

Impact of Extended Aging of RAS Mixes with Rejuvenators



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 - Mary Ryan, Doug Herlitzka, and Steve Engber
- Mathy Construction Staff
 - John Jorgenson and Chad Lewis

Motivation

- Cracking is the most prominent state agency concern
 - High levels of binder replacement, especially from RAS can cause durability concerns.
 - Materials used to soften asphalt can have unintended consequences.
 - Concerns Over Current Proposals for Long Term Aging of up to 20 Days of Mix Prior to Performing Mix Design
- Performance risks of using high binder replacement aren't apparent until after long-term aging.
- Evaluate different long-term aging methods.

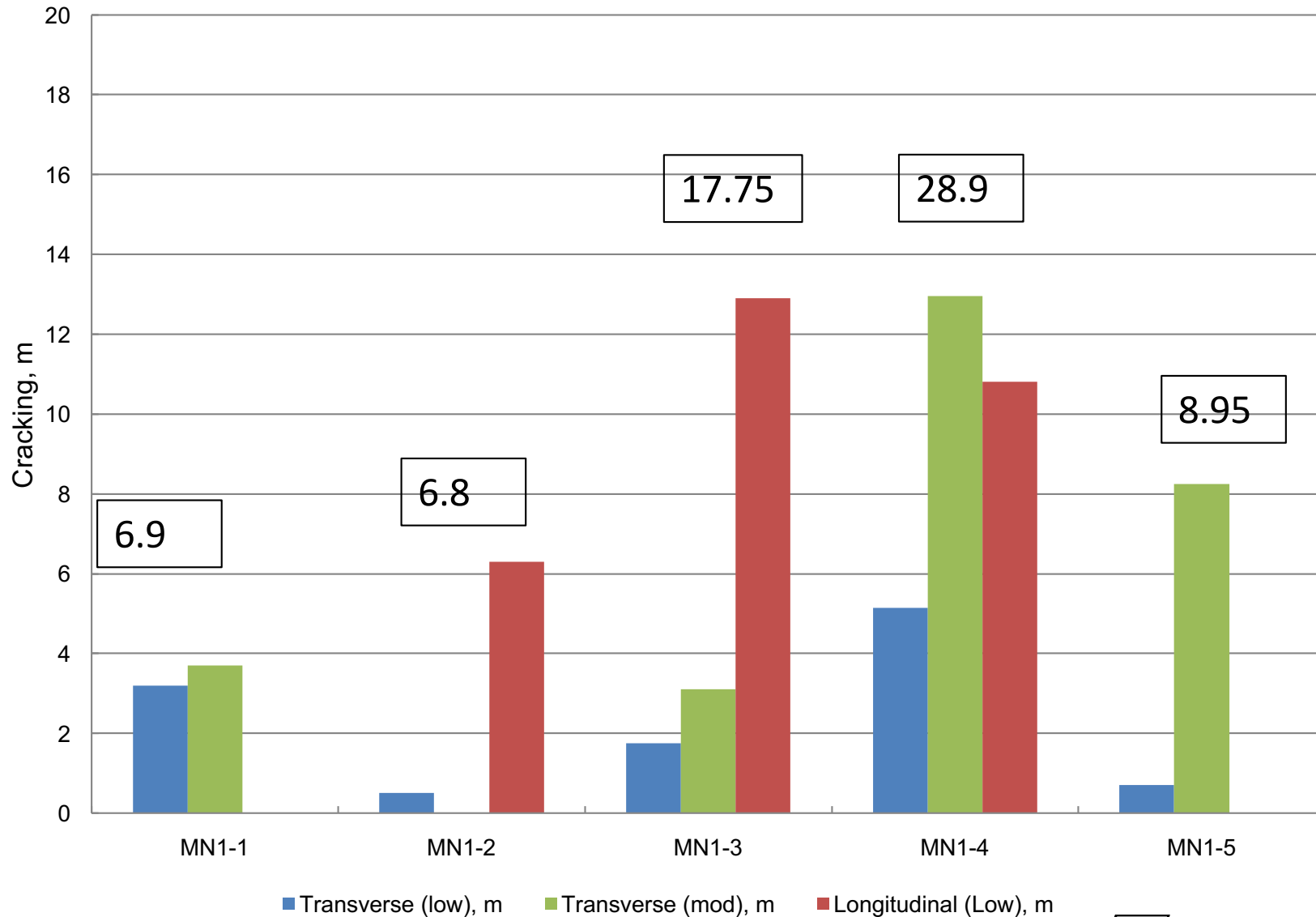
Background

- Current long term aging protocols in specifications
 - Binder (M320/M332): 1 PAV aging cycle.
 - Mix (R30): 2 or 4 hours loose mix aging at 135°C followed by 5 days compacted mix aging at 85°C
- This study focuses on extended aging. Why?
 - Identify aging susceptible materials in the mix (RAS) and whether materials marketed as rejuvenators can mitigate the effect of aging
 - Under current specifications most of these materials appear acceptable.

WHY EXTENDED AGING MATTERS

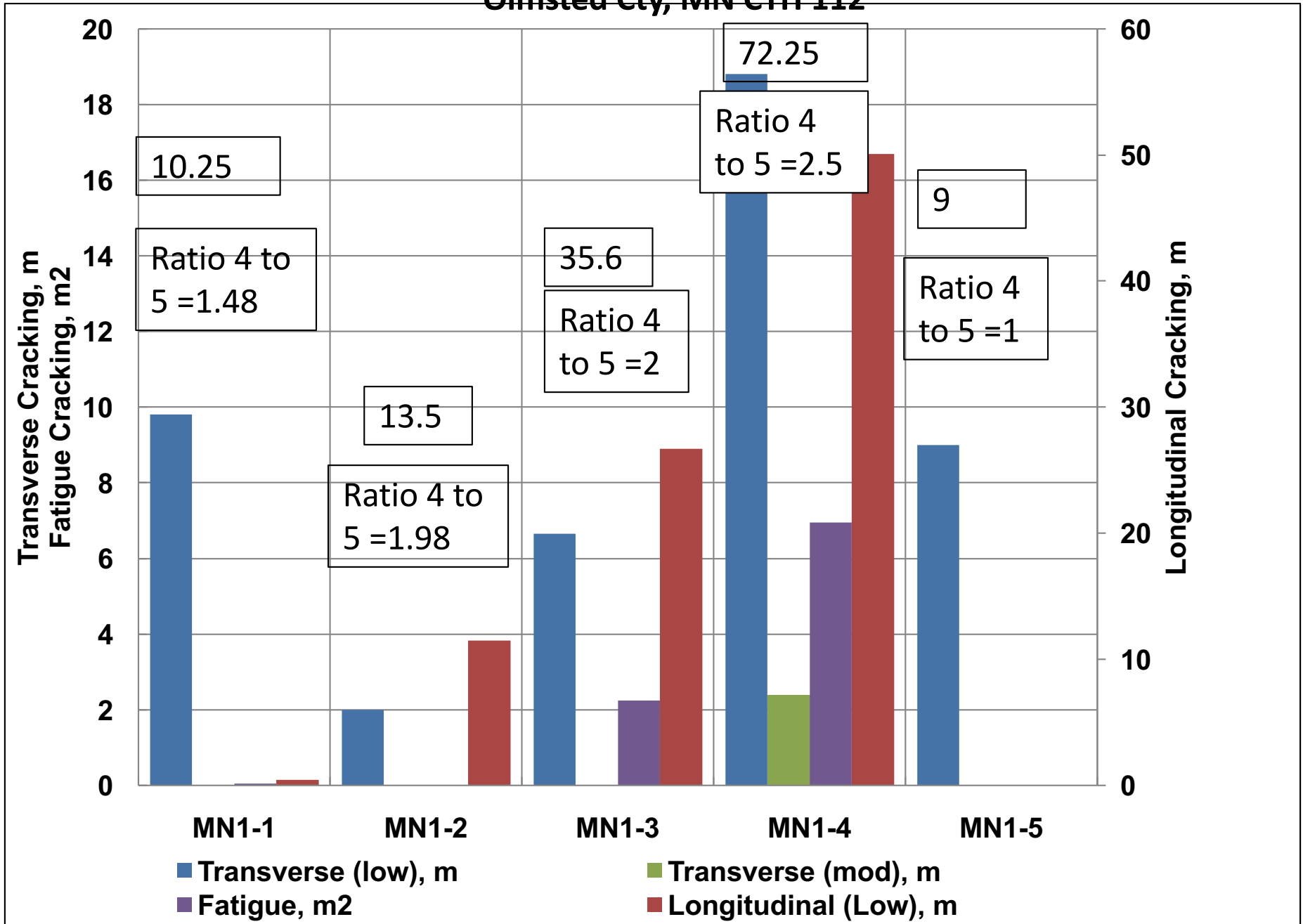
- Field evaluations which we have studied shows that mixture deterioration begins after 4 to 5 years in service (in our climate)
- The impact of field aging could be more accelerated in warmer regions
- Consequently testing mixtures or evaluating the properties of binders without performing extended aging won't provide information on long term performance

