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TPF-5(153) Optimal Timing of Preventive Maintenance for Addressing Environmental Aging in Hot-mix Asphalt Pavements

R. Michael Anderson, Asphalt Institute

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Acknowledgments

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- TPF-5(153)
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    - Minnesota (Lead State)
    - Maryland
    - Ohio
    - Texas
    - Wisconsin
    - Local Road Research Board (LRRB)
  - Thomas J. Wood, Lead Agency Contact

Acknowledgments

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- Airfield Asphalt Pavement Technology Program (AAPTP) Project 06-01
  - Techniques for Prevention and Remediation of Non-Load-Related Distresses on HMA Airport Pavements
  - AAPTP sponsors and research panel
    - Federal Aviation Administration
    - AAPTP Director Monte Symons
    - AAPTP 06-01 Project Panel
- Member Companies of the Asphalt Institute

Research Team

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- Asphalt Institute
  - Mike Anderson, PI
  - Phil Blankenship, Senior Research Engineer
- AMEC
  - Doug Hanson, Researcher
- Consultant
  - Gayle King, Researcher

Research Objectives

- Primary Objective
  - to develop and validate technology that can be used by the Minnesota DOT (Mn/DOT) and other highway agencies to determine the proper timing of preventive maintenance in order to mitigate damage caused by asphalt aging.
    - Help highway agencies to define a pavement preservation strategy which optimizes life-cycle cost while maintaining safety and serviceability for the driving public, with primary emphasis on countering the deleterious effects of asphalt aging

Expected Deliverables

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- Expected deliverables:
  - Identification of an asphalt binder or mixture parameter related to durability as a result of environmental aging that can be determined from testing of pavement cores.
  - Specification limits (Warning and Action limits) for the durability parameter that indicate the need for preventive maintenance.
  - Guidelines for monitoring the durability parameter during the life of an asphalt pavement.
  - Economic evaluation of the cost effectiveness of applying surface treatments at various times in the life of an asphalt pavement.
  - Final Report describing the results of the research.

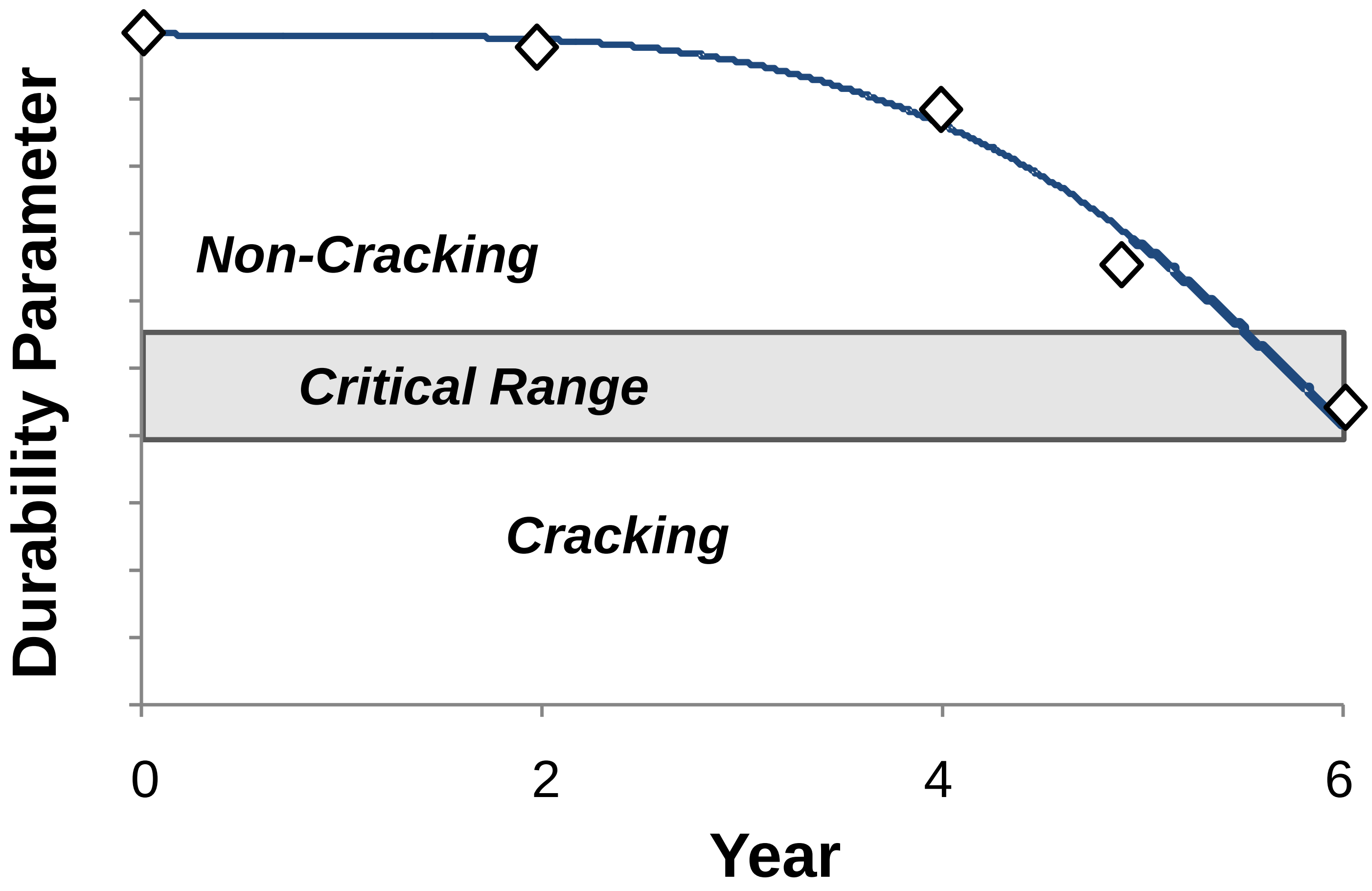
AAPTP 06-01 Research Objectives

- Develop a practical guide identifying means to prevent and mitigate cracking caused by environmental effects.
- Develop one or more test procedures that could be used by a pavement manager to determine when preventative maintenance is needed to prevent the development of cracking (specifically block cracking).

AAPTP 06-01 Research Question

- As the Airport Manager…
  - What test do I run or what calculation can I do that will tell me when the pavement is expected to begin showing significant non-load related distress?

Concept


Durability Parameter
Non-Cracking
Critical Range
Cracking
0
2
4
6
Year

General Concept

- Impact of in-service aging is oxidation and loss of flexibility at intermediate and low temperatures
  - Block-cracking
    - when environmental (non-load) conditions create thermal stresses that cause strain in the asphalt mixture that exceeds the asphalt's failure strain
  - Preventing or mitigating distress
    - identify a property of the asphalt binder or mixture that sufficiently correlates with its flexibility
    - provide a procedure to monitor when flexibility reaches a state where corrective action is needed

Asphalt Durability

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- A durable asphalt:
  - has physical properties necessary for desired initial product performance, and
  - is resistant to change in physical properties during long-term, in-use environmental aging

Petersen, J.C., “Chemical Composition of Asphalt as Related to Asphalt Durability-State of-the-Art”, TRR. 999, 1984

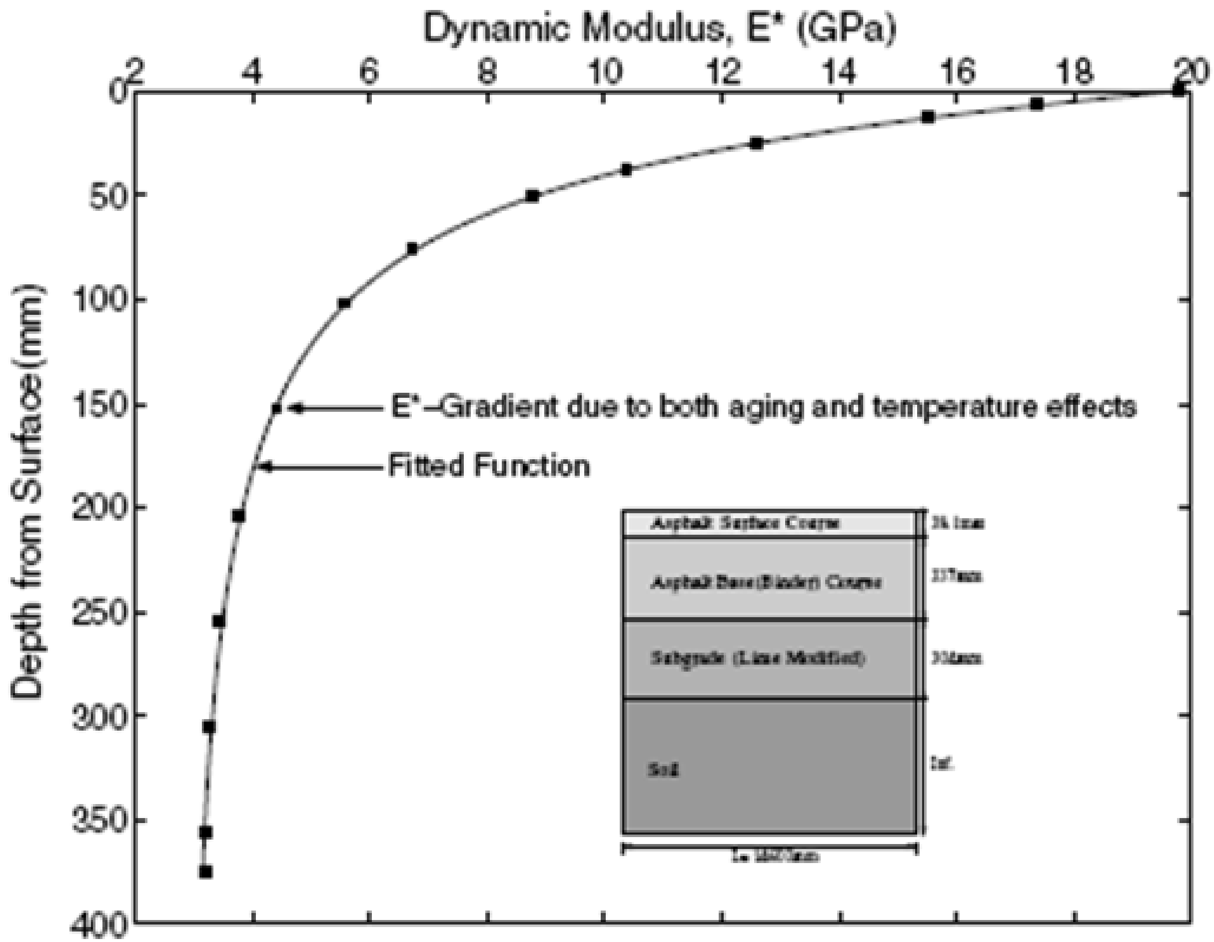
Asphalt Oxidation

Vallerga: Age-Embrittlement

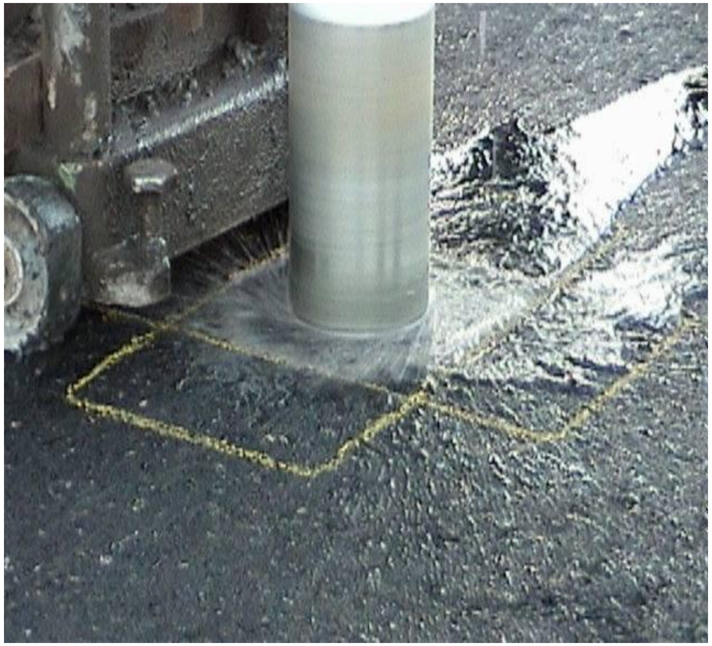
Raveling

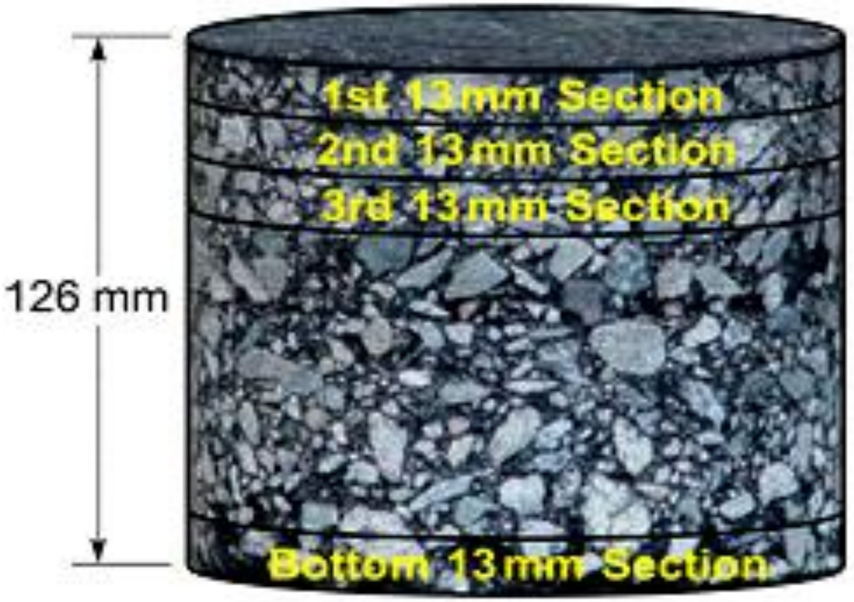
Block Cracking

Witczak and Mirza: Global Aging Model (1995)



