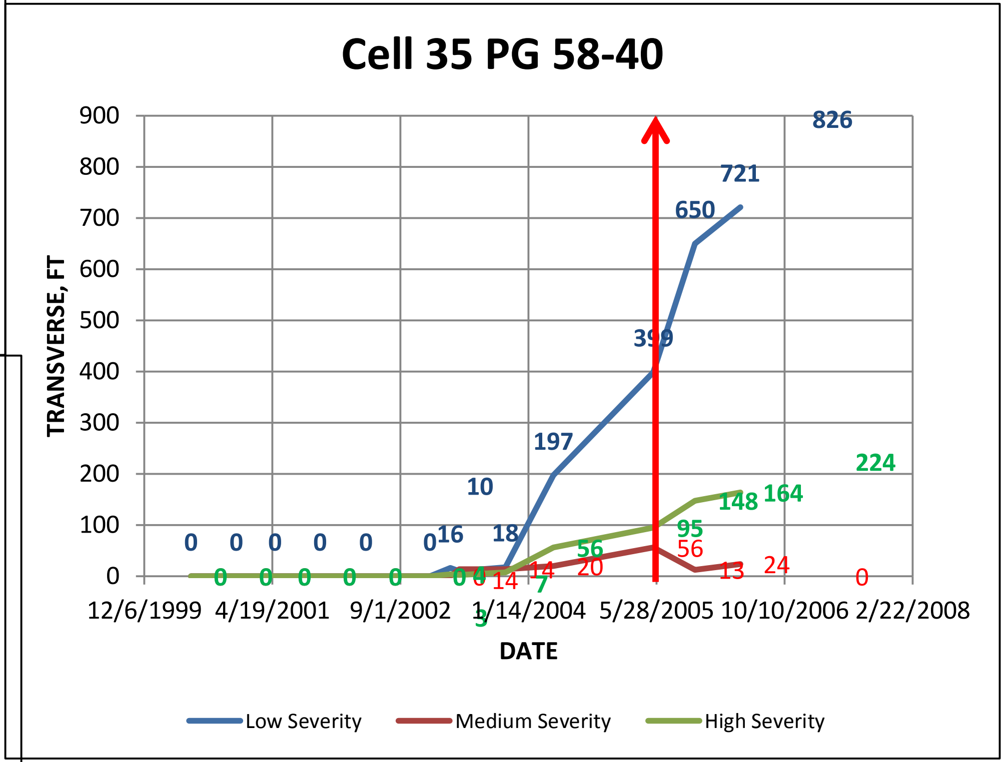
MnROAD TEST OF 3 BINDERS

1. CONSTRUCTED IN SEPT 1999
2. 3 BINDERS
   a. PG 58-28
   b. PG 58-34
   c. PG 58-40
3. TRAFFICED UNTIL APRIL 2007
4. ANNUAL OR NEARLY ANNUAL PAVEMENT DISTRESS SURVEYS CONDUCTED