Cracking Results from 2010 Survey of Olmsted County, MN CTH 112, 4 years old

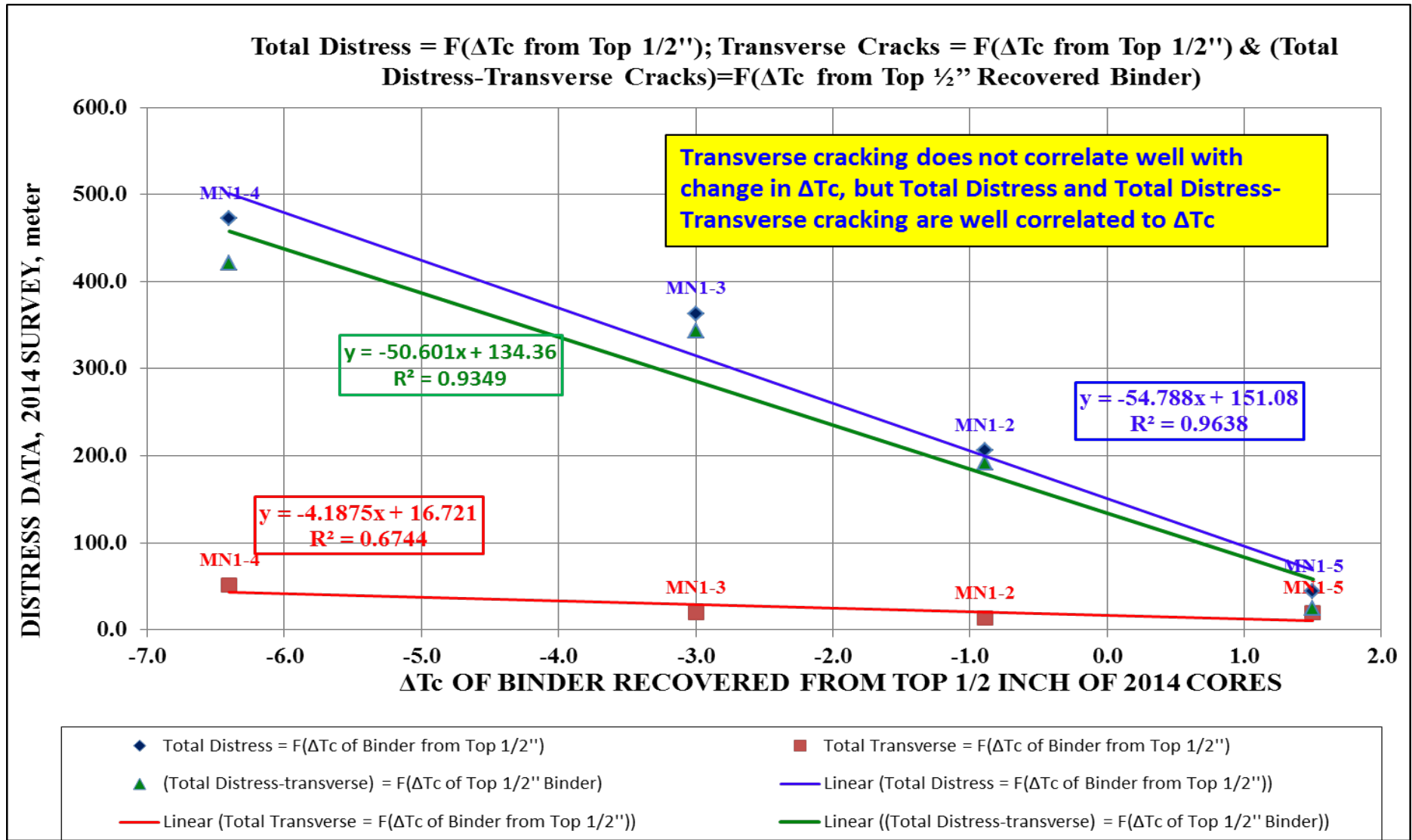


■ Transverse (low), m ■ Transverse (mod), m ■ Longitudinal (Low), m

**Cracking Data from October 2011 survey, 5 years old
Olmsted Cty, MN CTH 112**

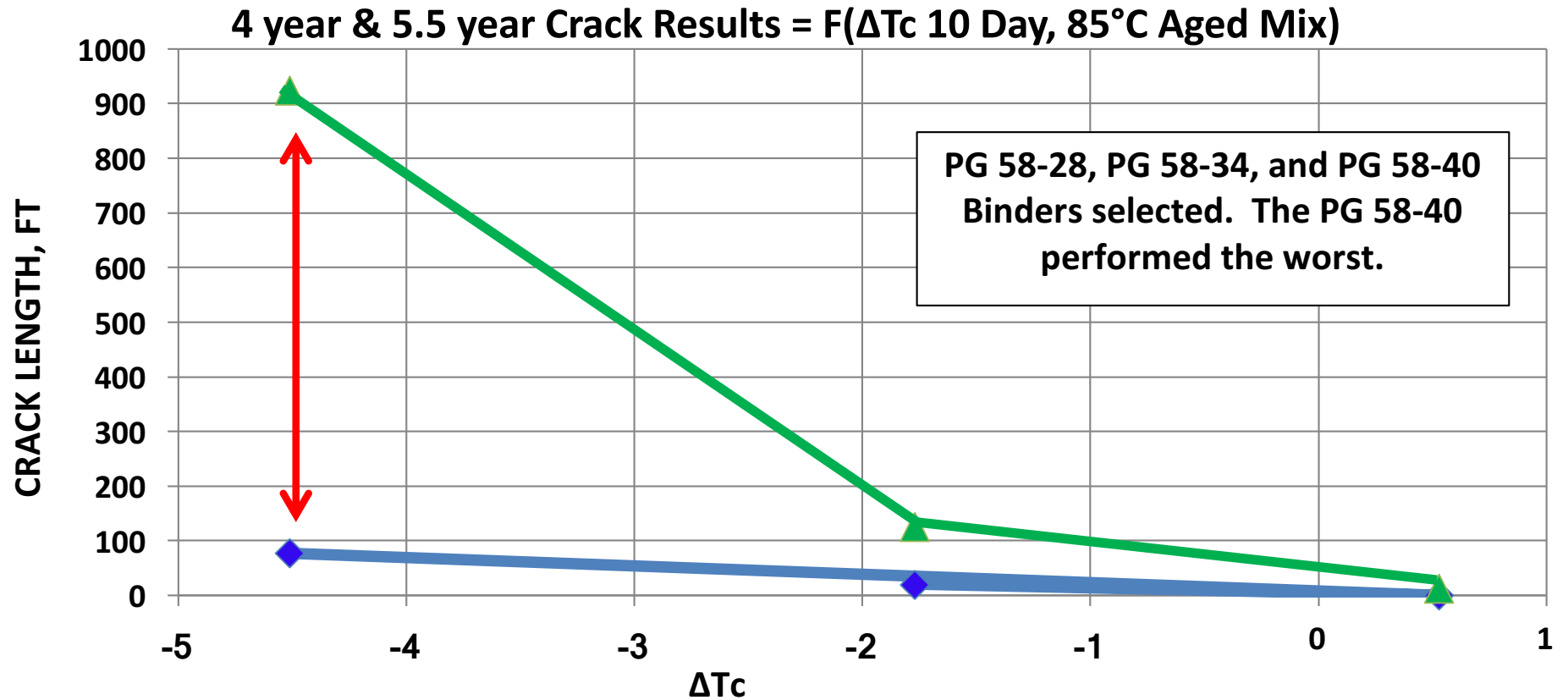


Olmsted County, MN CTH 112 (8 yrs)



Why do we need long term aging?

MnRoad (1999) Binder Grade Study



Total Cracks (Non-CL) after 4 years in-service

Total Cracks (Non-CL) aft 5.5 years in service

Mix Aging Study

Objectives

1. Compare aging stability of bio-based rejuvenator modified binders to conventional PG asphalt.
2. Evaluate effects of multiple aging methods and conditioning times on physical properties and composition.
3. Evaluate Mixture Modulus and Relaxation properties after extended aging

Mix Aging Study

Materials

- RAS: Tear-off shingles from a commercial source in Central-WI (TOS #1)
- Asphalt: PG 58-28 and PG 52-34 sampled from MIA.
- Additives:
 - Experimental Product (EP #1)
 - Bio-based Oils (BO #1 and BO #2)
- Blends
 - PG 58-28 + 5% bio oil was used to target a final grade of PG 52-34.

Mix Aging Study

Just remember the more negative ΔT_c becomes the more likely the mix containing that binder will be prone to cracking

Ble	(Unaged)	20hr PAV	hr PAV	20 hr PAV	ΔT_c 40 hr PAV
PG 52-34	54.0	-35.3	-32.2	0.5	-1.9
PG 52-34 + 5% EP#1	52.7	-34.2	-32.7	0.56	0.61
PG 52-34 + 2.5% BO#1 + 5% EP#1	48.3	-36.5	-35.6	1.6	0.4
PG 58-28	59.6	-29.7	-25.1	-0.2	-3.1
PG 58-28 + 5% BO#1	51.2	-36.5	-33.3	-0.4	-1.5
PG 58-28 + 5% BO#2	49.3	-36.2	-33.1	0.6	-0.5

1. ΔT_c = S critical Temp – m- value critical Temp using 4 mm DSR based on work by
2. Farrar, Sui, et al. 4 mm Plate Development – TRB 2011, 2012, Eurobitume 2012 and others.

MIX AGING STUDY—PROPERTIES OF BINDER RECOVERED FROM 5% RAS MIXTURES AFTER 2 HOURS OF LOOSE MIX AGING AT 135°C WHICH IS TYPICAL STOA PROCEDURE THESE DATA REPRESENT THE STARTING POINT FOR ALL THESE MIXTURES

Recoverd binder from 2 hr. 135C loose mix, all mixes contained 5% RAS	High-temp_2.2k Pa	Low_temp	ΔTc	CI	R-VALUE
PG 58-28	73.7	-31.80	0.11	2.610	2.43
PG 58-28 + 5% BO#2	66.5	-38.20	1.80	2.546	2.38
PG 58-28 + 5% BO#1	65.9	-38.70	0.28	2.704	2.43
PG 52-34	66.8	-37.20	0.65	2.555	2.34
PG 52-34 + 5% EP#1	63.0	-36.76	1.40	2.614	2.12
PG 52-34 + 5% EP#1, 2.5% BO#1	60.4	-36.12	1.40	2.546	2.13

Mix Aging Study

RAS Binder Properties

RAS Binder	R – value	HT PG	LT PG	ΔT_c	S(60)	m(60)
TOS #1	6.03	146	6.0	-31.4	-25.4	6.0

- RAS AC content = 22.1%
- All mixes used in this study included 5% RAS by weight.