Arizona Validation Site

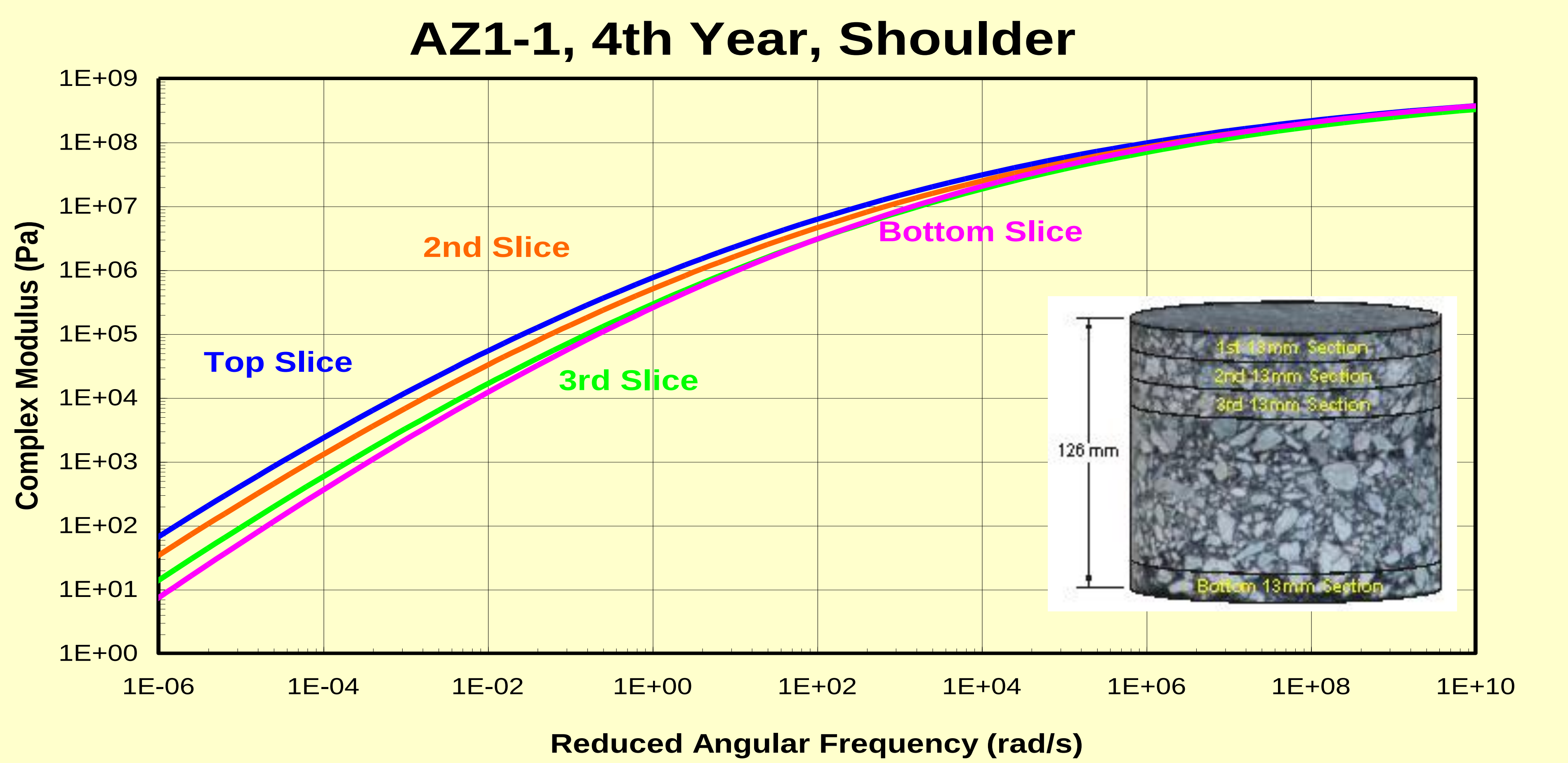




Constructed Nov. 2001
Shoulder cored Nov. 2005

2 63-mm lifts, 19-mm NMS dense graded aggregate, 4.7% AC)

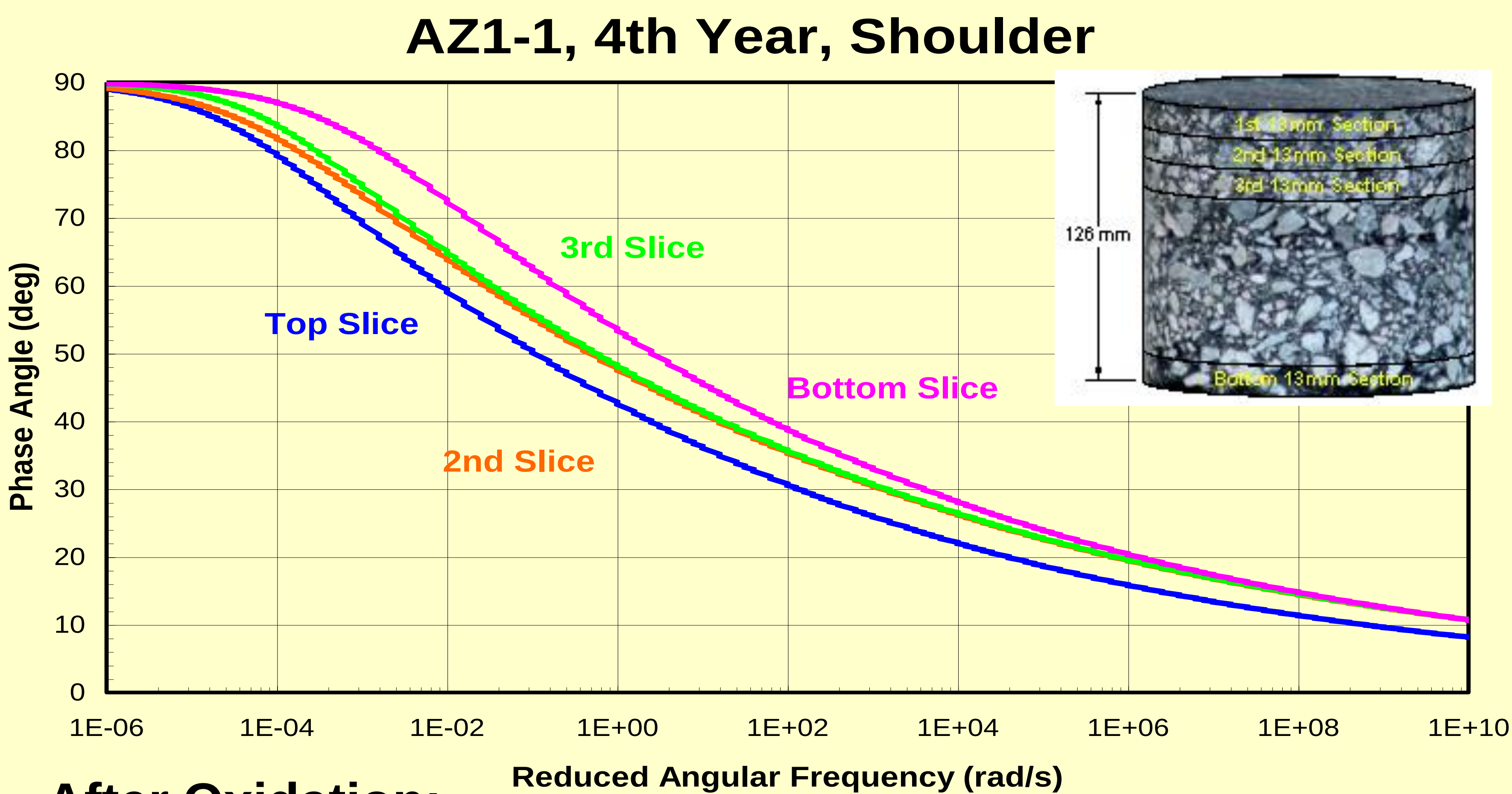
Effect of Pavement Depth on Aged Asphalt Properties



After Oxidation:

Top slice > 2nd slice > 3rd slice > Bottom slice

Effect of Pavement Depth on Aged Asphalt Properties



After Oxidation:

Top slice > 2nd slice > 3rd slice > Bottom slice

Asphalt Oxidation
Physical Changes - Ductility

Conventional Wisdom:

Kandhal tied block cracking severity to ductility at 60ºF (15ºC)

- Loss of surface fines as ductility → 10cm
- Surface cracking evident when ductility falls to 5 cm
- Serious surface cracking at ductility falls below 3 cm

"Low-Temperature Ductility in Relation to Pavement Performance", ASTM STP 628, 1977

Background

- Texas A&M Research (Glover, et.al.)
  - 2005
  - "Development of a New Method for Assessing Asphalt Binder Durability with Field Evaluation"
  - Build on work by Kandhal (1977) and others suggesting block cracking and raveling is tied to low binder ductility after aging
  - Identified rheological parameter related to ductility

AAPTP 06-01

- Lab Study
  - Asphalt Binder Study
    - Various aged conditions
  - Asphalt Mixture Study
    - Various aged conditions
- Field Study
  - Limited validation of lab findings
  - Asphalt binder and mixture tests

Asphalt Binders

- Three asphalt binders representing different expected aging characteristics
  - Selected based upon the relative relationships between low temperature stiffness (S) and relaxation (m-value)
  - West Texas Sour (PG 64-16)
    - 3.1°C m-controlled
  - Gulf Southeast (PG 64-22)
    - 1.3°C m-controlled
  - Western Canadian (PG 64-28)
    - 0.6°C S-controlled

Experimental Matrix

- Asphalt Binders
  - West Texas Sour (PG 64-16)
  - Gulf-Southeast (PG 64-22)
  - Western Canadian (PG 64-28)

Table 1: Asphalt Binder Testing Matrix

	Unaged	PAV20	PAV40	PAV80
DSR Mastercurve				
DSR Function (Texas A&M)				
DSR Monotonic (Wisconsin)				
Ductility, 15°C				
Force Ductility				
BBR				
DTT				

Tests

- DSR
  - Mastercurve at 15°C
    - 8-mm parallel plate, 1% strain
    - 5, 15, and 25°C
    - Frequency sweep (0.1 to 100 rad/s)
    - Obtain Texas A&M (Glover) parameter at 0.005 rad/s
      - $G'/(\eta'/G')$
      - Related to ductility at 15°C and 1 cm/min.

