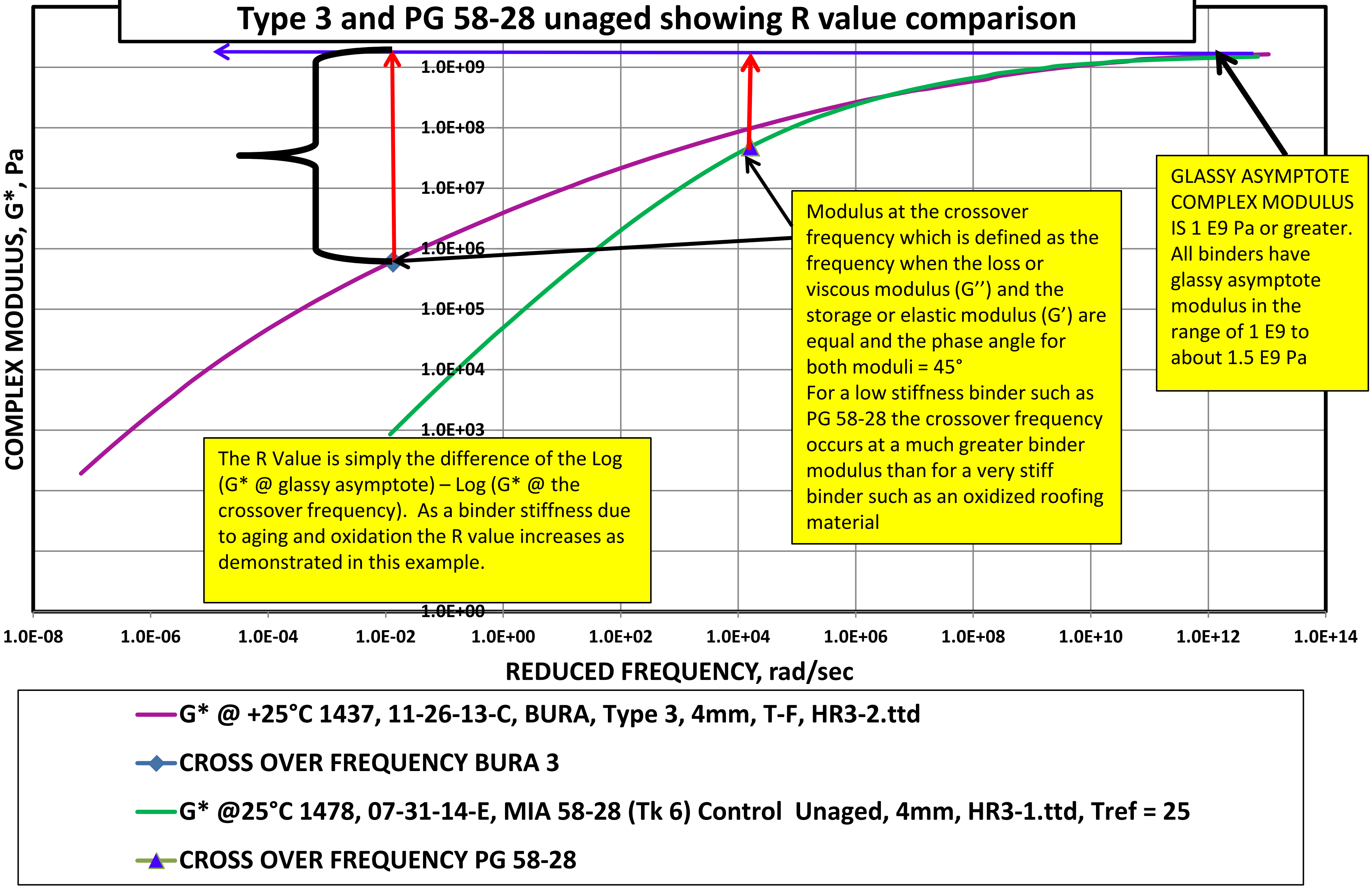
A DISCUSSION OF SOME FACTORS IMPACTING PERFORMANCE OF BINDERS BLENDED WITH ADDITIVES FOR REDUCING LOW TEMPERATURE PROPERTIES OF ASPHALT BINDERS & THEIR IMPACT ON MIX PERFORMANCE

MARY RYAN, DOUG HERLITZKA, STEVE ENGBER,
ALEX ENGSTLER, SCOTT VEGLAHN,
ANDREW HANZ, GERALD REINKE
MATHY TECHNOLOGY AND ENGINEERING SERVICES, INC
JOHN JORGENSON, CHAD LEWIS OF MATHY
CONSTRUCTION MIXTURE LAB

Mathy Technology & Engineering

COMPLEX MODULUS: Comparison @ +25°C of G* mastercurves for BURA Type 3 and PG 58-28 unaged showing R value comparison



Bitumen in colloid science: a chemical, structural and rheological approach
By L. Loeber, et al *Fuel* Vol. 77, No. 13, pp. 1443-1450, 1998

$$CI = \frac{\text{dispersed constituents}}{\text{flocculated constituents}} = \frac{\text{aromatics + resins}}{\text{saturates + asphaltenes}}$$

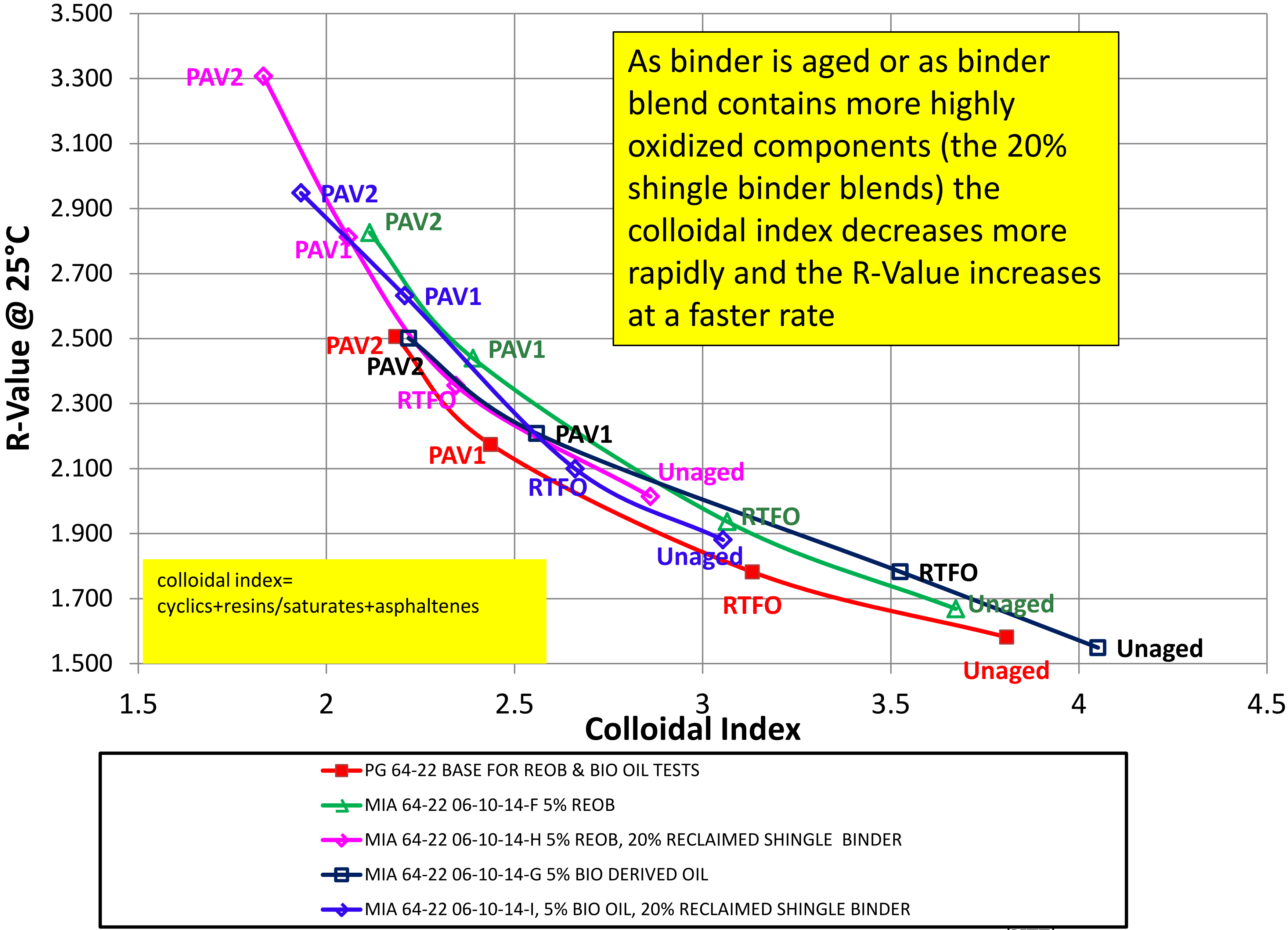
A higher colloidal index means that the asphaltenes are more peptized by the resins in the oil based medium. As the binder ages the asphaltenes tend to agglomerate and increase and aromatics decrease. The result is the colloidal index decreases as binder ages.