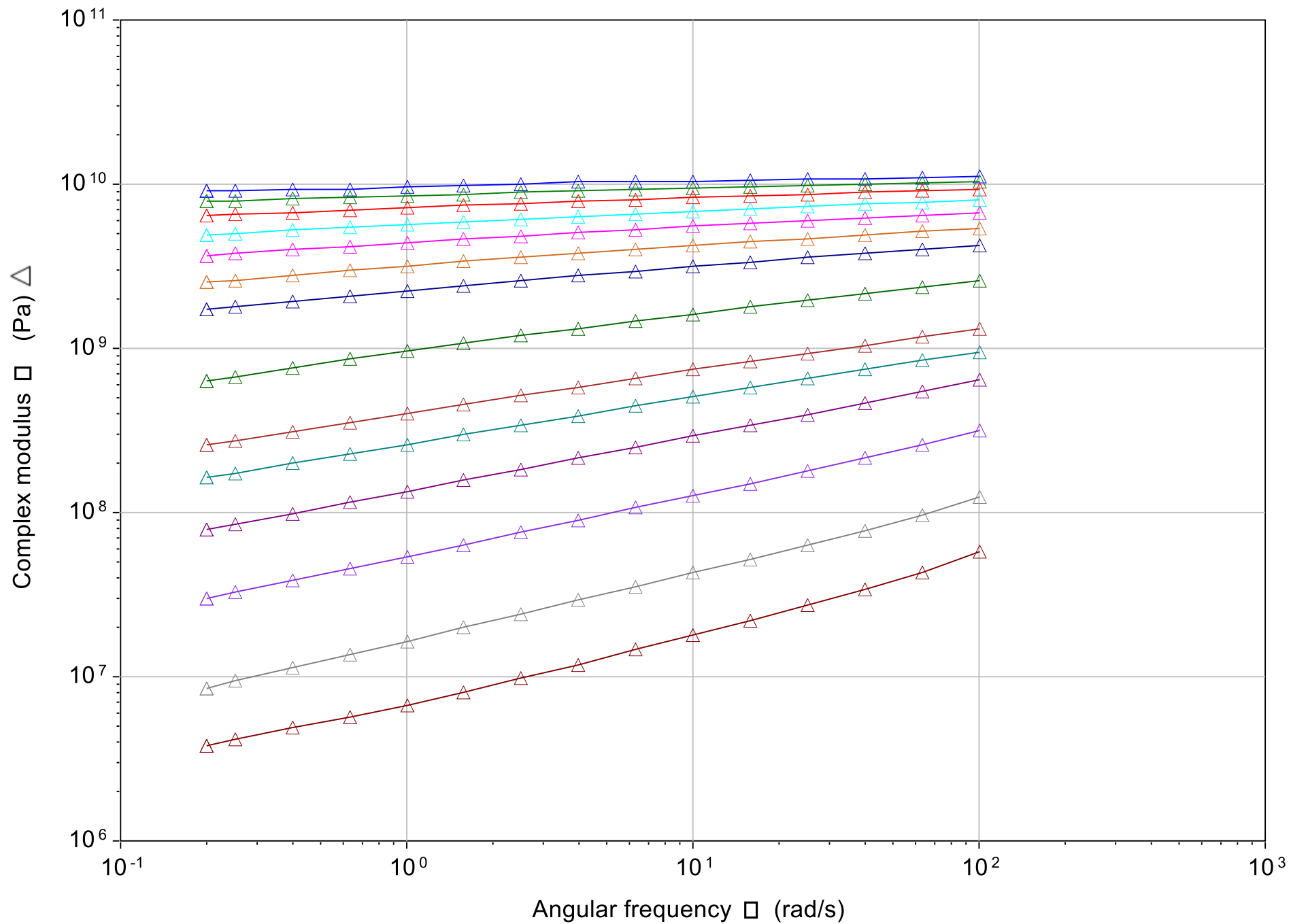
MIX TORSION BAR TEST

≈50 mm X 12 mm X 7 mm

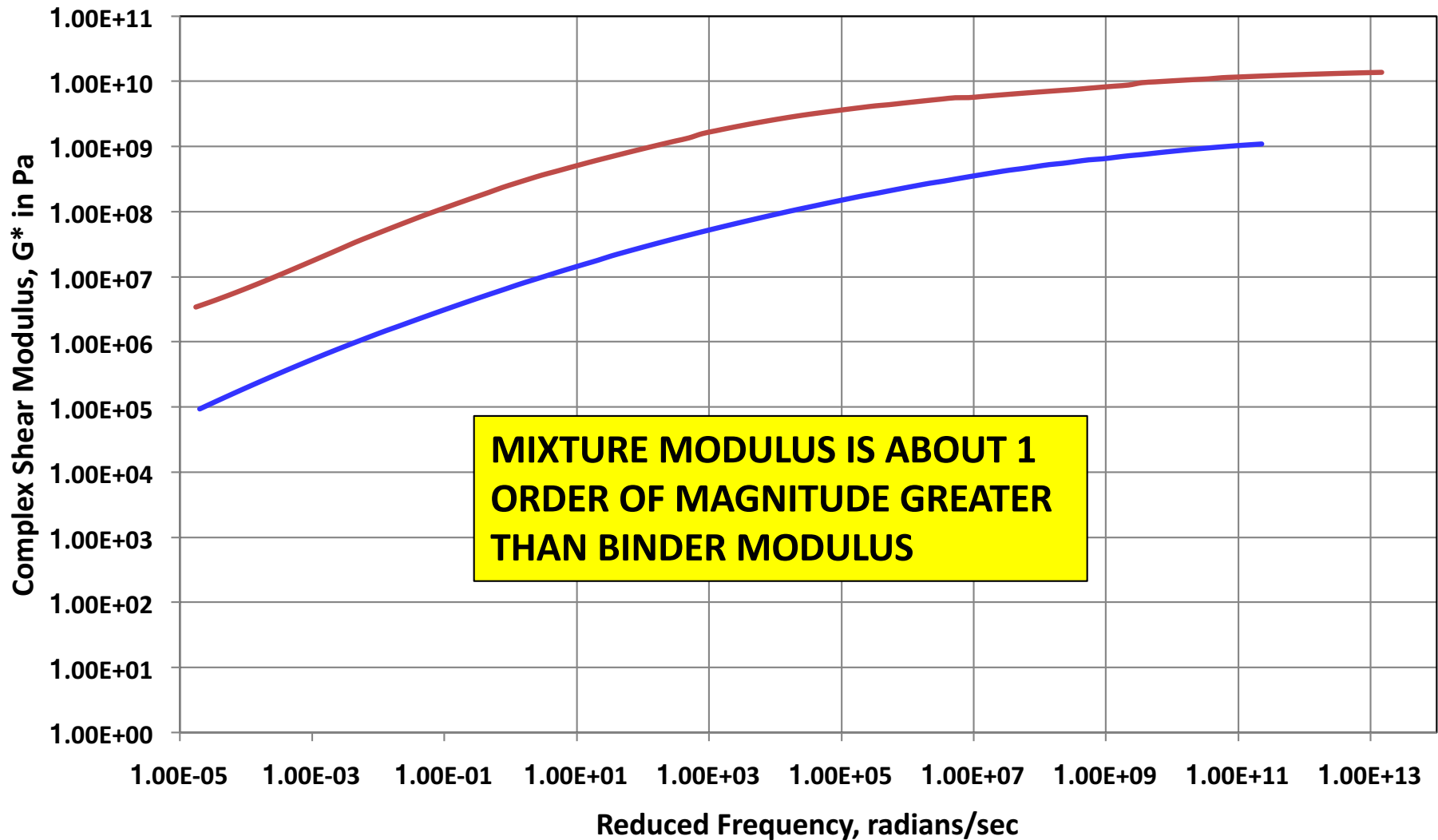
TESTED AT -40°C TO +40-80° DEPENDING ON
MIX STIFFNESS



1531, 07-05-16-AY, 58-28,5% BO#1, 20d85, RSS, HR3-3



COMPARISON OF MIXTURE MODULUS AND BINDER MODULUS MASTERCURVES @ 25°C REFERENCE TEMPERATURE



— G^* @ +25°C 1531, 06-20-16-Q, 58-28 w 5% BO#1, 5% RAS, Rec AC, 4mm, HR3-2 (1)

— G^* @+25°C 1531, 07-05-16-AY, 58-28,5% BO#1, 20d85, RSS, HR3-3

Mix Aging Study

Mix Design

- Mix represents a normal surface course used for intermediate traffic levels in WI.
 - Design Traffic Level: 3 million ESALs (E3), 75 gyrations for Ndes.
 - NMAAS: 12.5 mm
- Aggregate Source: Granite + 25% nat. sand
- Gradation: Fine, 70% passing the #4 sieve.
- Design AC: 5.7% (19.4% binder replacement from RAS)

Mix Aging Study

Aging Methods

Aging Method	Aging Condition
Loose Mix + PAV	As-Recovered (after 2 hrs at 135°)
	As-Recovered + PAV (Blending Chart)
	As-Recovered + 2PAV
Loose Mix	12 hrs at 135°C
	24 hrs at 135°C
Compacted Mix	5 days at 85°C (AASHTO R30) – <i>Test results pending</i>
	10 days at 85°C
	20 days at 85°C

Mix Aging Study

Description of Work

- After the prescribed aging protocol asphalt binder was extracted and recovered from mix.
- Recovered residue evaluated using:
 - DSR: 25 mm and 4mm Parallel Plate
 - Iatroscan: Determine compositional factors
- Torsion bar modulus on 10 and 20 day 85°C aged compacted mix samples.

Mix Aging Study

Effects of Additives and Aging on Physical Properties

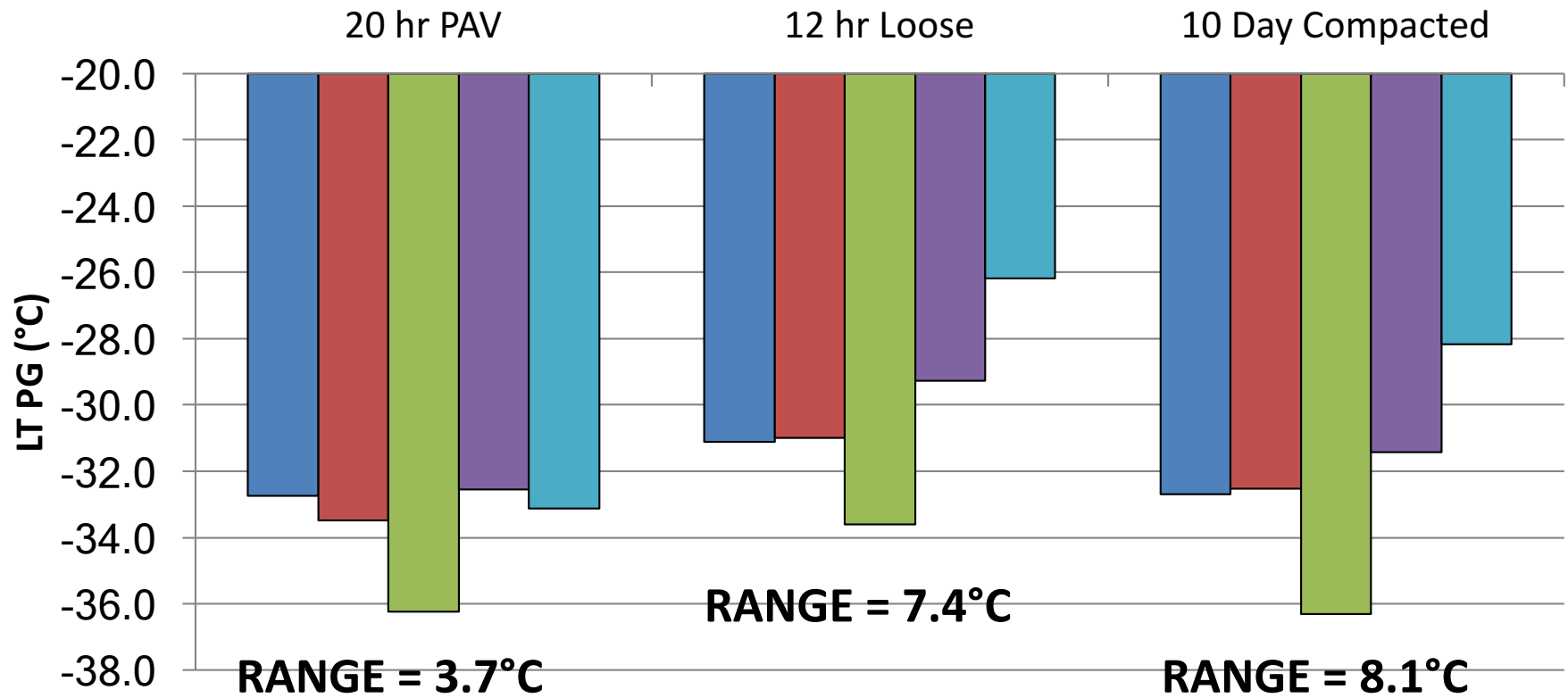
- Low Temperature Properties: PG grade
- Durability: ΔT_c

Two Analysis Cases

1. Softer Binder Grade vs. Rejuvenating additives
 - Control: PG 52-34
 - PG 52-34 +5% EP#1 and PG 52-34 +2.5% BO#1 + 5% EP#1
 - PG 58-28 modified with 5% BO#1 and BO#2. Target grade for modification is PG 52-34.
2. Do nothing alternative
 - Compare PG 58-28 to the PG 58-28 modified asphalts in Case #1.