Relationship between Ductility and DSR Parameter

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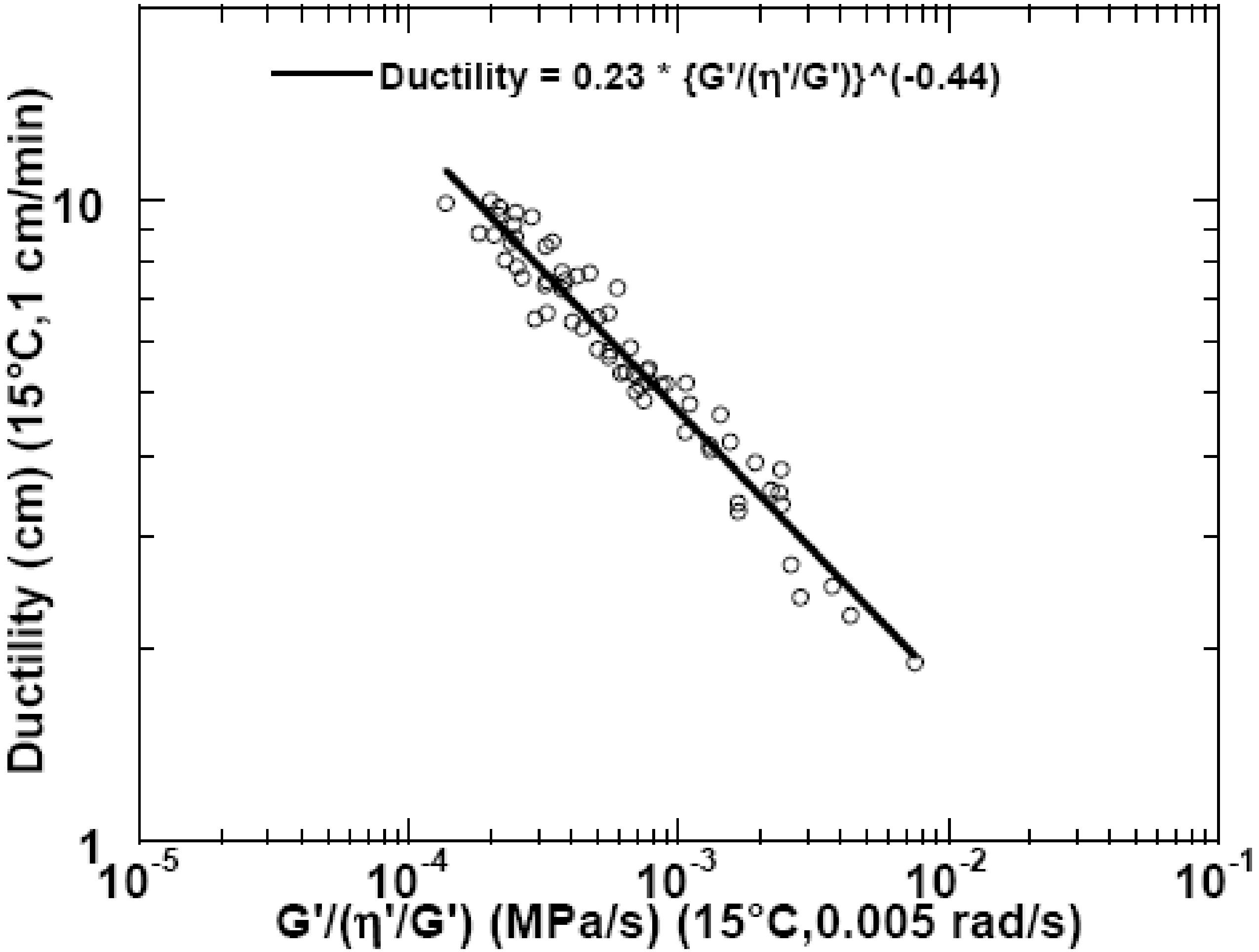

(Glover et.al., 2005)

Tests

- DSR
  - Mastercurve at 15°C time-consuming
    - Approximately two hours of testing followed by analysis of isothermal data to generate mastercurve
  - Direct testing?
    - Approximately 20 minutes to complete one oscillatory cycle at 0.005 rad/s

Tests

- DSR
  - Solution
    - Use TTSP to get equivalent temperature/loading conditions
    - 44.7°C, 10 rad/s
    - 25-mm parallel plate, 10% strain
      - Noted some non-linearity suggesting that the target strain should have been lower

DSR Parameter (derived from Mastercurve)

Table 5: G′/(η′/G′) at 15°C, 0.005 rad/s (MPa/s) – WC Asphalt Binder

	PAV0	PAV20	PAV40	PAV80
Replicate 1	3.53E-07	1.98E-04	6.36E-04	5.72E-03
Replicate 2	2.66E-07	2.04E-04	6.13E-04	6.25E-03
Replicate 3	3.77E-07	1.98E-04	7.56E-04	2.92E-03
Average	**3.32E-07**	**2.00E-04**	**6.68E-04**	**4.96E-03**
Std. Deviation (1s)	5.48E-08	3.46E-06	7.67E-05	1.79E-03
Coefficient of Variation (1s%)	17.6%	1.7%	11.6%	36.1%

Relationship between DSR Parameter and Ductility

	Texas A&M Standard DSR		Mastercurve	
Measured Ductility (cm)	Measured $G'/(\eta'/G')$ MPa/s	Predicted Ductility (cm)	Measured $G'/(\eta'/G')$ MPa/s	Predicted Ductility (cm)
0.5	3.38E-03	2.8	2.09E-02	1.3
1	1.18E-03	4.5	6.23E-03	2.1
1	1.73E-03	3.8	4.96E-03	2.4
1	2.18E-04	9.4	1.89E-03	3.6
4	2.55E-04	8.8	2.03E-03	3.5
4.25	3.40E-04	7.7	1.42E-03	4.1
5	3.90E-04	7.3	6.68E-04	5.7
6	1.20E-04	12.2	4.11E-04	7.1
10	1.45E-04	11.2	2.00E-04	9.8

$$\text{Ductility (15°C, 1cm/min.)} = 0.23*[G'/(\eta'/G')]^{-0.44}$$

Relationship between DSR Parameter and Ductility

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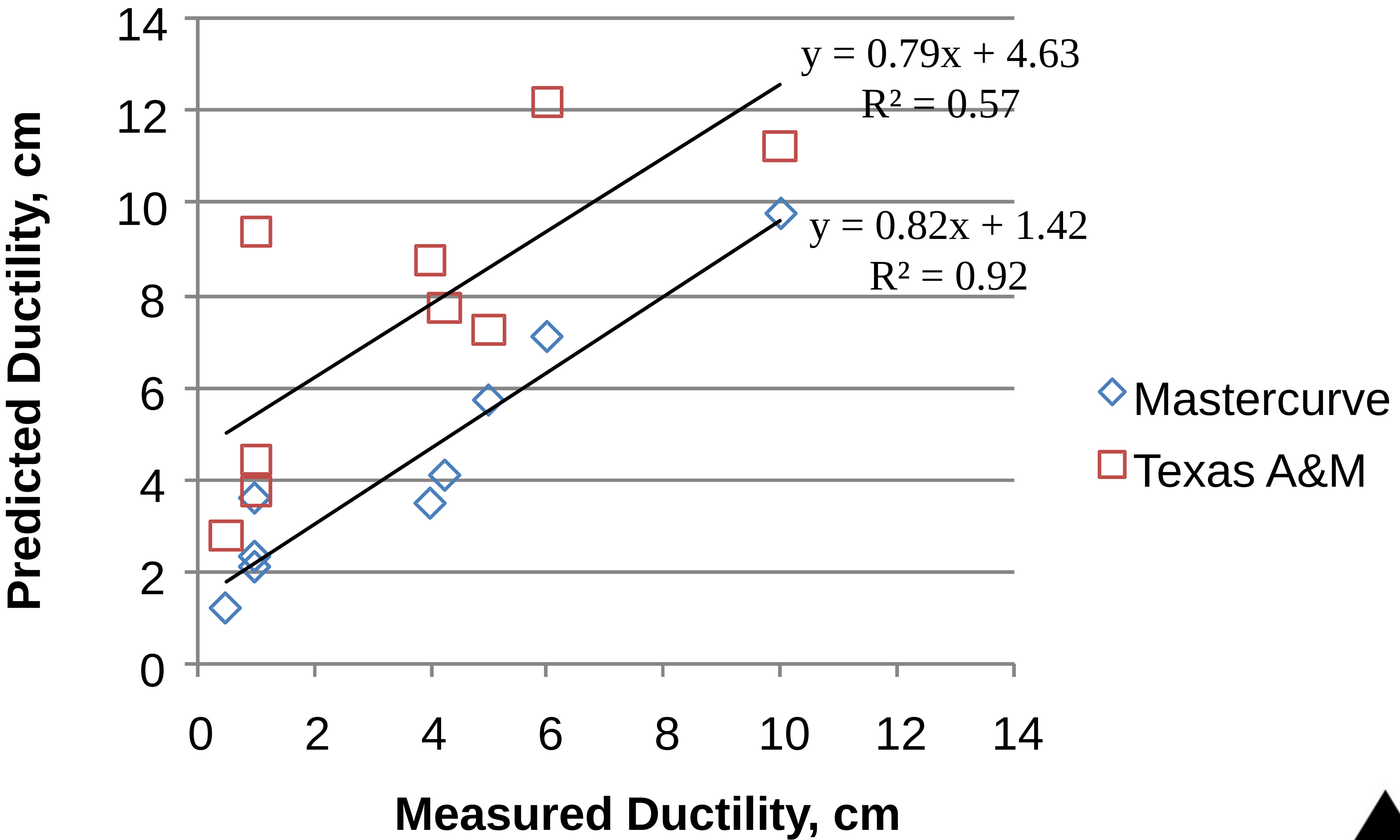

Mastercurve Procedure

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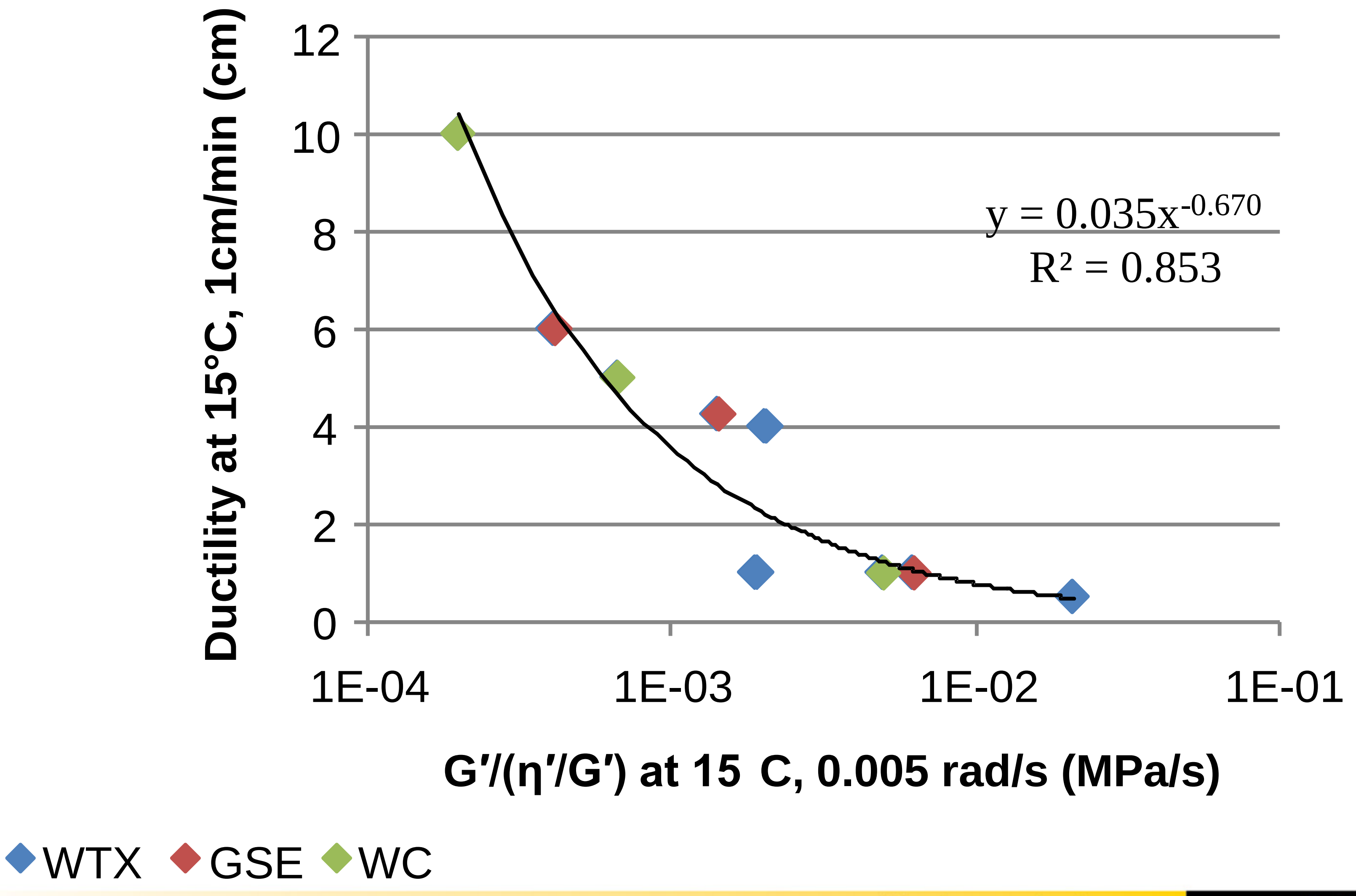
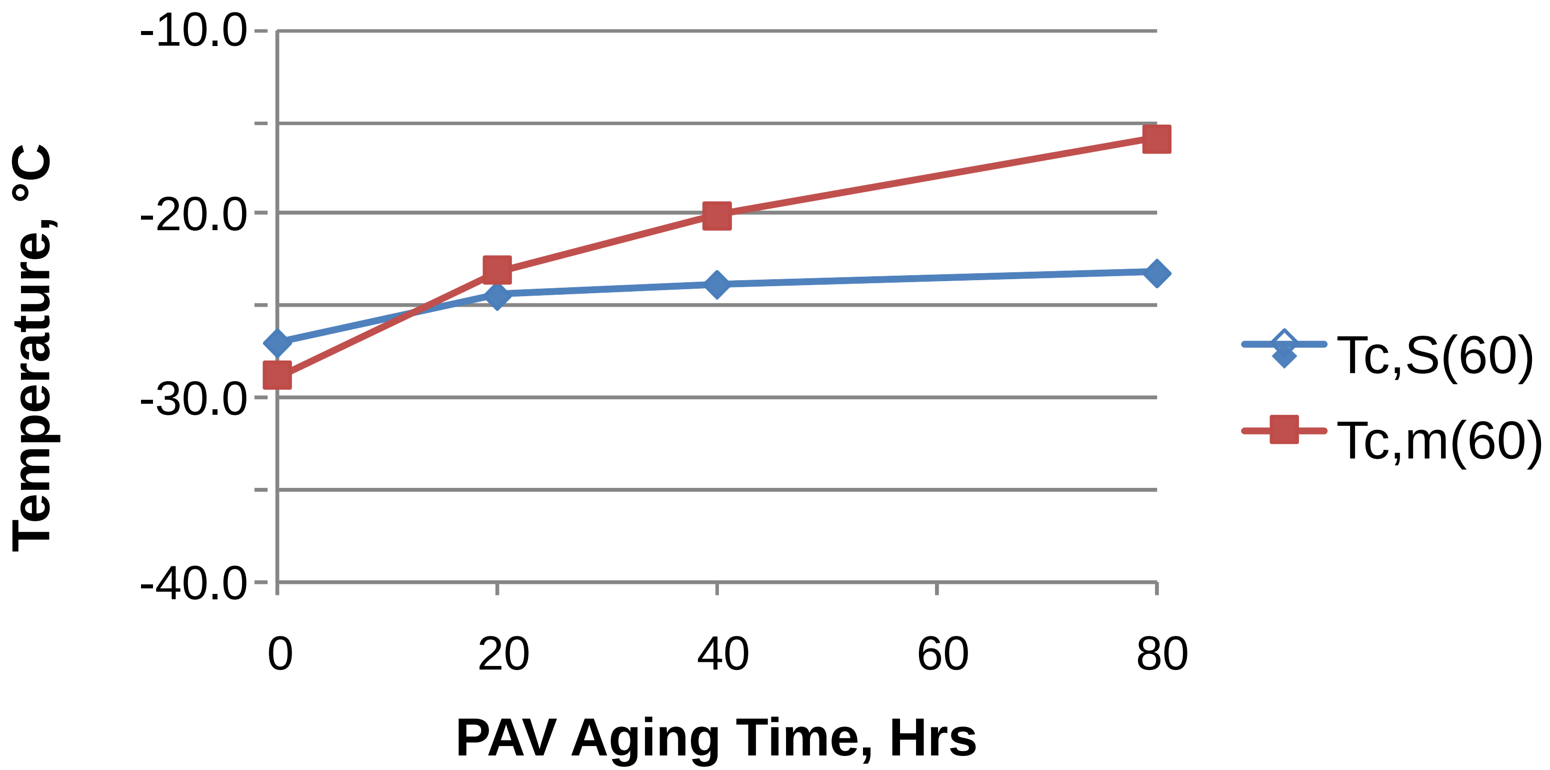