PROPERTIES FOR PG 64-22 BASE BINDER USED FOR THE REOB INVESTIGATIONS REPORTED IN THIS PRESENTATION
THE IMPORTANT PARAMETERS TO WATCH ARE Δ G(t)-m, R VALUE, AND COLLOIDAL INDEX

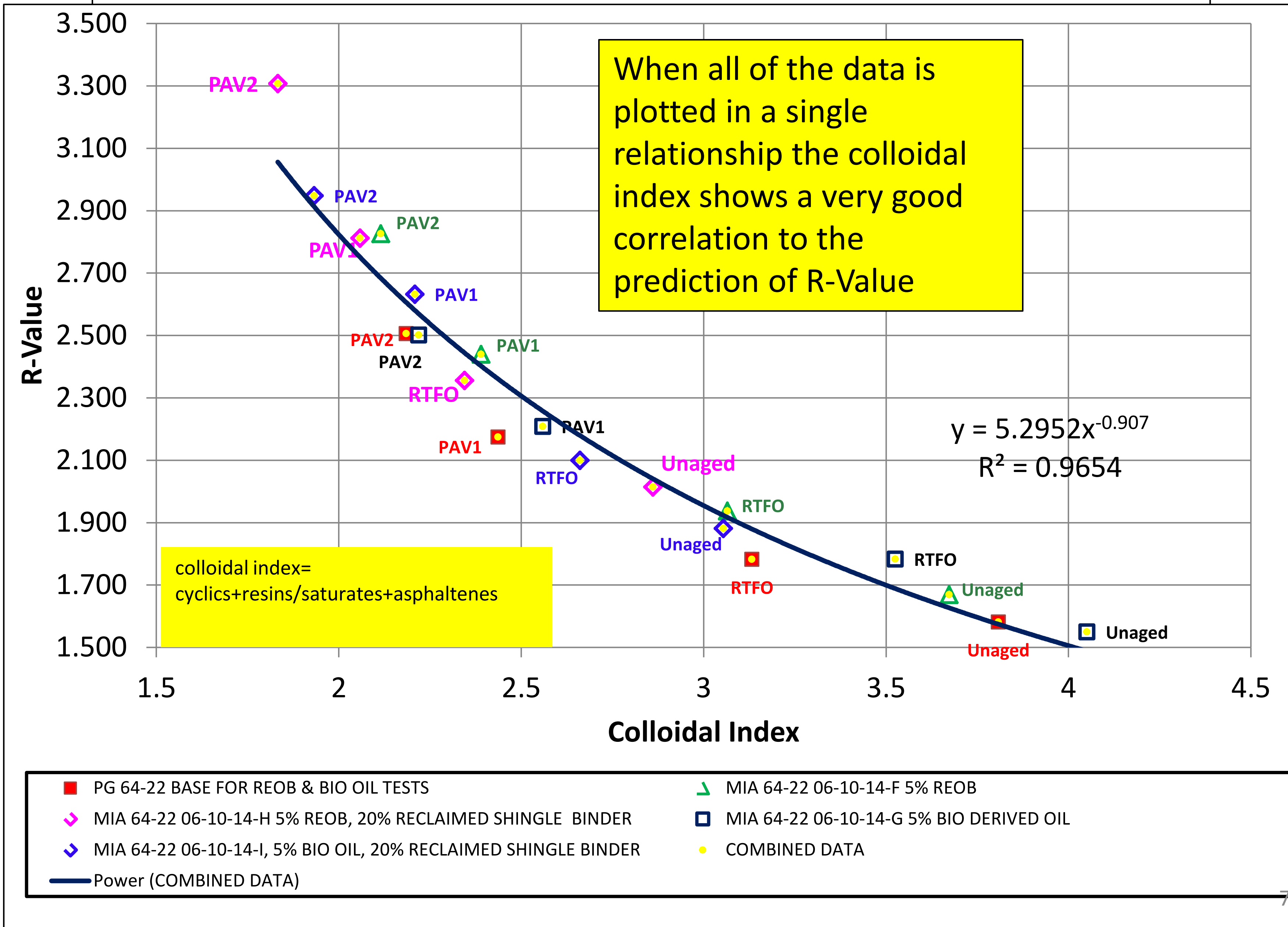
MATERIAL	AGING	high temp grade, ODSR	Δ G(t)-m	S critical	m critical	R-value	Asphaltenes	CI
64-22 base	unaged	67.1	1.8	-30.3	-32.2	1.582	15.8	3.808
64-22 base	RTFO	68.3	1.3	-29.4	-30.7	1.782	19.1	3.132
64-22 base	PAV1		-0.86	-27.1	-26.2	2.174	24.3	2.436
64-22 base	PAV2		-2.55	-25.8	-23.2	2.506	26.1	2.185

MATERIAL	AGING	high temp grade, ODSR	Δ G(t)-m	S critical	m critical	R-value	Asphaltenes	CI
64-22 + 5% REOB	unaged	64.3	1.3	-34.6	-35.6	1.669	15.600	3.673
64-22 + 5% REOB	RTFO	65.5	0.6	-32.9	-33.4	1.937	18.500	3.065
64-22 + 5% REOB	PAV1		-2.7	-30.9	-28.2	2.439	23.000	2.390
64-22 + 5% REOB	PAV2		-5.8	-29.8	-24	2.826	25.500	2.115
64-22 + 5% BIO DERIVED OIL	unaged	58.3	2.2	-37.1	-39.3	1.549	15.500	4.051
64-22 + 5% BIO DERIVED OIL	RTFO	59.9	1.2	-35.8	-37.1	1.783	17.600	3.525
64-22 + 5% BIO DERIVED OIL	PAV1		-1.1	-33.3	-32.2	2.208	23.100	2.559
64-22 + 5% BIO DERIVED OIL	PAV2		-1.9	-31.5	-29.6	2.501	26.000	2.219
64-22 +20% SB+ 5% REOB	unaged	69.5	0.9	-34.5	-35.4	2.014	19.600	2.861
64-22 +20% SB+ 5% REOB	RTFO	72.1	-0.6	-33	-32.4	2.355	23.200	2.344
64-22 +20% SB+ 5% REOB	PAV1		-3.3	-31.9	-28.6	2.812	26.300	2.058
64-22 +20% SB+ 5% REOB	PAV2		-7.1	29.8	-22.7	3.307	28.500	1.833
64-22 + 20% SB + 5% BIO DERIVED OIL	unaged	63.5	1.6	-38.2	-39.8	1.881	19.600	3.054
64-22 + 20% SB + 5% BIO DERIVED OIL	RTFO	65.7	1.8	-35.9	-37.7	2.099	22.100	2.661
64-22 + 20% SB + 5% BIO DERIVED OIL	PAV1		-1.5	-33.9	-32.4	2.632	25.900	2.208
64-22 + 20% SB + 5% BIO DERIVED OIL	PAV2		-3.8	-31.5	-27.7	2.948	28.900	1.933

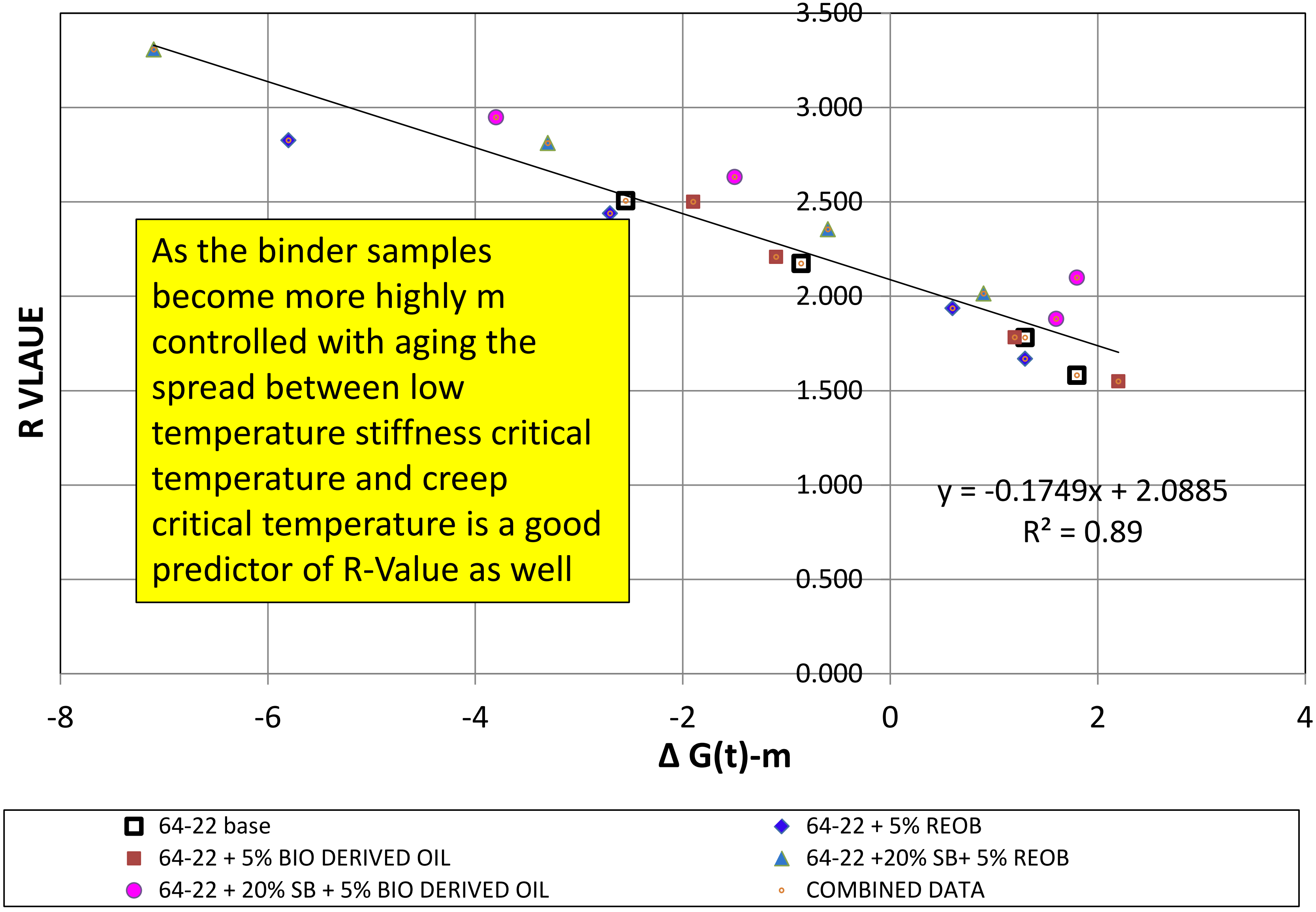
ALL LOW TEMPERATURE PROPERTIES ARE BASED ON 4 mm DSR TESTING


As binder is aged or as binder blend contains more highly oxidized components (the 20% shingle binder blends) the colloidal index decreases more rapidly and the R-Value increases at a faster rate
colloidal index= cyclics+resins/saturates+asphaltenes
R-Value @ 25°C
Colloidal Index
3.500
3.300
3.100
2.900
2.700
2.500
2.300
2.100
1.900
1.700
1.500
1.5
2
2.5
3
3.5
4
4.5
PAV2
PAV1
RTFO
Unaged
PG 64-22 BASE FOR REOB & BIO OIL TESTS
MIA 64-22 06-10-14-F 5% REOB
MIA 64-22 06-10-14-H 5% REOB, 20% RECLAIMED SHINGLE BINDER
MIA 64-22 06-10-14-G 5% BIO DERIVED OIL
MIA 64-22 06-10-14-I, 5% BIO OIL, 20% RECLAIMED SHINGLE BINDER

PLOT OF R-VALUE AS A FUNCTION OF COLLOIDAL INDEX FOR PG 64-22 & BINDERS BLENDED WITH REOB, BIO OIL and SHINGLE BINDER



PLOT OF R-VALUE AS A FUNCTION OF Δ G(t)-m FOR PG 64-22 & BINDERS BLENDED WITH REOB, BIO OIL and SHINGLE BINDER



As the binder samples become more highly m controlled with aging the spread between low temperature stiffness critical temperature and creep critical temperature is a good predictor of R-Value as well

5% 130 vis base oil added to PG 64-22			
ORIGINAL DSR	60°C		
RTFO	64.3°C		
RTFO LOSS	-0.506		
LOW TEMP RESULTS	STIFFNESS	M VALUE	Δ G(t)-m
UNAGED	-37.7	-39	1.3
RTFO	-34.2	-34.6	0.4
PAV 1	-33.6	-30.5	-3.1
PAV 2	-33.7	-25	-8.7

It is my belief based on the data we have generated that REOB products *per se* are not the cause of the properties shown in previous slides. The issue I think is due to the paraffinic nature of the oil. To investigate that concept 2 blends were produced with 5% and 10% of a virgin base oil using the same PG 64-22 base binder. None of the additives commonly added to engine oil, nor the metals found in REOB were present. These data show the same properties & trends as blends produced with REOB.

