NCHRP Project 9-54
Long-Term Aging of Asphalt Mixtures for Performance Testing and Prediction

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Bozeman, MT
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Outline

- NCHRP 09-54 objectives
- Proposed Long-Term Aging Method
- Proposed Aging Duration Maps Based on Climatic Data
- Pavement Aging Model for M-E Analysis and Design
- Summary

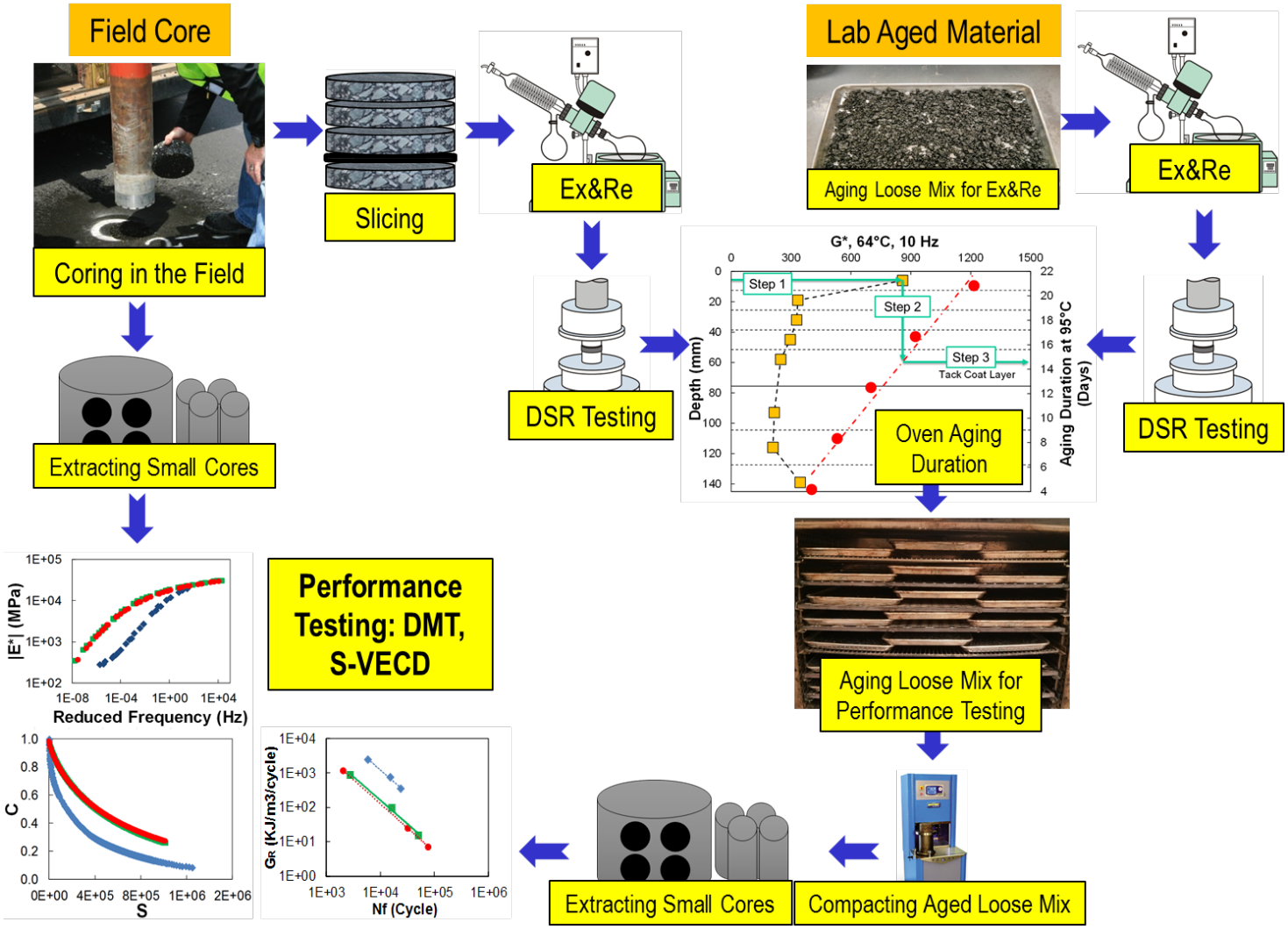
NCHRP 09-54 Objectives

- Develop a calibrated and validated procedure to simulate long-term aging of asphalt mixtures for performance testing and prediction.
- Develop a pavement aging model as a function of climate, age, and pavement depth.

Proposed Long-Term Aging Method

- Oven aging
- Loose mix aging
- 95°C

Experimental Steps



NCHRP 9-54 Kinetics Model

$$\log G^* = \log G_0^* + M\left(1 - \frac{k_c}{k_f}\right)\left(1 - \exp\left(-k_f t\right)\right) + k_c M t$$

where

G^* = dynamic modulus,

G_0^*, M - Material dependent parameters

A_f, A_c, E_{af}, E_{ac} - Universal constants

M = binder aging rate,

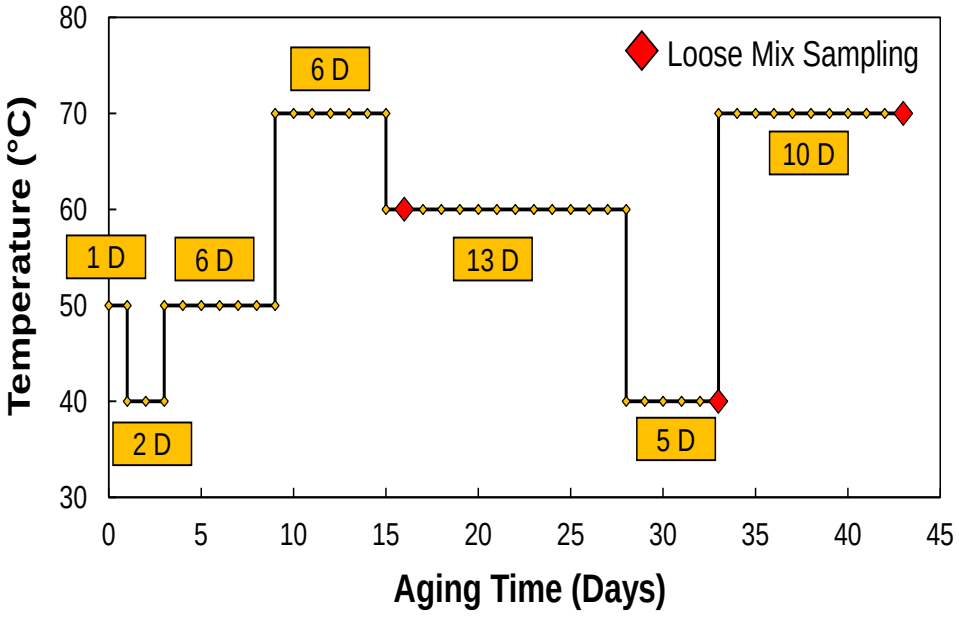
$$k_f = A_f \exp\left(-E_{af}/RT\right),$$

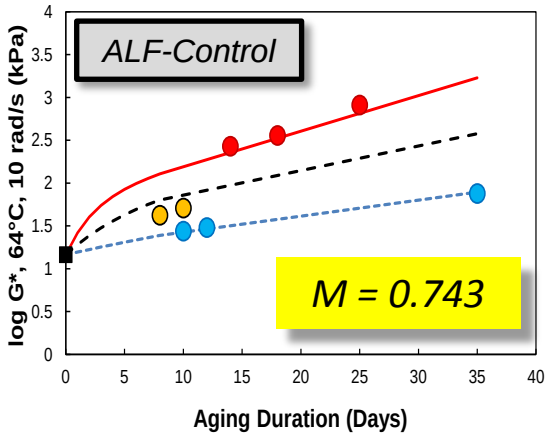
$$k_c = A_c \exp\left(-E_{ac}/RT\right), \text{and}$$

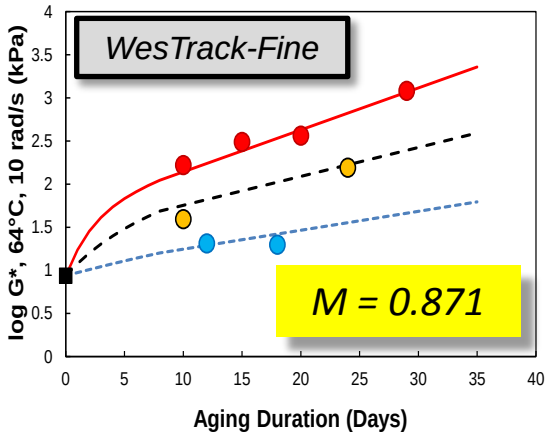
T = temperature in Kelvin.

Non-Isothermal Aging Verification

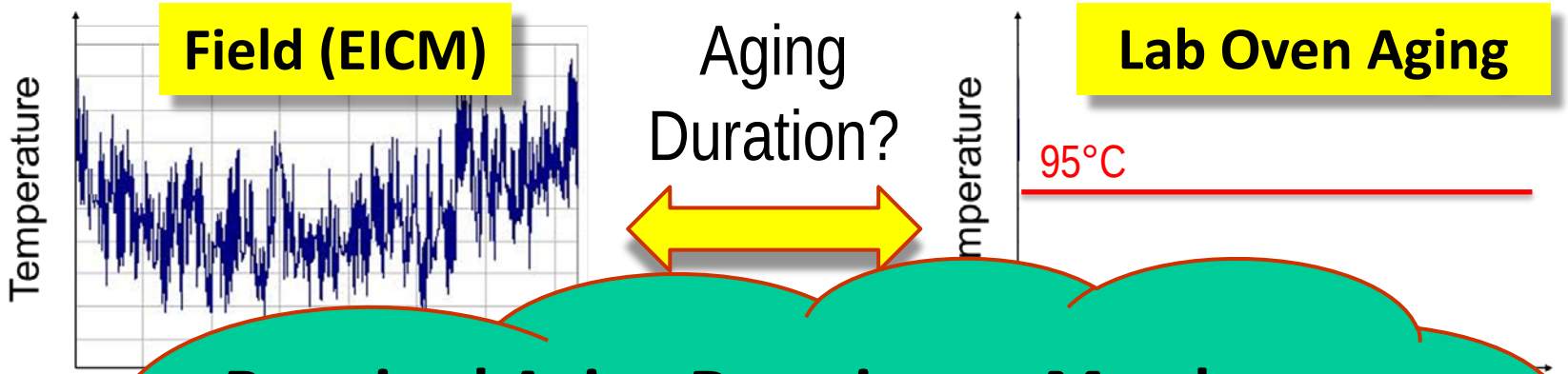
- Non-Isothermal Laboratory Aging Trial
  - FHWA ALF Control
  - WesTrack Fine 1995







Kinetics Modeling to Find Required Duration to Match Field Aging



Required Aging Duration to Match Field Aging is Independent of Binder Source/Type (i.e., STA G* and M)

$$\log G_{Lab}^{*} = \log G_{o}^{*} - [(1 - \exp(-k_f t)) + k_c t]_{Lab}$$

$$[(1 - {}^{k_c}/_{k_f})(1 - \exp(-k_f t)) + k_c t]_{Field} = [(1 - {}^{k_c}/_{k_f})(1 - \exp(-k_f t)) + k_c t]_{Lab}$$

Aging Durations Based on Climatic Data

Climatic Aging Index (CAI)

$$CAI = \sum_{i=1}^{24} \left(D \times A \times \exp\left({}^{-E_a}/_{RT_i}\right)/24\right) = t_{oven}$$

$$D = \begin{cases} 3.4311\ d^{-0.683} & \text{for } 6\ mm \leq d \leq 35\ mm \\ 0.3026 & \text{for } d > 35\ mm \end{cases}$$

where

D = depth correction factor,

A, E_a = fitting parameters,

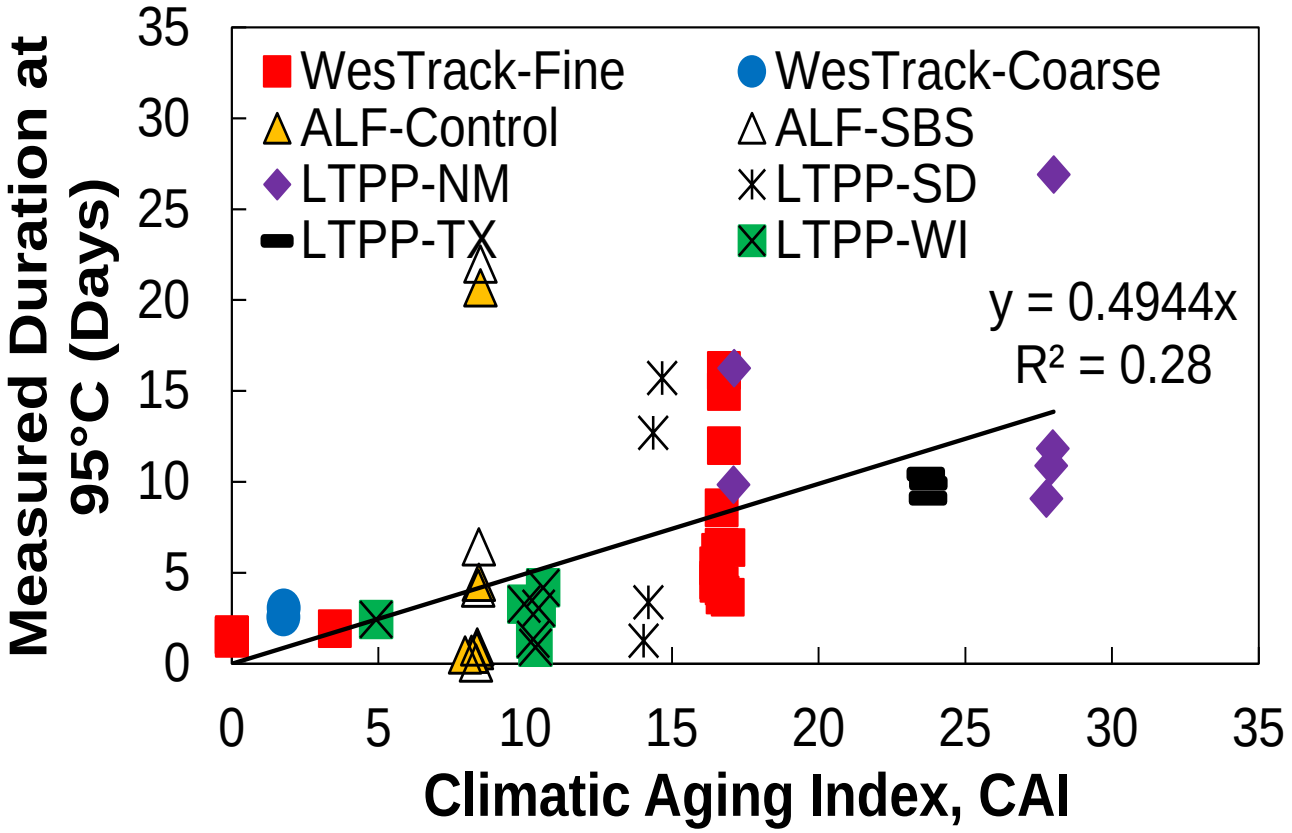
R = universal gas constant,

T = air temperature (Kelvin), and

d = depth of interest (mm).