TRANSVERSE CRACKING DATA FOR THE THREE CELLS







By year 5.5 some transverse cracking was appearing in all cells

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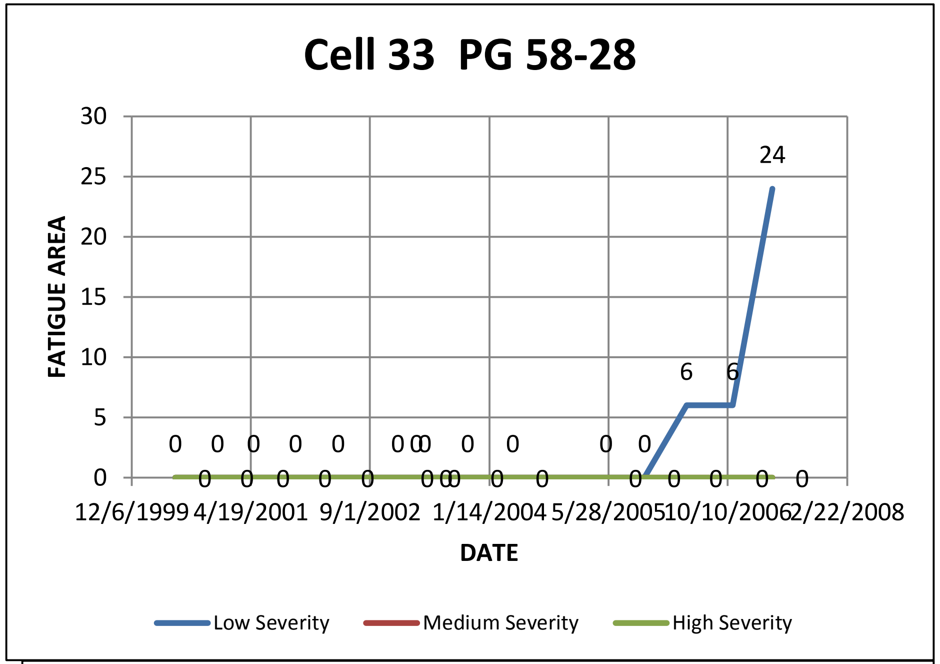
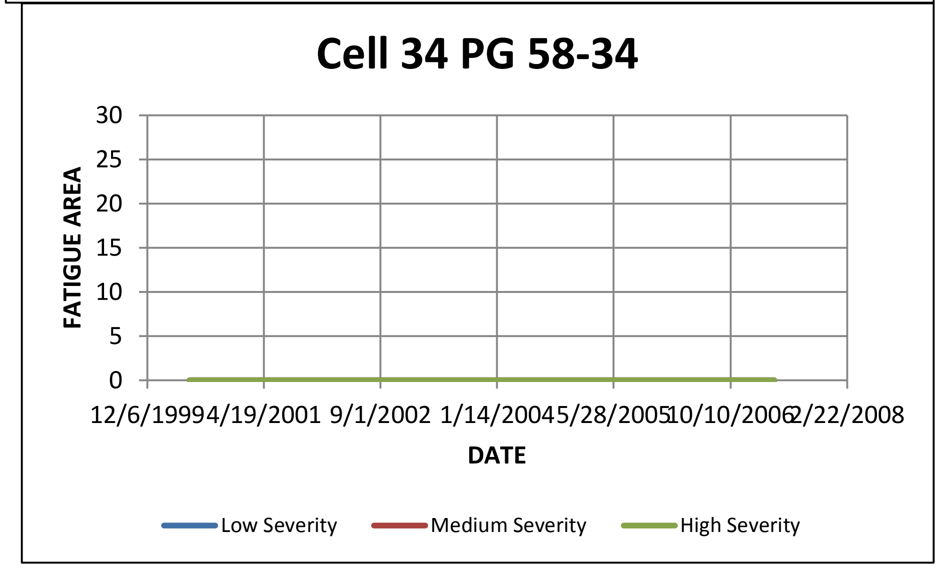
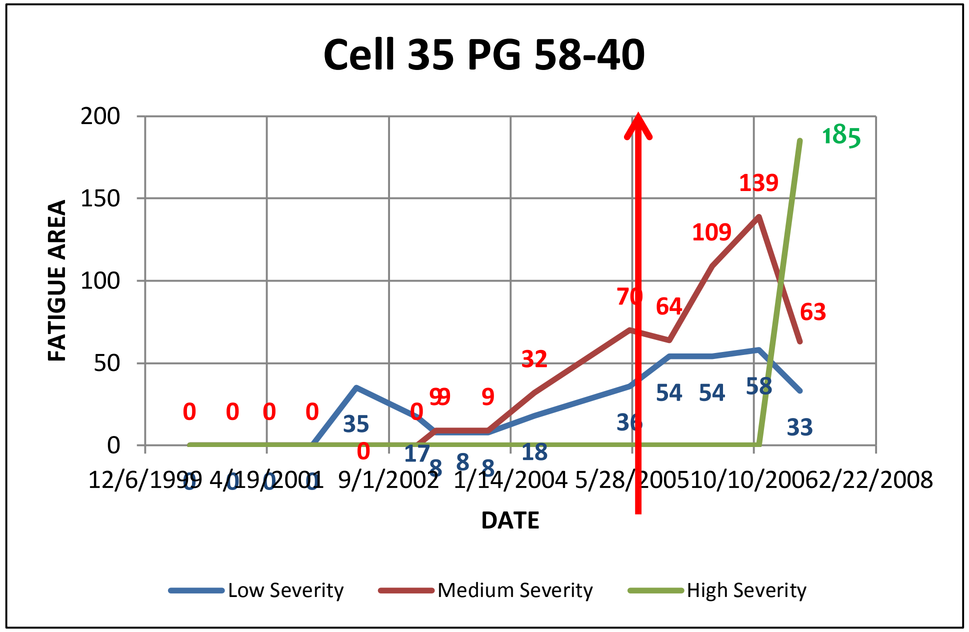
FATIGUE CRACKING DATA FOR THE THREE CELLS