A 10% BASE OIL BLEND WAS PRODUCED AND THE DELTA VALUE ON PAV 1 = -5.1°C AND ON PAV 2 = -9.1°C

4% BURING OIL IN PG 64-22

ORIGINAL DSR	61.4	Flash Point	545°F
RTFO	64.2		
RTFO LOSS	-0.804		
LOW TEMP RESULTS			Δ G(t)-m
UNAGED	-36.4	-38.6	2.2
RTFO	-34.3	-34.3	0
PAV 1	-31.2	-29.5	-1.6
PAV 2	-30.9	-25.5	-5.4

It has been suggested that it would be impossible for anyone to use just drain oil added to asphalt binder to produce altered PG grades. The data in this slide and the next show that not to be the case. The burning oil is a drain oil that has been dewatered and filtered to remove some particulates and has typically been used as a fuel in hot mix plants. The data, however shows that with attention to detail it is possible to produce a PG binder meeting all spec's. In this case a PG 64-22 was converted to a PG 58-28.

3.75% BURING OIL IN PG 58-28

ORIGINAL DSR	55	Flash point	545°F
RTFO	57.1		
RTFO LOSS	-0.888		
LOW TEMP RESULTS			Δ G(t)-m
UNAGED	-40.6	-43	2.5
RTFO	-35.6	-38.9	3.3
PAV 1	-34.9	-35.2	0.2
BBR PAV 1	-34.9	-34.8	-0.1
PAV 2	-35	-32.4	-2.6
BBR PAV 2	-34.3	-31.4	-2.8

This blend was a little more challenging, but with careful blending is was possible to convert a PG 58-28 into a PG 52-34.

REOB & PPA

- A comment was made at the August 2014 AI TAC meeting that one possible use of REOB would be to reduce a PG grade to a -34 and then use PPA to boost the high temperature grade back up to a PG 58, thus producing a PG 58-34
- There might be incentive to produce such a binder, but is it really what agencies are looking for when they specify a PG 58-34?
- I decided to see what such a product might look like upon aging

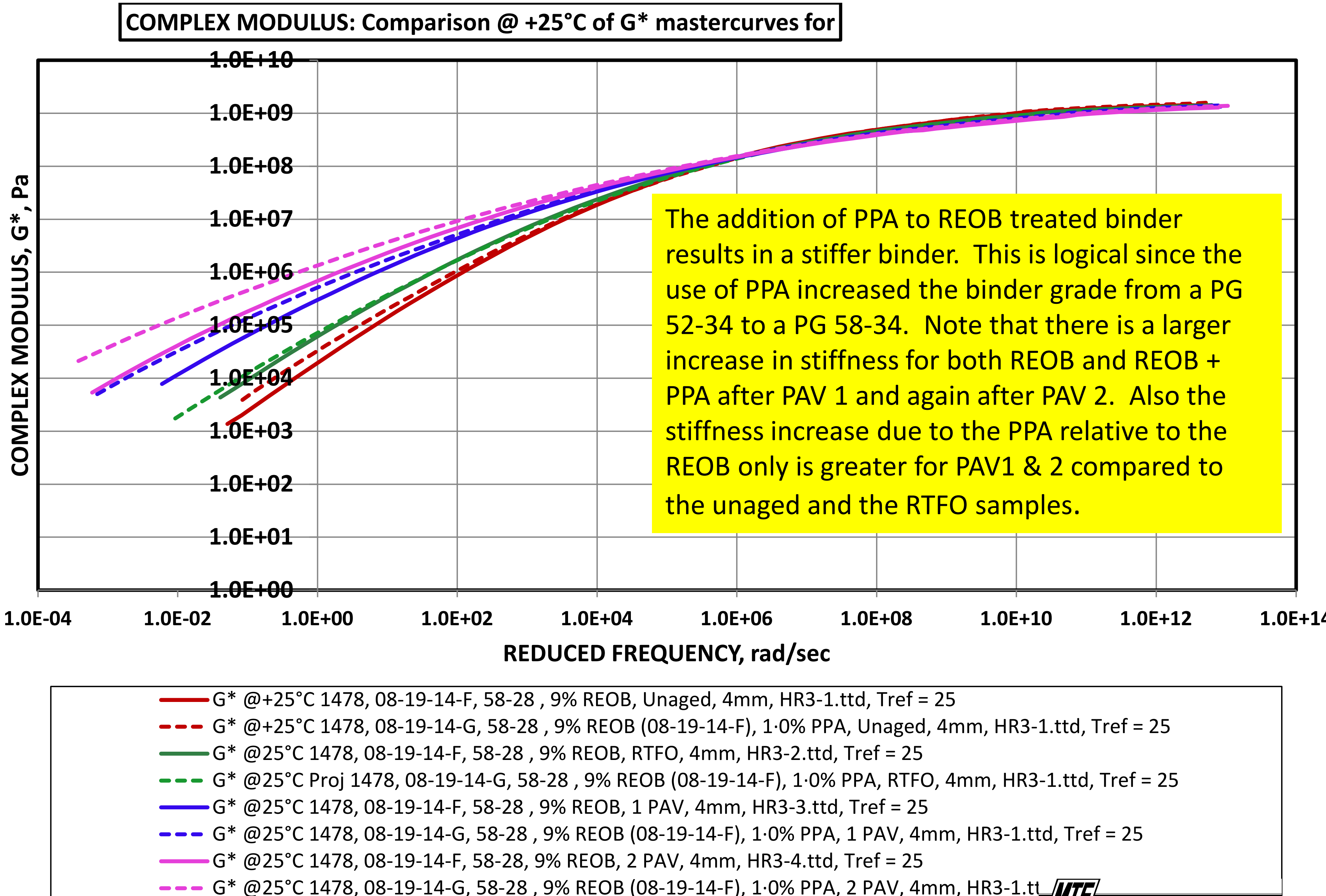
PROPERTIES FOR PG 58-28 BASE BINDER USED IN THESE STUDIES				
SAMPLE	UNAGED	RTFO	PAV 1	PAV 2
PG 58-28 BASE BINDER, STIFFNESS GRADE	-35.7	-34.9	-31.4	-30.7
PG 58-28 BASE BINDER, m VALUE GRADE	-38.8	-36.2	-30.9	-27.8
PG 58-28 BASE BINDER, Δ G(t)-m	3.1	1.3	-0.5	-2.9
R VALUE	1.532	1.817	2.296	2.614
COLLOIDAL INDEX	3.500	2.937	2.286	1.918
ASPHALTENE %	14.8	17.8	23.2	27

COMPARE THE HIGHLIGHTED Δ G(t)-m DATA FOR THIS BASE BINDER AND THE 2 SAMPLES SHOWN IN THE NEXT SLIDE. THESE DATA INDICATE THAT TENDENCY TO INCREASE IN m CONTROL AS SHOWN BY Δ G(t)-m IS ATTRIBUTABLE TO THE USE OF THE REOB ADDITIVE

High Temperature PG Grade for 9% REOB + 1% PPA was 60.0

SAMPLE	UNAGED	RTFO	PAV 1	PAV 2
PG 58-28 + 9% REOB, STIFFNESS GRADE	-40.7	-39.4	-38.1	-37.3
PG 58-28 + 9% REOB, m VALUE GRADE	-42.5	-40.4	-34.6	-31.3
PG 58-28 + 9% REOB, Δ G(t)-m	1.8	1	-3.5	-6
PG 58-28 + 9% REOB, + 1% PPA, STIFFNESS GRADE	-40.8	-40.1	-37.6	-36.6
PG 58-28 + 9% REOB, + 1% PPA, m VALUE GRADE	-42.5	-40.8	-35.4	-32.4
PG 58-28 + 9% REOB, +1% PPA Δ G(t)-m	1.7	0.7	-2.2	-4.2

PPA appears to retard the rate at which the binder becomes m controlled NOTE: this is an observation and not a recommendation