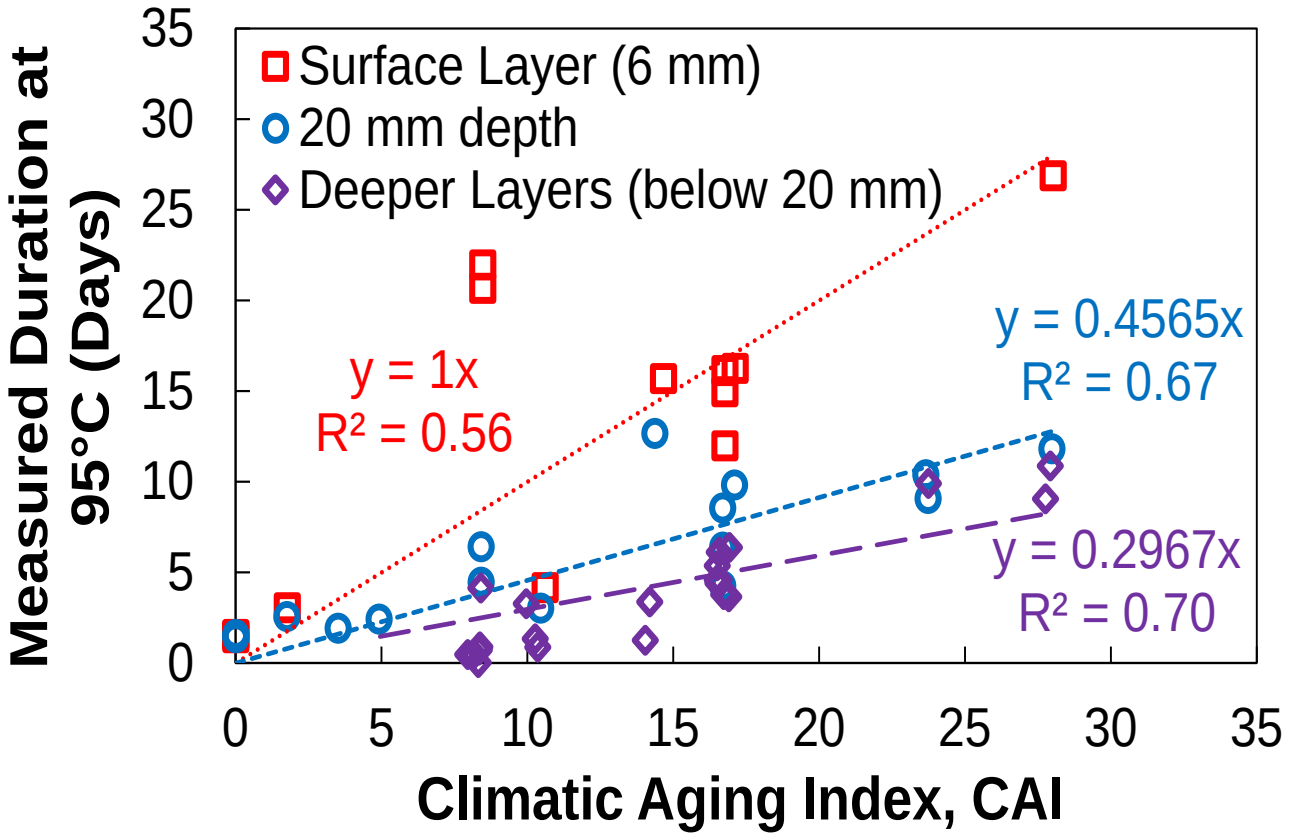
Aging Durations Based on Climatic Data

fitting without depth correction factor (D)