BBR: Gulf-Southeast (GSE)



BBR Cracking Parameter - ΔTc

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$$\Delta Tc = T_c\,(\text{m-value} = 0.30) - T_c(\text{S} = 300\ \text{MPa})$$

- Relationship to ductility
- Relationship to G’/(η’/G’)
- Relationship to R-value (CA model)

Effect of PAV Aging Time on ΔT_c

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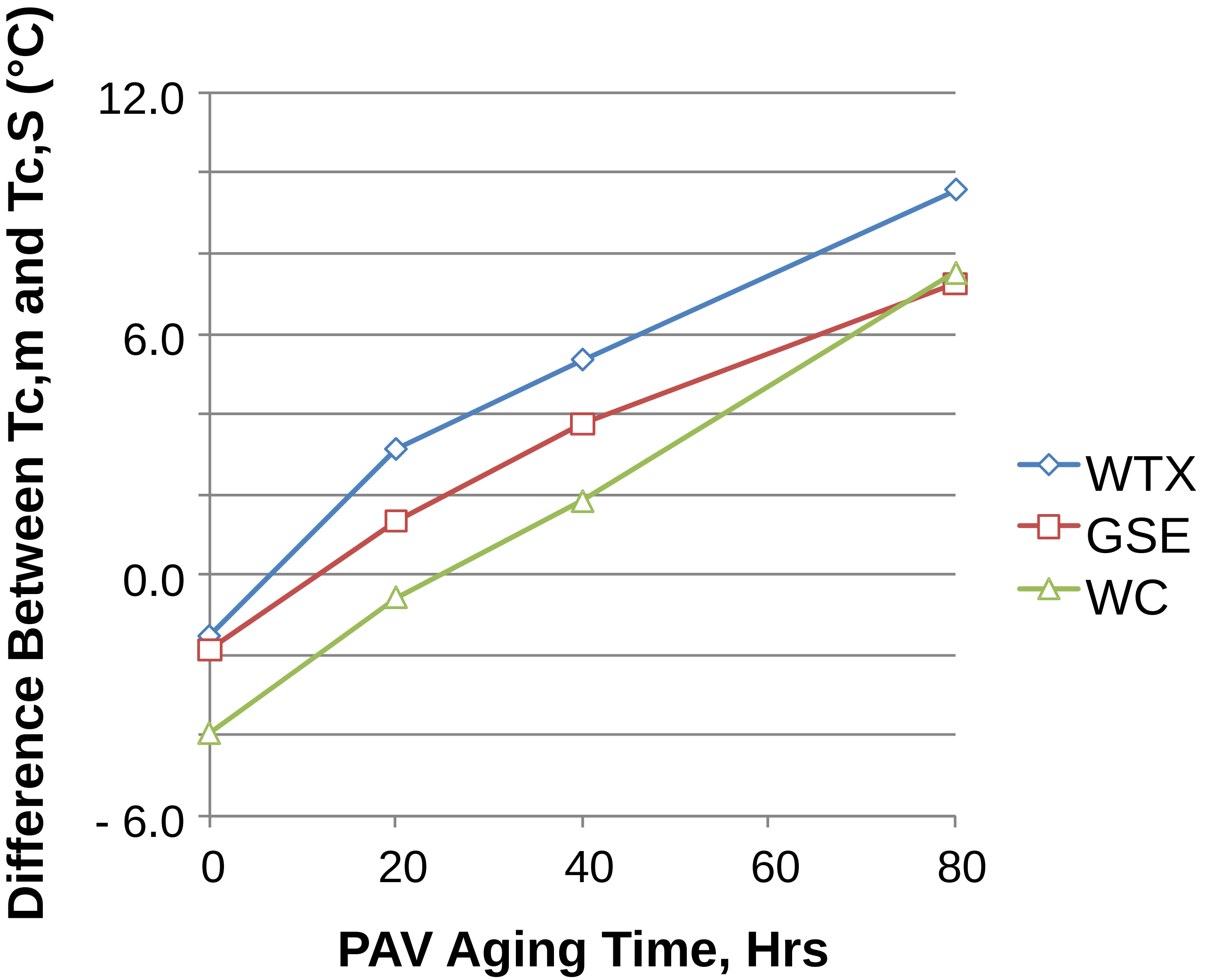

Relationship between ΔT_c and Ductility

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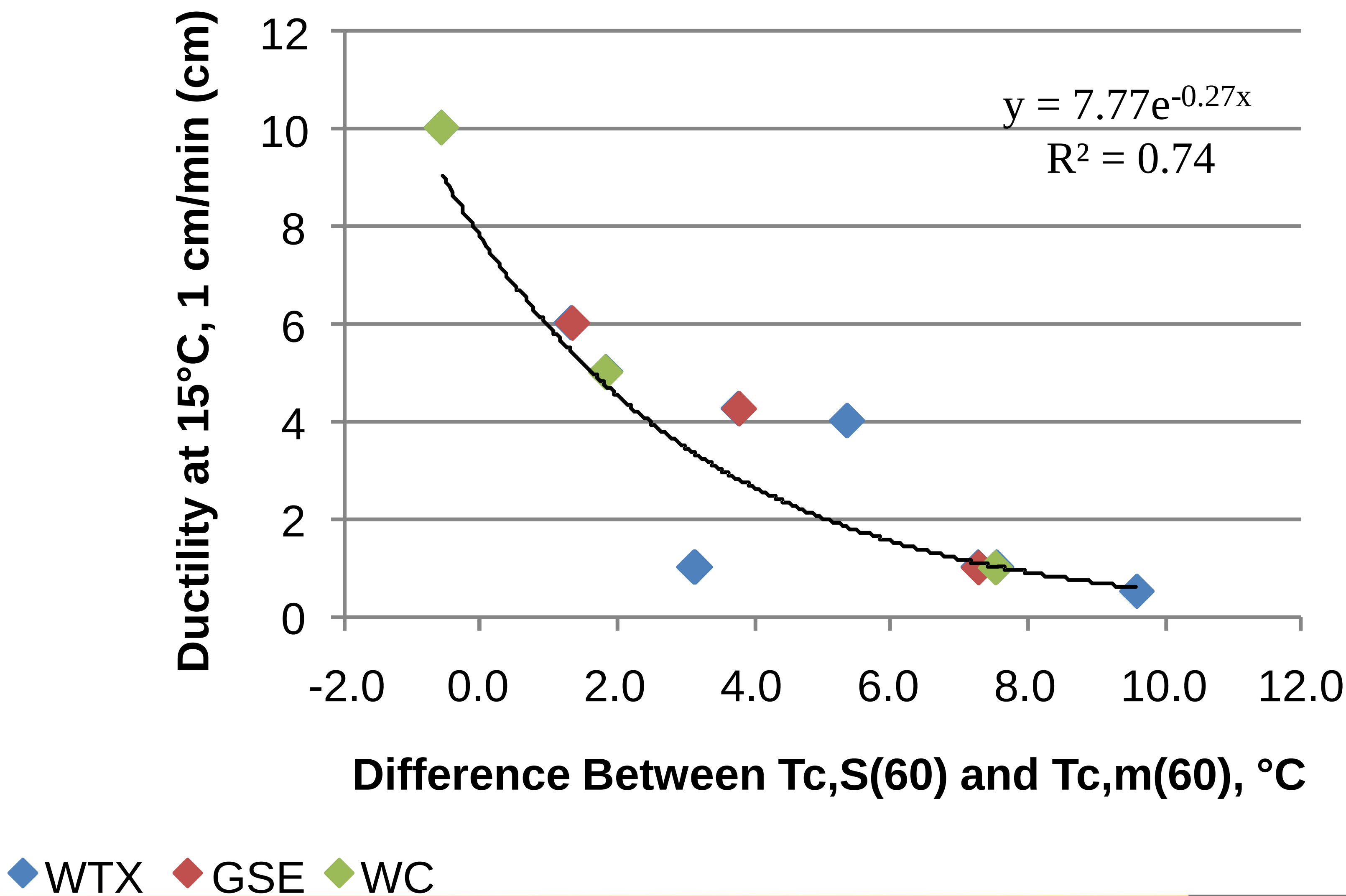
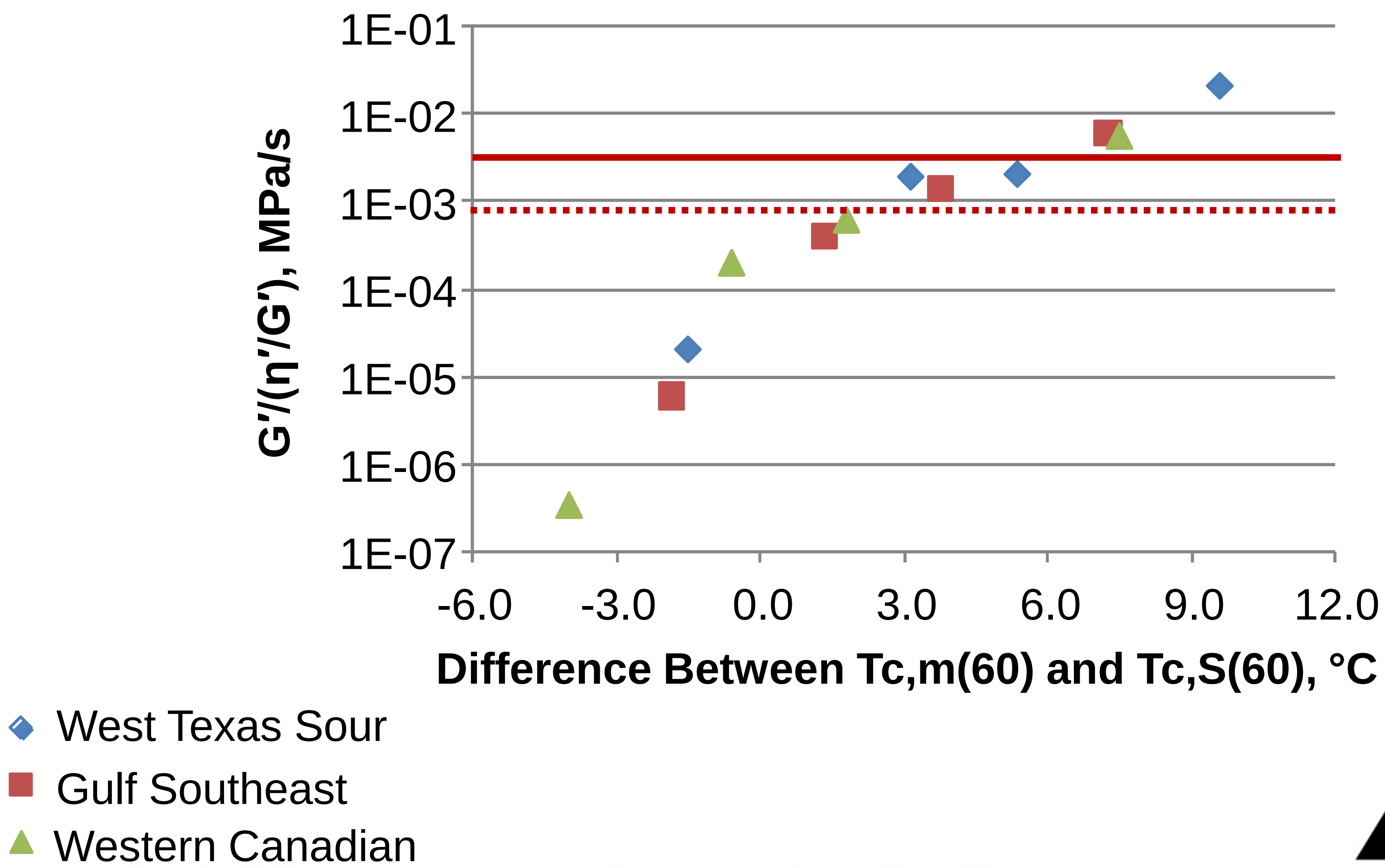
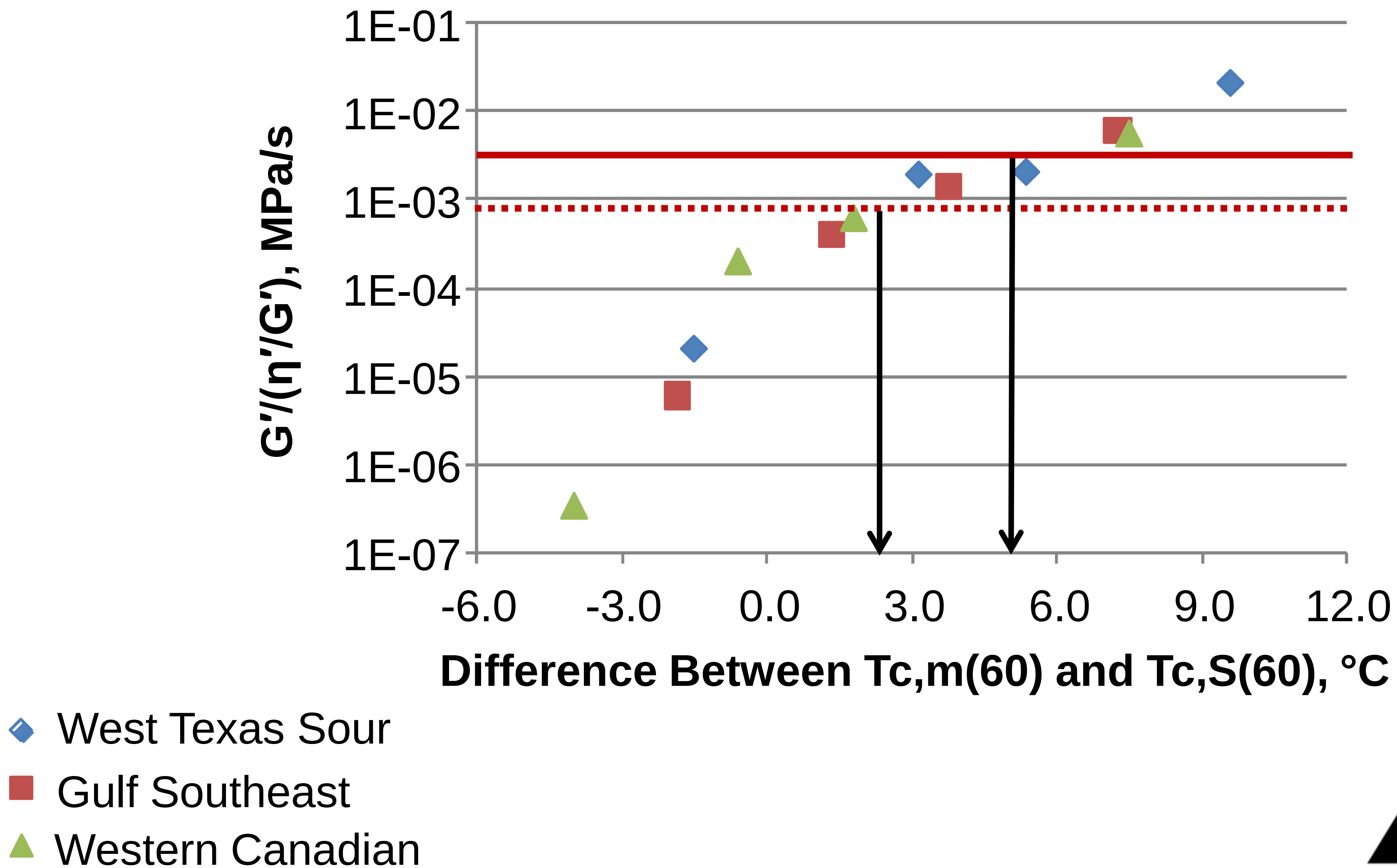