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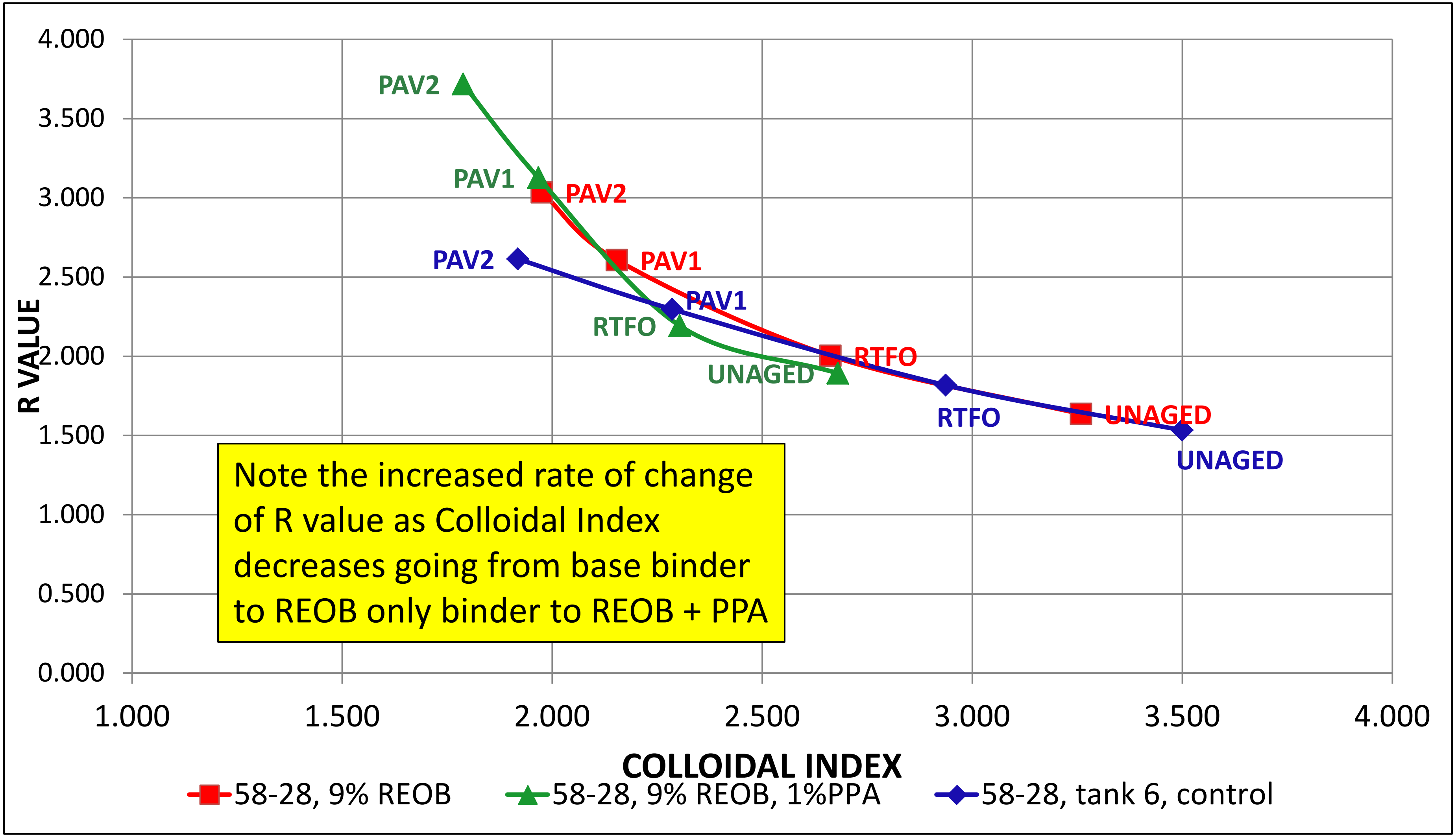
COMPARISON OF R VALUE vs.. COLLOIDAL INDEX FOR BASE PG 58-28, PG 58-28 + 9% REOB, and PG 58-28 + 9% REOB TREATED WITH 1% PPA



MIX INVESTIGATION

- 3 BINDERS
  - PG 58-28 CONTROL ODSR=60.3, RDSR=61.8
  - PG 64-22 + 8% REOB ODSR=62.7, RDSR=63.7
  - PG 64-22 + 4 % BIO DERIVED OIL ODSR= 60.4, RDSR= 61.4
- LOOSE MIX AGED FOR 12 HRS AND 24 HRS AT 135°C
- SPECIMENS COMPACTED FOR DCT & SCB (FATIGUE) TESTING

The Effect of Long Term Laboratory Aging on Hot Mix Asphalt Fracture Energy
By Andrew Braham, et al AAPT 2009

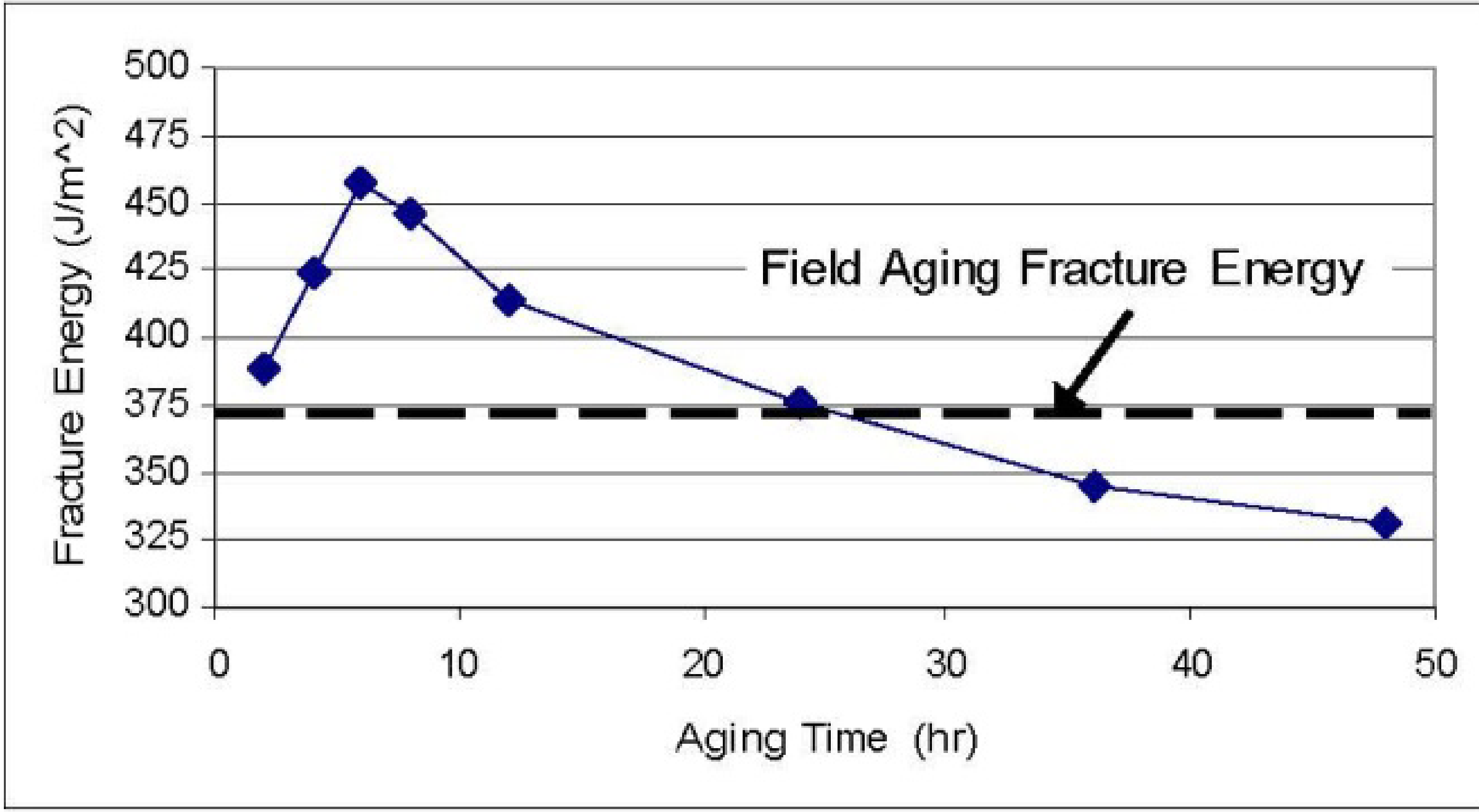


Figure 6 – Effect of 135°C Aging on M3 Fracture Energy

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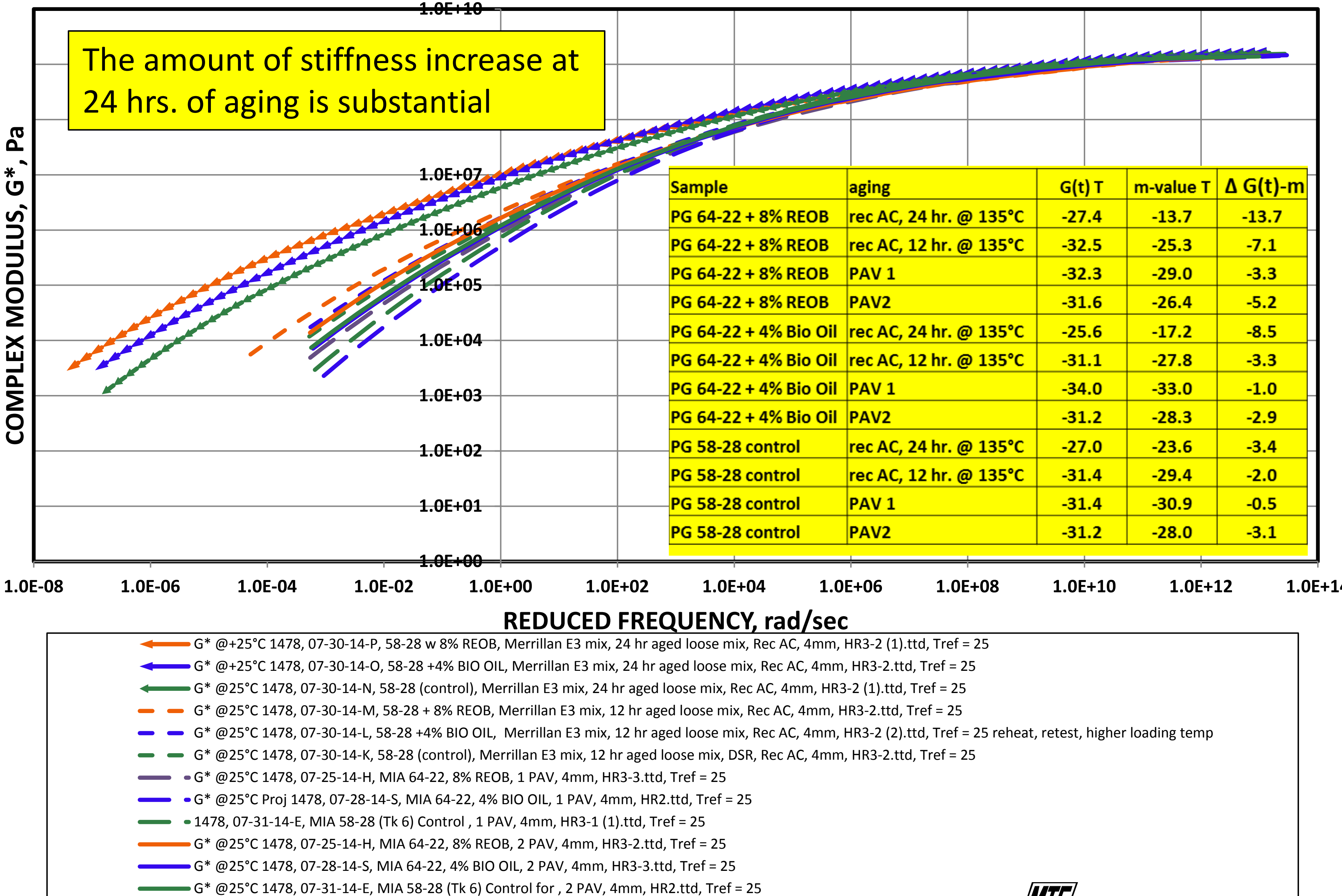
COMPLEX MODULUS: Comparison @ +25°C of G* mastercurves for