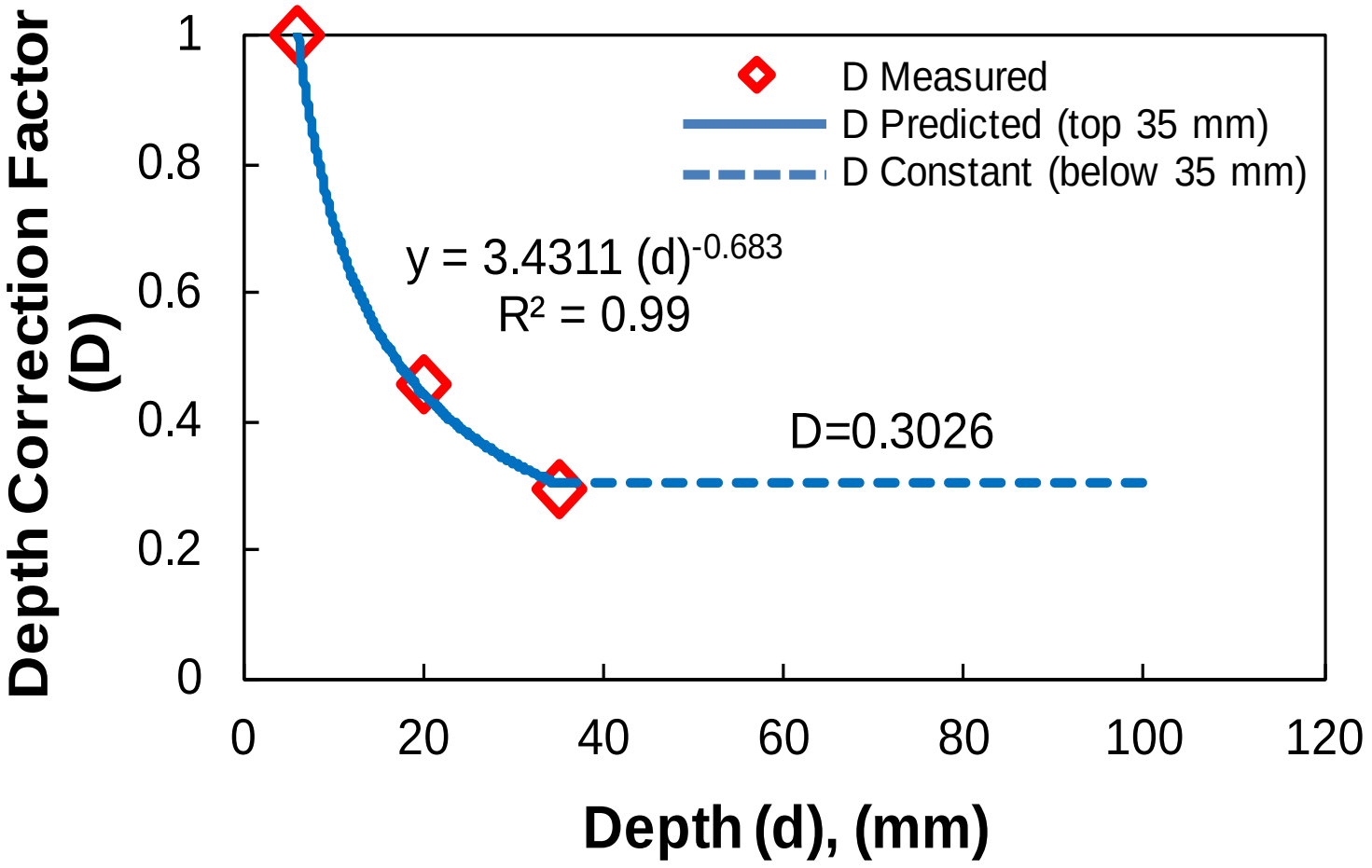


Aging Durations Based on Climatic Data

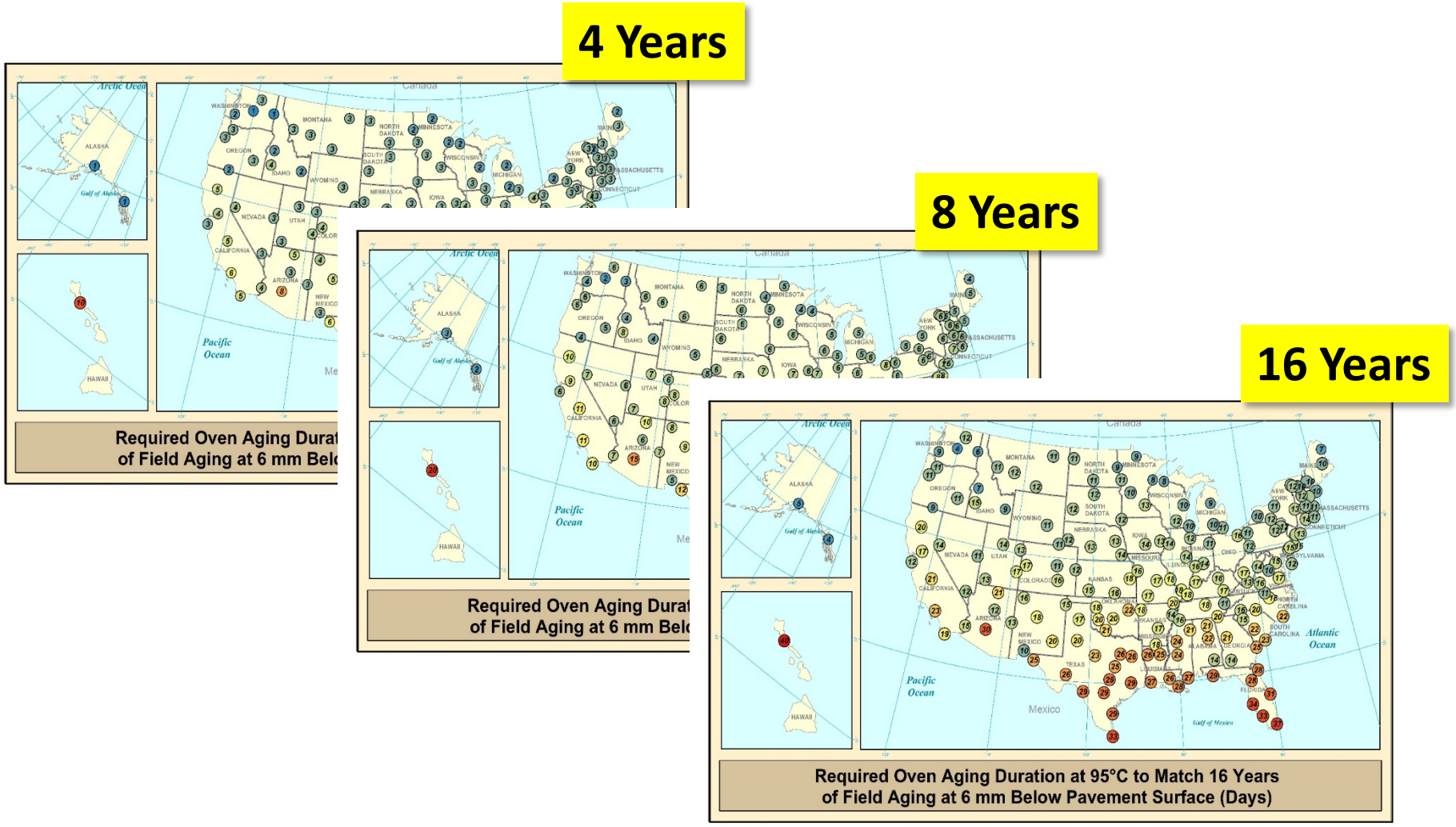
fitting for individual layer depths



Depth Correction Factor



Aging Duration Maps for 6 mm Depth

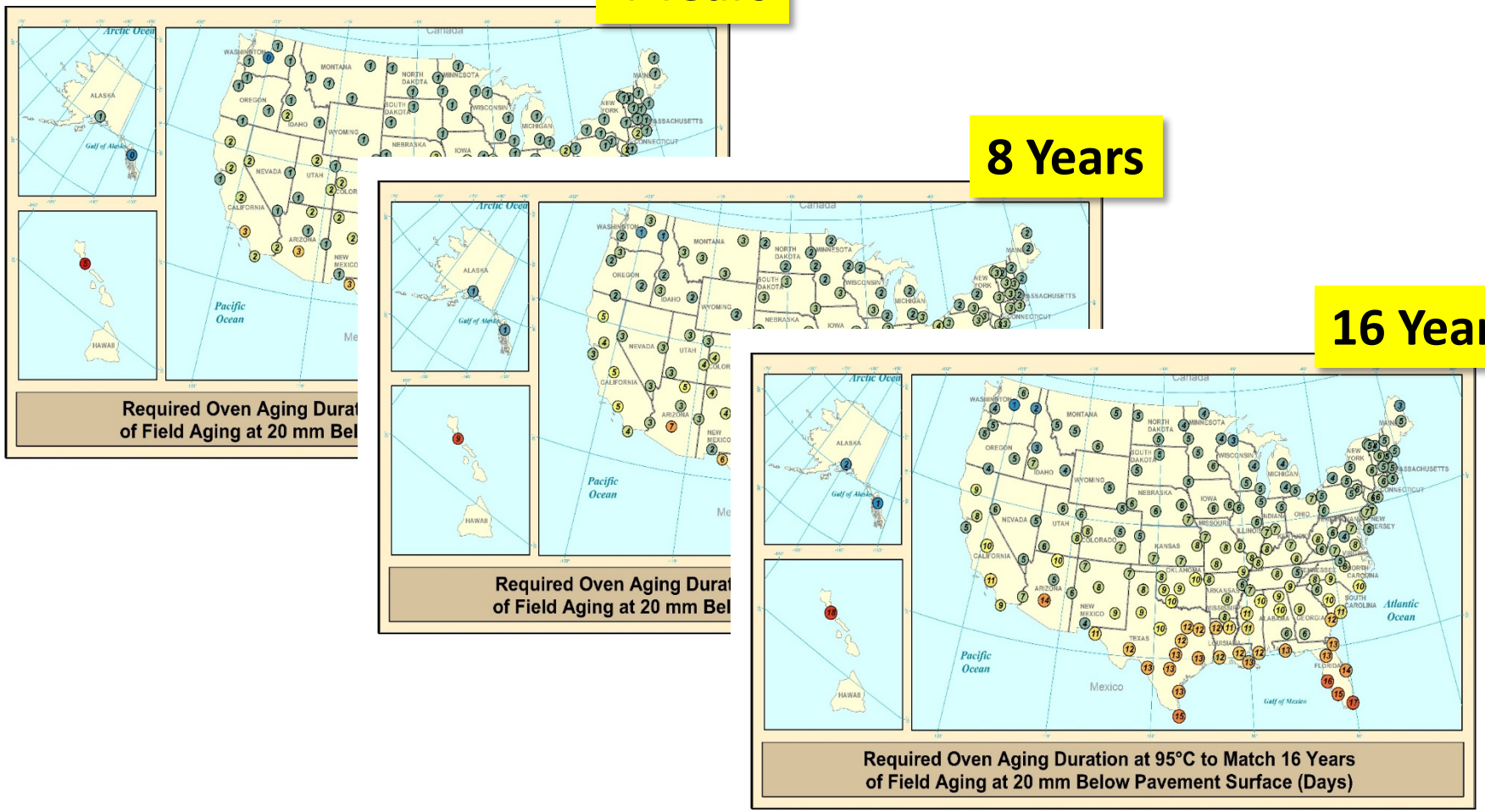


Aging Duration Maps for 20 mm Depth

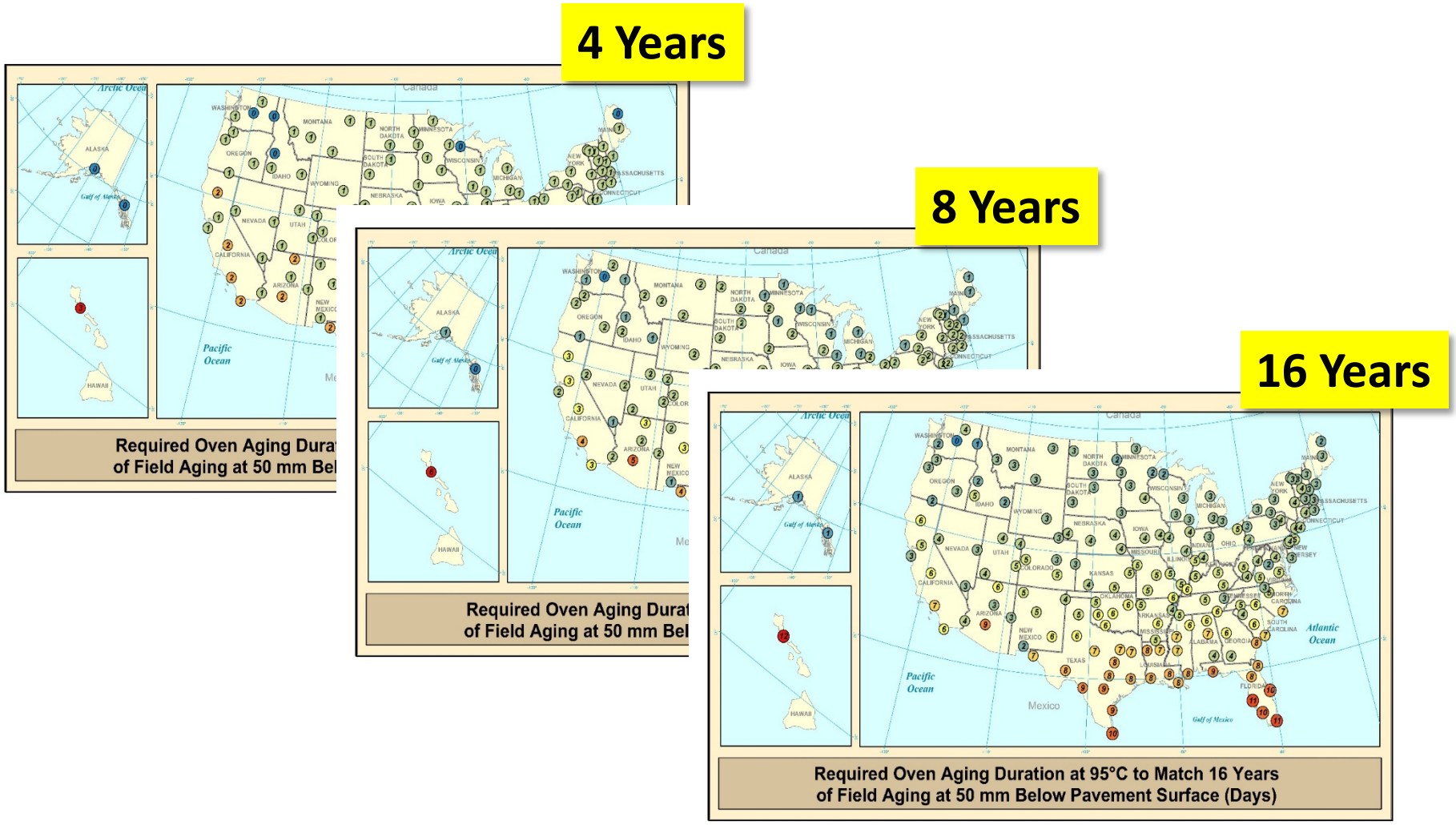
4 Years

8 Years

16 Years



Aging Duration Maps for 50 mm Depth



G_{mm} in LTA Condition

LTPP-South Dakota

Aging Duration (days)	G_{mm}
Short-Term Aged	2.419
Long-Term Aged (4 days)	2.440
Long-Term Aged (8 days)	2.444
Long-Term Aged (16 days)	2.446

LTPP-Texas

Aging Duration (days)	G_{mm}
Short-Term Aged	2.428
Long-Term Aged (3 days)	2.442
Long-Term Aged (11 days)	2.446
Long-Term Aged (17 days)	2.448

Proposed AASHTO Specification

Standard Method of Test for

Long-Term Conditioning of Asphalt Mixture for Mixture Performance Testing

AASHTO Designation: TP ###-##

AASHTO
THE VOICE OF TRANSPORTATION

1. SCOPE

1.1. This practice describes procedures for long-term conditioning of uncompacted asphalt mixture for mixture mechanical property testing to simulate the aging that occurs over the service life of a pavement. The long-term conditioning for mixture mechanical property testing procedure is preceded by the procedure for short-term conditioning for mixture mechanical property testing.

Pavement Aging Model (Preliminary)

Prediction of Field Aging Using Mix-Specific Kinetics Parameters

$$\log G^* = \log G_0^* + M\left(1 - \frac{k_c}{k_f}\right)\left(1 - \exp\left(-k_f t\right)\right) + k_c M t$$

where

$$k_f = A_f \exp\left(\frac{-E_{af}}{RT}\right) \quad k_c = A_c \exp\left(\frac{-E_{ac}}{RT}\right)$$

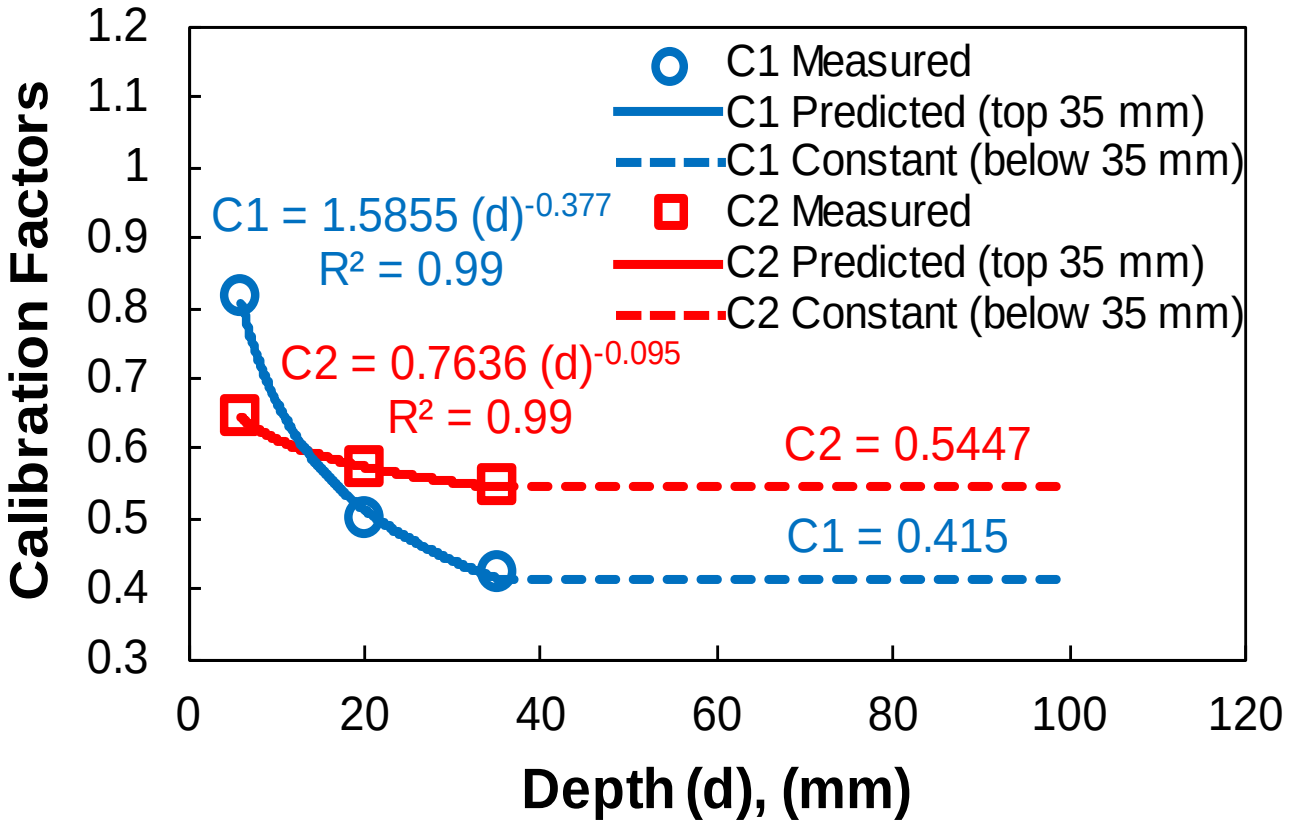
$$\log G^*_{field-measured} = C_1 + C_2 \times \log G^*_{field-predicted}$$

where

C_1, C_2 = calibration factors

Prediction of Field Aging Using Mix-Specific Kinetics Parameters

$$log\ G^*_{field-measured} = C_1 + C_2 \times log\ G^*_{field-predicted}$$



Prediction of Field Aging Using Mix-Specific Kinetics Parameters

$$log\ G^*_{field-measured} = C_1 + C_2 \times log\ G^*_{field-predicted}$$

$$C_1 = \begin{cases} 1.5855\ d^{-0.377}, & 6\ mm \le d \le 35\ mm \\ 0.415, & d > 35\ mm \end{cases}$$

$$C_2 = \begin{cases} 0.7636\ d^{-0.095}, & 6\ mm \le d \le 35\ mm \\ 0.5447, & d > 35\ mm \end{cases}$$

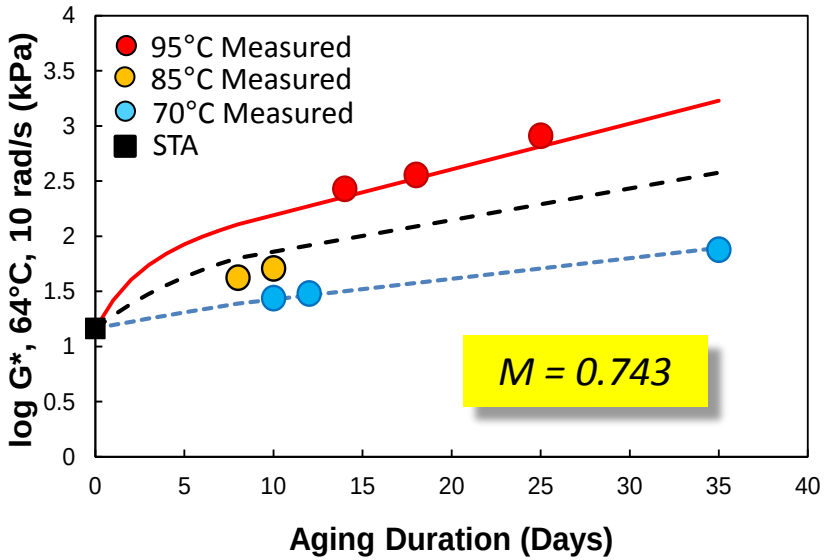
where

C_1, C_2= calibration factors and

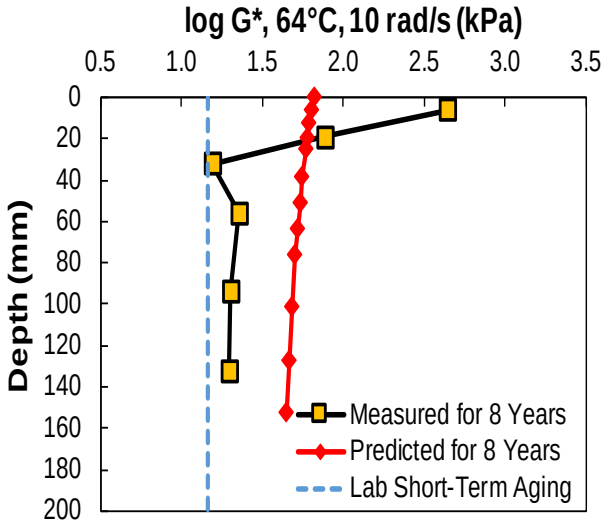
d = depth of interest (mm).

Prediction of Field Aging

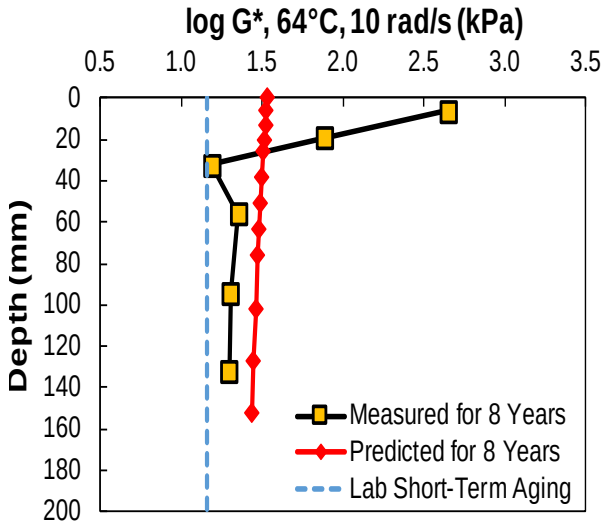
ALF-Control (8 Years)



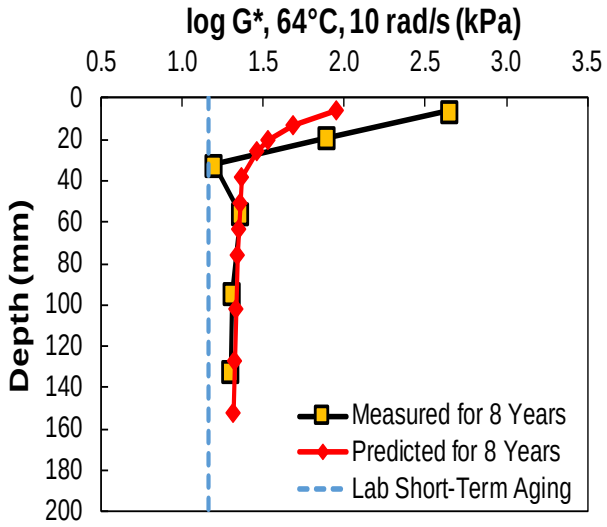
Without Field Calibration



20 mm Calibration Factor

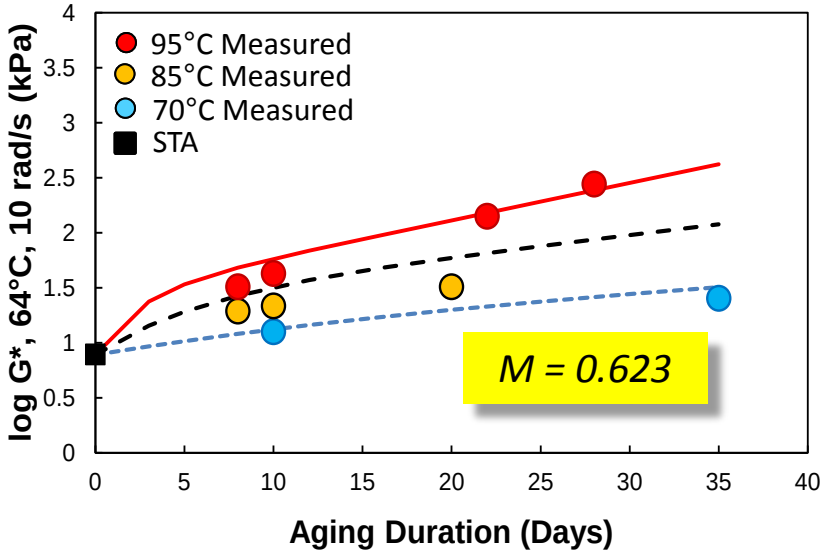


Depth Dependent Calibration



Prediction of Field Aging

ALF-SBS (8 Years)