Relationship between $G'/(\eta'/G')$ and ΔT_c



Relationship between G′/(η′/G′) and ΔT$_c$



Black Space Diagram: Western Canadian Asphalt Binder

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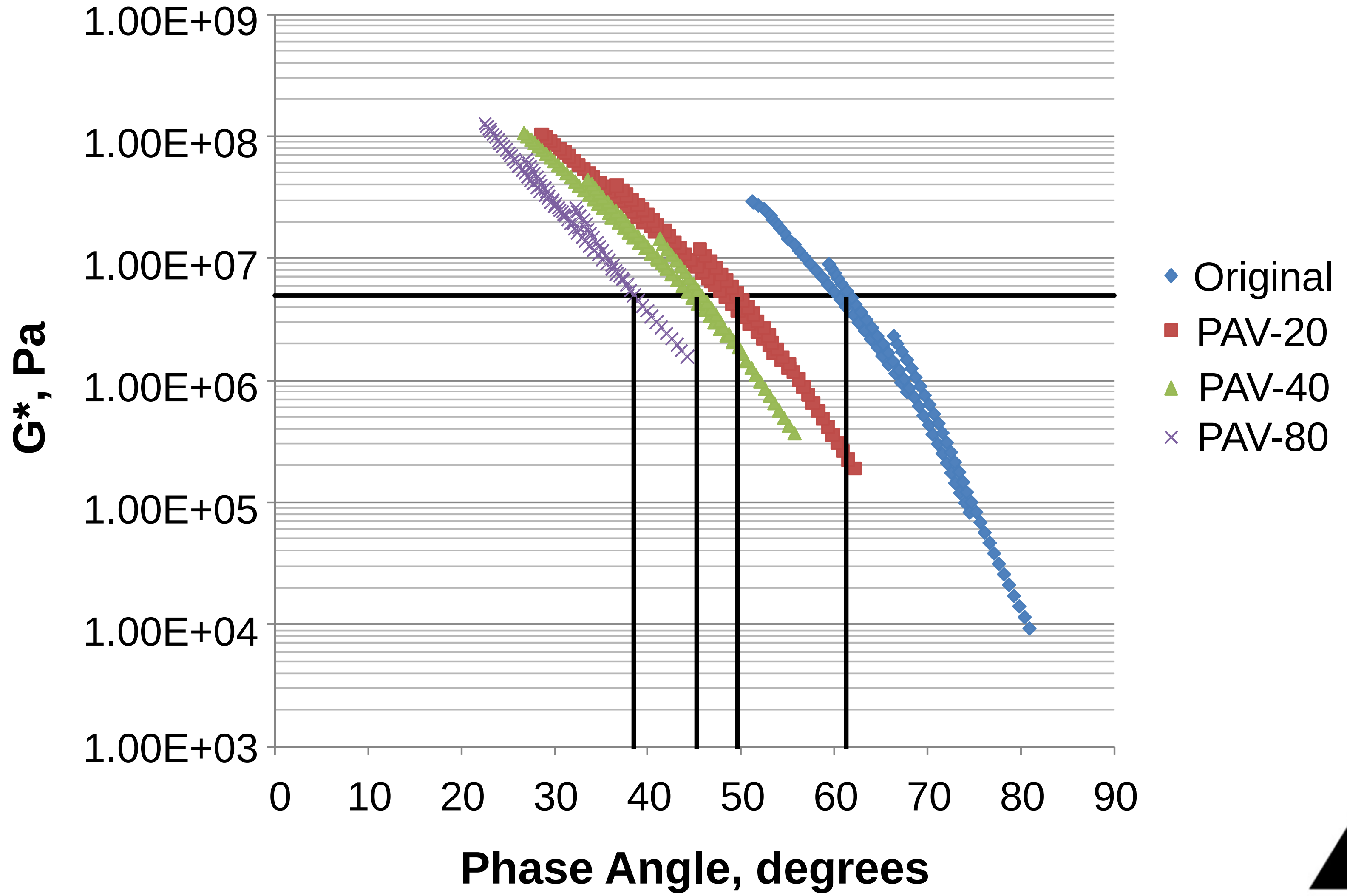
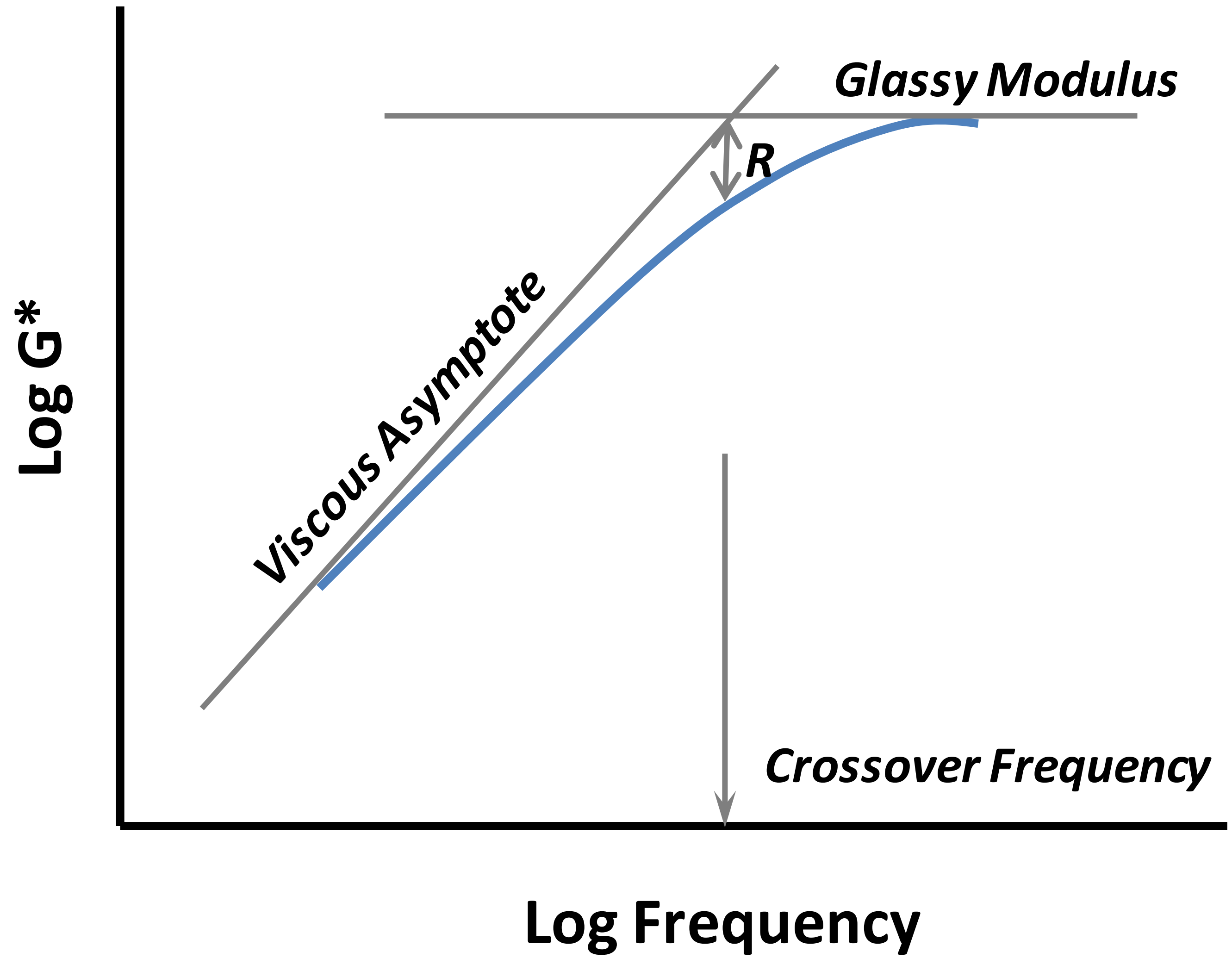
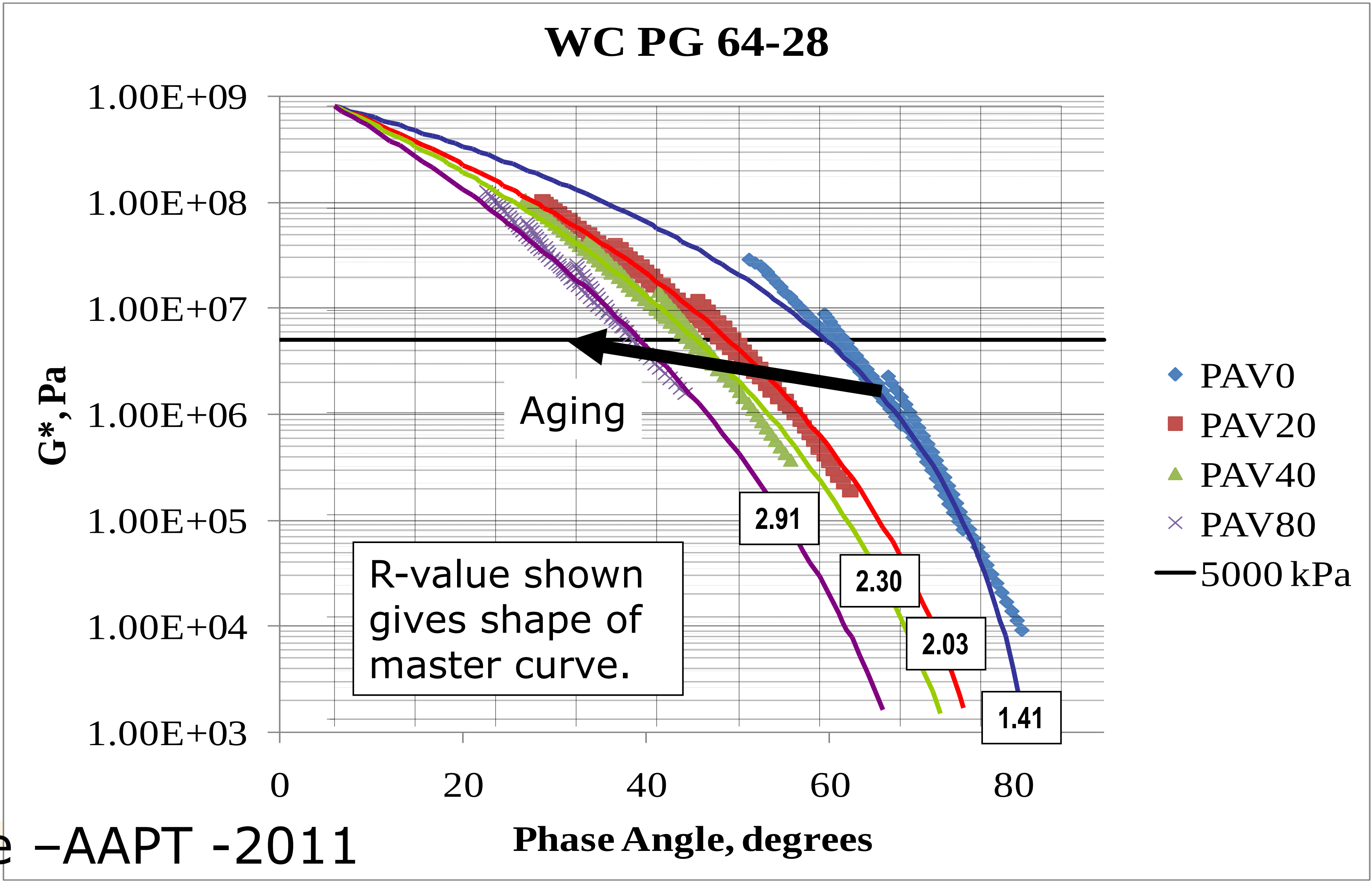