Results Case #1

LT PG - Intermediate Aging



PG 52-34

PG 52-34 + 2.5% BO#1 + 5% EP#1

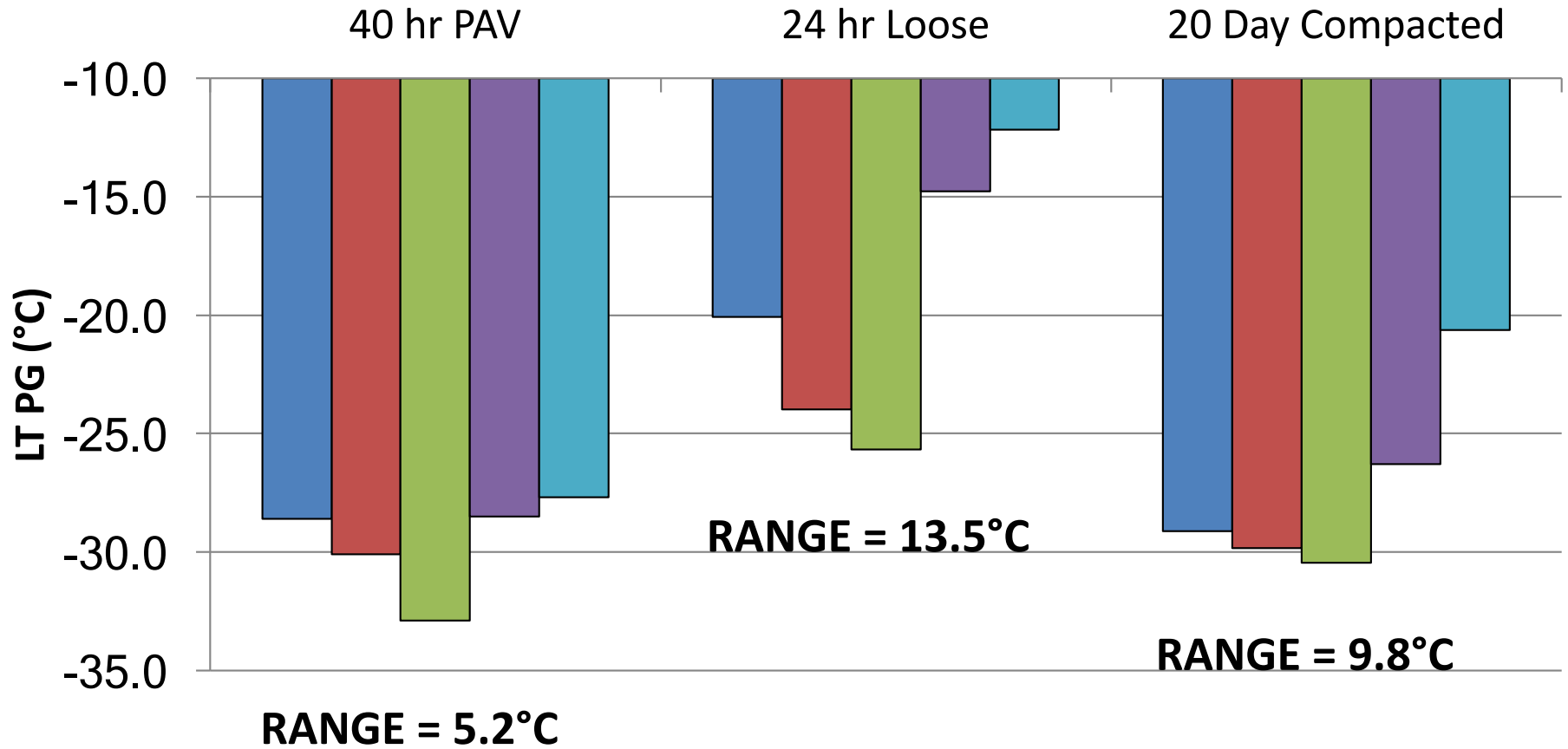
PG 58-28 + 5% BO#2

PG 52-34 + 5% EP#1

PG 58-28 + 5% BO#1

Results Case #1

Extended Aging



- PG 52-34
- PG 52-34 + 2.5% BO#1 + 5% EP#1
- PG 58-28 + 5% BO#2

- PG 52-34 + 5% EP#1
- PG 58-28 + 5% BO#1

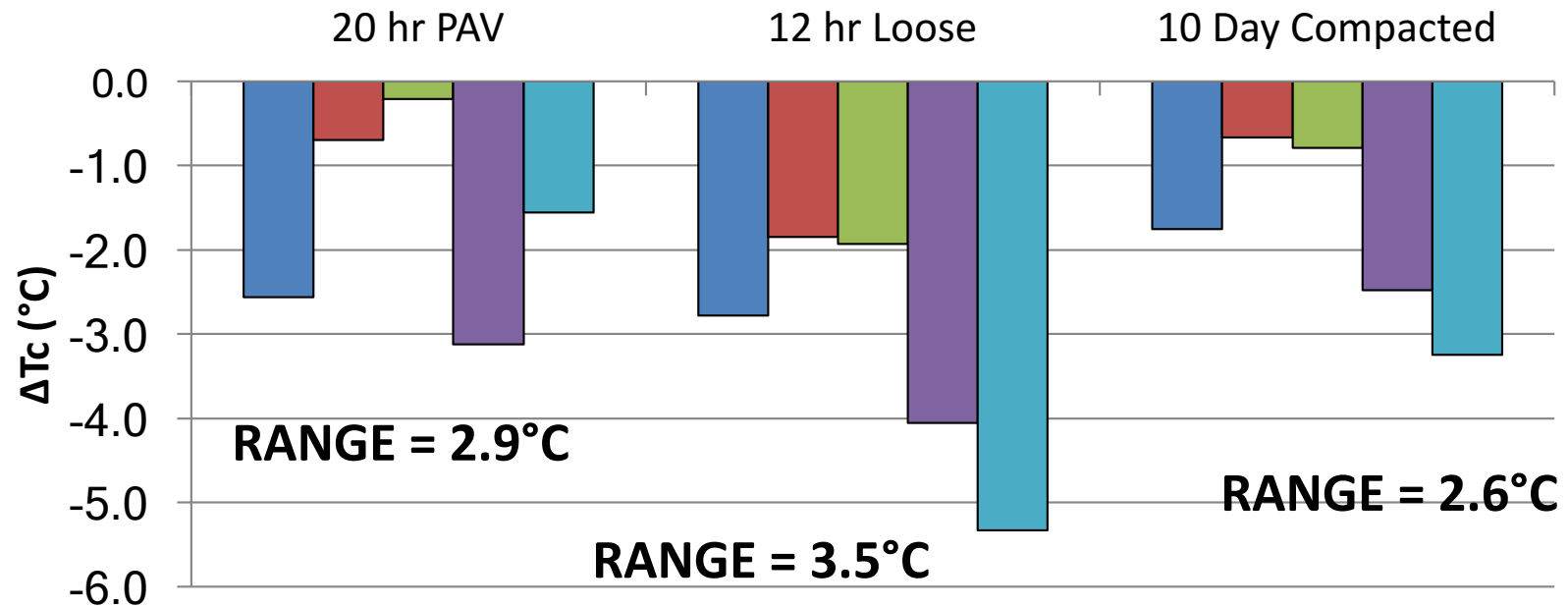
Case #1 Summary

LT PG

- PAV aging at both conditions did not discriminate between materials as well as loose mix or compacted mix aging.
- EP#1 maintained better low temperature grading relative to PG 52-34 control and other additives, even with extended aging.
- Combination of EP#1 and BO#1 performed best.
- No benefit of additives observed in maintaining low temperature PG with extended aging. BO #2 was worst in most categories, PG 52-34 was marginally better than BO #1 at intermediate aging and substantially better after extended aging.

Summary of Results

Intermediate Aging



PG 52-34

PG 52-34 + 5% EP#1

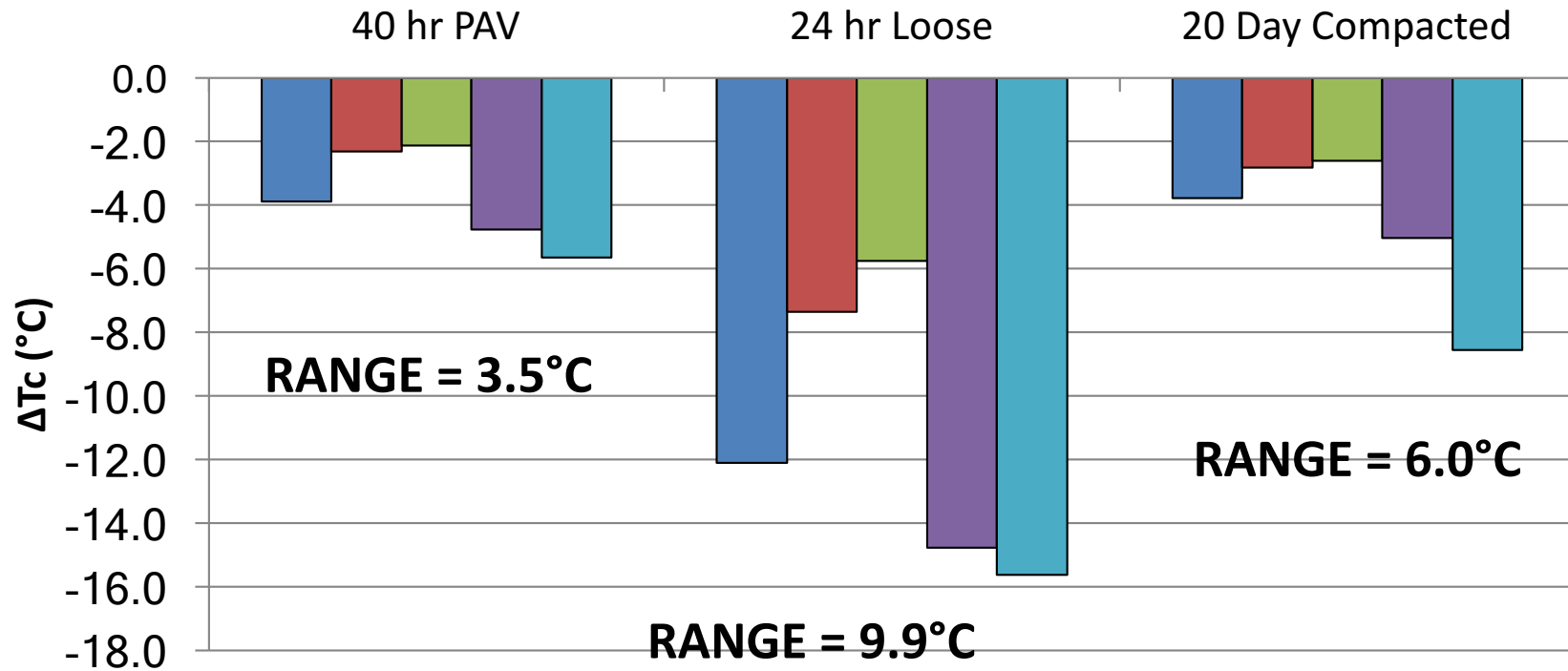
PG 52-34 + 2.5% BO#1 + 5% EP#1

PG 58-28 + 5% BO#1

PG 58-28 + 5% BO#2

Summary of Results

Extended Aging



PG 52-34

PG 52-34 + 5% EP#1

PG 52-34 + 2.5% BO#1 + 5% EP#1

PG 58-28 + 5% BO#1

PG 58-28 + 5% BO#2

Observations

- Significant differentiation was observed after extended aging, particularly loose mix.
- EP#1 improved ΔT_c at all aging conditions.
- BO#1 and BO#2 resulted in worse values of ΔT_c relative to using a softer binder grade.

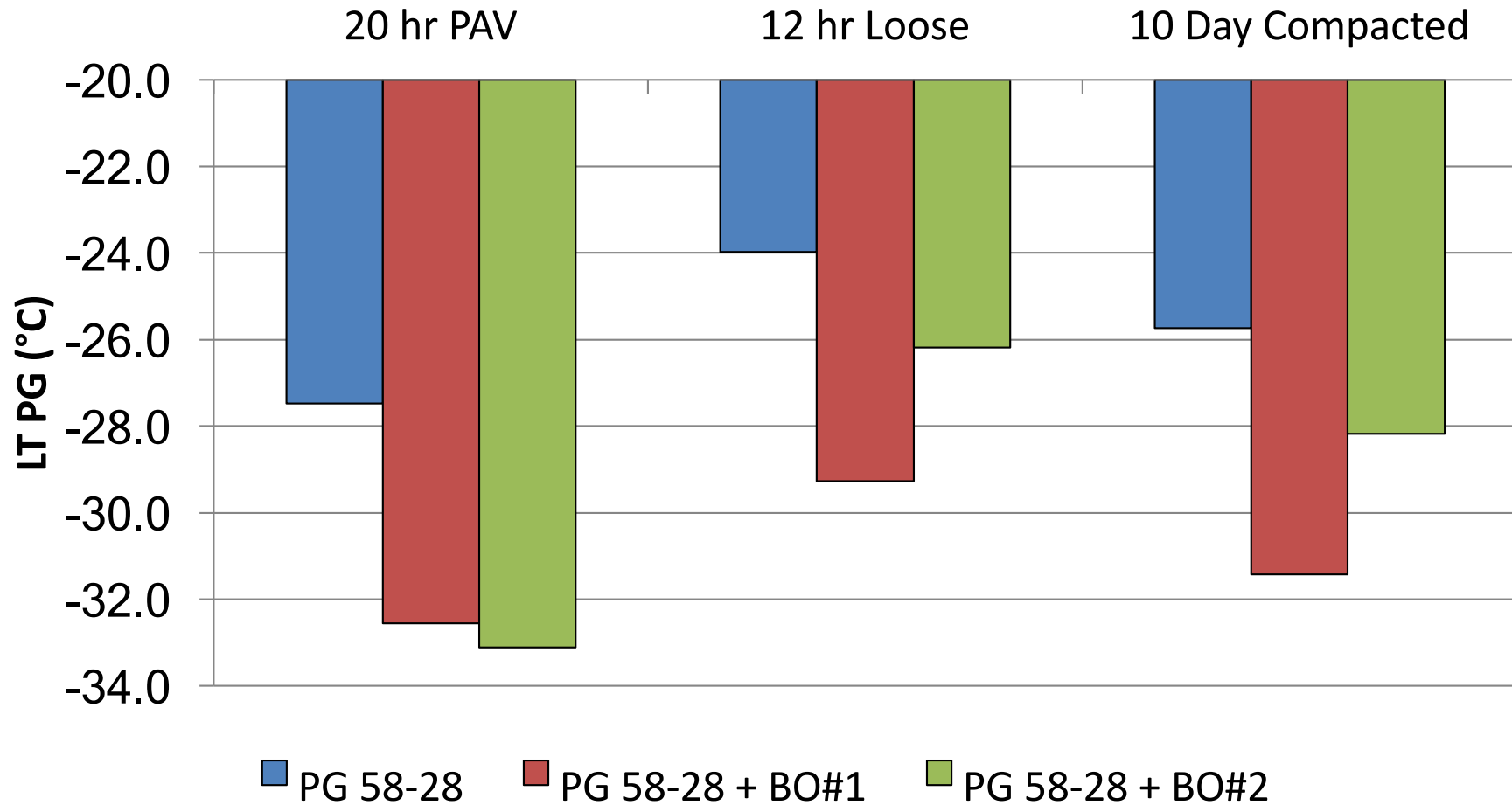
Case #2

“Do Nothing” Alternative

- Evaluate the effectiveness of using rejuvenators vs. not changing PG.
 - Control: PG 58-28
 - Additives: PG 58-28 + BO#1 and PG 58-28+BO#2
- Target climate for mix is -28°C