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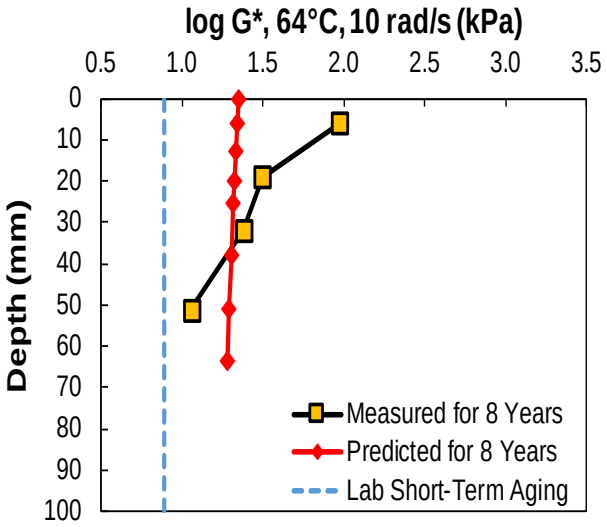
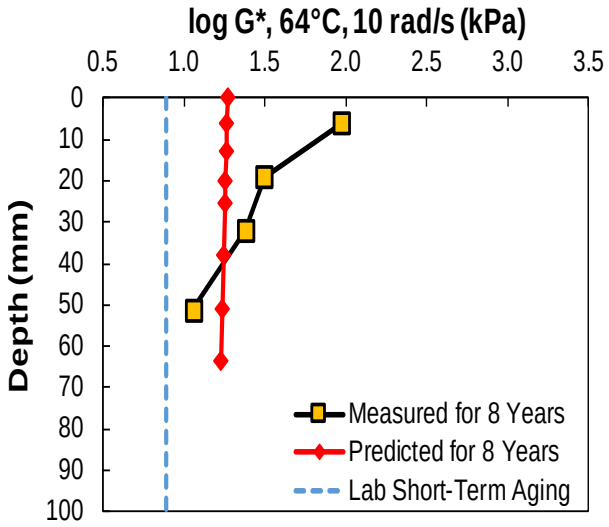
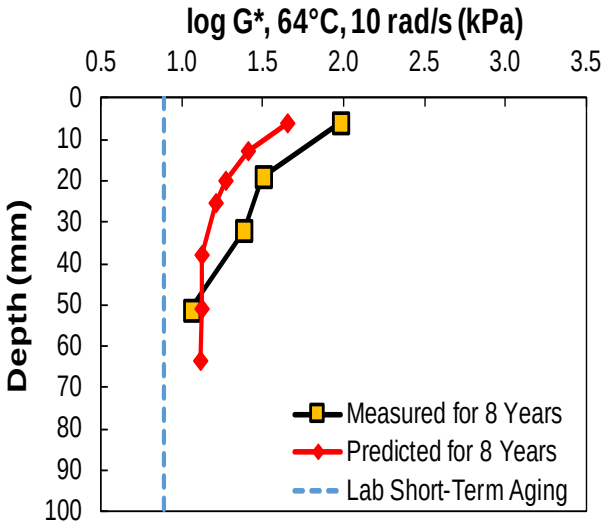


20 mm Calibration Factor

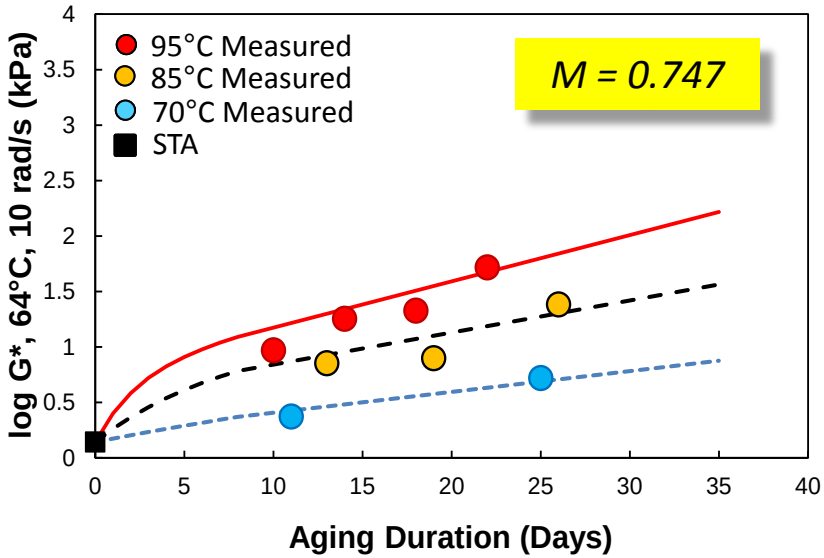


Depth Dependent Calibration



Prediction of Field Aging

LTPP-South Dakota (14 and 21 Years)



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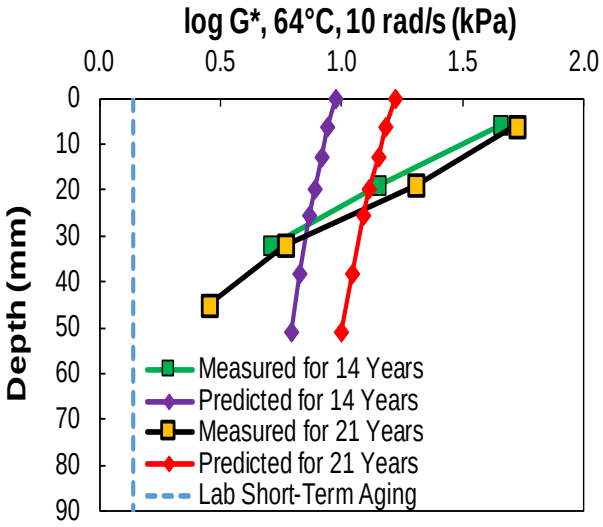
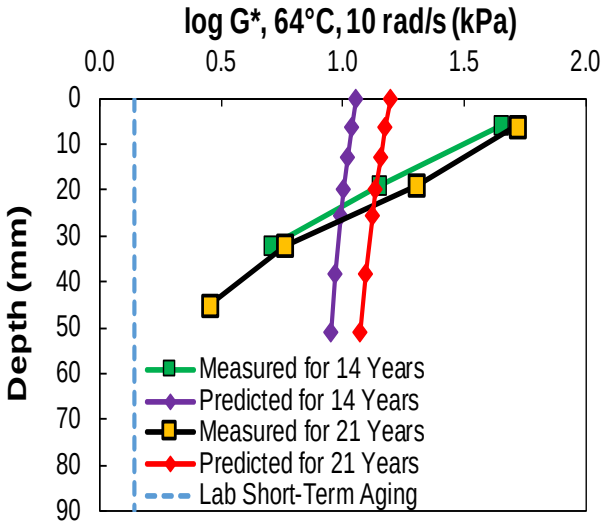
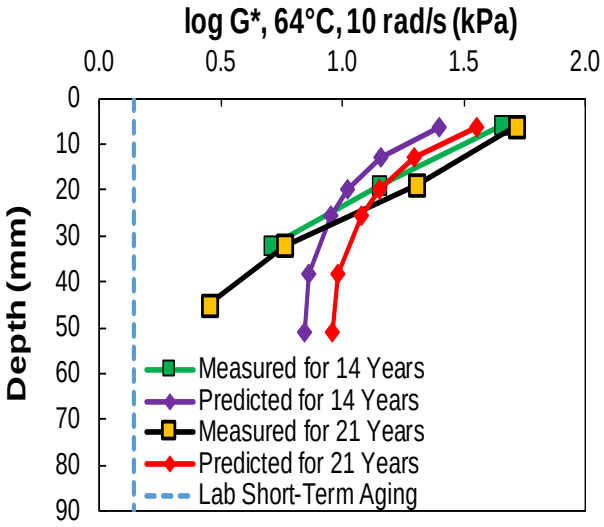


20 mm Calibration Factor

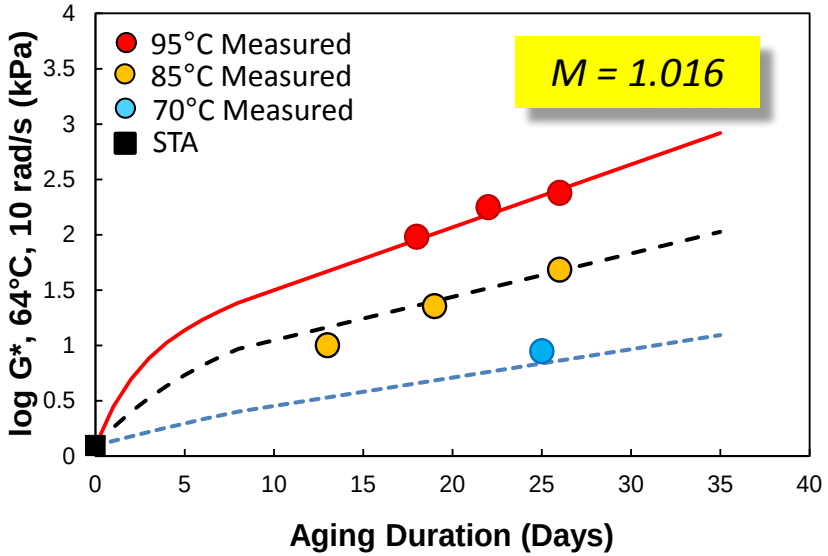


Depth Dependent Calibration

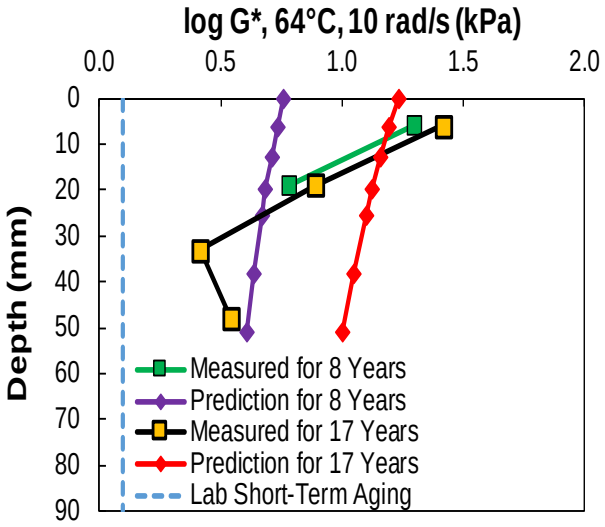


Prediction of Field Aging

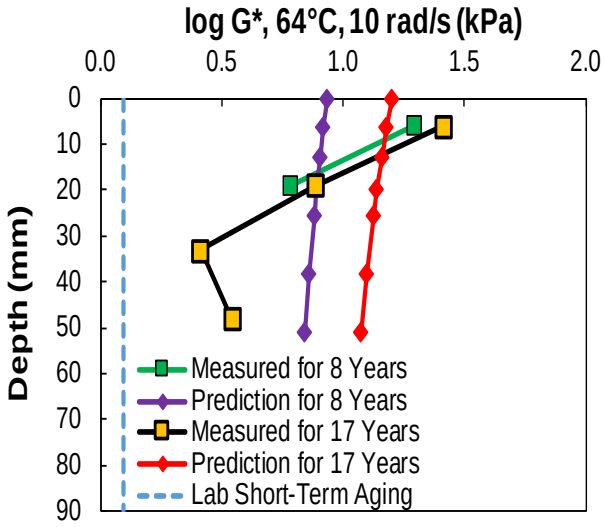
LTPP-Wisconsin (8 and 17 Years)



Without Field Calibration



20 mm Calibration Factor



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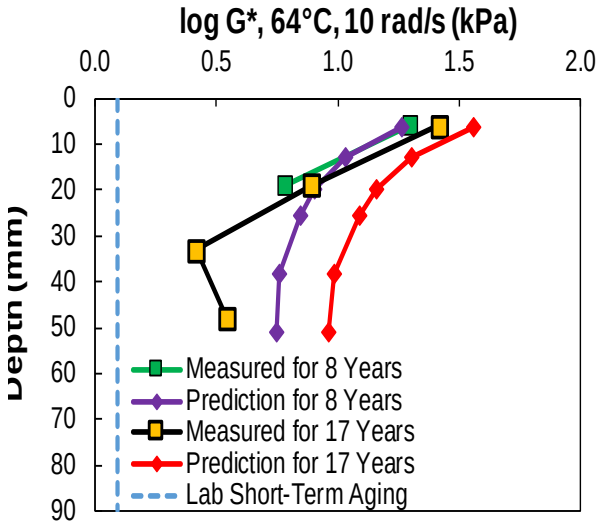
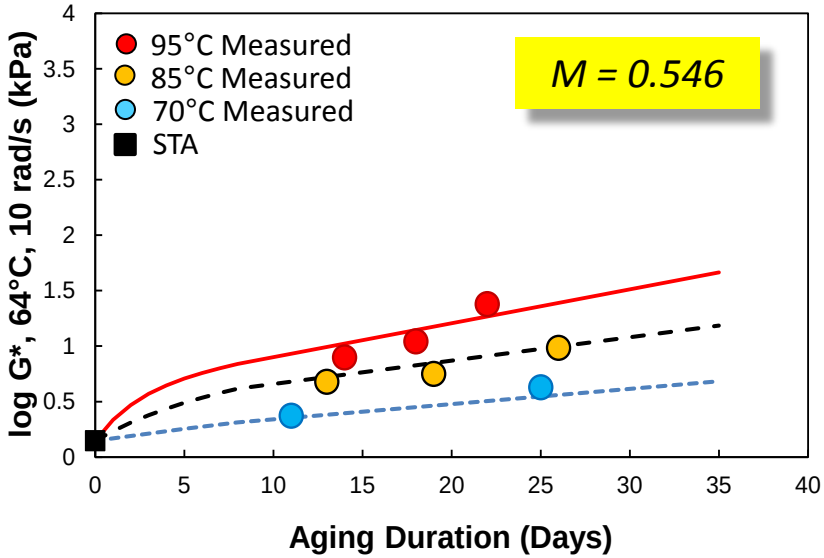
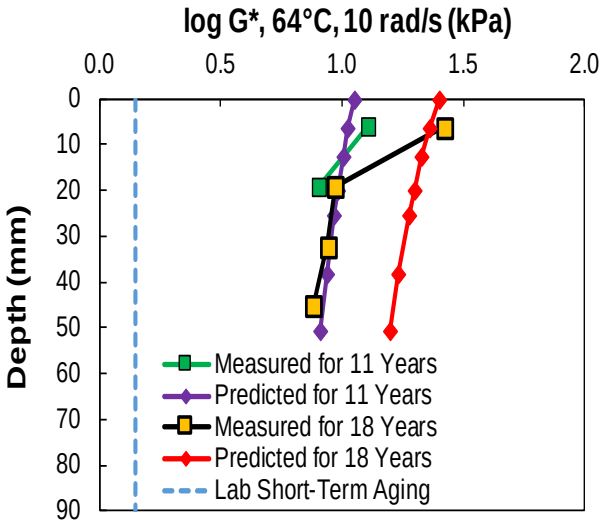


Prediction of Field Aging

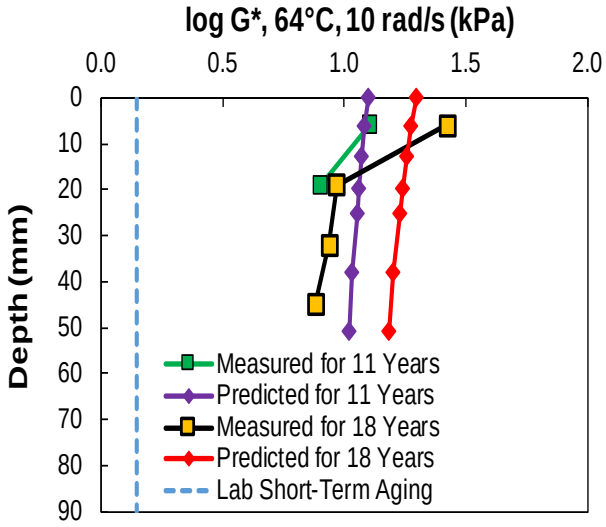
LTPP-New Mexico (11 and 18 Years)