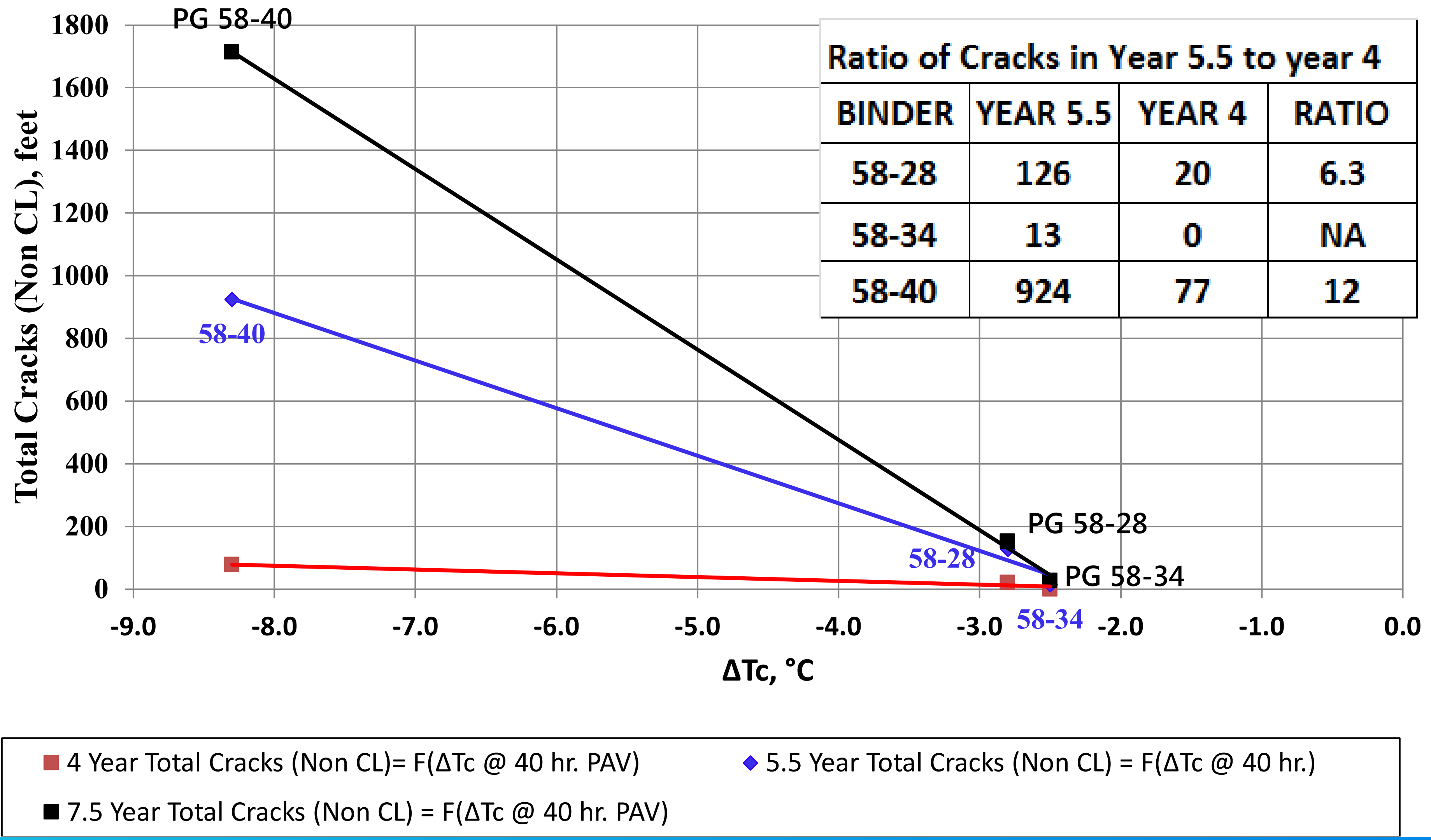






However fatigue cracking was only an issue on the PG 58-40 binder section

Total Crack Length (Non CL) @ years 4, 5.5 & 7.5 =F(ΔTc 40 hr PAV)



Ratio of Cracks in Year 5.5 to year 4

BINDER	YEAR 5.5	YEAR 4	RATIO
58-28	126	20	6.3
58-34	13	0	NA
58-40	924	77	12

COMMENTS

1. Between years 4 and 5.5 a substantial increase in cracking took place for the PG 58-40 section. While the increases for the other 2 sections were not as severe they also showed an increase after 5.5 years
2. Regardless of the years in service, the cracking trended with the ΔTc of the 40 hour PAV residue.
3. No binder was recovered from field cores over the course of the project.

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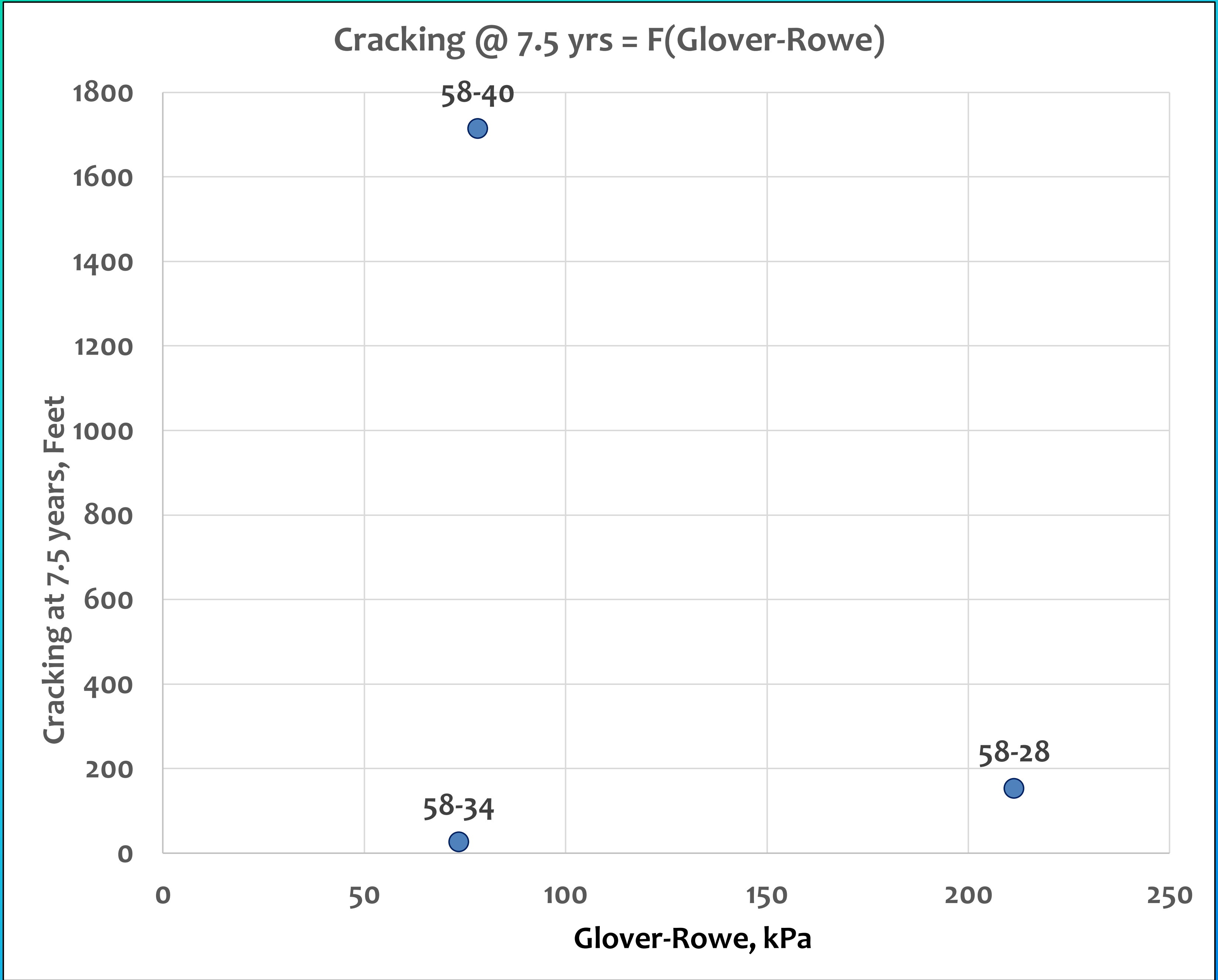
MnROAD Cracking @ 7.5 years as a Function of Glover-Rowe for 40 hr. PAV