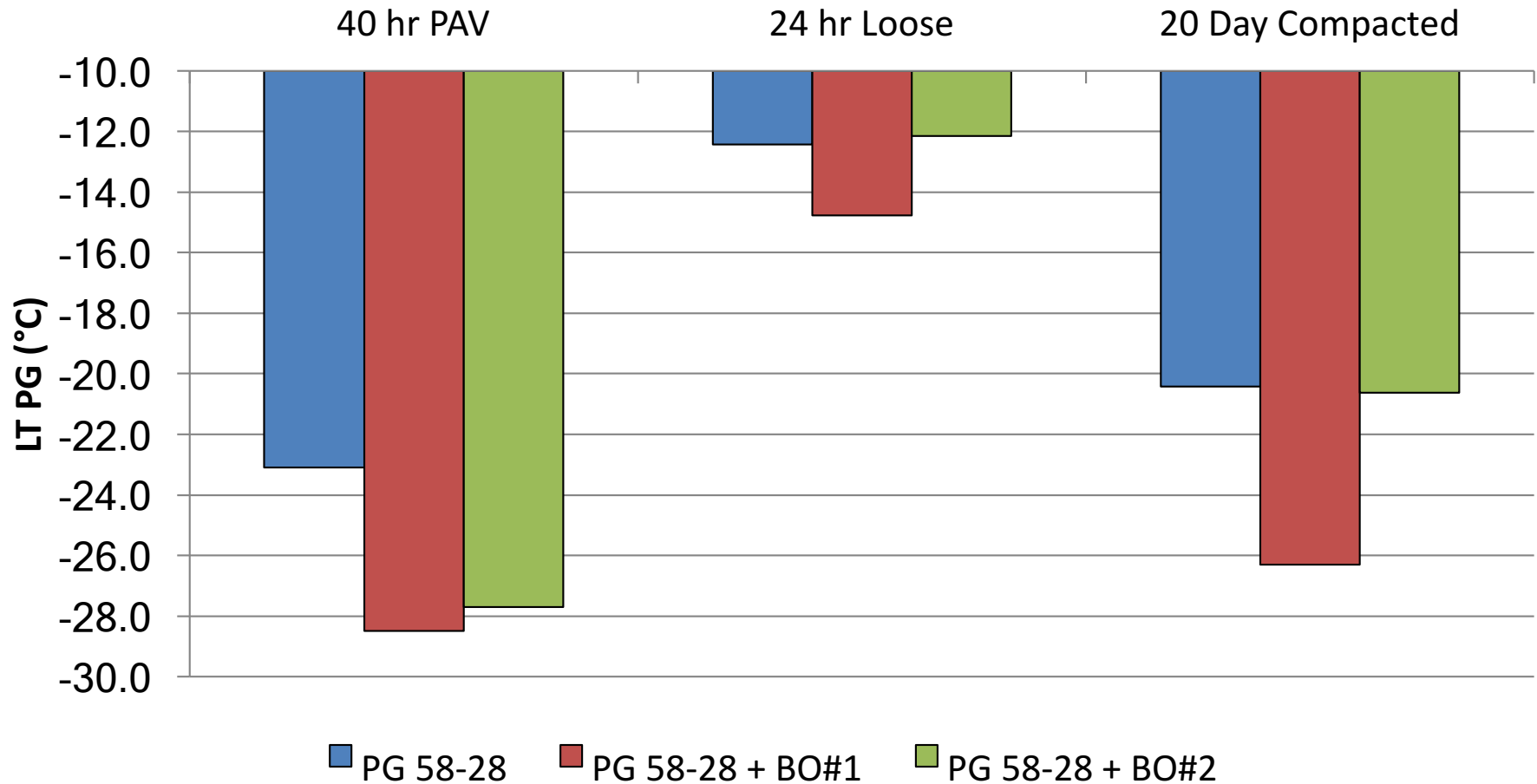
Case # 2 Summary LT PG

Intermediate Aging



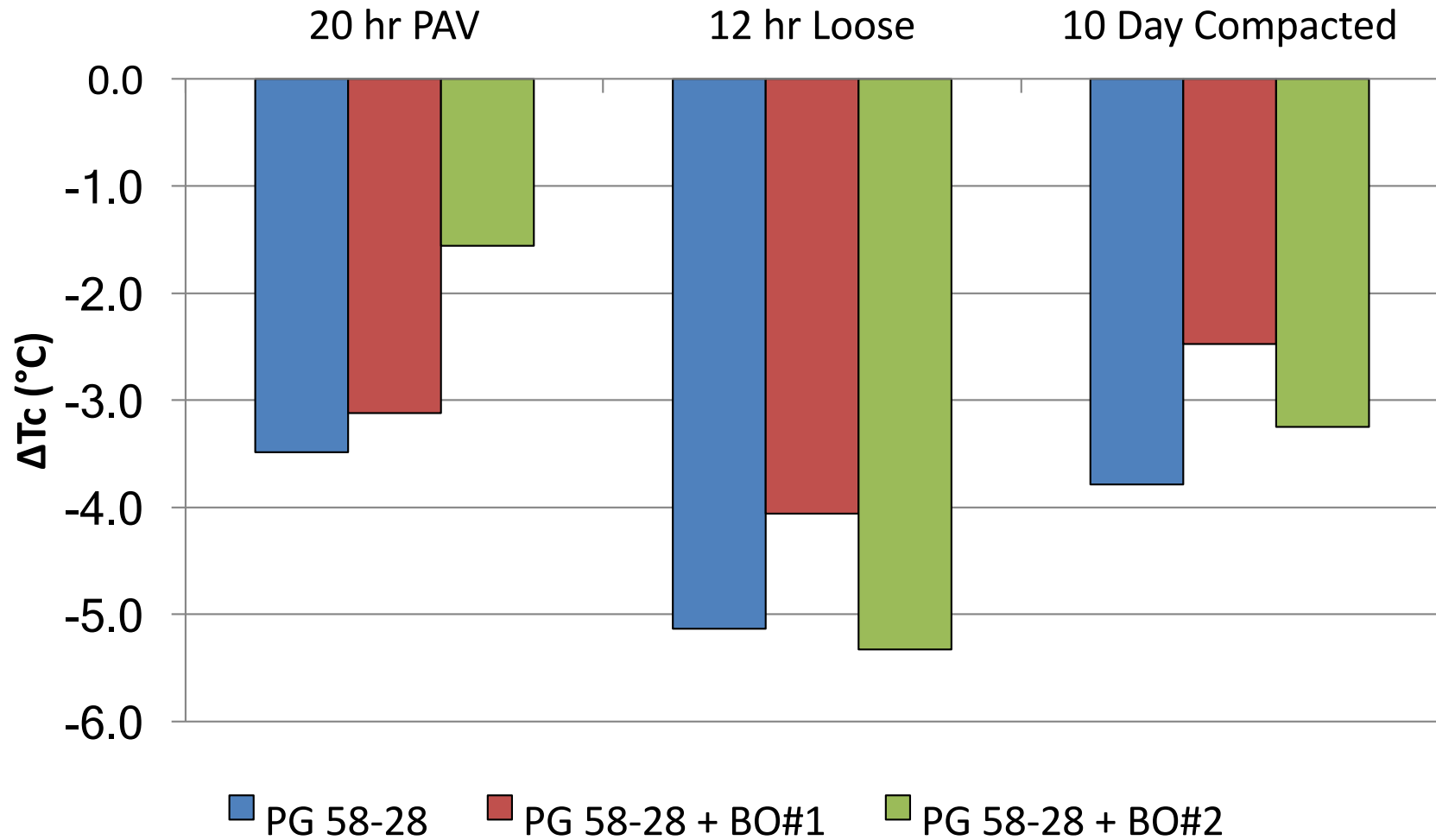
Case #2 Summary LT PG

Extended Aging



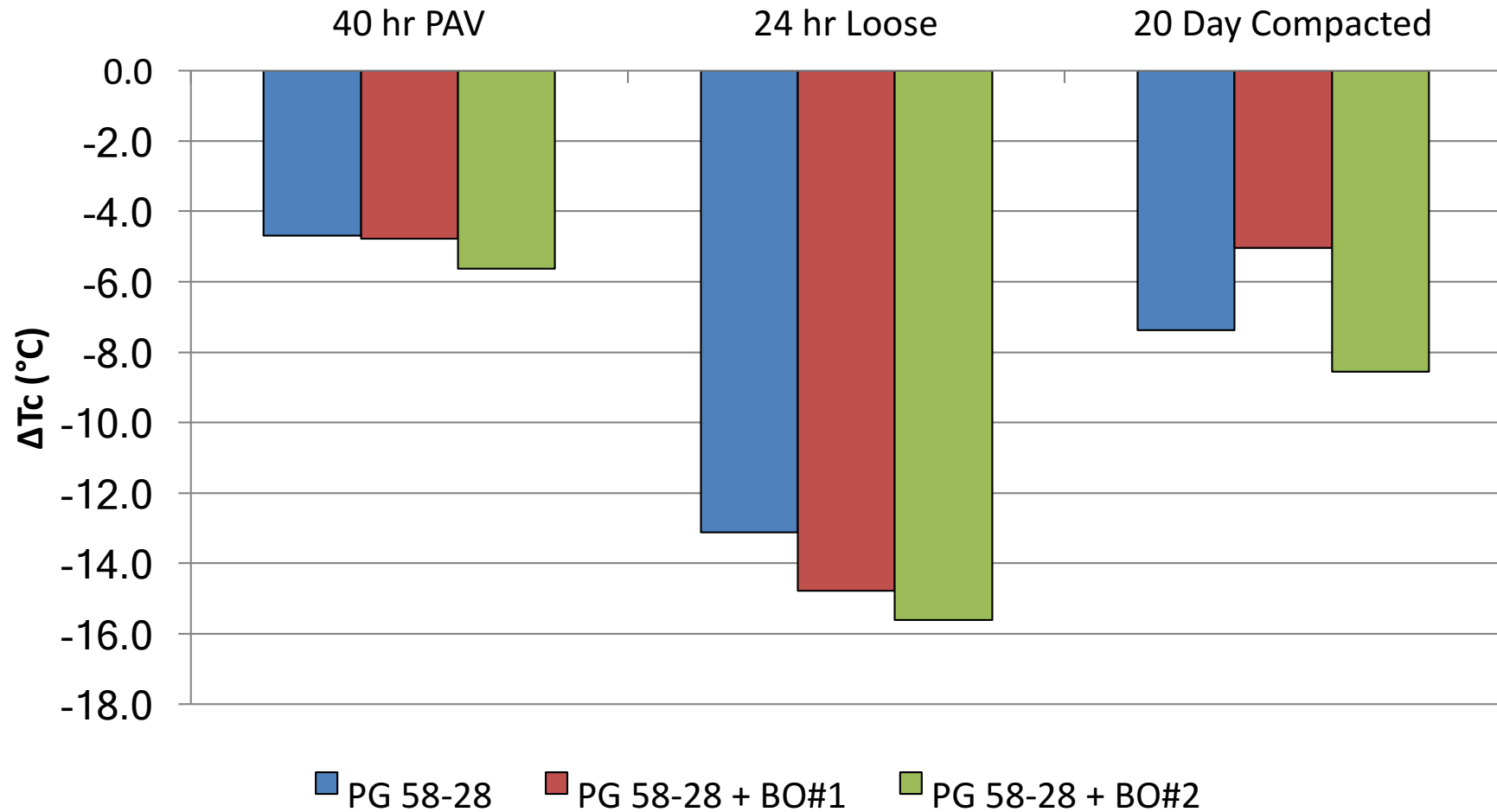
Case #2 Summary ΔT_c

Intermediate Aging



Case #2 Summary ΔT_c

Extended Aging



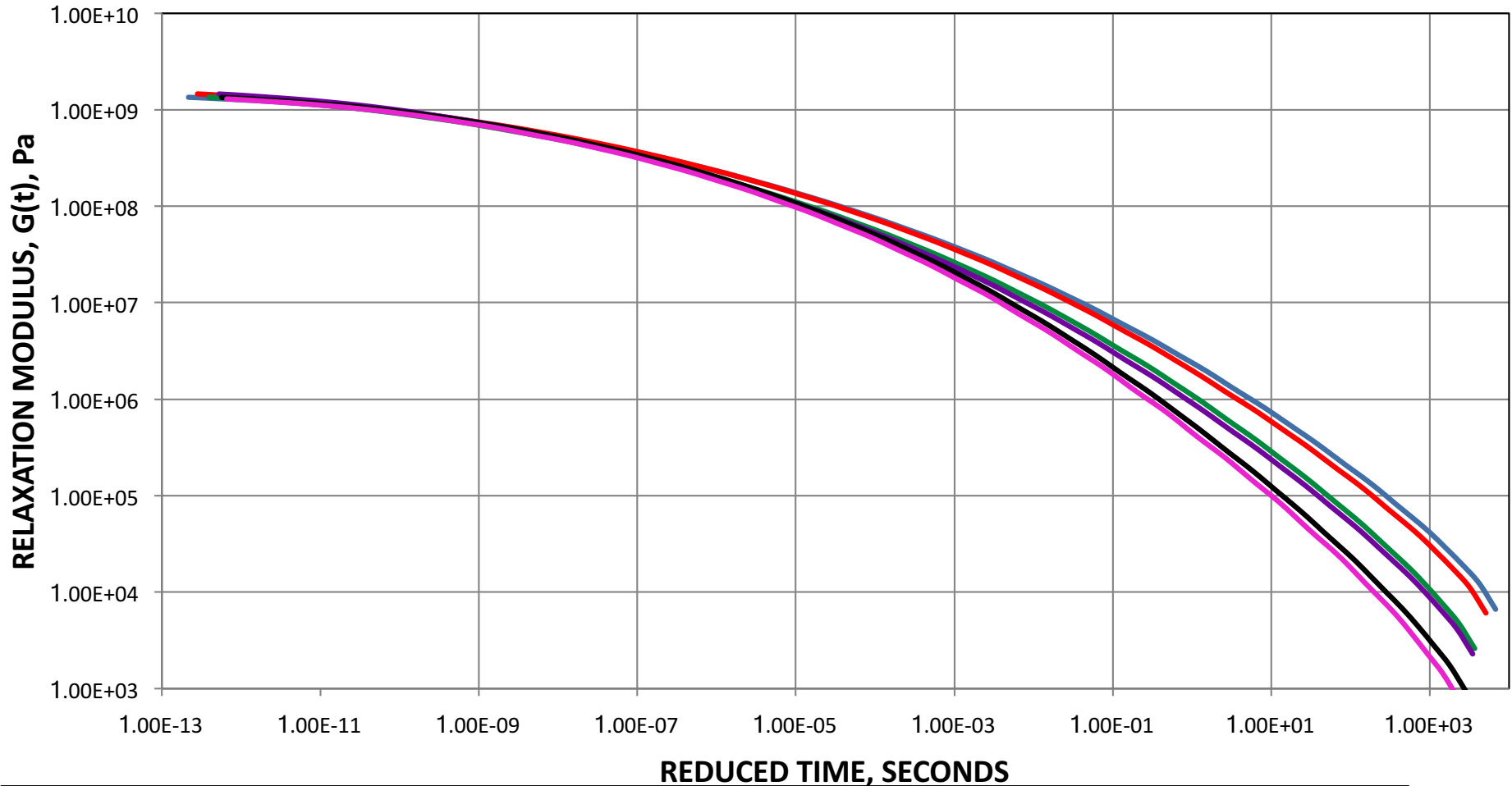
Case #2 Observations

- Diminishing returns in using rejuvenating additives.
 - LT PG: Softening due to use of additives remains after intermediate aging. Additive effect diminishes after extended aging for BO#2.
 - ΔT_c : No significant benefit of additives for most aging conditions (ESPECIALLY 40 HR. PAV, 20 DAY @ 85°C and 24 HR., 135°C LOOSE MIX)
- Extended aging needed to evaluate additives used to soften the binder.

IS TESTING OF RECOVERED BINDER FROM AGED RAS MIXTURES MEANINGFUL?

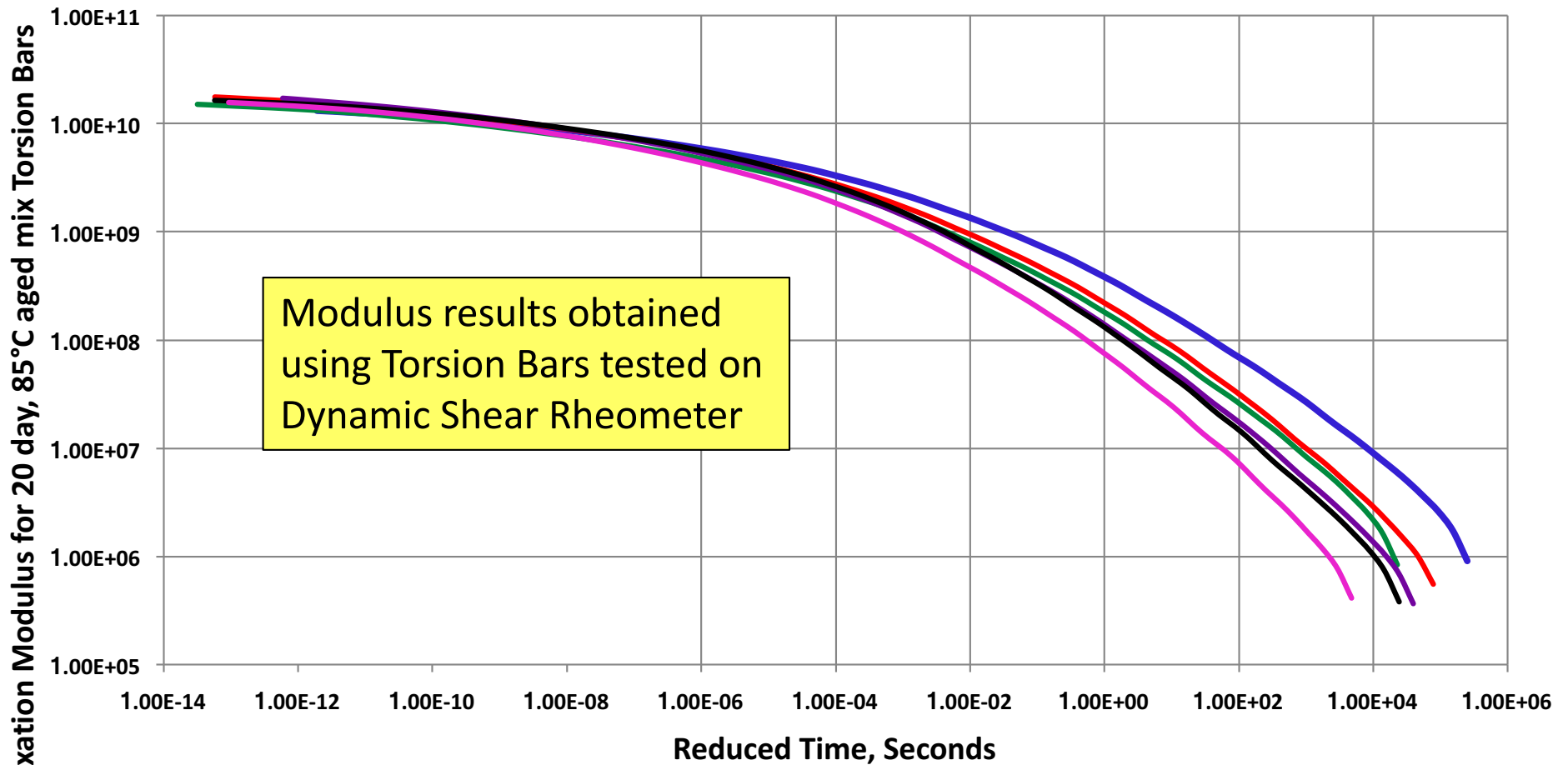