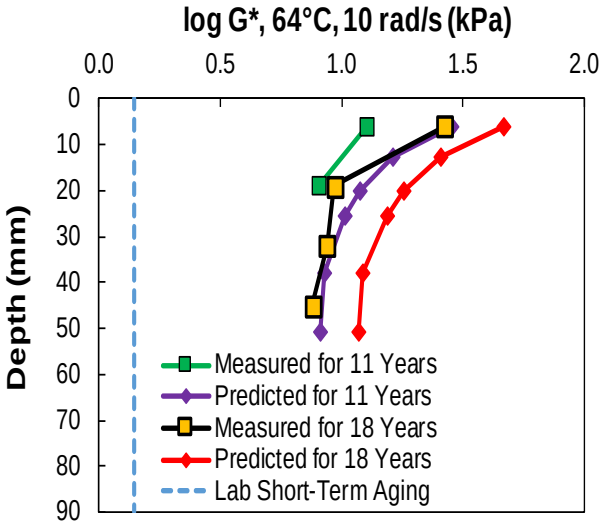
Without Field Calibration



20 mm Calibration Factor

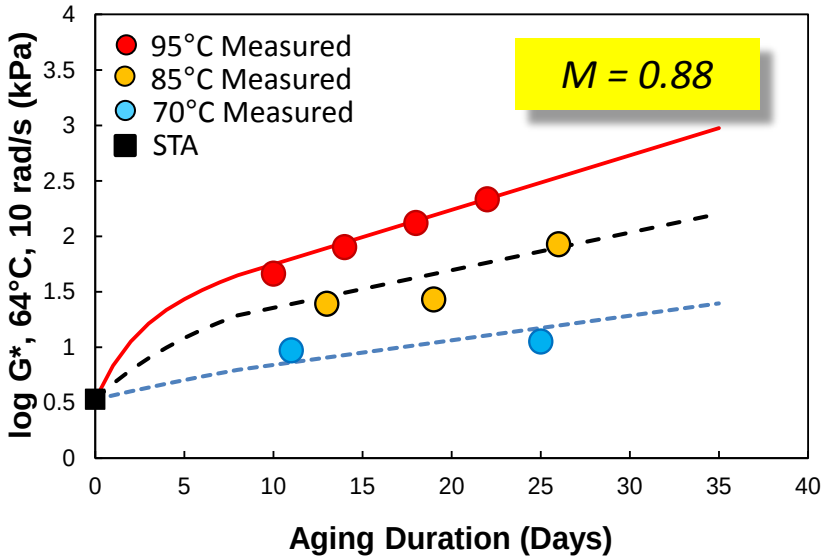


Depth Dependent Calibration

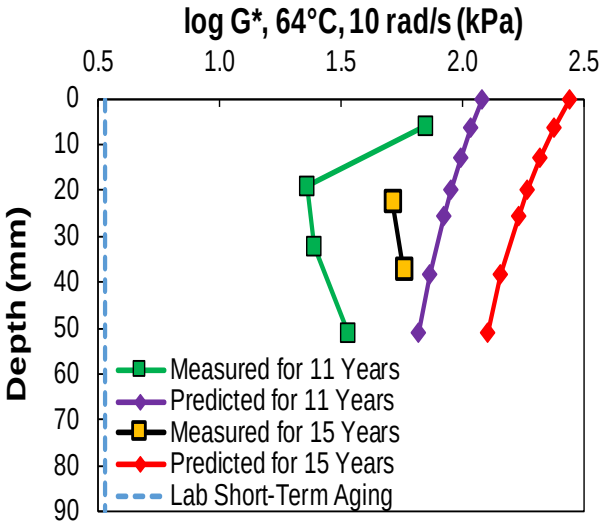


Prediction of Field Aging

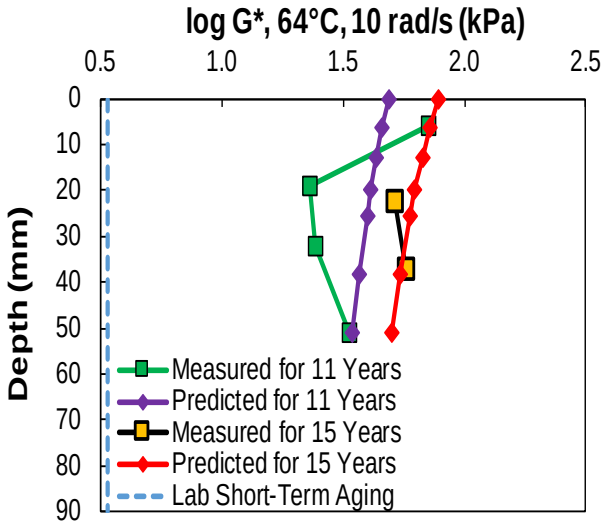
LTPP-Texas (11 and 15 Years)



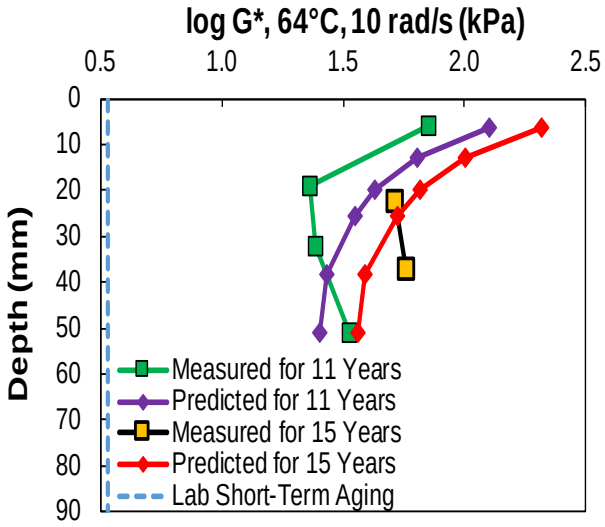
Without Field Calibration



20 mm Calibration Factor



Depth Dependent Calibration

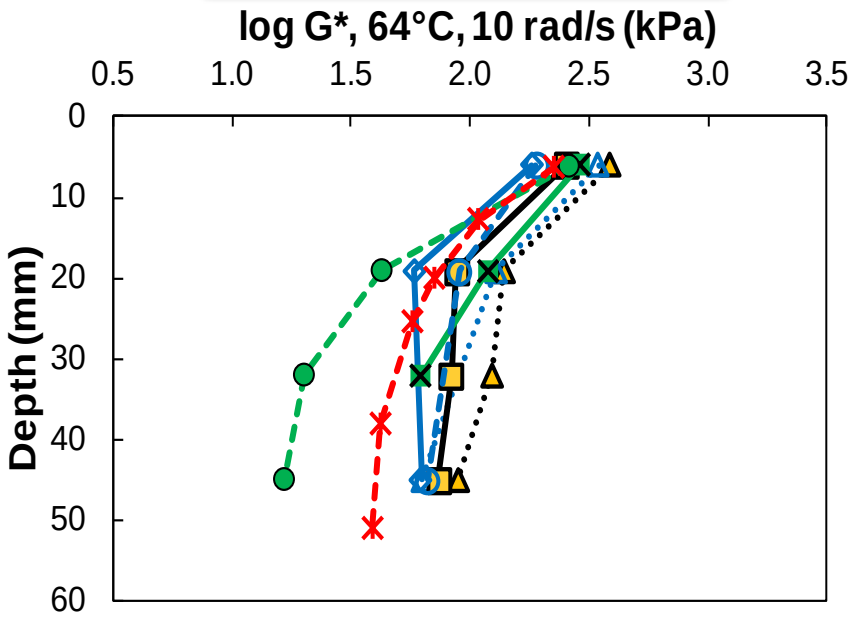


Diffusion Effect

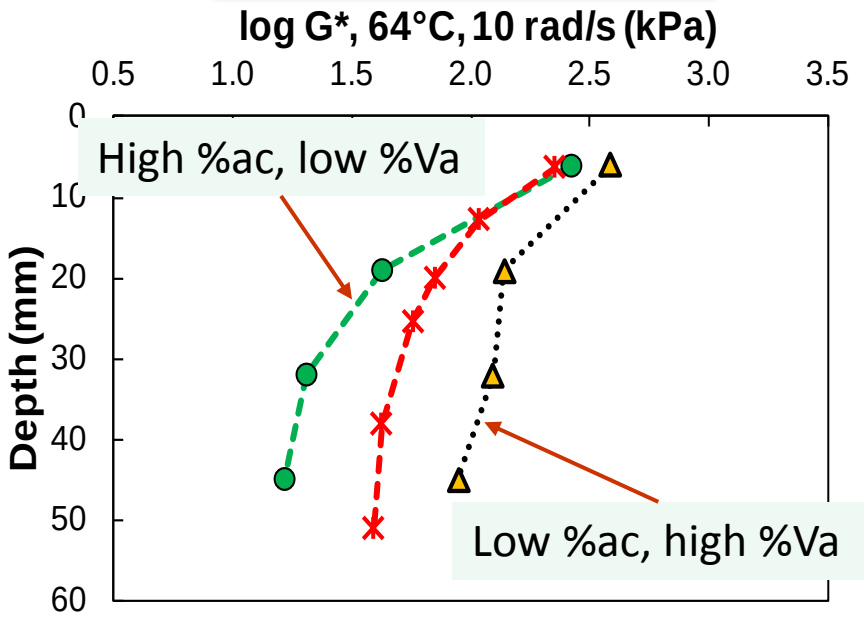
WesTrack Fine Sections (19 years)

- Predicted log G* for 19 Years of Field Aging
- Measured log G* for Low %ac and High %Va
- Measured log G* for Low %ac and Medium %Va
- Measured log G* for Optimum %ac and High %Va
- Measured log G* for Optimum %ac and Medium %Va
- Measured log G* for Optimum %ac and Low %Va
- Measured log G* for High %ac and Medium %Va
- Measured log G* for High %ac and Low %Va

All Seven Sections



Extreme Sections

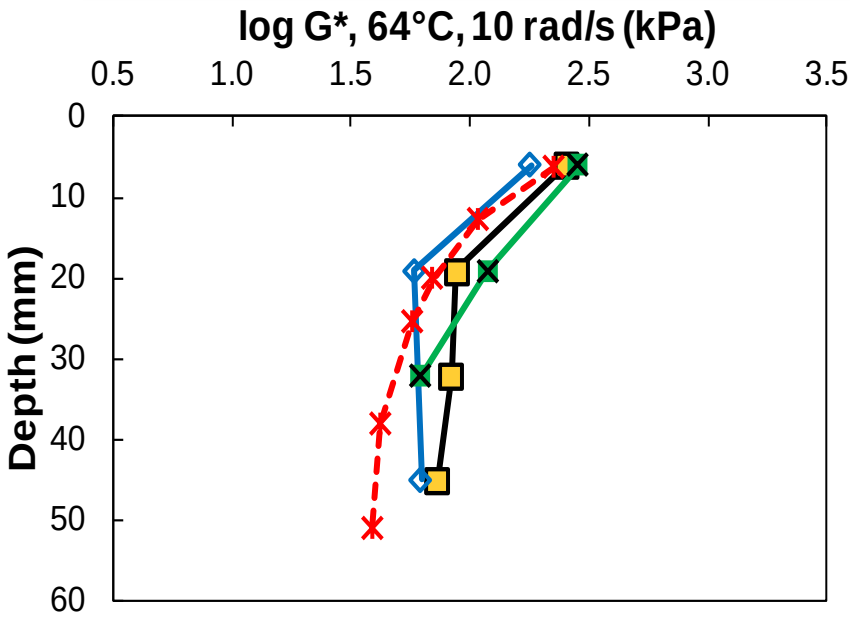


Diffusion Effect

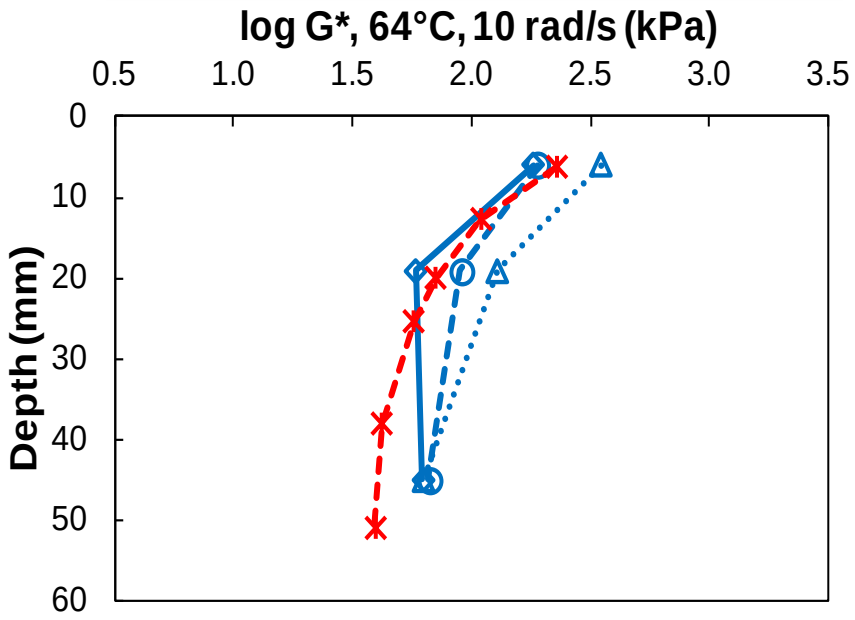
WesTrack Fine Sections (19 years)

- Predicted log G* for 19 Years of Field Aging
- Measured log G* for Low %ac and High %Va
- Measured log G* for Low %ac and Medium %Va
- Measured log G* for Optimum %ac and High %Va
- Measured log G* for Optimum %ac and Medium %Va
- Measured log G* for Optimum %ac and Low %Va
- Measured log G* for High %ac and Medium %Va
- Measured log G* for High %ac and Low %Va