COMMENTS

1. The Glover-Rowe results for both PMA binders (PG 58-34 and PG 58-40) are similar and in the 70 MPa range. The Glover-Rowe value for PG 58-28 is 211 which is above the cracking limit of 180 MPa
2. We don't know what the binder properties of the field mix were at 7.5 years, but based on data from Olmsted CTH 112 the 8 year field core binders had ΔTc values that were ≈ 1.2-1.5°C better than the 40 hr. PAV ΔTc values. Therefore the 40 hour data for the MnROAD binders is not significantly over estimating the binder response.
3. Next slide shows the CTH results

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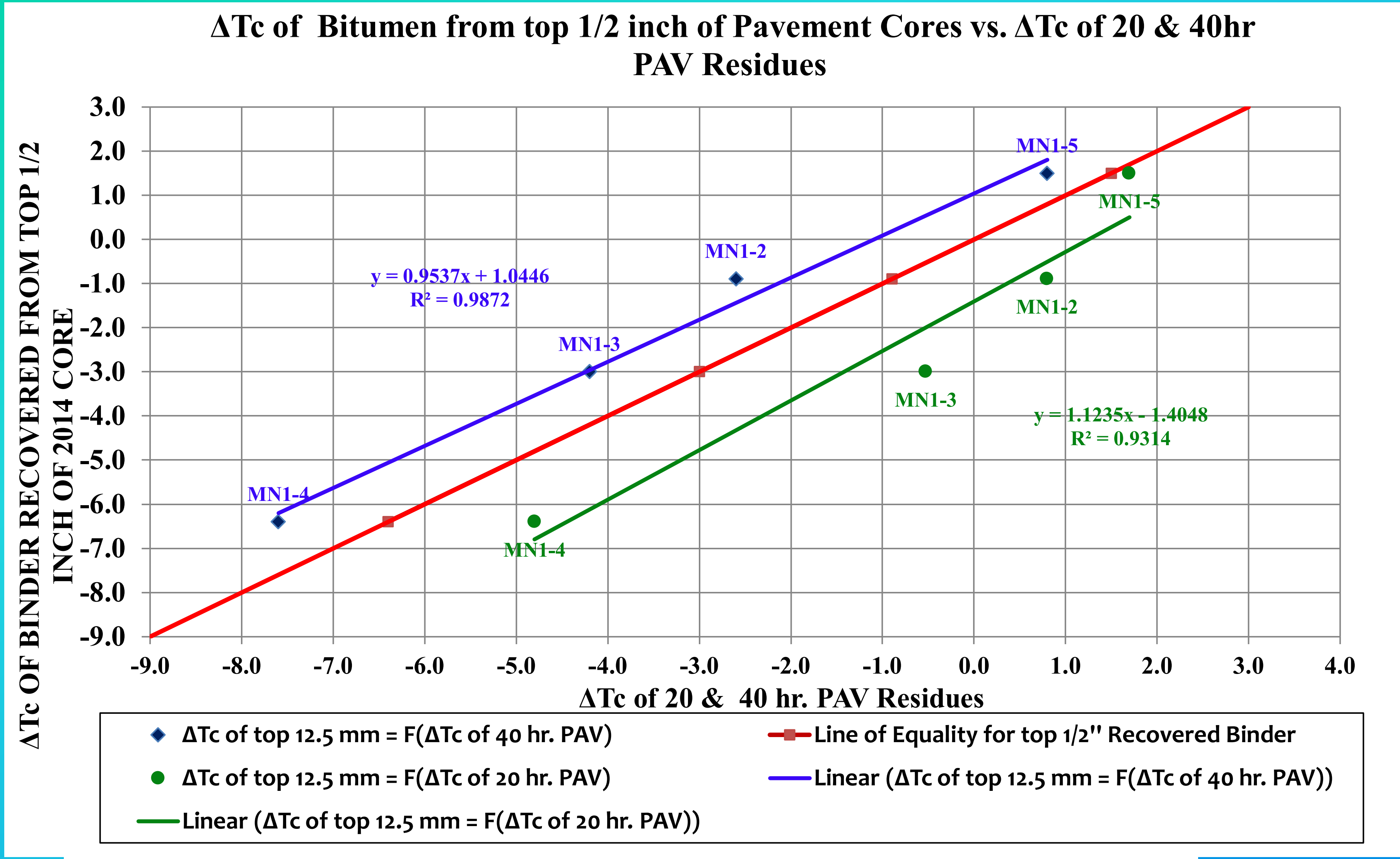

ΔTc of 20 HR. PAV UNDER PREDICTS THE ΔTc VALUE OF 8 YEAR FIELD CORE BINDER (TOP ½") TO A SLIGHTLY GREATER EXTENT THAN THE 40 HR. PAV OVERPREDICTS THE ΔTc VALUE