- To evaluate this we looked at relaxation modulus of recovered binder from 20 day aged @ 85°C compacted mix compared to relaxation modulus of the 20 day aged mix based on torsion bar testing
- At the very least we should expect the relaxation modulus to rank order the same for the recovered binder and the mix

Relaxation Modulus of Binder Recovered from 20 day, 85°C Compacted Mix with 5% RAS and Different Binders



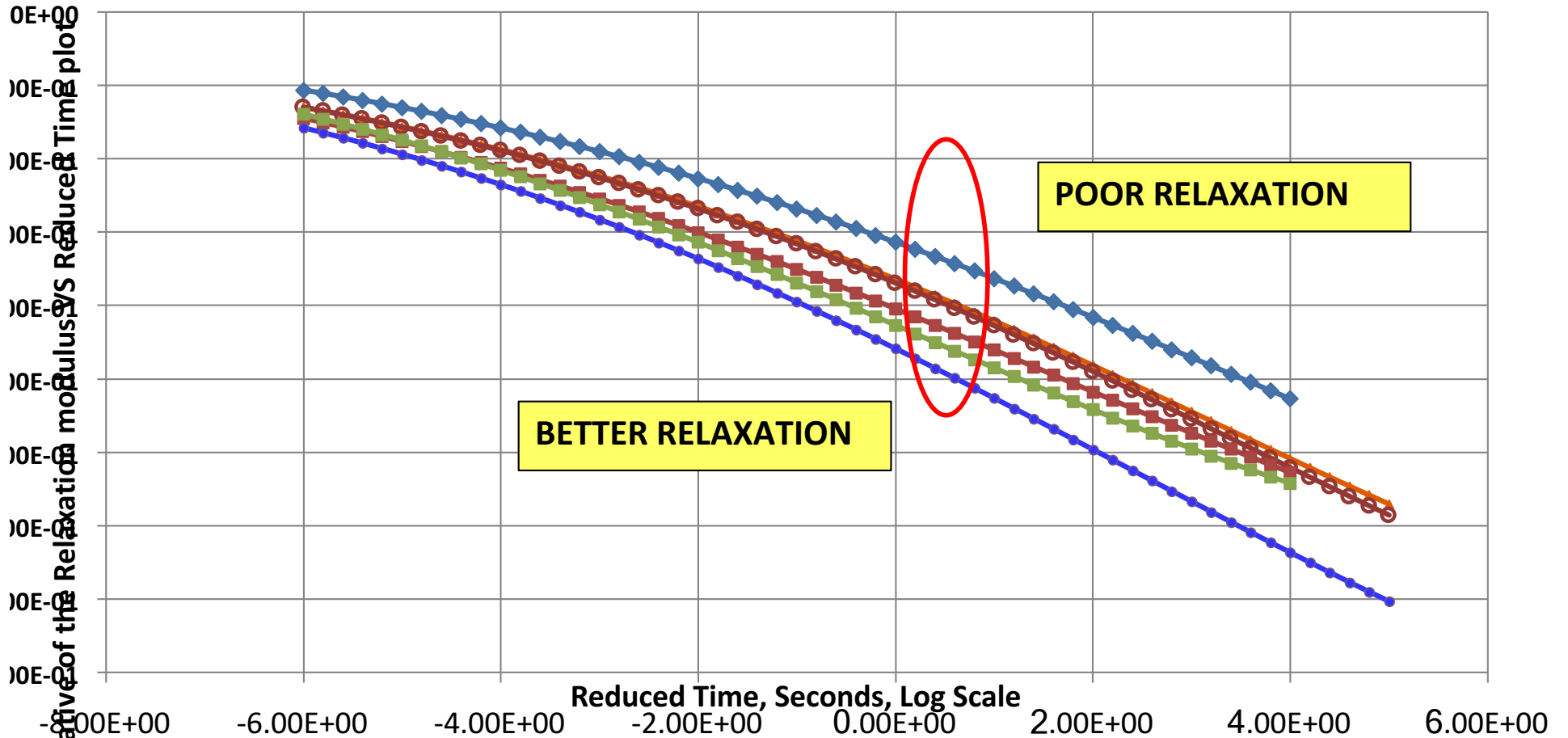
- G(t) @25°C 1531, 07-05-16-BB, 58-28 straight, 2, 20d85, rec ac, 4mm, hr3-2
- G(t) @25°C 1531, 07-05-16-AV, 58-28, 5% BO#2 20d85, Rec AC, 4mm, HR3-2
- G(t) @25°C 1531, 07-05-16-AY, 58-28, 5%, BO#1, 20d85, Rec AC, 4mm, HR3-2
- G(t) @25°C 1531, 07-05-16-AP, 52-34 20d85, rec ac, 4mm, hr3-2
- G(t) @25°C 1531, 07-05-16-AM, 52-34 w5% EP#1, 20d85, rec ac
- G(t) @25°C 1531, 07-05-16-AS, 52-34 w5% EP#1, 2.5% BO#1 20d85, rec ac