Optimum %ac, Varying %Va



Medium %Va, Varying %ac

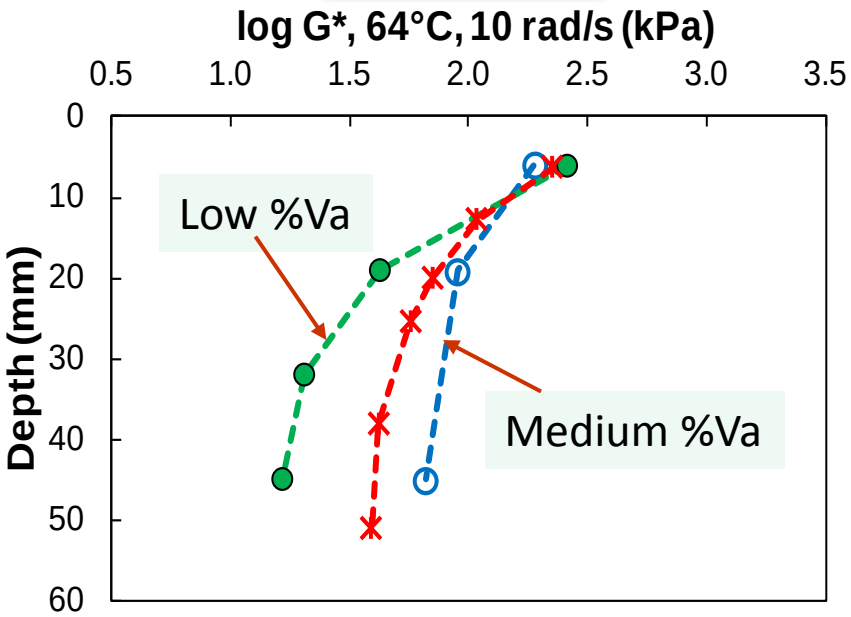


Diffusion Effect

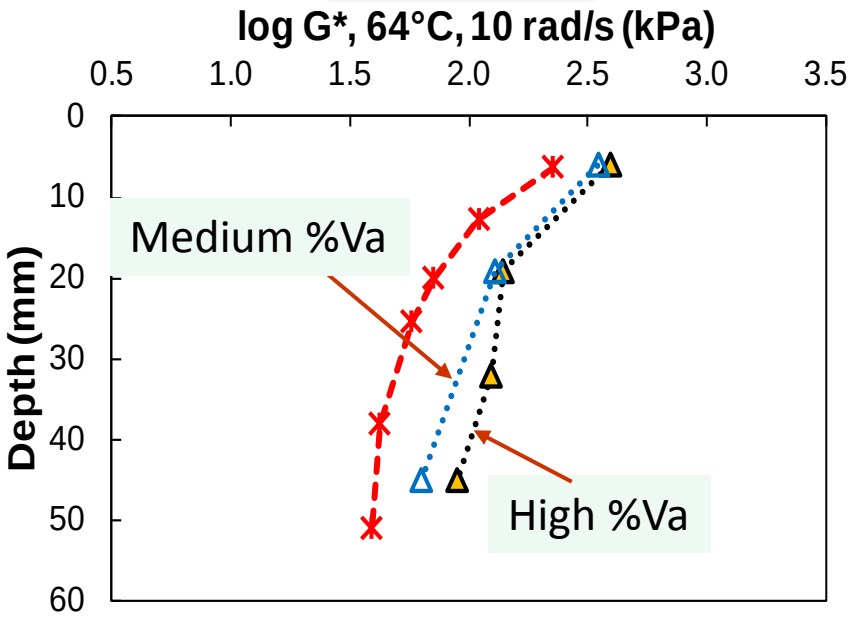
WesTrack Fine Sections (19 years)

- Predicted log G* for 19 Years of Field Aging
- Measured log G* for Low %ac and High %Va
- Measured log G* for Low %ac and Medium %Va
- Measured log G* for Optimum %ac and High %Va
- Measured log G* for Optimum %ac and Medium %Va
- Measured log G* for Optimum %ac and Low %Va
- Measured log G* for High %ac and Medium %Va
- Measured log G* for High %ac and Low %Va

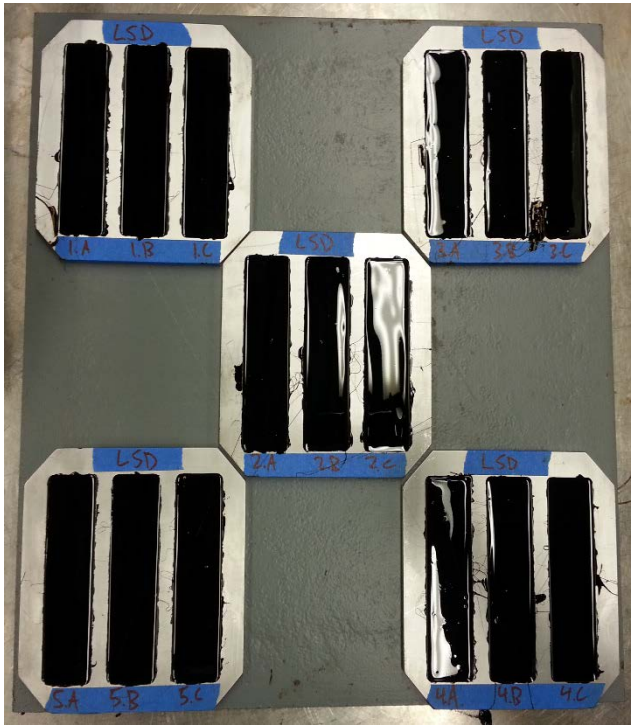
High %ac



Low %ac

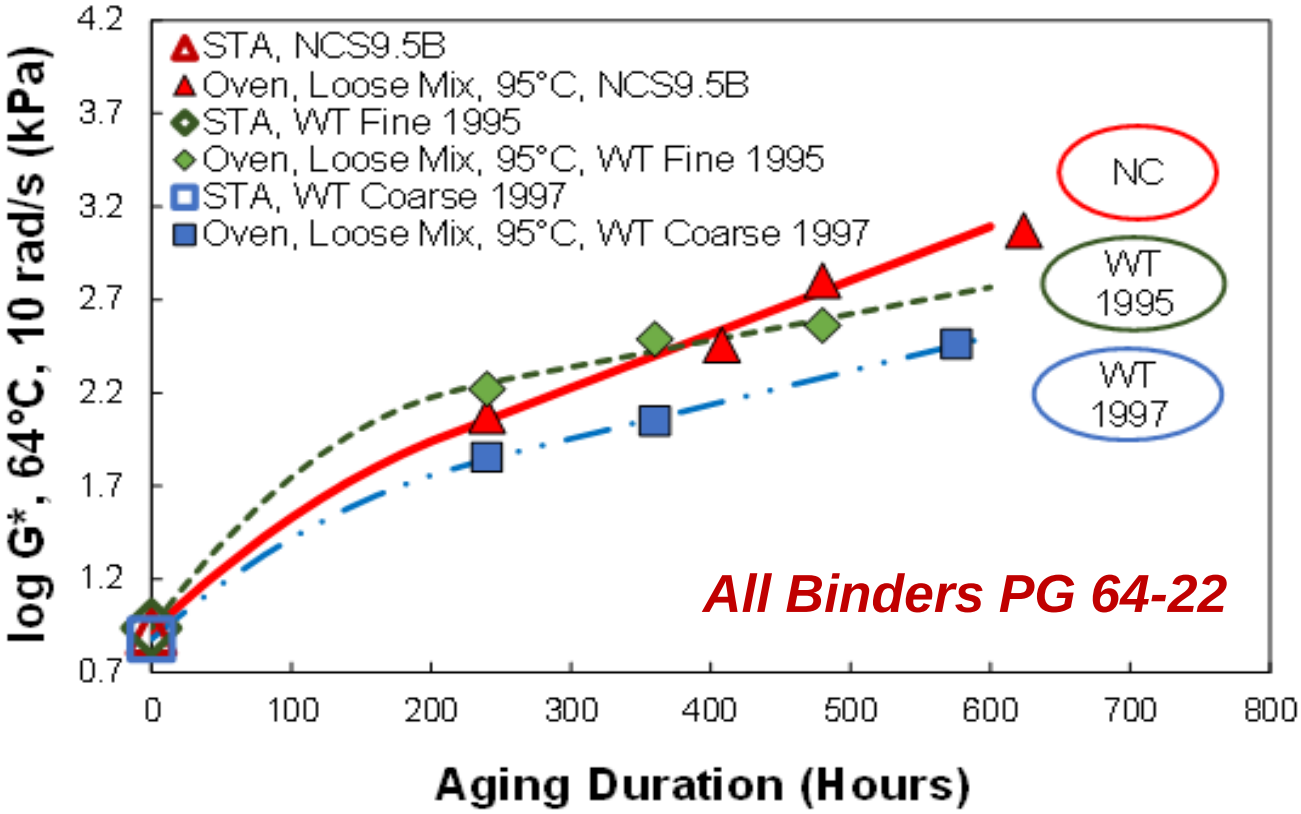


Binder USAT Aging in Place of Loose Mix Aging

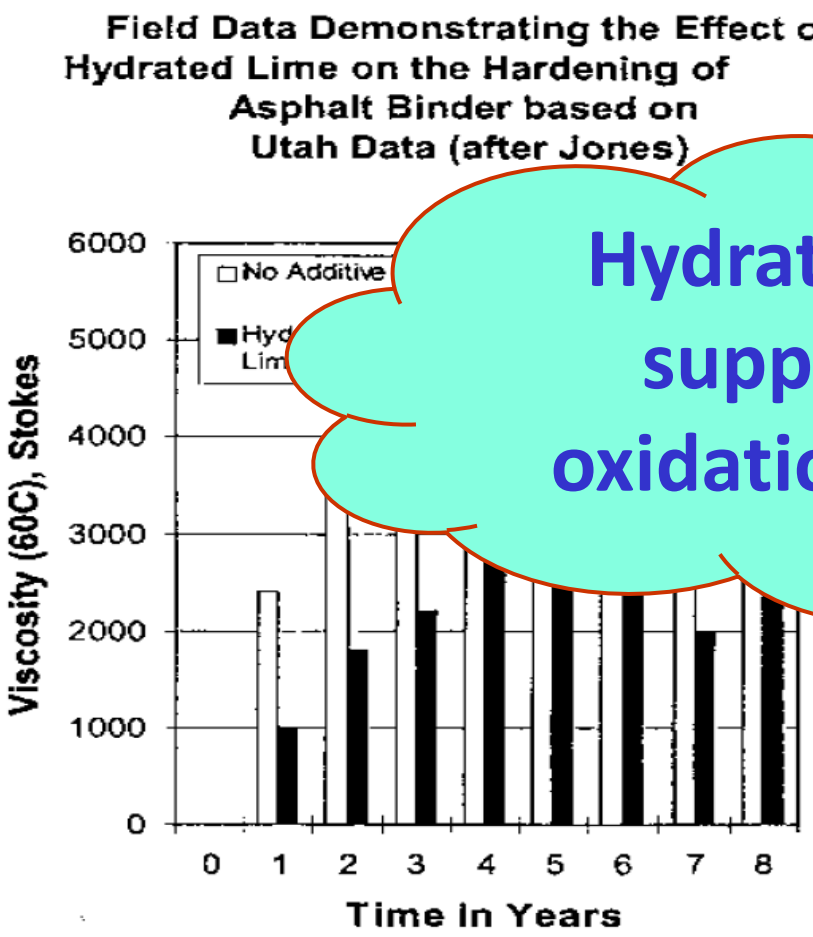


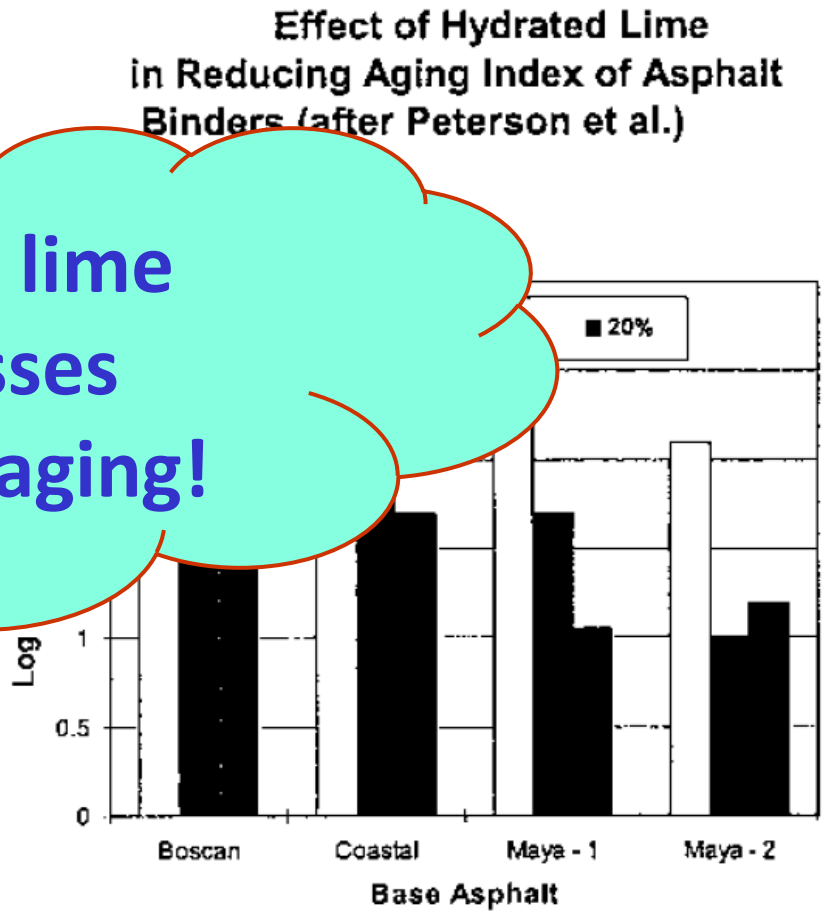
Motivation for Binder-Specific Aging

- Example of binders with similar PG grades and quite different oxidation rates



Effect of Hydrated Lime





Hydrated lime suppresses oxidation aging!

(Jones 1997)

(Petersen et al. 1987)

Study Mixture Details

	Hydrated Lime	Aggregate Type	%Pass Sieve #200 (P_{200})	Binder Content	Binder Source	Binder Grade	P_{200} to Binder Content Ratio
FHWA ALF - Control	✔ (1%)	Limestone/ Diabase (Traprock)	6.3%	5.3%	Citgo-Venezuelan Bachaquero	PG 70-22	1.19
WesTrack – Coarse	✔ (1.5%)	Crushed Andesite/ Sand	6.5%	5.7%	Idaho Asphalt	PG 64-22	1.14
WesTrack – Fine	✔ (1.5%)	Andesite/ Granite/ Sand	5.4%	5.4%	West Coast Refinery	PG 64-22	1
Validation							
SHRP-AAD	✔ (1%)	Limestone/ Diabase (Traprock)	6.3%	5.3%	CA Coast	PG 58-28	1.19
SHRP-AAG	✔ (1%)	Limestone/ Diabase (Traprock)	6.3%	5.3%	CA Valley	PG 58-10	1.19

Mixture Details

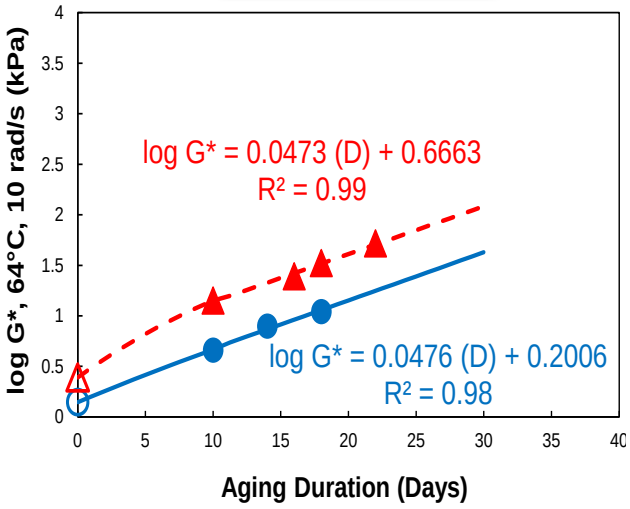
	Hydrated Lime	Aggregate Type	%Pass Sieve #200 (P_{200})	Binder Content	Binder Source	Binder Grade	P_{200} to Binder Content Ratio
LTPP - NM	None	N/A	6.1%	7.6%	N/A	AC-20	0.8
LTPP - SD	None	N/A	4.6%	5.9%	N/A	120-150 Pen	0.78
LTPP - TX	None	N/A	5.7%	5.4%	N/A	AC-20	1.06
LTPP-WI	None	N/A	4.1%	5.9%	N/A	N/A	0.69
Validation							
NC	None	Granite	5.7%	6.6%	Citgo – Wilmington, NC	PG 64-22	0.86