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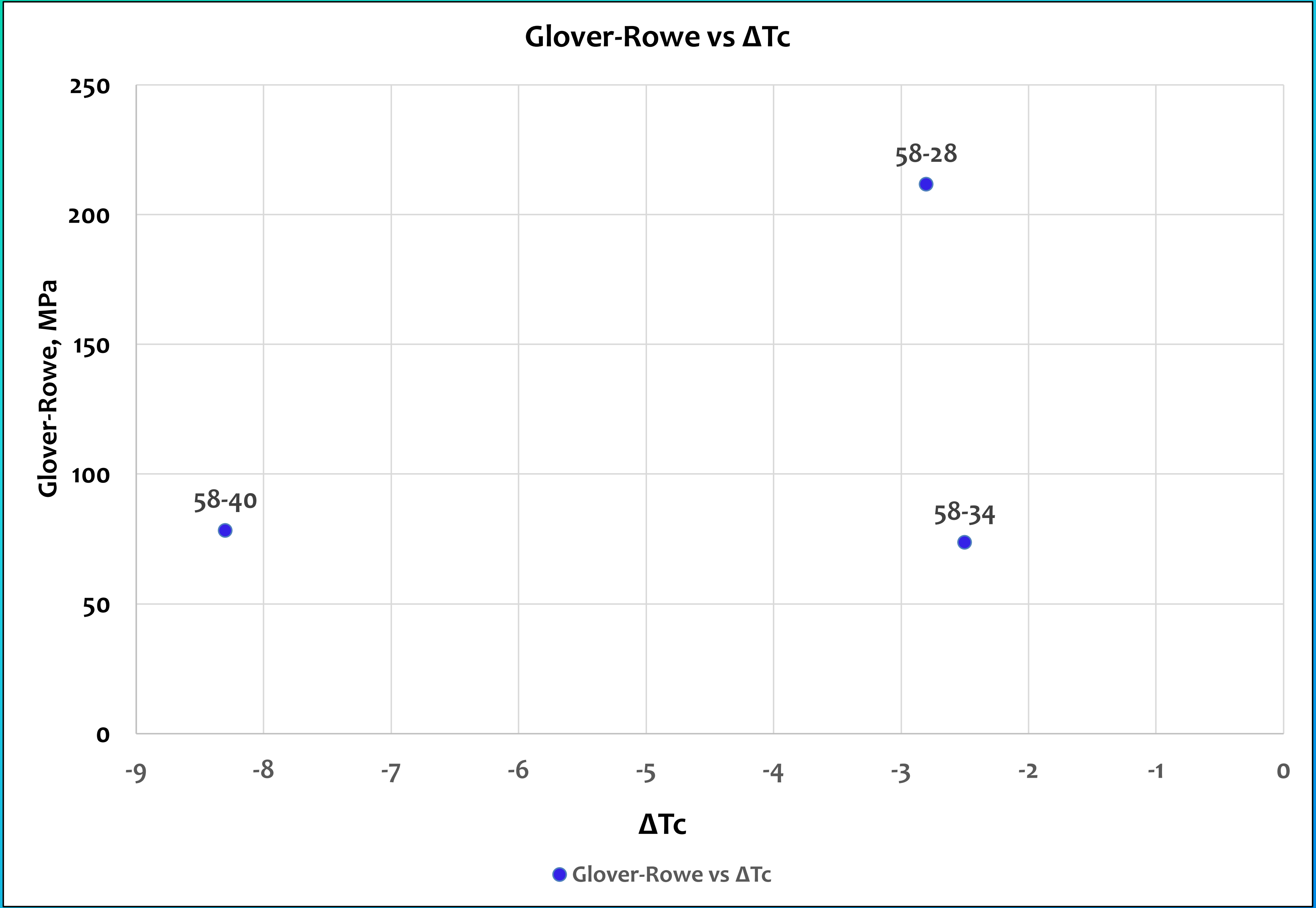

COMMENTS

1. It is not surprising that Glover-Rowe does not correlate to ΔTc.
2. ΔTc correlates to cracking but Glove-Rowe does not and therefore one should not expect ΔTc to correlate to Glover-Rowe

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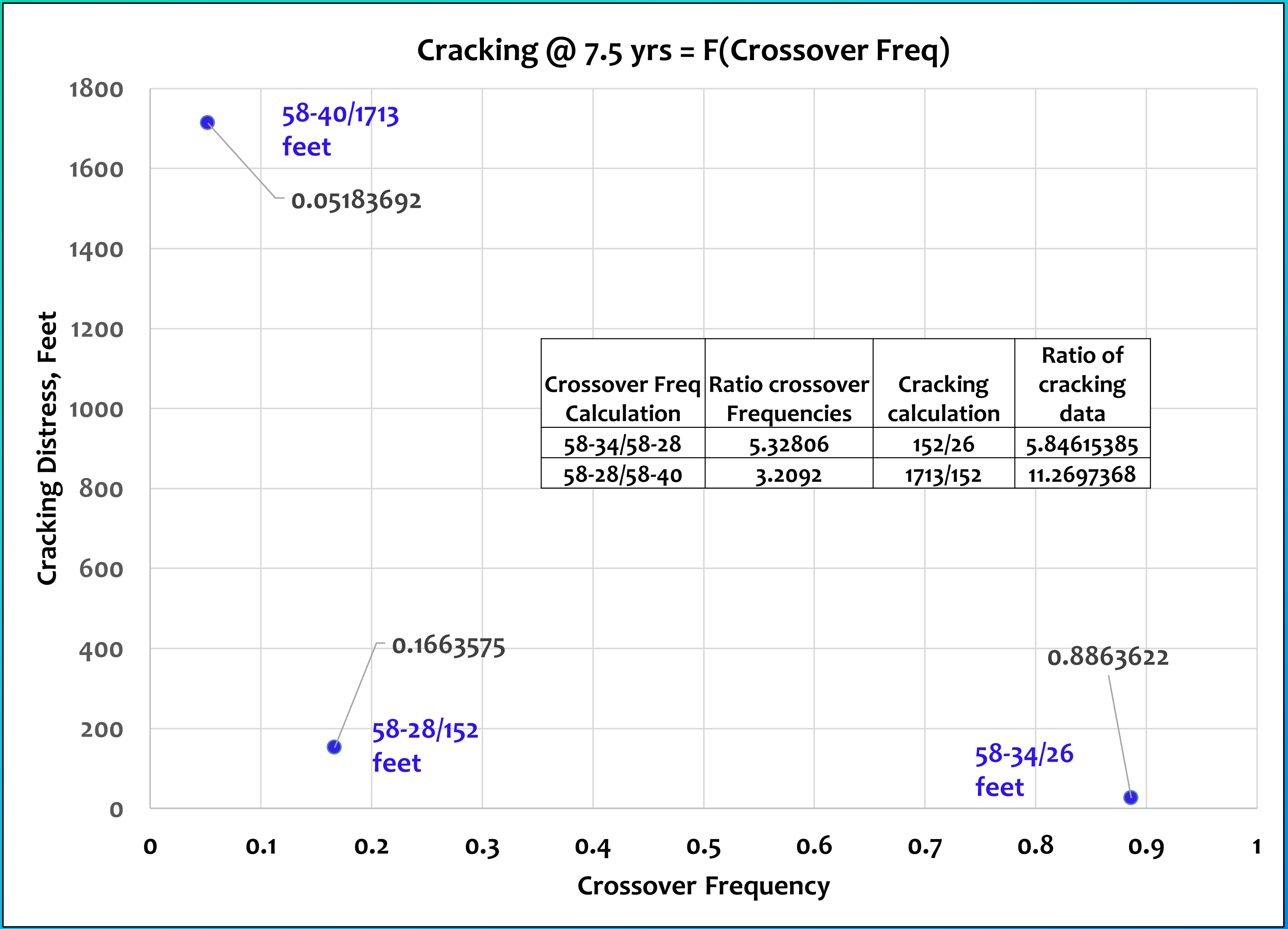