Relaxation Modulus of Commpacted Mix aged 20 days @ 85°C
all mixes contained 5% RAS, different Binders and Additives were employed



- G(t) @+25°C 1531, 07-05-16-BB 58-28, 5% RAS 20D aged @ 85°C
- G(t) @25°C 1531, 07-05-16-AV, 58-28,5% RAS, R% BO#2, 20D aged @ 85°C.
- G(t) @25°C Summary 1531, 07-05-16-AY, 58-28,5% Cargill 1103, 20d85, RSS.
- G(t) 1531 @25°C Summary 07-05-16-AP 52-34 + 5% RAS
- G(t) @+25°C 1531, 07-05-16-AM. 5% RAS + 5% EP#1, 20 D aged @ 85°C
- G(t) @25°C, 07-05-16-AS, 52-34, 5% RAS +5% EP#1, 2.5% BO#2, 20 D aged @ 85°C

Slope of Torsion Bar Relaxation Modulus of 20 day, 85°C aged mix

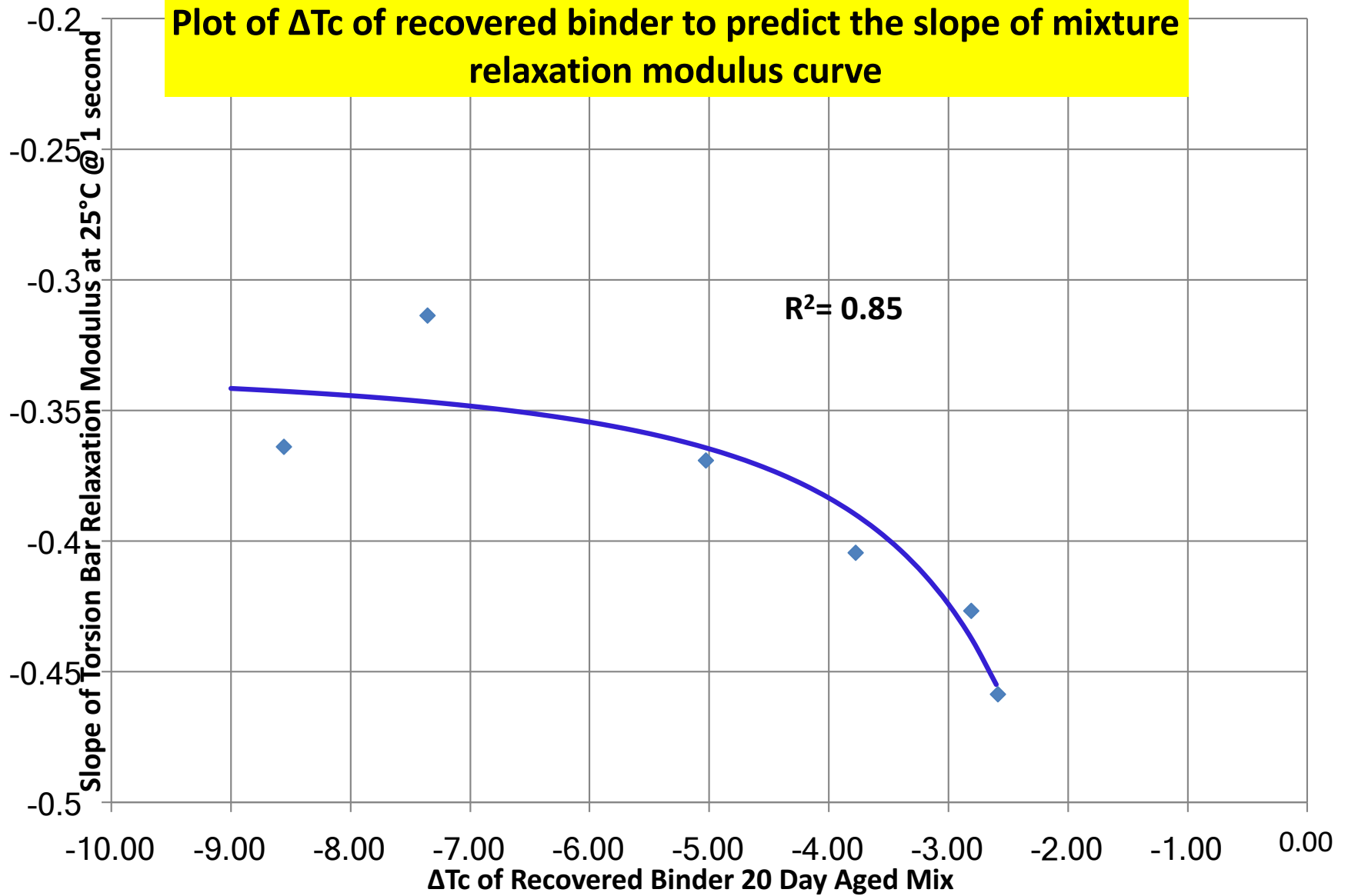


POOR RELAXATION

BETTER RELAXATION

- ◆ $dG(t)/dt$ 1531 Summary 07-05-16-BB 58-28, 5% RAS only
- ▲ $dG(t)/dt$ 1531 Summary 1531, 07-05-16-AV, 58-28,5% AZ RS1100, 20d85, RSS.
- $dG(t)/dt$ 1531 Summary 1531, 07-05-16-AY, 58-28,5% Cargill 1103, 20d85, RSS.
- $dG(t)/dt$ 1531 Summary 07-05-16-AP 52-34, 5% RAS only
- $dG(t)/dt$ 1531 Summary 07-05-16-AM 52-34 5% RAS, 5% sterol
- $dG(t)/dt$ 1531 summary 07-05-16-AS 52-34, 5% sterol, 2.5% 1103, 5% RAS, 20 d aged.

Plot of ΔT_c of recovered binder to predict the slope of mixture relaxation modulus curve



◆ Slope of Relaxation Modulus @ 1 sec as Function of ΔT_c of Binder recovered from 20 day aged mix
— Fitted Curve

How Can We Decide on a Reasonable Mix Aging Approach?

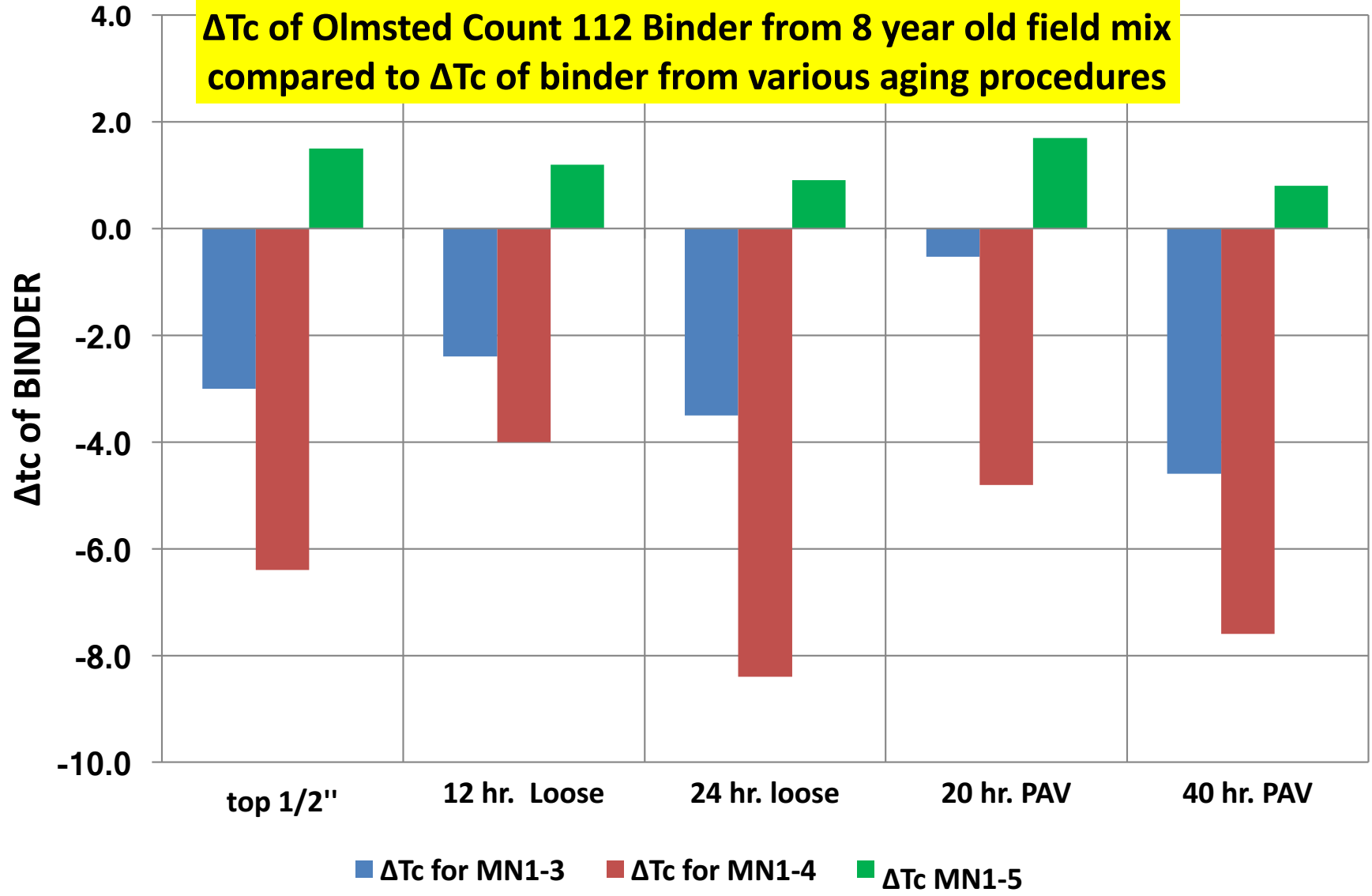
1. It should be somewhat predictive of aging in the field (*but that will vary with climate*)
2. If you are a contractor or someone responsible for producing mix designs you want it to be as rapid as possible
3. No matter who you are you will want the procedure to have been validated so that you can have faith in what you are doing

MnRoad/WRI Binder Source Study

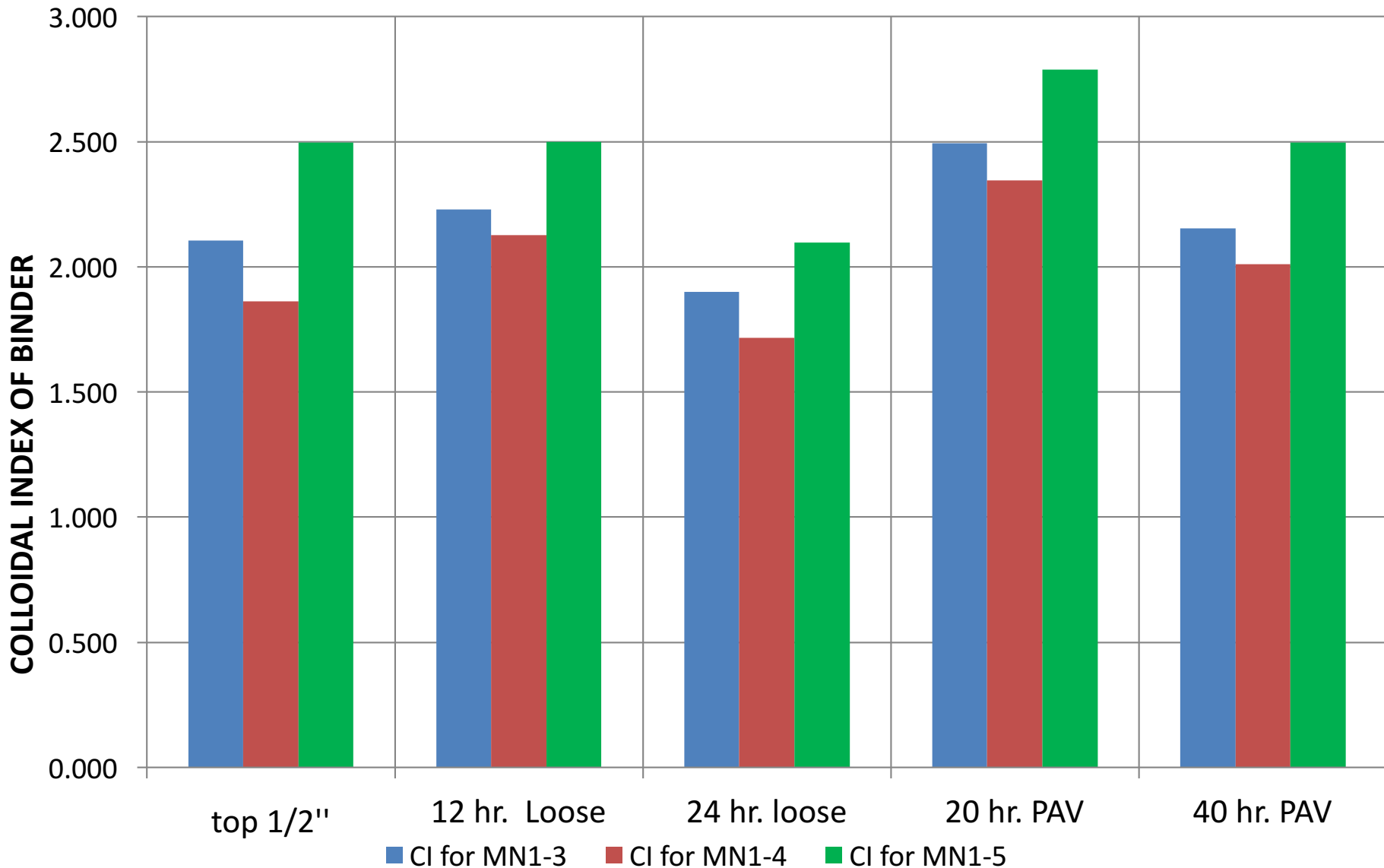
Olmstead County (2006)