Sample	aging	G(t) T	m-value T	Δ G(t)-m
PG 64-22 + 8% REOB	rec AC, 24 hr. @ 135°C	-27.4	-13.7	-13.7
PG 64-22 + 8% REOB	rec AC, 12 hr. @ 135°C	-32.5	-25.3	-7.1
PG 64-22 + 8% REOB	PAV 1	-32.3	-29.0	-3.3
PG 64-22 + 8% REOB	PAV2	-31.6	-26.4	-5.2
PG 64-22 + 4% Bio Oil	rec AC, 24 hr. @ 135°C	-25.6	-17.2	-8.5
PG 64-22 + 4% Bio Oil	rec AC, 12 hr. @ 135°C	-31.1	-27.8	-3.3
PG 64-22 + 4% Bio Oil	PAV 1	-34.0	-33.0	-1.0
PG 64-22 + 4% Bio Oil	PAV2	-31.2	-28.3	-2.9
PG 58-28 control	rec AC, 24 hr. @ 135°C	-27.0	-23.6	-3.4
PG 58-28 control	rec AC, 12 hr. @ 135°C	-31.4	-29.4	-2.0
PG 58-28 control	PAV 1	-31.4	-30.9	-0.5
PG 58-28 control	PAV2	-31.2	-28.0	-3.1

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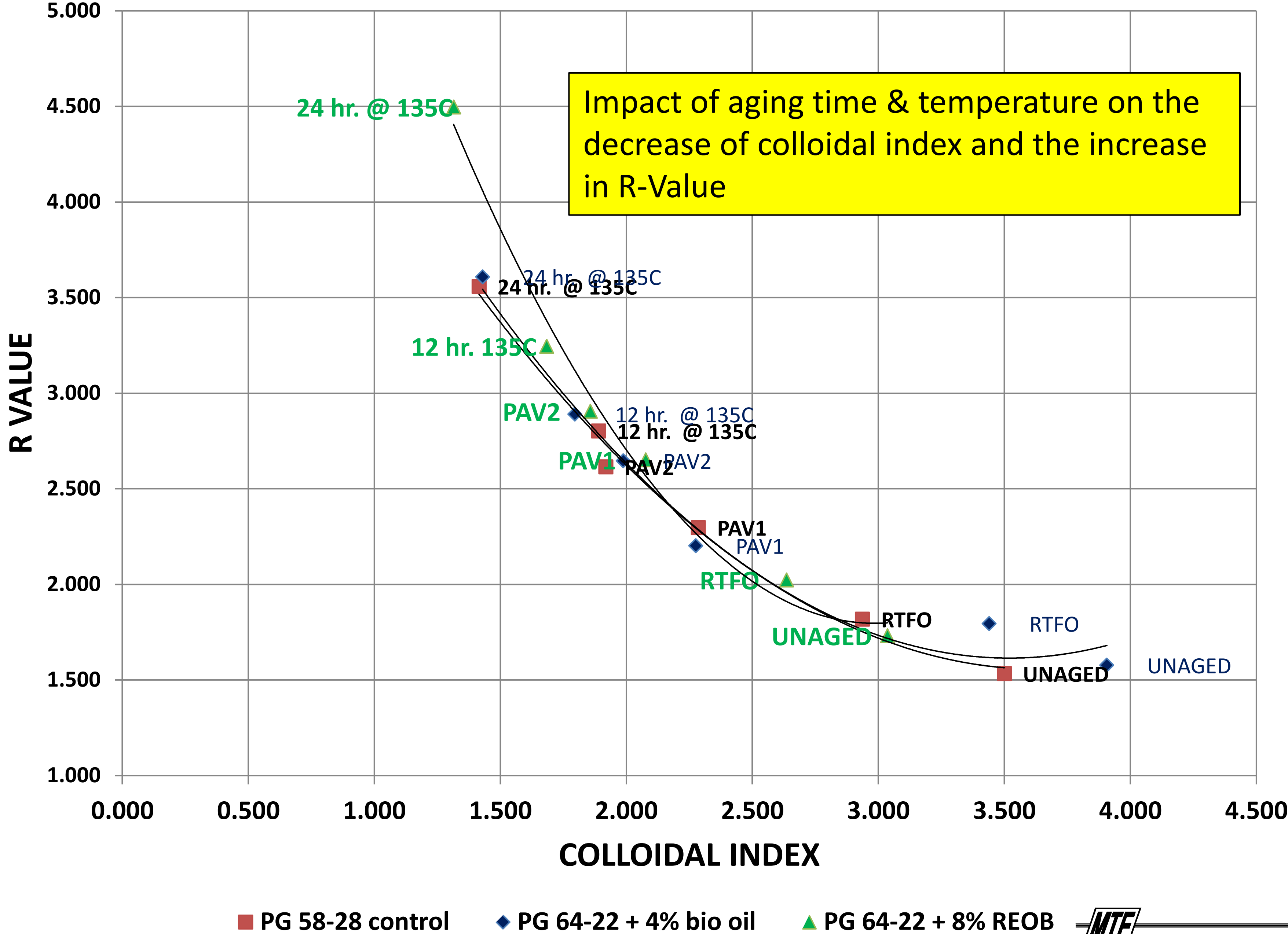

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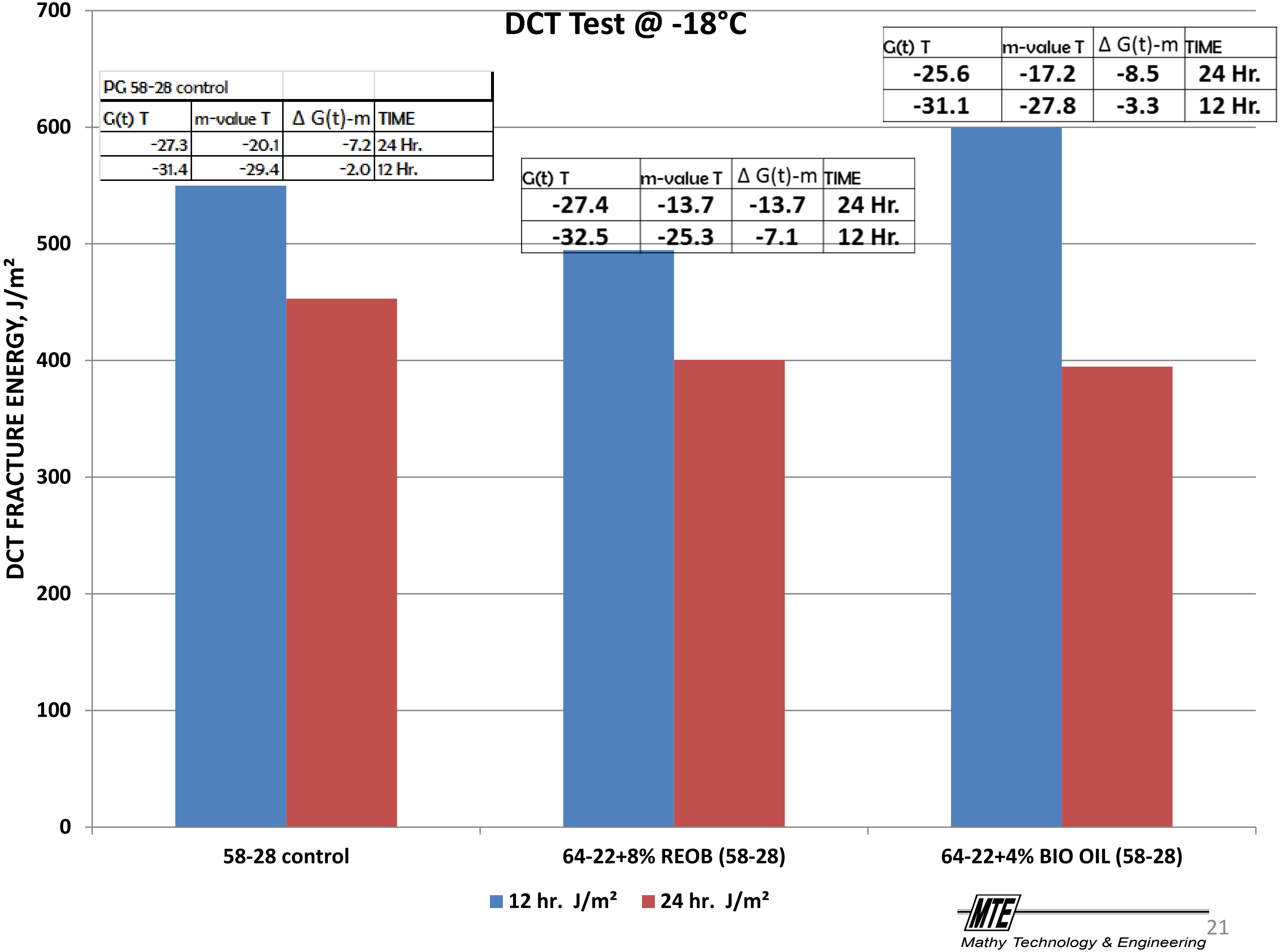