Crossover Freq Calculation	Ratio crossover Frequencies	Cracking calculation	Ratio of cracking data
58-34/58-28	5.32806	152/26	5.84615385
58-28/58-40	3.2092	1713/152	11.2697368

COMMENTS

1. It does not appear as though there is a good correlation between crossover frequency and pavement cracking
2. An exponential function could be fit to the 3 data points, but it is unlikely that the change in crossover frequency between 0.166 and 0.052 radians/sec (a 3 fold decrease) could result in binder property degradation sufficient to result in an 11 fold increase in cracking distress.

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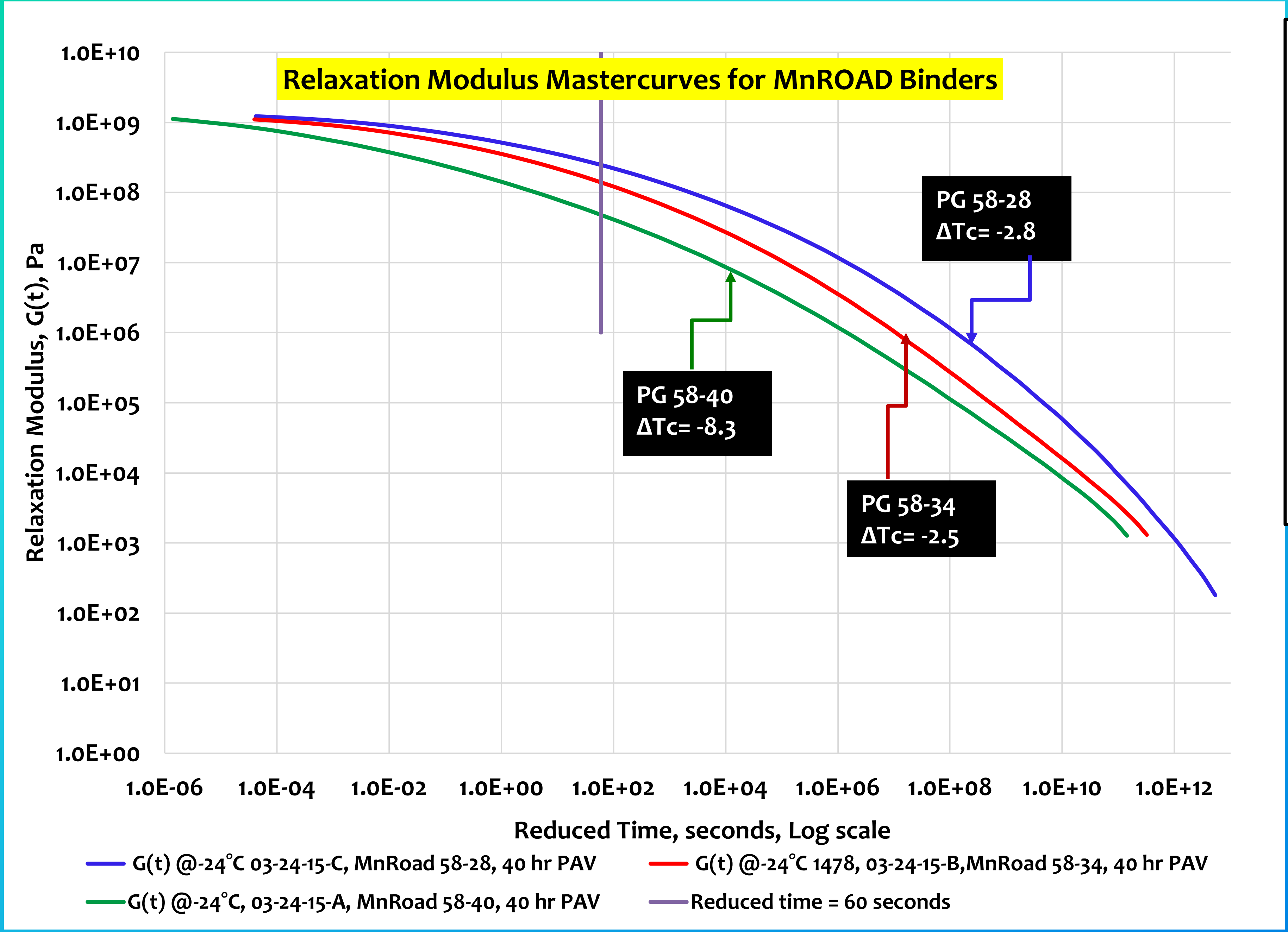