Binder USAT and Loose Mix Aging Rates

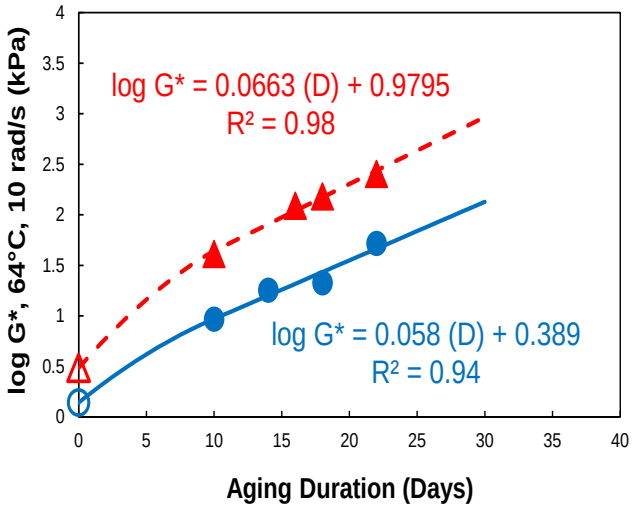
No Lime

● Loose Mix Aging
▲ Binder USAT Aging

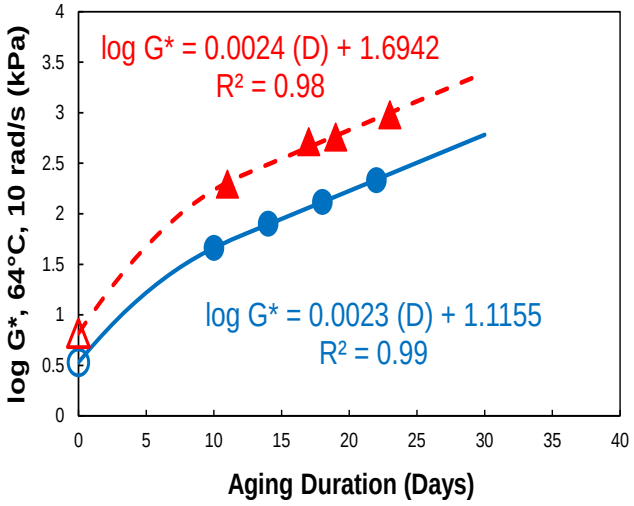
LTPP-NM



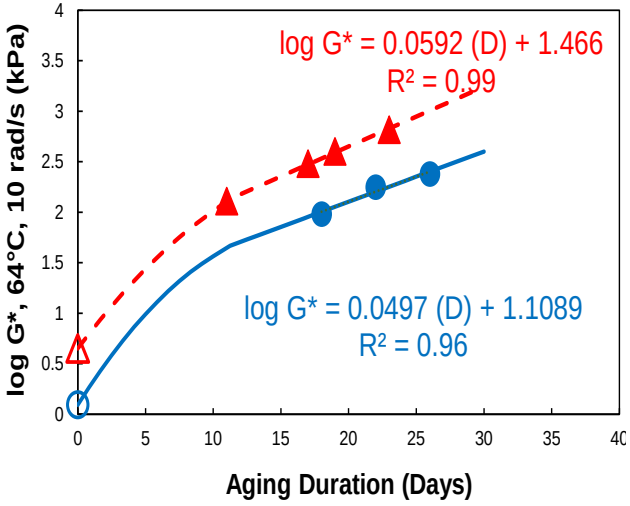
LTPP-SD



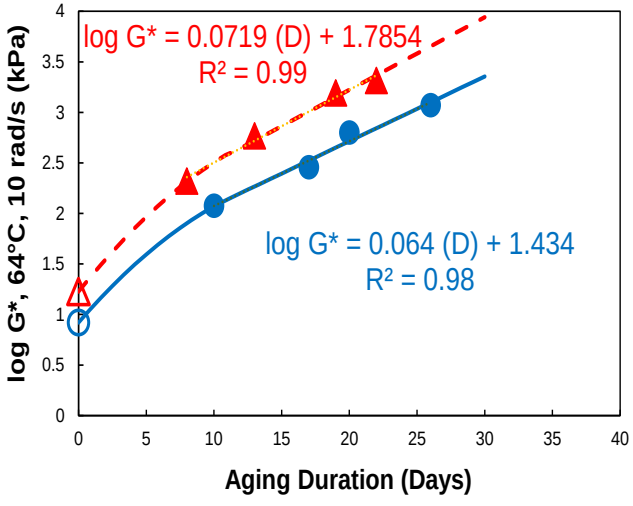
LTPP-TX



LTPP-WI



NC S9.5B

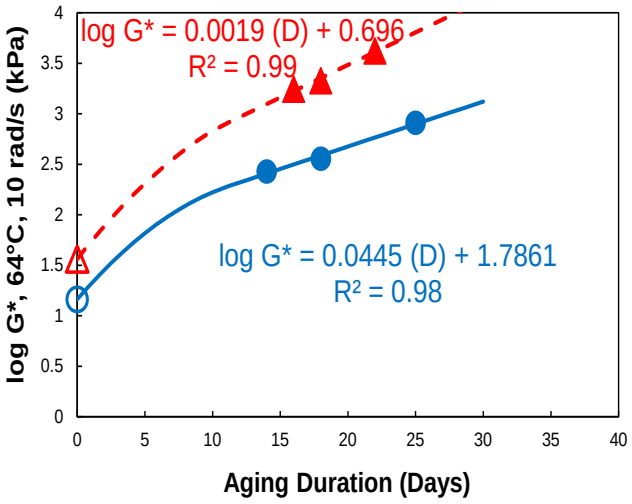


Binder USAT and Loose Mix Aging Rates

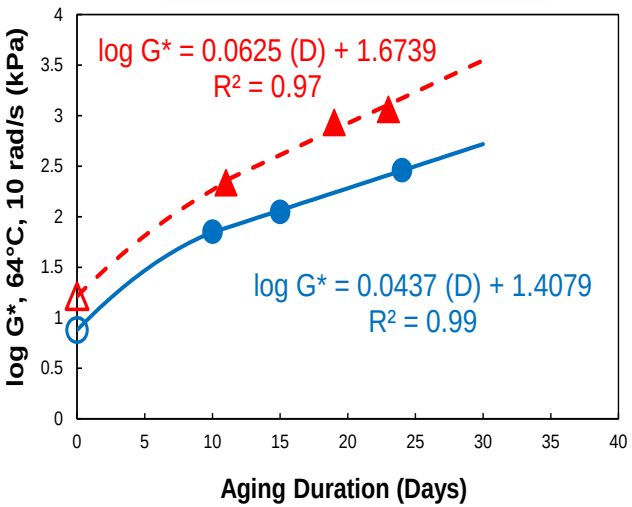
With Lime

● Loose Mix Aging
▲ Binder USAT Aging

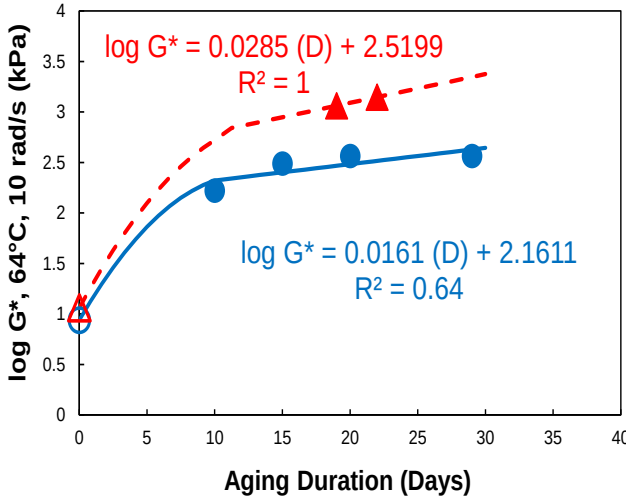
ALF-Control



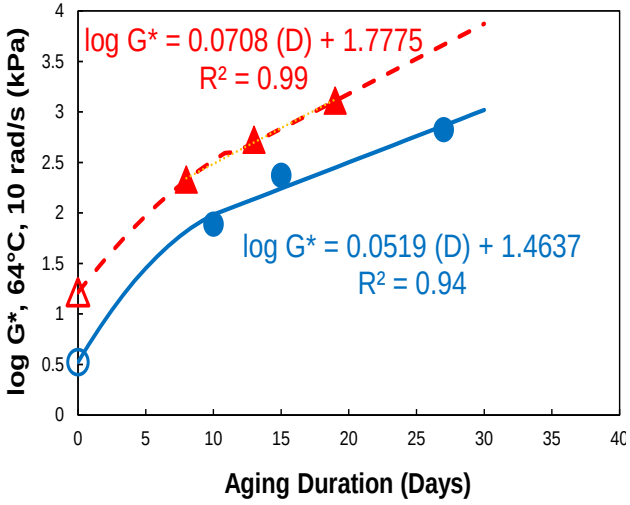
WesTrack-Coarse



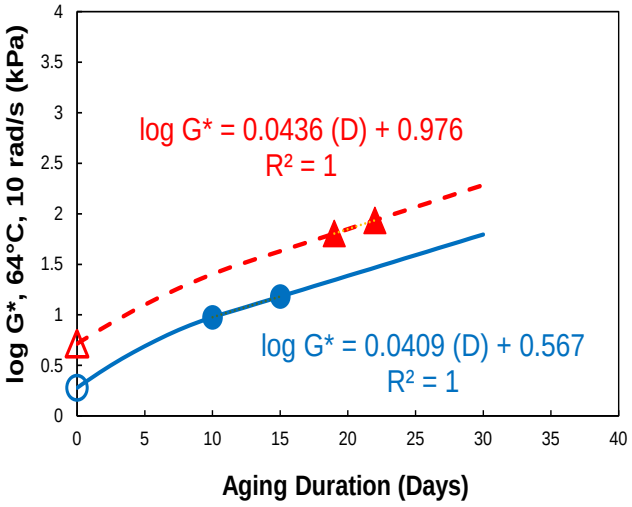
WesTrack-Fine



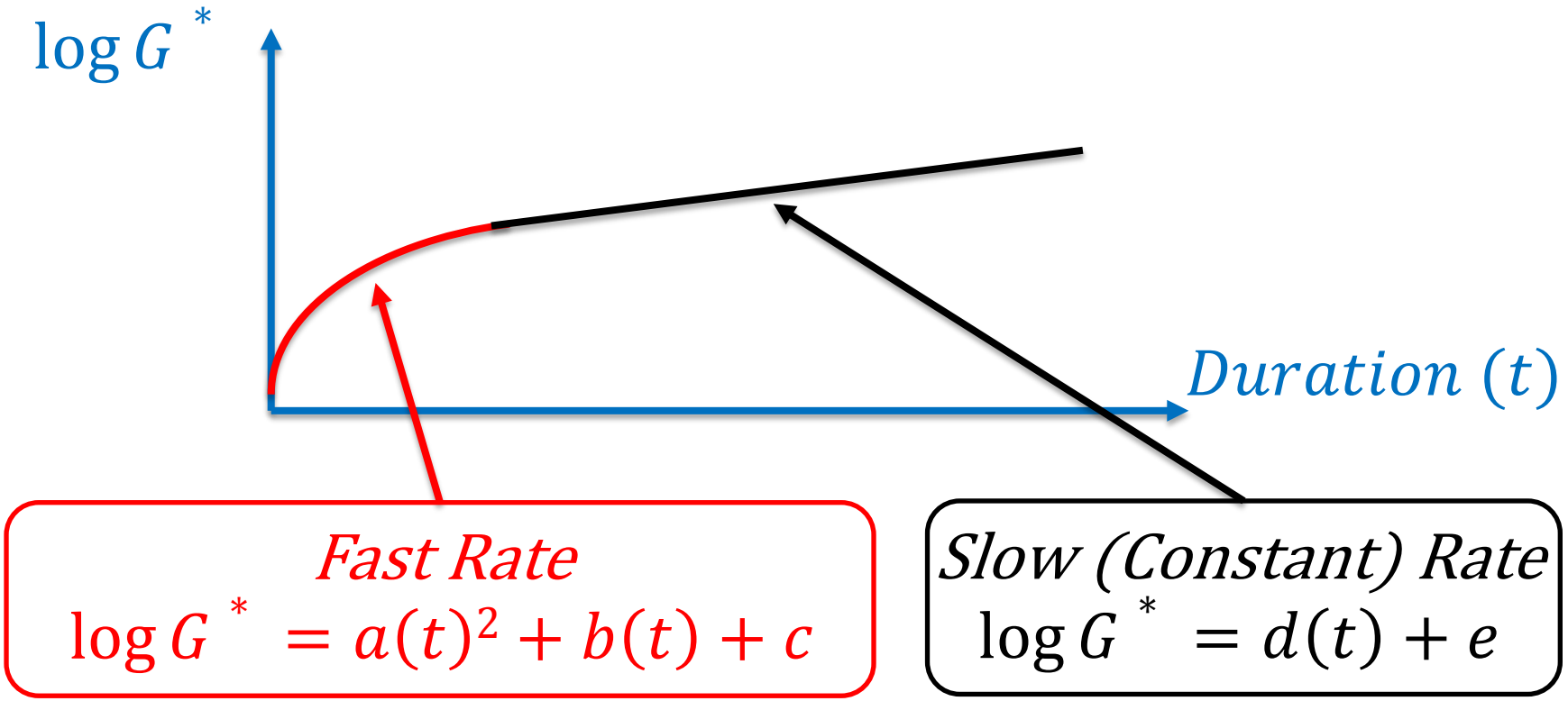
SHRP AAD-1



SHRP AAG-1



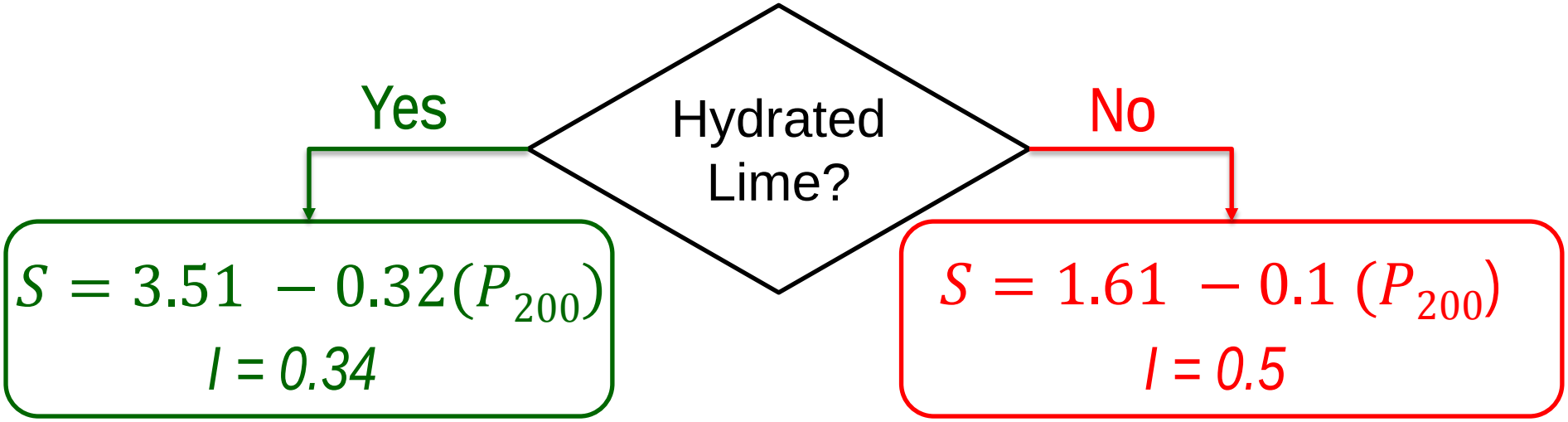
Model Parameters



$$Loose\ Mix: al, bl, c_l, d_l, e_l$$

$$USAT: au, bu, c_u, d_u, e_u$$

Prediction Parameters



$$\log G^{*}_{\ fast\ rate} = a(t)^2 + b(t) + c \qquad \log G^{*}_{\ slow\ rate} = d(t) + e$$