DCT Test @ -18°C
DCT FRACTURE ENERGY, J/m²
0
100
200
300
400
500
600
700
PG 58-28 control
G(t) T | m-value T | Δ G(t)-m | TIME
-27.3 | -20.1 | -7.2 | 24 Hr.
-31.4 | -29.4 | -2.0 | 12 Hr.
G(t) T | m-value T | Δ G(t)-m | TIME
-27.4 | -13.7 | -13.7 | 24 Hr.
-32.5 | -25.3 | -7.1 | 12 Hr.
G(t) T | m-value T | Δ G(t)-m | TIME
-25.6 | -17.2 | -8.5 | 24 Hr.
-31.1 | -27.8 | -3.3 | 12 Hr.
58-28 control
64-22+8% REOB (58-28)
64-22+4% BIO OIL (58-28)
12 hr. J/m²
24 hr. J/m²
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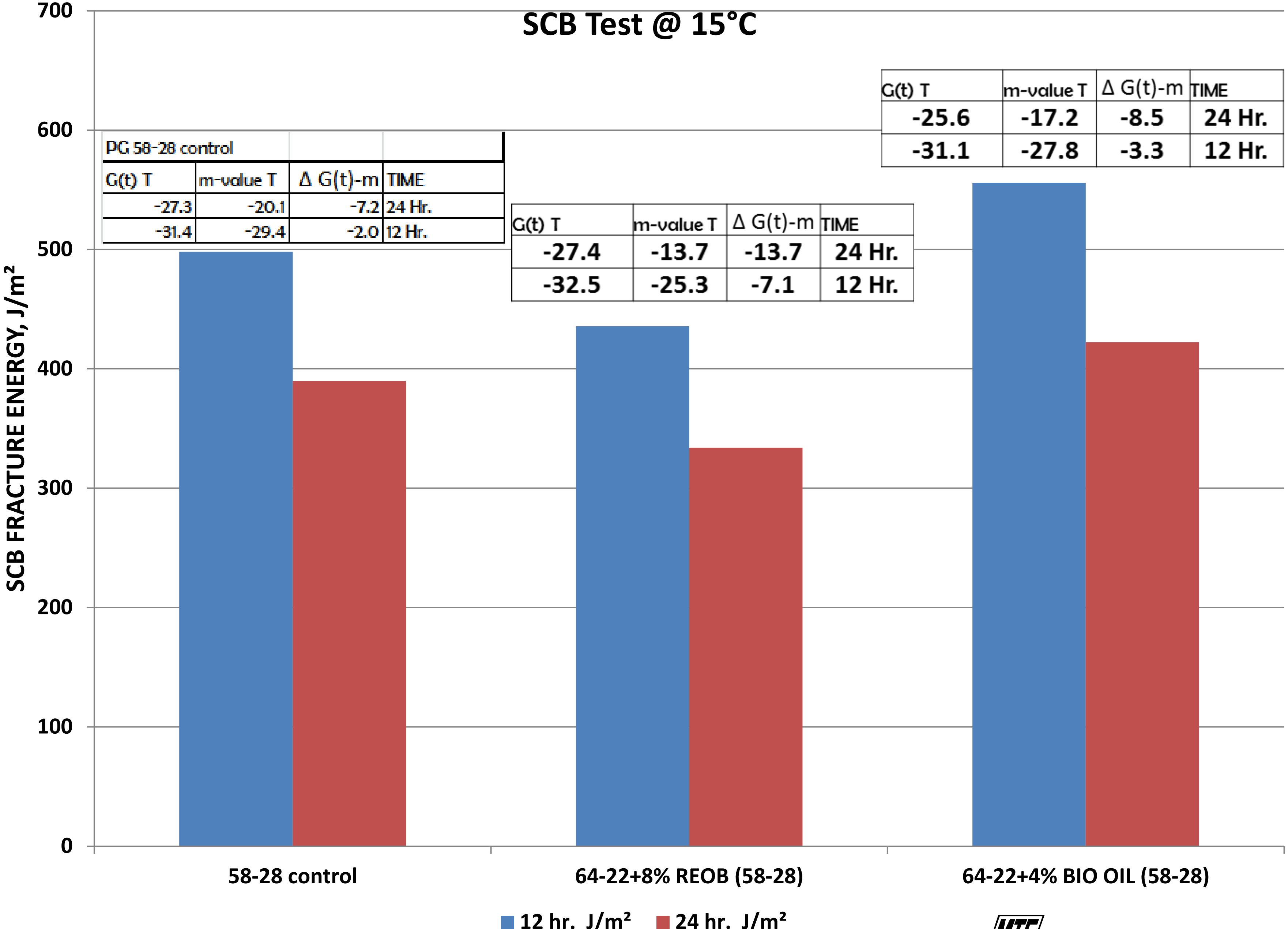

PG 58-28 control			
G(t) T	m-value T	Δ G(t)-m	TIME
-27.3	-20.1	-7.2	24 Hr.
-31.4	-29.4	-2.0	12 Hr.

G(t) T	m-value T	Δ G(t)-m	TIME
-27.4	**-13.7**	**-13.7**	**24 Hr.**
-32.5	**-25.3**	**-7.1**	**12 Hr.**

G(t) T	m-value T	Δ G(t)-m	TIME
-25.6	**-17.2**	**-8.5**	**24 Hr.**
-31.1	**-27.8**	**-3.3**	**12 Hr.**

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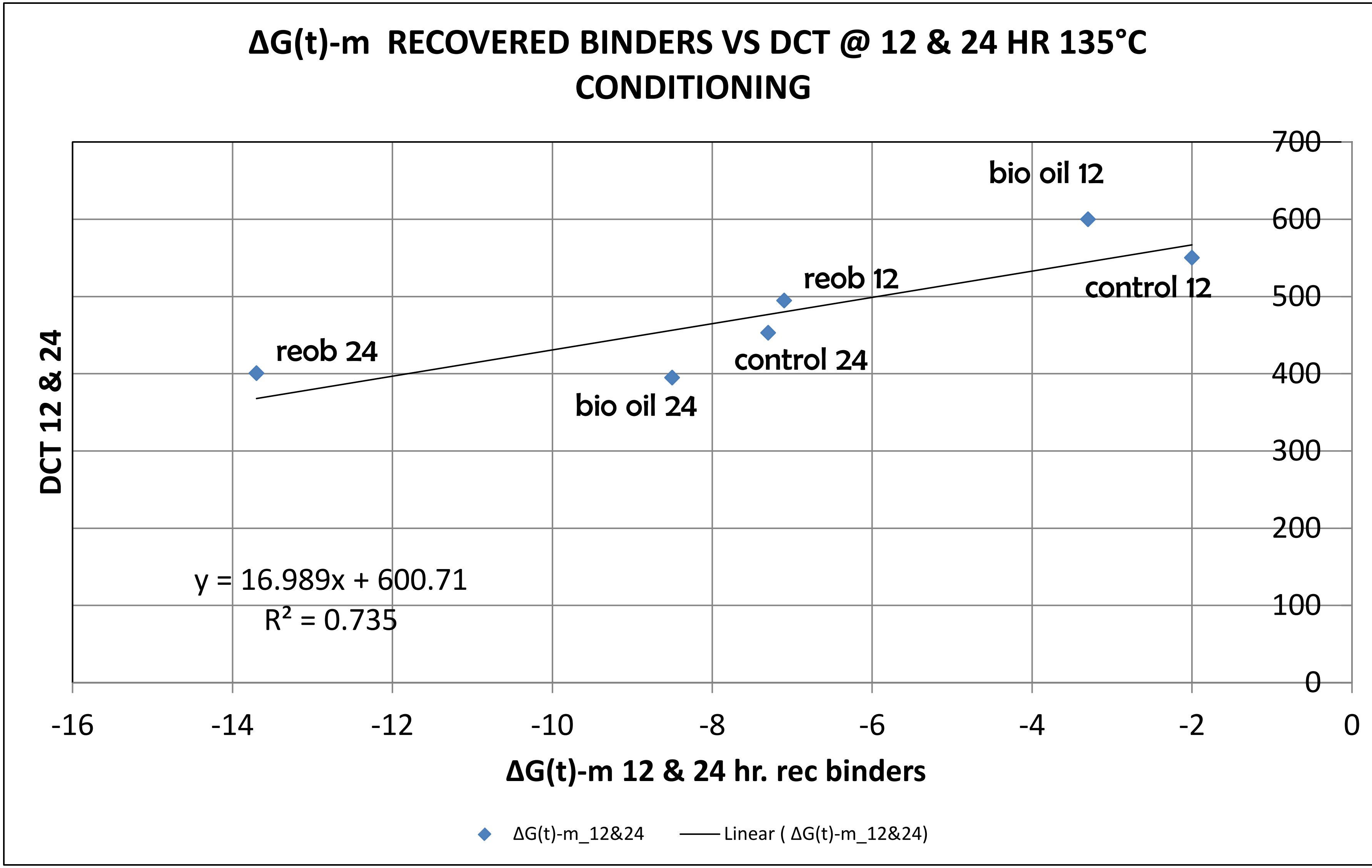