COMMENTS

1. It is difficult from this view of the data to understand why the binder with the lowest relaxation modulus has the worst ΔTc
2. As with the previous discussions the answer lies in the rate of relaxation which is explored in the next 2 slides

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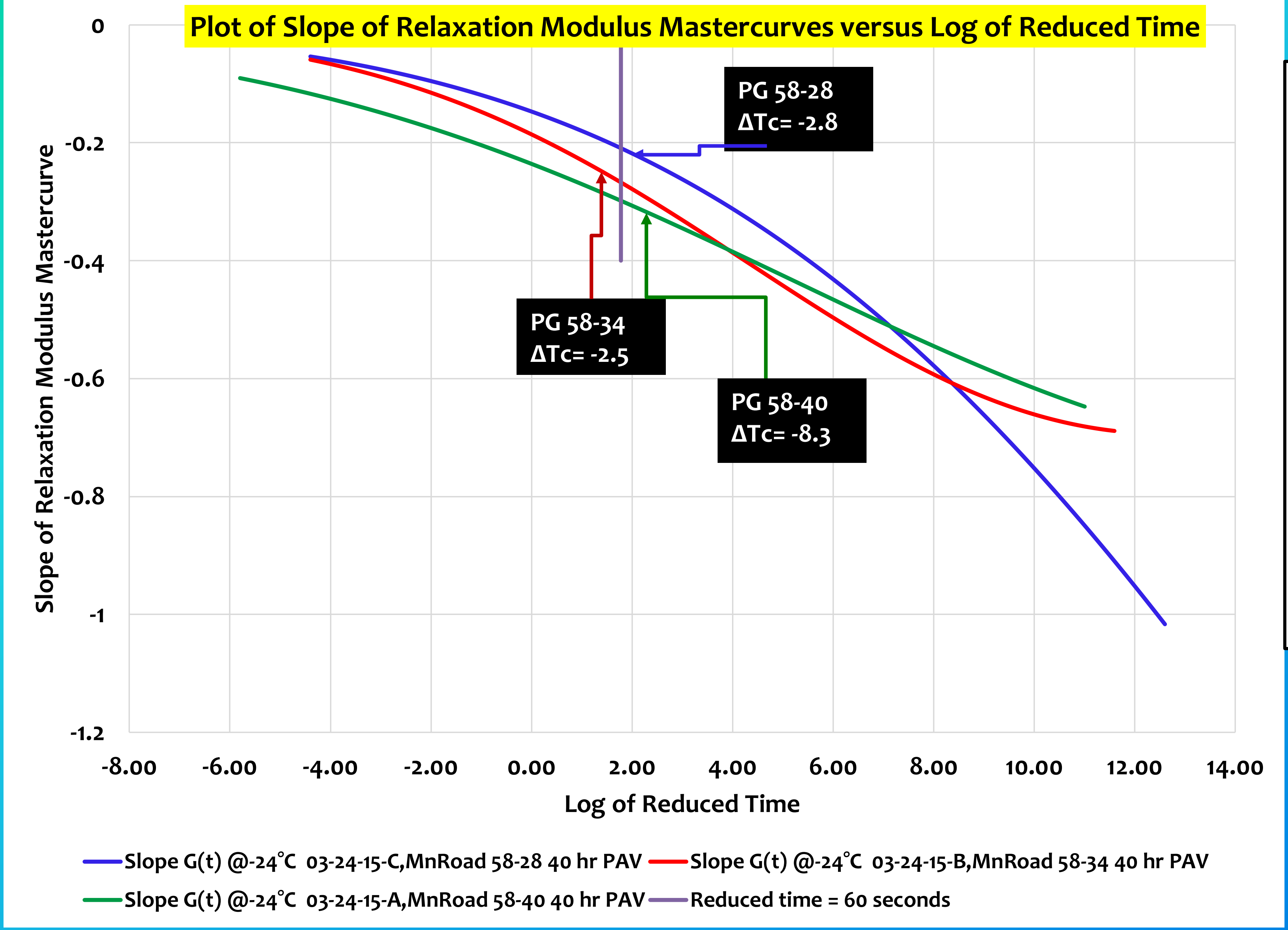

COMMENTS

1. The plots of relaxation modulus slopes indicate if you look carefully that PG 58-34 relaxes at a faster rate than PG 58-28. Both binders have beginning slopes nearly the same but by 60 seconds the slope of the PG 58-34 has decreases more rapidly
2. It is also clear that the PG 58-40 slope is the flattest and decreases at the slowest rate