Loose Mix Parameters

$a_l, bl\ , c_l\ , d_l\ , e_l$

USAT Parameters

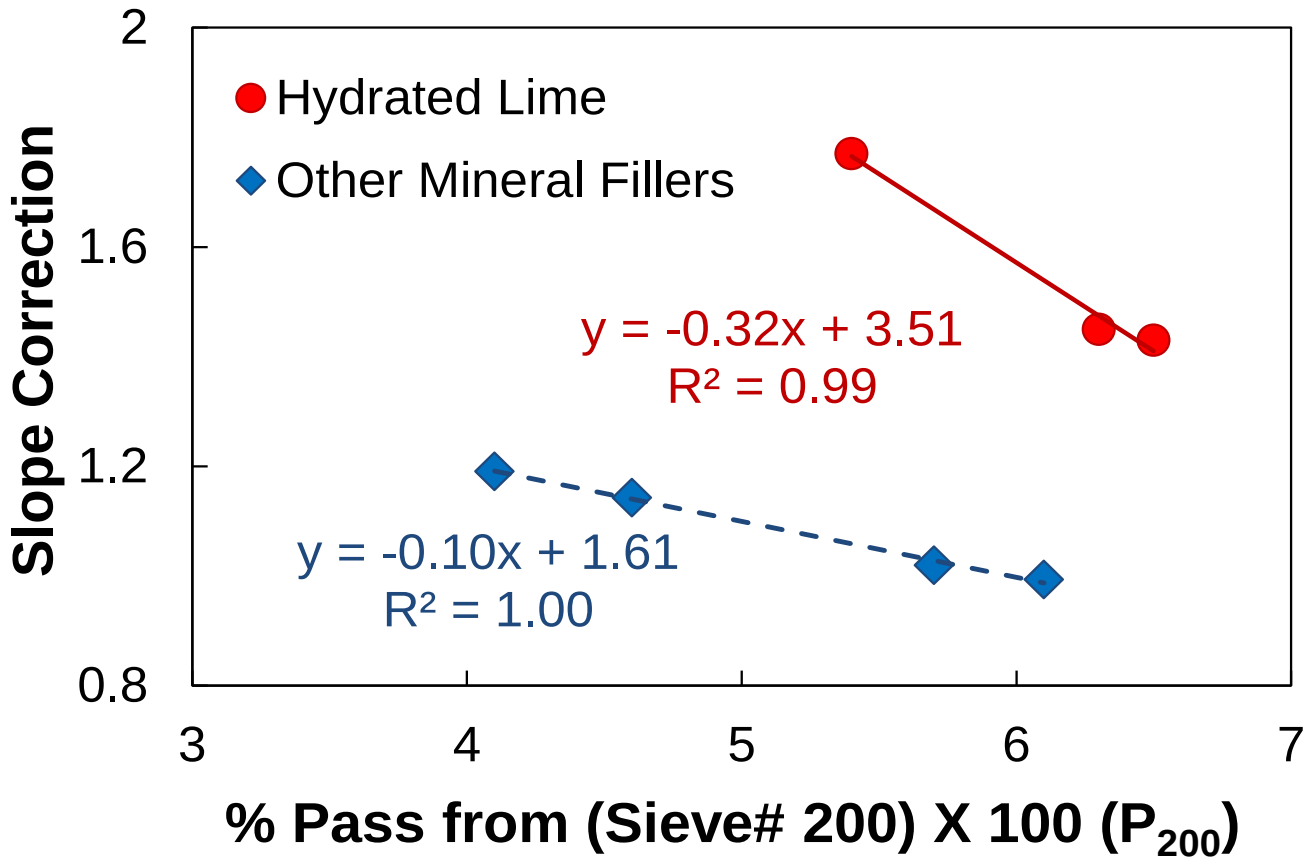
$a_u, bu\ , c_u\ , d_u\ , e_u$

$$a_l = aU \qquad b_l = bU - F \qquad c_l = cU - I$$

$$d_l = dU / S \qquad e_l = e_U - I$$

$$F = \frac{[(c_l + b_U \times 10 + a_l \times (10)^2) - (d_l \times 10 + e_l)]}{10}$$

Slope Correction (S)

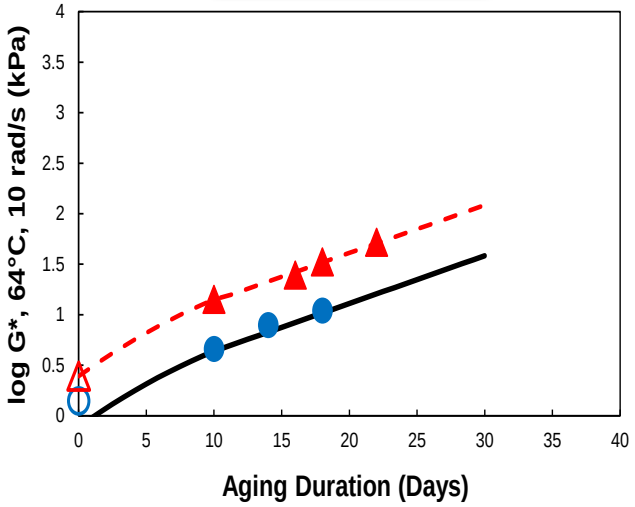


Predicted Loose Mix Aging Rates

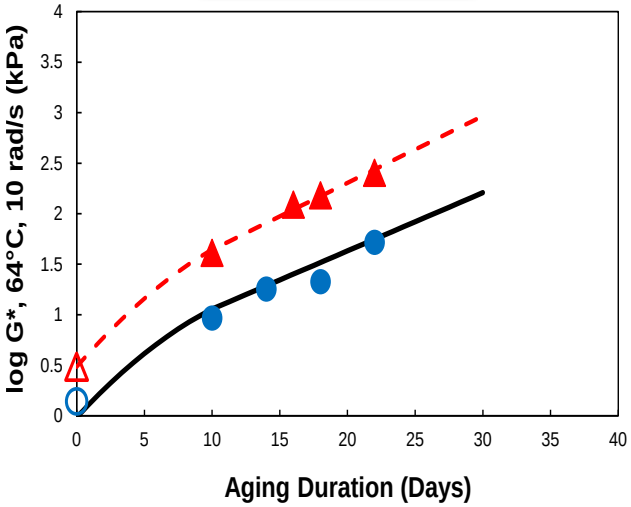
No Lime

- Loose Mix Aging
- Binder USAT Aging
- Prediction

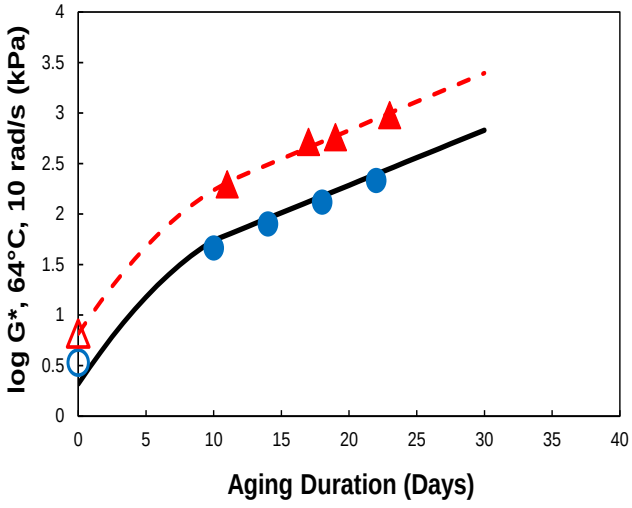
LTPP-NM



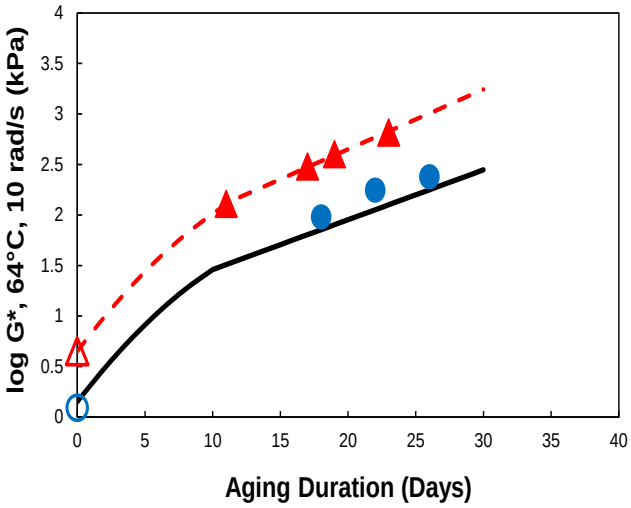
LTPP-SD



LTPP-TX



LTPP-WI

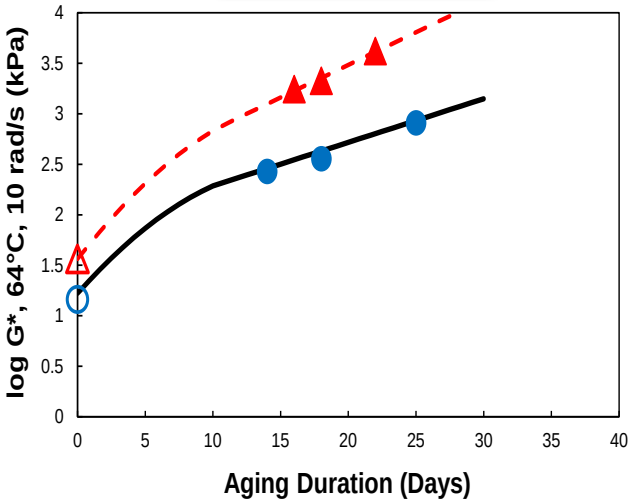


Predicted Loose Mix Aging Rates

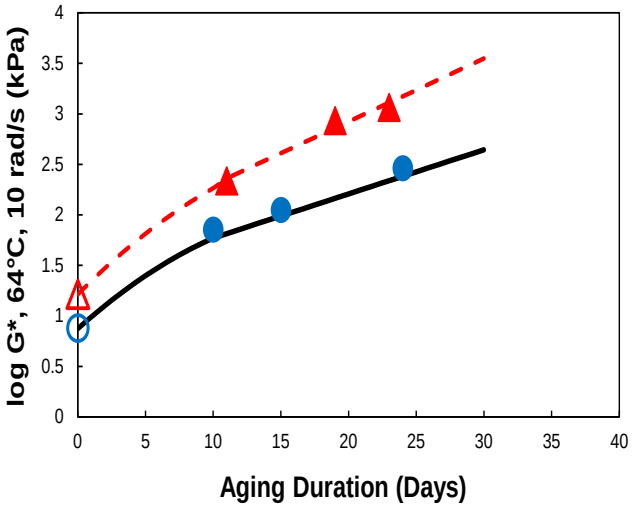
With Lime

- Loose Mix Aging
- Binder USAT Aging
- Prediction

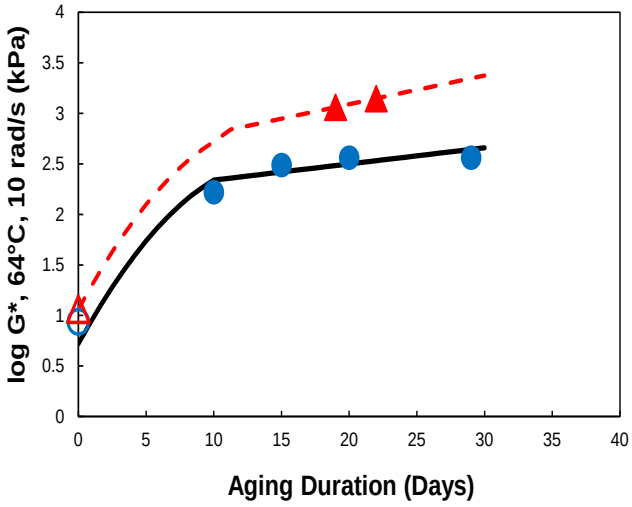
ALF-Control



WesTrack-Coarse



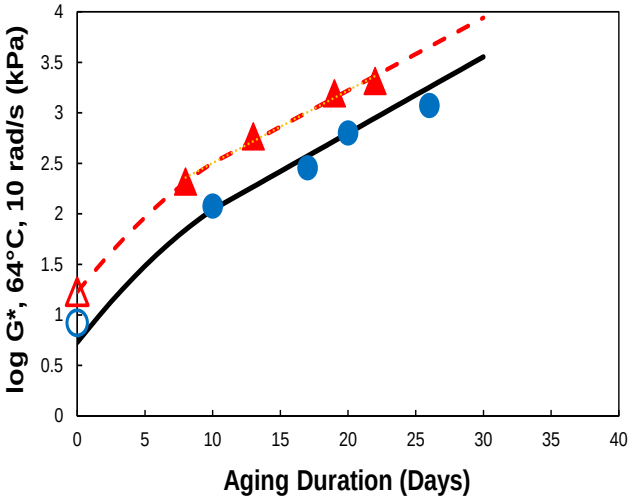
WesTrack-Fine



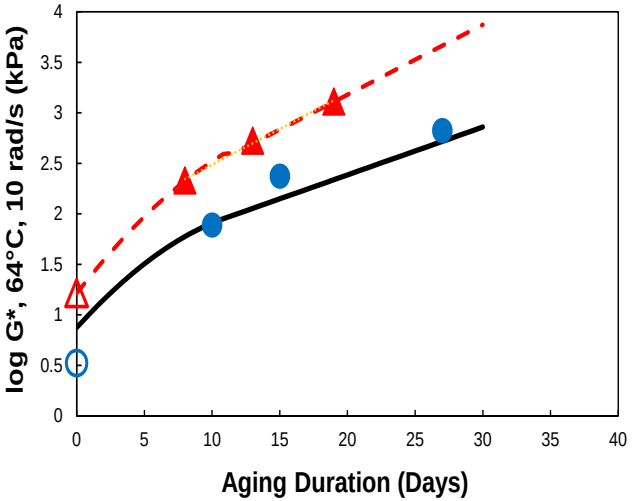
Model Validation

Loose Mix Aging
Binder USAT Aging
Prediction

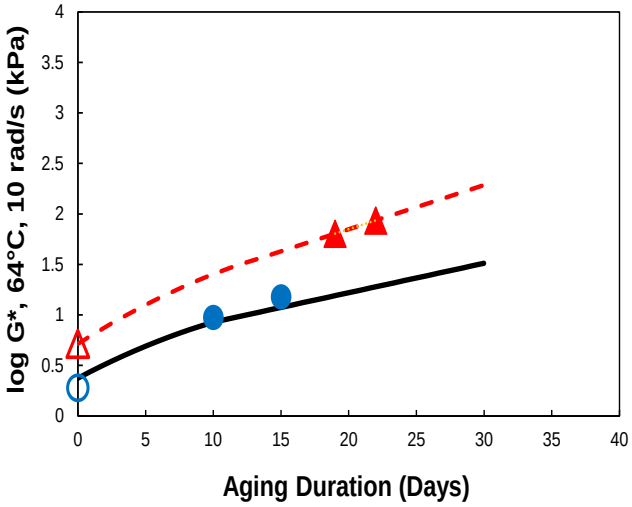
NCS9.5B



SHRP-AAD-1



SHRP-AAG-1



Summary

- Oven aging of loose mixture at 95°C recommended
- G*-based kinetics model developed and verified
- Aging duration maps developed using the climate data
- Draft AASHTO specification developed for long-term aging of asphalt mixtures for performance testing
- Preliminary pavement aging model established based on mixture-specific kinetics parameters and pavement depth dependent calibration factors
- Developed and verified the methodology to predict loose mixture aging from USAT aging

Questions?