Rheological Index – R

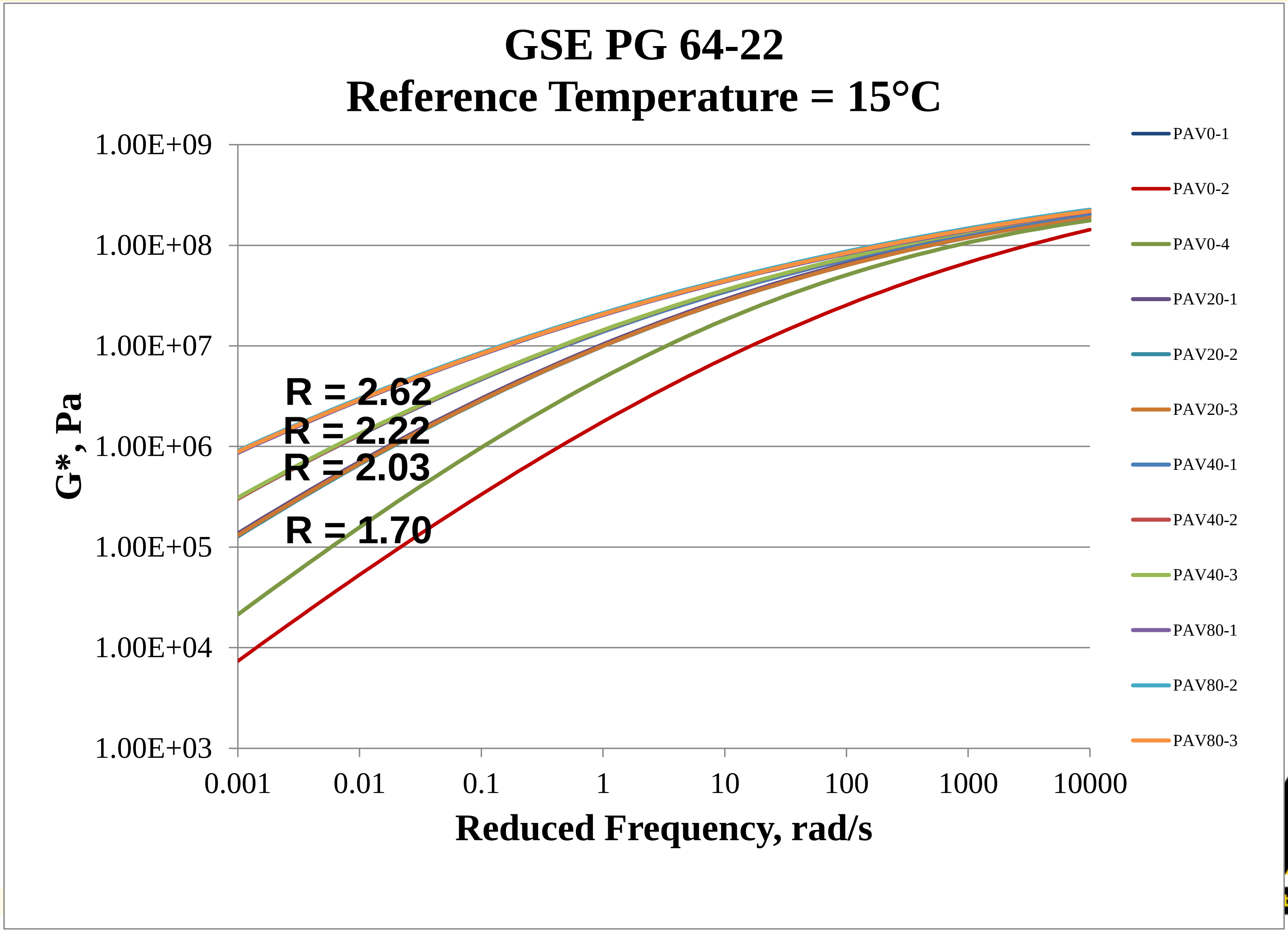


Western Canadian PG 64-28
Plot of R-values in Black Space



Rowe –AAPT -2011

AAPTP 06-01


GSE PG 64-22
Reference Temperature = 15°C
1.00E+09
1.00E+08
1.00E+07
1.00E+06
1.00E+05
1.00E+04
1.00E+03
G*, Pa
R = 2.62
R = 2.22
R = 2.03
R = 1.70
0.001
0.01
0.1
1
10
100
1000
10000
Reduced Frequency, rad/s
PAV0-1
PAV0-2
PAV0-4
PAV20-1
PAV20-2
PAV20-3
PAV40-1
PAV40-2
PAV40-3
PAV80-1
PAV80-2
PAV80-3

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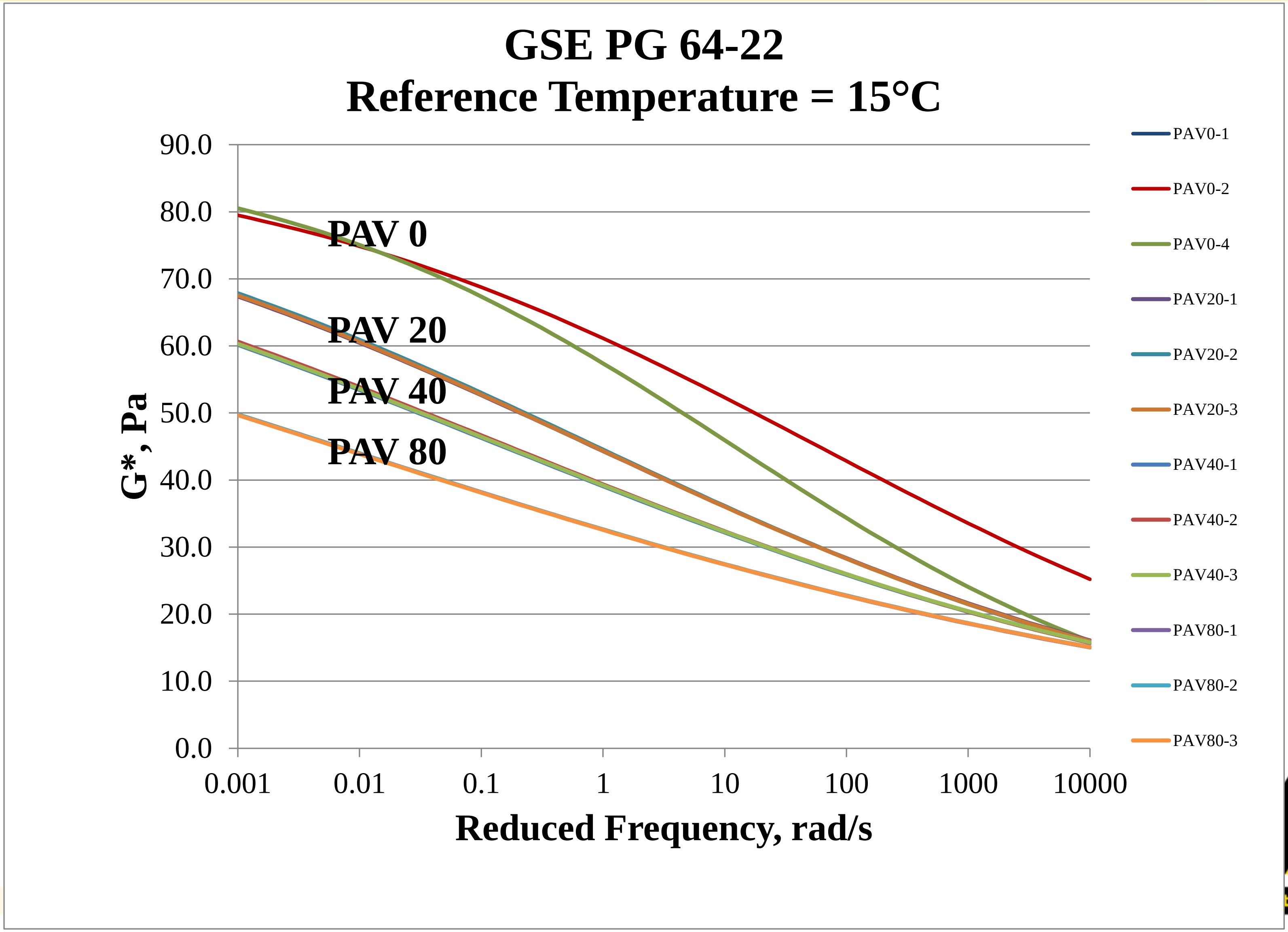

Field Validation

- Three general aviation (GA) airport projects representing four in-service pavements
  - Roundup (Montana)
    - Recently received an overlay of an older, cracked pavement
    - Upper layer representing the new pavement (Roundup Top)
    - Lower layer representing the older pavement (Roundup Bottom)

Field Validation

- Three general aviation (GA) airport projects representing four in-service pavements
  - Clayton (New Mexico)
    - Paved in 2004 using 85-100 penetration asphalt binder from a local supplier (likely using West Texas Sour)
    - Some low-severity longitudinal cracking and raveling was identified

Field Validation

- Three general aviation (GA) airport projects representing four in-service pavements
  - Conchas Lake (New Mexico)
    - Paved in 2001 using 85-100 penetration asphalt binder from same local supplier (likely using West Texas Sour)
    - Some low-to-moderate severity raveling was identified over most of the paved area
    - Pavement surface appeared slightly oxidized

Field Core Data

Table 18: Comparison of Durability Parameters for Recovered Asphalt Binder Data

	Roundup Top	Roundup Bottom	Clayton	Conchas Lake
G'/(η'/G')[1], MPa/s	3.28E-04	6.80E-04	4.65E-04	6.66E-04
ΔTc, °C	0.5	2.9	2.2	3.5
Predicted Ductility[2], cm	7.8	5.7	6.7	5.7

[1] Determined at 15°C and 0.005 rad/s.