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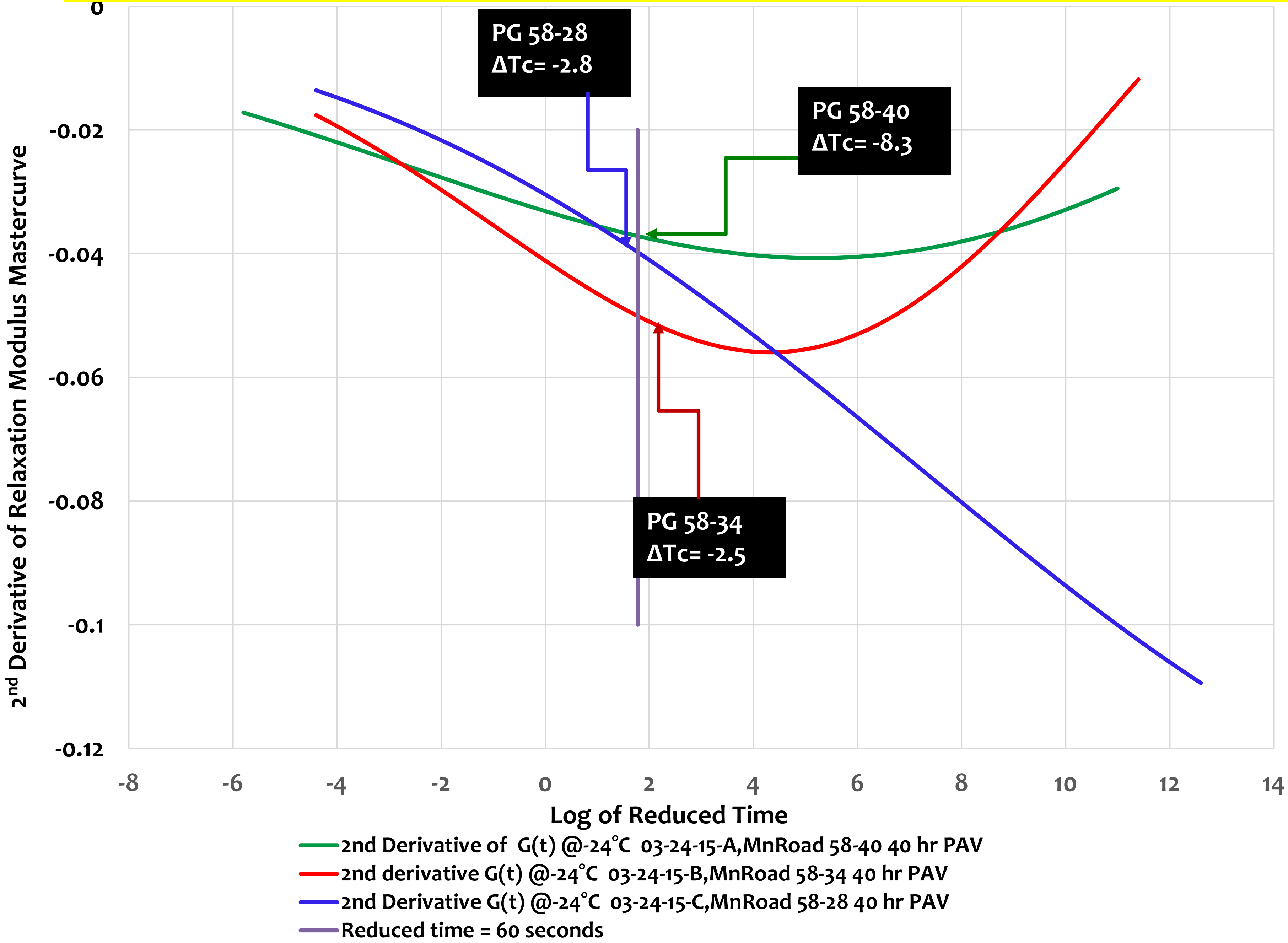
Plot of 2nd Derivative of Relaxation Modulus Mastercurve verse Reduced Time



COMMENTS

1. When the 2nd derivative of the relaxation modulus (the actual rate of relaxation) is plotted it is clear that the PG 58-40 with the lowest ΔTc also has the lowest rate of relaxation.
2. The PG 58-28 has a slightly lower rate of relaxation, but it is also continuing to relax as time increases.
3. The PG 58-34 has the most rapid rate of relaxation and increase at extended relaxation times is due to the effect of the polymer. There is a similar effect for PG 58-40 but it occurs at much lower relaxation rates

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Conclusions

1. Kandhal noted in the conclusions to his report ***"Due to its empirical nature, it is not clearly understood what fundamental property is being measured by the ductility test. However, it is a desirable value indicating pavement performance. More research is needed to develop a rational test method which can be used more effectively to predict performance"*** ✓
2. **I suggest ΔTc is the answer to Kand hal's search**
   a) **This is the most straight forward way to quantify the binder relaxation properties** ✓
3. **It is easy to perform, virtually every asphalt lab has a BBR** ✓
4. **What is missing is a suitable aging protocol to match field aging in different locales (in Glover's 2005 report he advocated a more severe aging procedure)**
   a) **Cracking really began to accelerate after 5 years in service, especially for poorest performing binders based on the two field studies discussed** ✓
5. **There is a need to age mixtures because (nearly) every mix contains RAP and/or RAS and may also contain deleterious softening agents. You can't identify potential problems by just testing the virgin binder added to the mix**

Conclusions

6. **Parameters other than ΔTc are indicative of binder relaxation**
   a) 15°C ductility
   b) Rheological Index or R-Value
   c) Glover parameter
   d) Glover-Rowe Parameter
   e) Crossover Frequency ✓
7. **However ΔTc is the only parameter that is independent of binder composition ✓**
8. **Whereas ΔTc correlates to performance across different binder grades and types when comparing binders used in the same mix; R-value, crossover frequency and Glover-Rowe will not rank conventional binders, PMA and RAS mixes the same. ✓**
   a) R-Value, crossover frequency and Glover-Rowe will yield different magnitudes for polymer modified binders or binders containing RAS. ✓
   b) ΔTc is capable of comparing and ranking performance across binder types because the composition and structure are not influencing the determination of the value

References

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2. Glover, Charles J, Davison, Richard, Domke, Chris, Ruan, Yonghong, Juristyarini, Pramitha, Knorr, Daniel, Jung, Sung, "Development Of A New Method For Assessing Asphalt Binder Durability With Field Validation", FHWA/TX-05/1872-2, August 2005
3. Anderson, R. M, King, G.N., Hanson, D.I., Blankenship, P.B. "Evaluation of the Relationship between Asphalt Binder Properties and Non-Load Related Cracking." Association of Asphalt Paving Technologists, 2011 Volume 80, pp 615-663, 2011
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5. EECongress in Istanbul, 2012, Farrar, et al

Thank you for your time and attention

Questions or Comments

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