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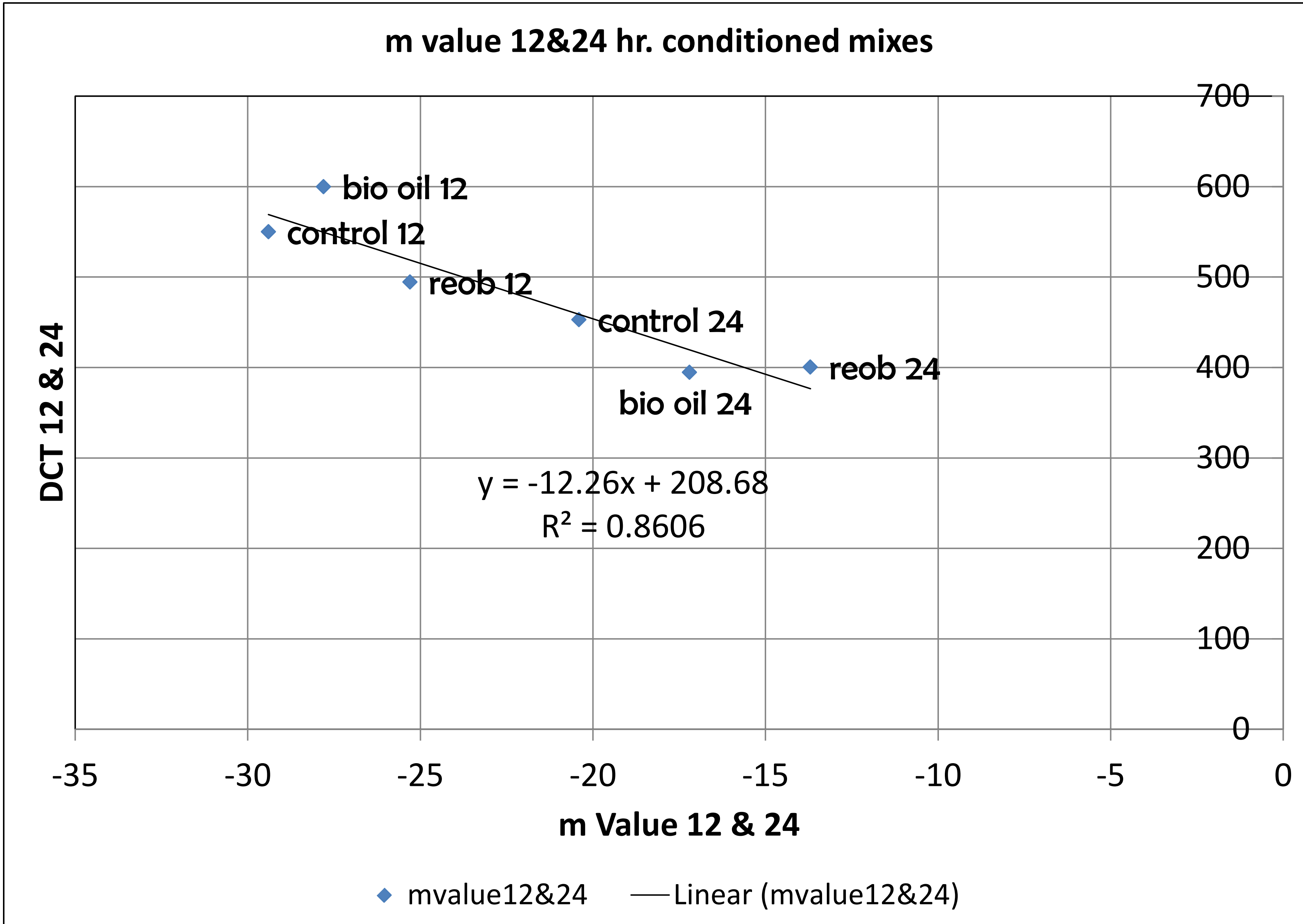
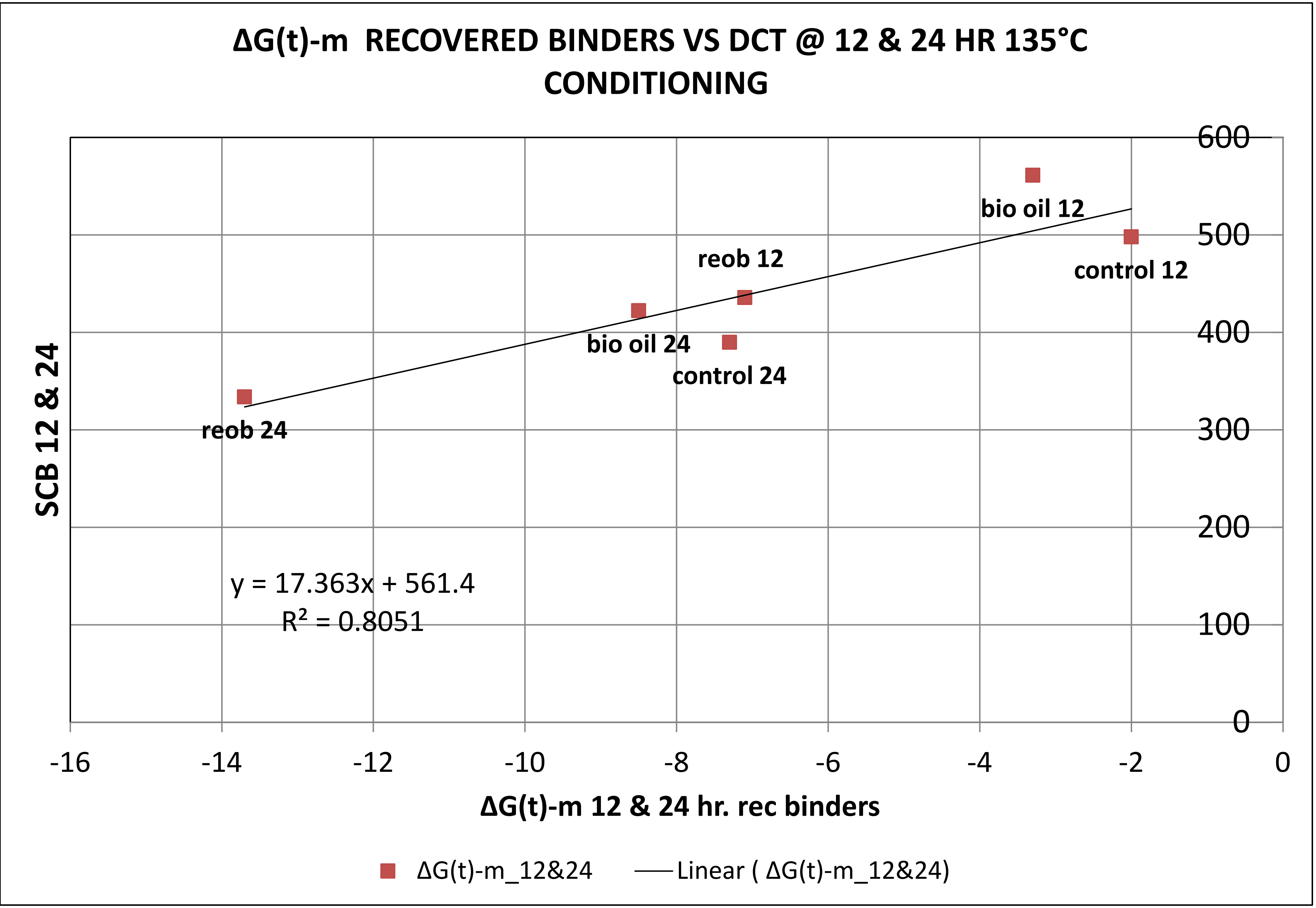

m value 12&24 hr. conditioned mixes
DCT 12 & 24
700
600
500
400
300
200
100
0
bio oil 12
control 12
reob 12
control 24
reob 24
bio oil 24
y = -12.26x + 208.68
R² = 0.8606
-35
-30
-25
-20
-15
-10
-5
0
m Value 12 & 24
mvalue12&24
Linear (mvalue12&24)



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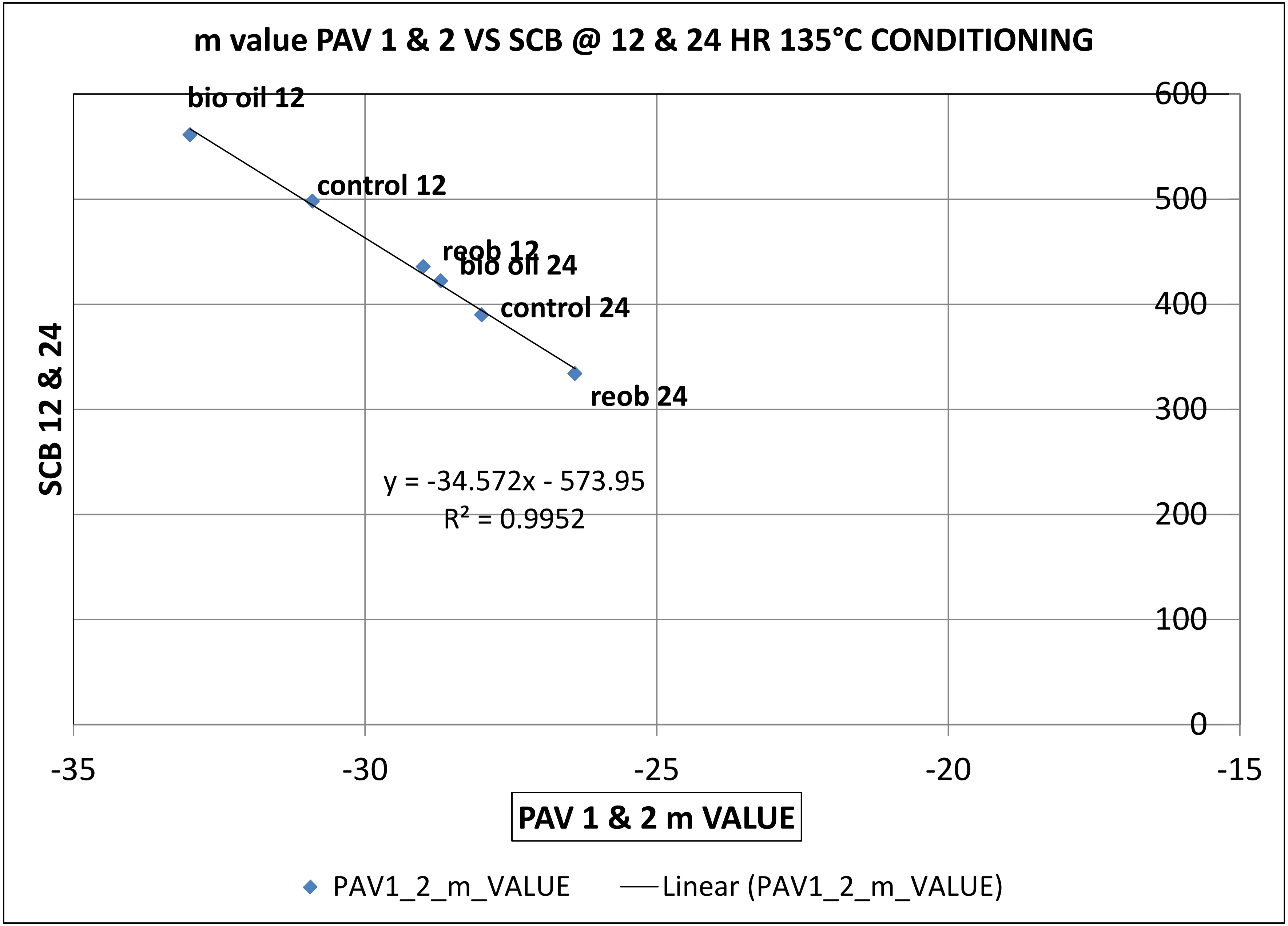