[2] Ductility predicted using G'/(η'/G') and equation in Figure 3.

Relationship between G′/(η′/G′) and ΔT$_c$ (with Field Cores)

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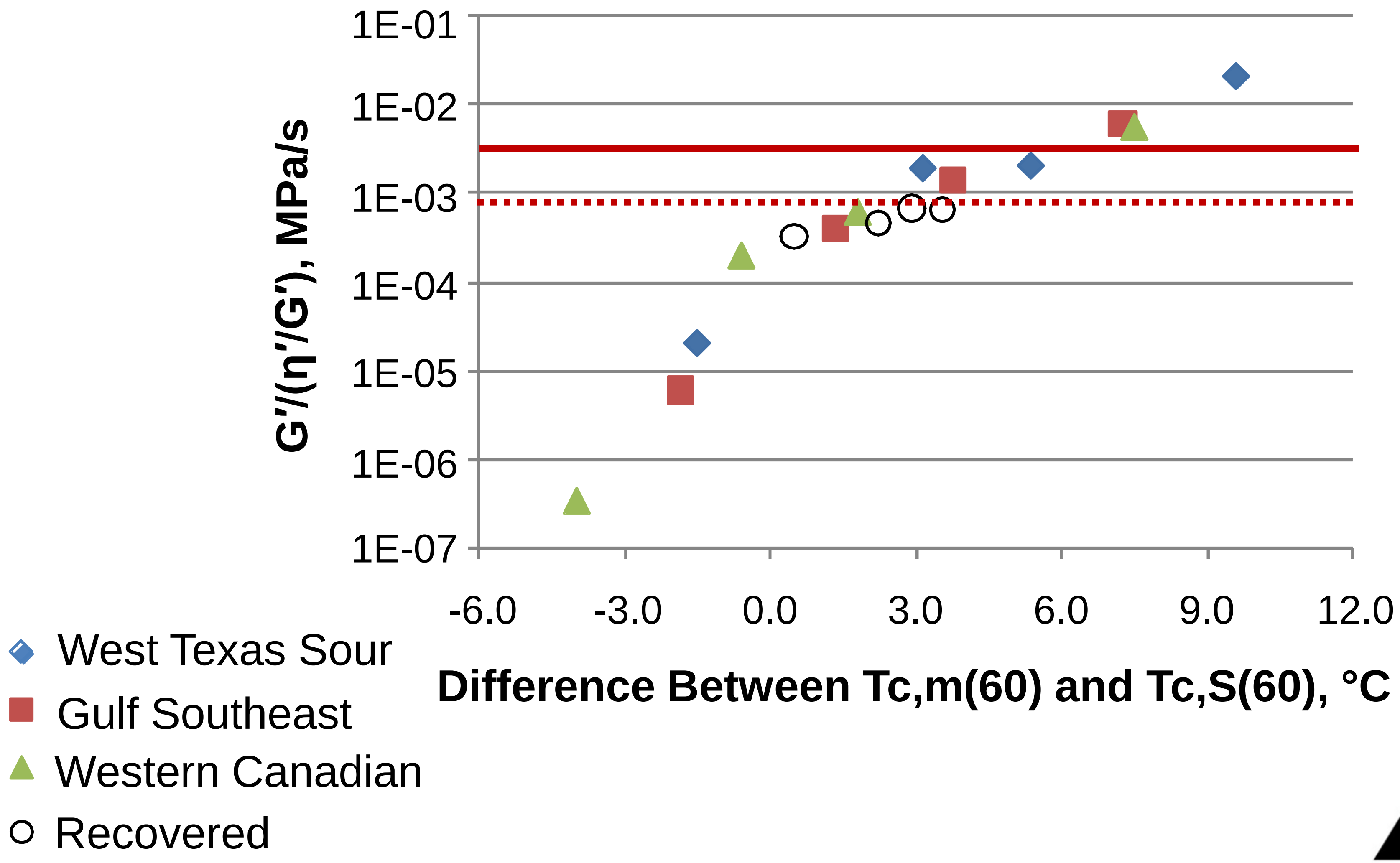

Summary

- Past research
  - Some relationship between ductility (conducted at an intermediate temperature) and the durability of an asphalt pavement
  - Texas A&M research validated through identification of DSR parameter, $G'/(\eta'/G')$, at 15 C and 0.005 rad/s

Summary

- Current research
  - Confirmed relationship of Texas A&M DSR parameter, G′/(η′/G′), at 15 C and 0.005 rad/s, to ductility
  - Identified similar parameter through BBR testing, ΔTc, which quantifies the difference in continuous grade temperature for stiffness and relaxation properties
  - Parameters appear to quantify the loss of relaxation properties as an asphalt binder ages

Summary

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- Field Studies
  - Four sections from three GA pavements in Montana and New Mexico
  - Findings generally matched the lab studies, with the newer pavements having values of $G'/(\eta'/G')$ and ΔTc that indicated less aging and more flexibility than the older pavements

Study Limitations and Future Research Needs

- Only three asphalt binders were evaluated in the laboratory studies
  - may or may not represent the range of expected aging performance of asphalt binders in the United States
- No modified asphalt binders were evaluated
  - The relationships found between physical properties and aging of unmodified asphalt binders may not be valid for modified asphalt binders
  - (N.B. modified asphalt binders may not be routinely used in GA airport asphalt pavements, rendering this limitation somewhat irrelevant).

Study Limitations and Future Research Needs

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- Only four airport asphalt pavements were studied in the field validation portion of the study
  - from three airports in two sets of environmental conditions
  - Unfortunately, none of the four pavements exhibited high levels of cracking needed to validate the proposed parameters.

Study Limitations and Future Research Needs

- The recommended use presumes that an airport manager will have the desire, time, and resources to conduct testing and analysis throughout the pavement's life.
  - Prequalification testing of the asphalt materials could be used to identify the risk for early cracking

Task 4

- Laboratory and Field Evaluation of MnROAD and Other Test Sections
  - Objective
    - identify test methods that correctly rank distress
    - determine critical binder or mixture failure limits that might be used as objective triggers for the various preservation strategies

Task 4

- Laboratory and Field Evaluation of MnROAD and Other Test Sections
  - Critical fracture parameters monitored throughout the life of the pavement
    - Appropriate remedial action can be taken as the critical limit is approached
  - Simple tests to be used for field monitoring purposes
    - physical properties from simple tests correlated to crack predictions from DC(t) or other more sophisticated fracture tests.

Concept for Non-Load Related Distress

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- Options
  - Use conventional construction data (e.g. binder properties, density, etc.) with climatic data together in an aging/cracking model to project time to remediation
  - Run mix test on cores at construction to get cracking property and fit data within aging/cracking model to project time to remediation

Concept for Non-Load Related Distress

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- Options
  - Run binder test on sample recovered from cores at construction to get cracking property and fit data within aging/cracking model to project time to remediation
  - Run binder and/or mix test at construction to get cracking property and continue to pull cores from pavement at periodic intervals to check progression of cracking property

Task 4

- Selected Test Sections
  - Inspected on a yearly basis for age-related damage
    - MnROAD performance measures will be supplemented with careful monitoring to classify the types and origins of visible cracks
  - Cores
    - 6
    - Between wheel path, closely spaced longitudinally

MnROAD Low Volume Road

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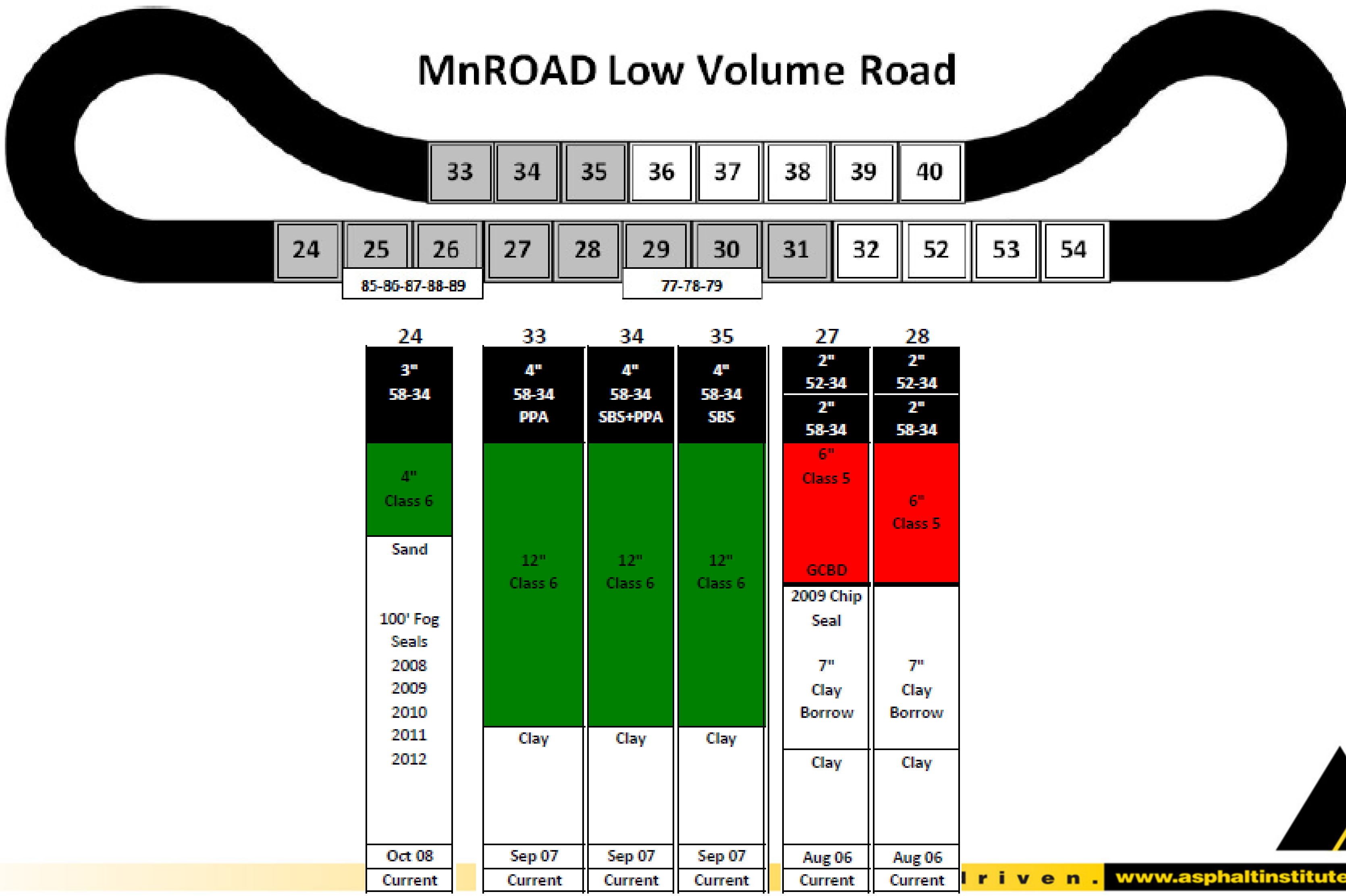
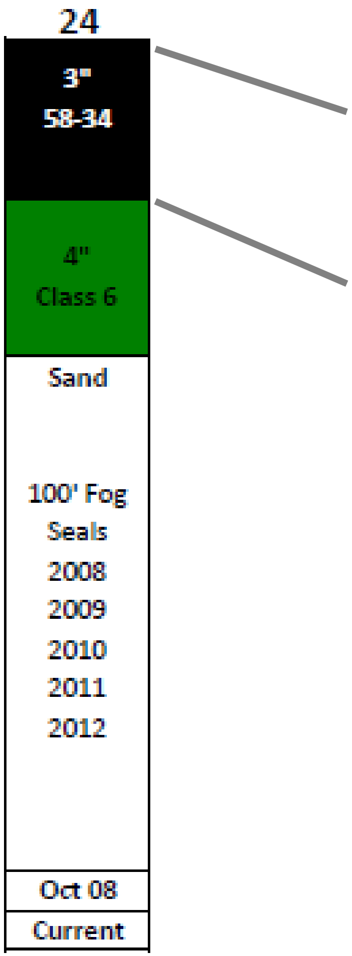
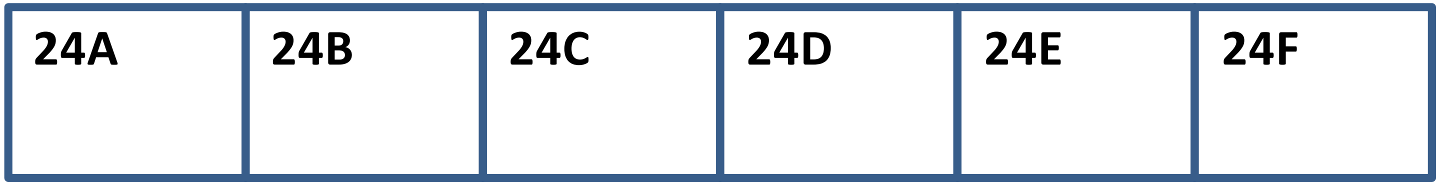


MnROAD Cell 24





MnROAD Cell 24

Cell 24A – section that had a fog seal applied in September 2008.
Cell 24B – section that had a fog seal applied in September 2009.
Cell 24C – section that had a fog seal applied in September 2010.
Cell 24D – section that will have a fog seal applied in 2011.
Cell 24E – section that will have a fog seal applied in 2012.
Cell 24F – section that will have a fog seal applied in 2013.