- How do laboratory aging protocols evaluated relate to the field?
- Study commissioned to evaluate the effect of asphalt binder source on performance.
- Control section was PMA PG 58-34 + 20% RAP.
- Test sections were virgin mixes, with the following binder sources.
 - MN 1-2: PMA PG 58-34
 - MN 1-3: PG 58-28 Canadian Blend
 - MN 1-4: PG 58-28 Middle Eastern Blend w/REOB
 - MN 1-5: PG 58-28 Venezuelan
- No mixes contained RAS.

ΔT_c of Olmsted Count 112 Binder from 8 year old field mix compared to ΔT_c of binder from various aging procedures

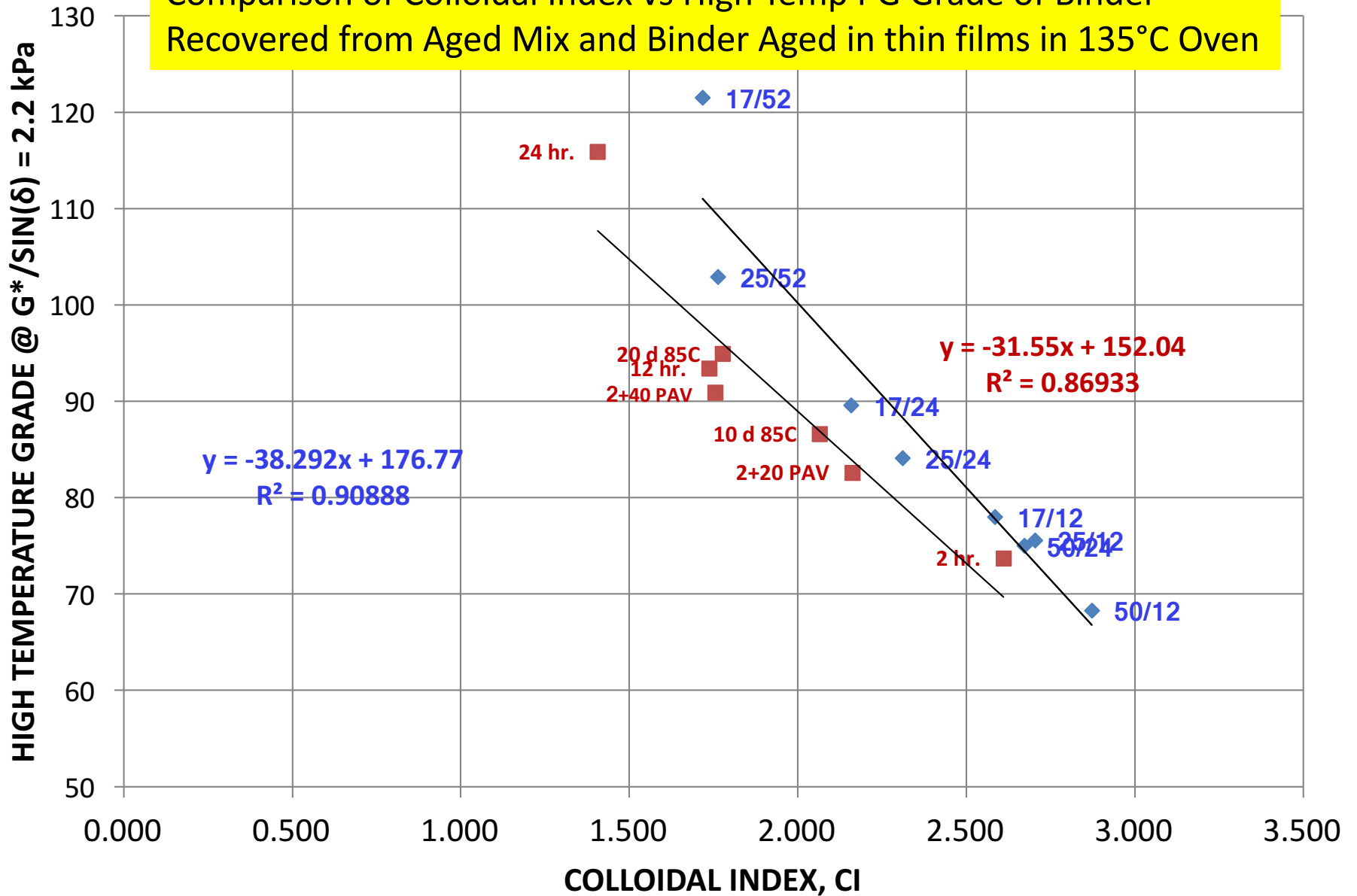


Colloidal Index of Olmsted Count 112 Binder from 8 year old field mix compared to CI of binder from various aging procedures



FOR COLLOIDAL INDEX LARGER VALUES REPRESENT LESS AGING OF THE BINDER

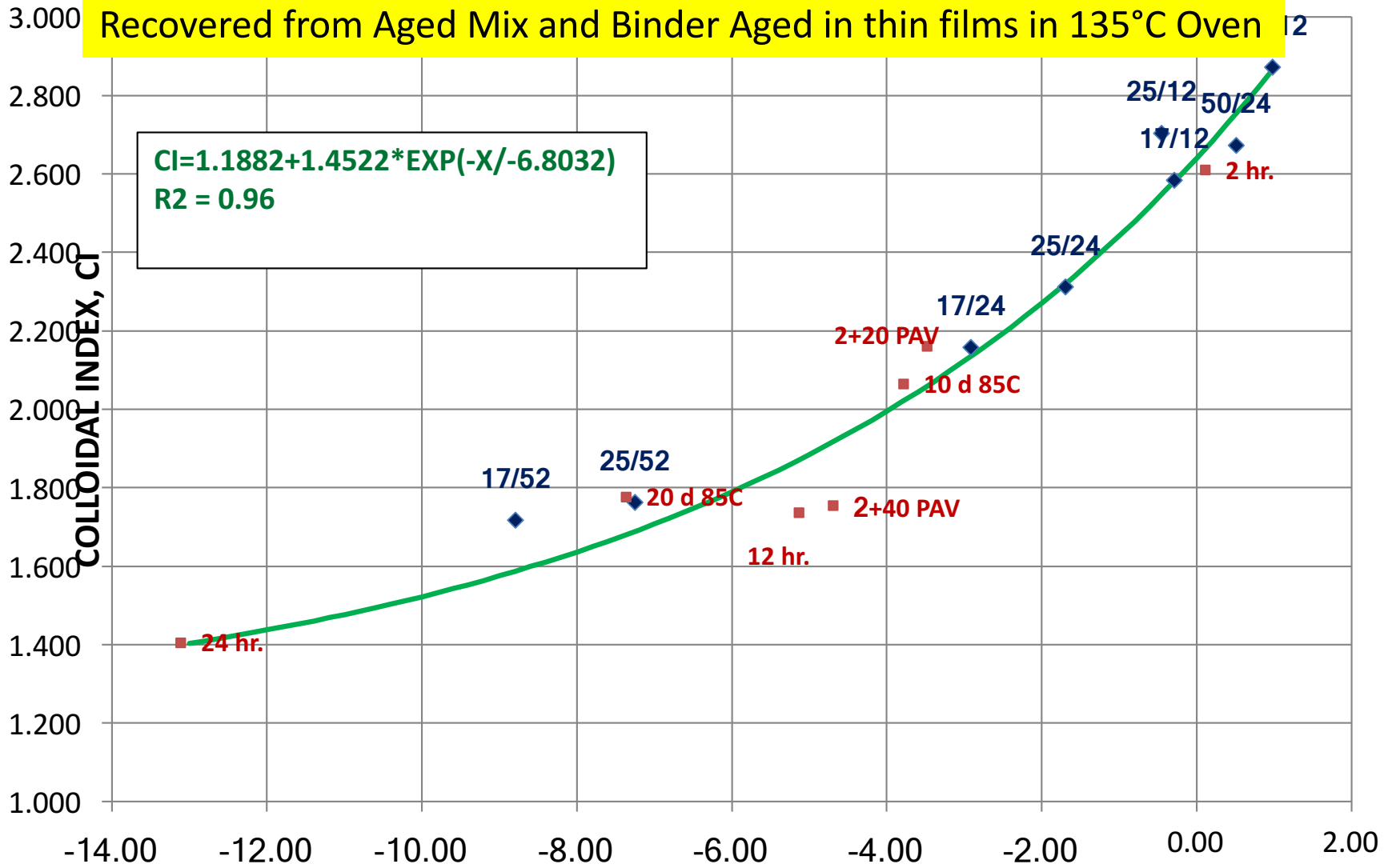
Comparison of Colloidal Index vs High Temp PG Grade of Binder Recovered from Aged Mix and Binder Aged in thin films in 135°C Oven



◆ PG 58-28 + 20% Recovered Shingle Binder

■ PG 58-28 + 5% RAS, Rec AC

Comparison of Colloidal Index as a Function of ΔT_c of Binder
 Recovered from Aged Mix and Binder Aged in thin films in 135°C Oven



◆ PG 58-28 + 20% RAS BINDER
■ ΔT_c PG 58-58 + 5% RAS
 ALL BINDERS
— FITTED CURVE ALL BINDER DATA

IS THERE AN (EASY) ANSWER

- Probably Not
- Every Binder is Different Based on Crude Source
- The film thickness on aggregate affects aging differently than other methods of aging binders
- Problem compounded by the use of greater levels of RAP, RAS and combinations
- Problem further compounded by continuing array of rejuvenating additives—who can test them all
- Err on the side of caution and possibly reject mixtures that might perform satisfactorily, but accelerated aging rejects??

Conclusions

- Aging Methods
 - Both compacted mix and loose mix aging methods were more severe than PAV aging. *Related to film thickness?*
 - Presence of RAS impacted extended aging behavior. In MnDOT study 40 hr PAV and 24 hr loose mix aging were similar, for the RAS mixes differences were significant.
 - 12 hr loose mix aging and 10 day compacted mix aging produced similar results. 24 hour aging was very severe and could not be replicated by any other aging protocols.
- RAS:
 - Mix aging methods showed a significant deterioration of properties with extended aging.
 - Revisions to PP78 were intended to address RAS durability risks, PAV vs. mix aging issue requires further investigation.

Conclusions

- Rejuvenating Additives
 - EP#1 demonstrated an ability to retard aging. Low temperature PG and ΔT_c were better relative to the PG 52-34 across multiple aging conditions.
 - The softening effects of BO#1 and BO#2 diminished with aging, ΔT_c was worse than the PG 52-34.
 - When compared to the “do nothing” alternative of using PG 58-28 with RAS mixes, similar ΔT_c values were observed after aging. LT PG was within ~one grade.

Thank You!

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