Task 4 Cores

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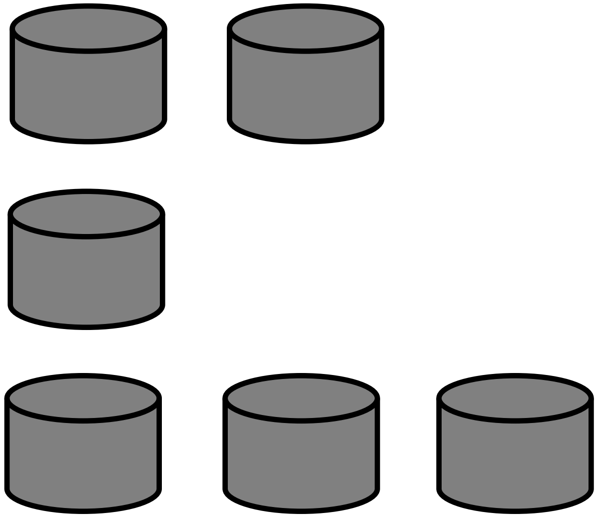
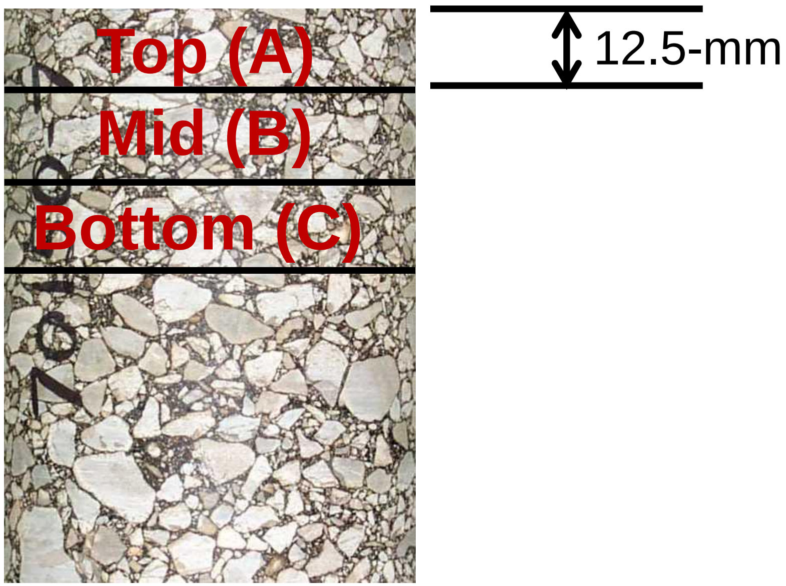


Recovered Binder Testing

Mixture BBR Testing

Mixture DC(t) Testing

Task 4 Cores: Recovered Binder Testing



- Extraction/Recovery
  - Centrifuge extraction using toluene/ethanol
  - Recovery using Rotavapor
- 2 Cores (150-mm diameter x 12.5-mm thickness)
  - ~50 grams asphalt

Task 4 Cores: Binder Testing

- Each Layer
  - DSR Frequency Sweep
    - Three temperatures (5, 15, 25°C) using 8-mm plates
      - Possible different temperatures?
    - Rheological mastercurves for modulus (G*) and phase angle (δ)

Task 4 Cores: Binder Testing

- Each Layer
  - BBR
    - 2-3 temperatures
    - T_c determined to the nearest 0.1°C for S(60) and m(60)
    - Difference in T_c (ΔT_c)

Implementation?

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- Airfield Pavement Manager
  - Coordinate the extraction and recovery of asphalt binder from the mixture and determine the value of $G'/(\eta'/G')$ and/or ΔT_c at the time of pavement construction to establish baseline values

Implementation?

- Airfield Pavement Manager
  - – Periodically coordinate the removal of one or more cores and have a testing lab perform a solvent extraction and recovery to obtain aged asphalt binder
    - Test to determine values of $G'/(\eta'/G')$ and/or ΔT_c at an aged state
    - As the values approach a critical state, consider that the risk of cracking is increased and preventative action should be taken

Concept

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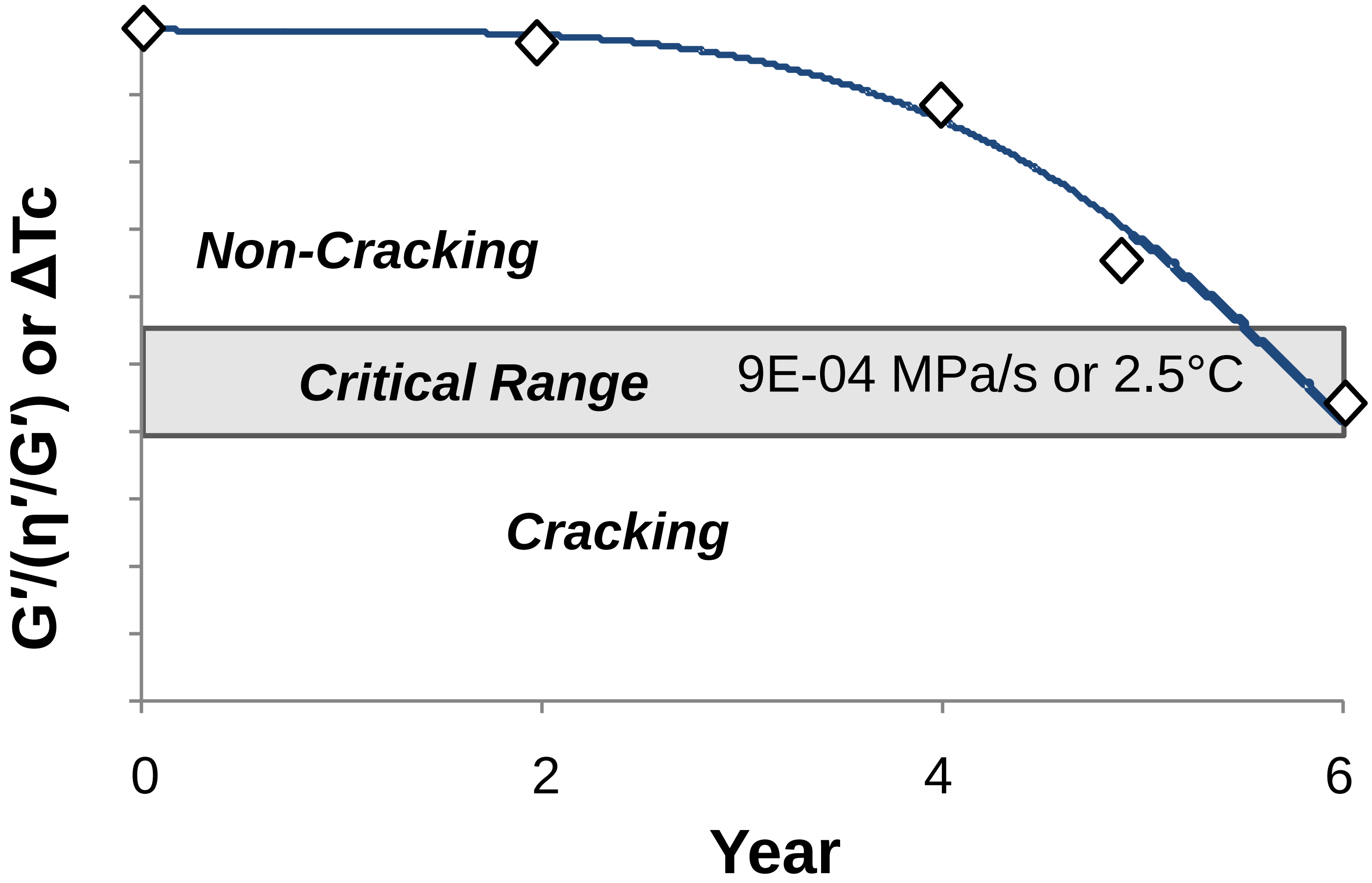

MnROAD Cell 24

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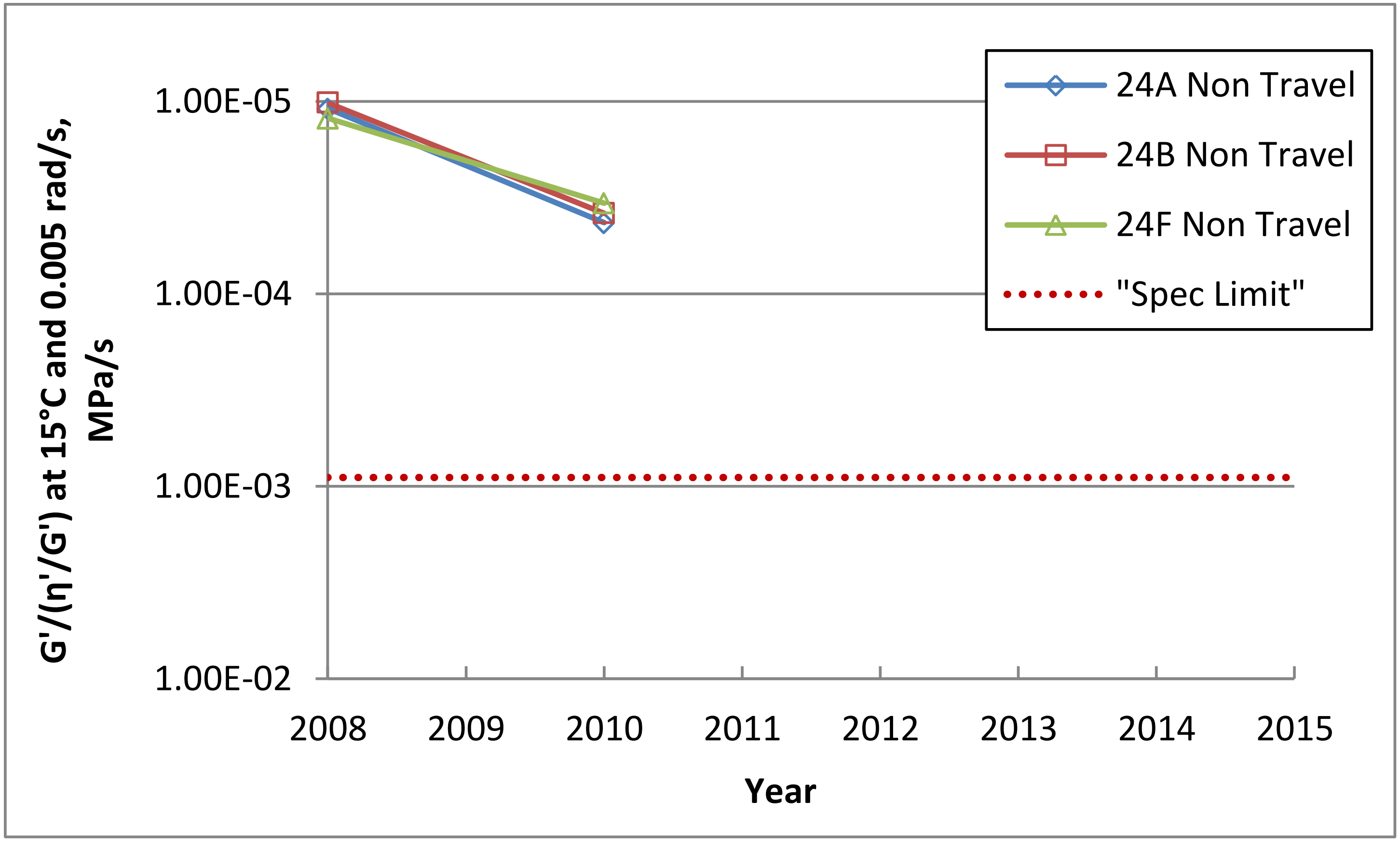

Thanks!