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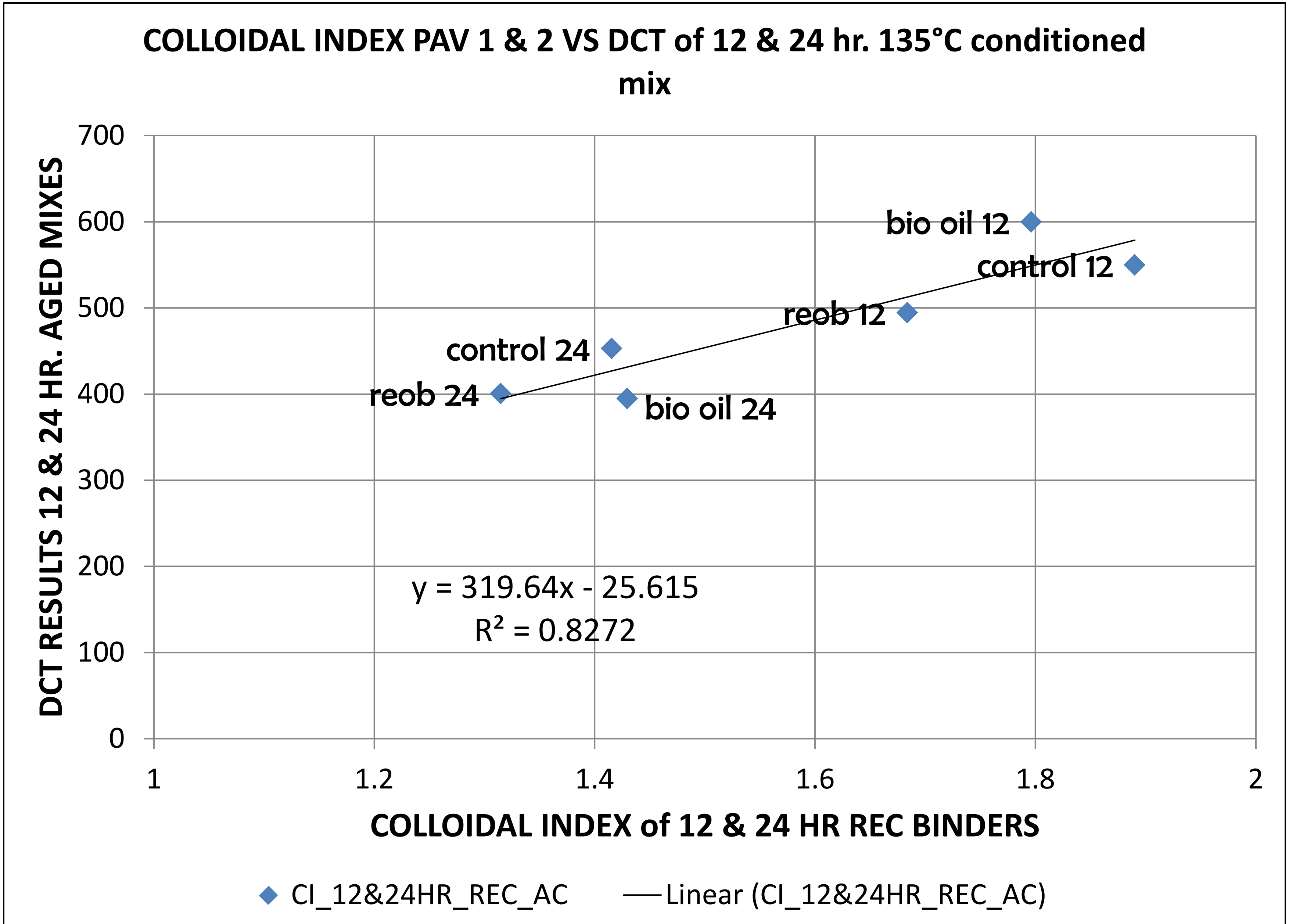
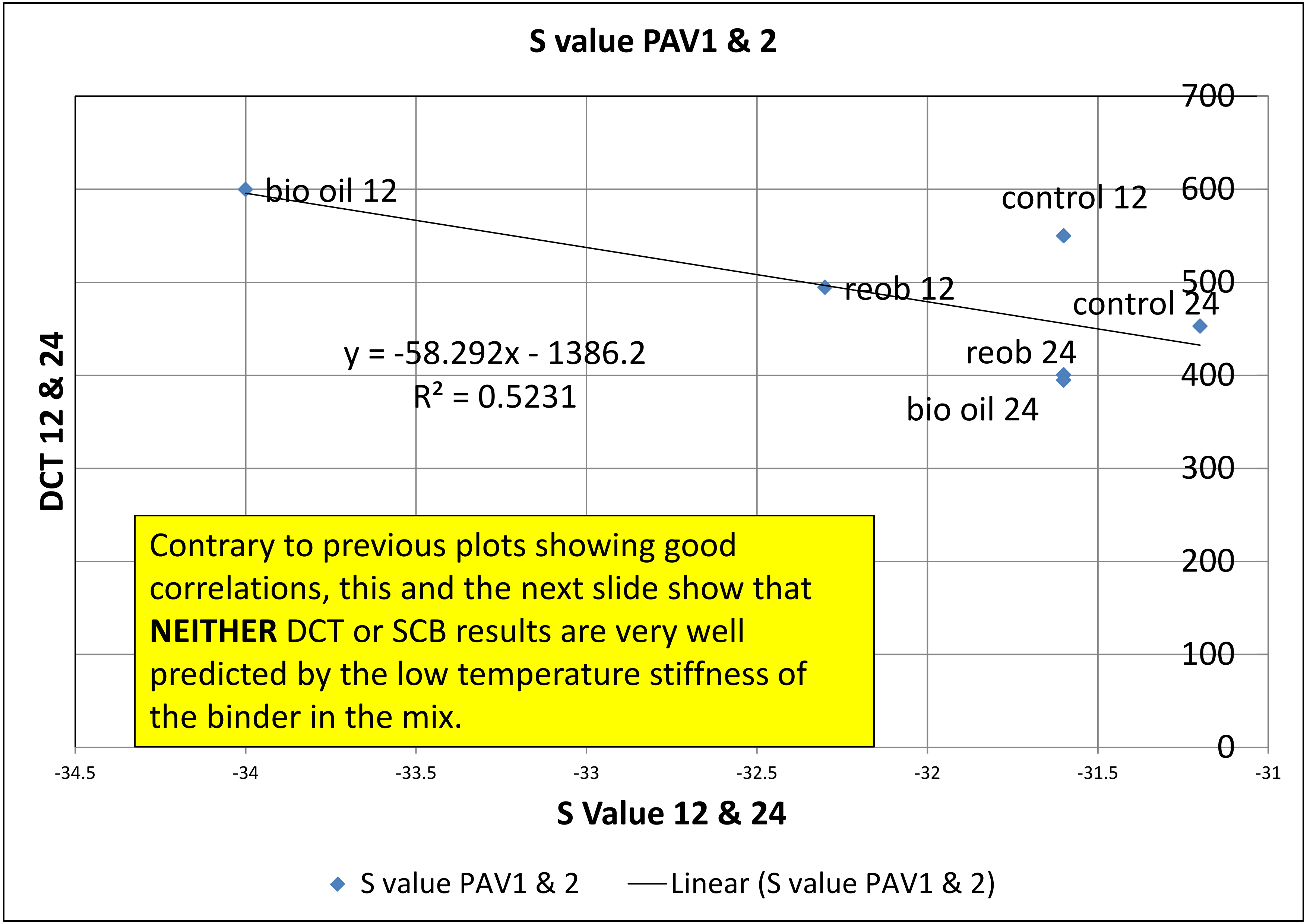

COLLOIDAL INDEX PAV 1 & 2 VS DCT of 12 & 24 hr. 135°C conditioned mix
DCT RESULTS 12 & 24 HR. AGED MIXES
COLLOIDAL INDEX of 12 & 24 HR REC BINDERS
0
100
200
300
400
500
600
700
1
1.2
1.4
1.6
1.8
2
bio oil 12
control 12
reob 12
control 24
reob 24
bio oil 24
y = 319.64x - 25.615
R² = 0.8272
CI_12&24HR_REC_AC
Linear (CI_12&24HR_REC_AC)



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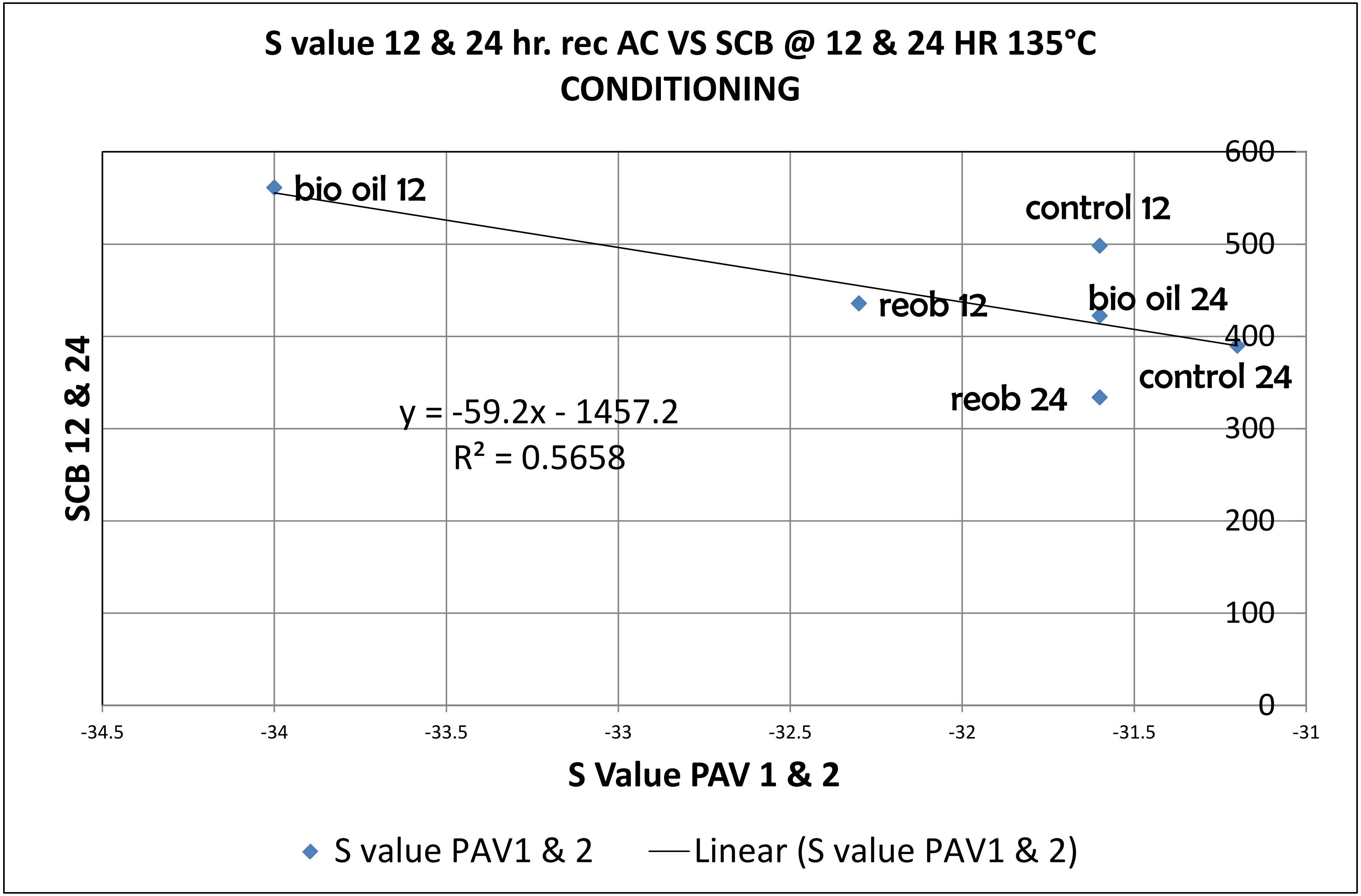

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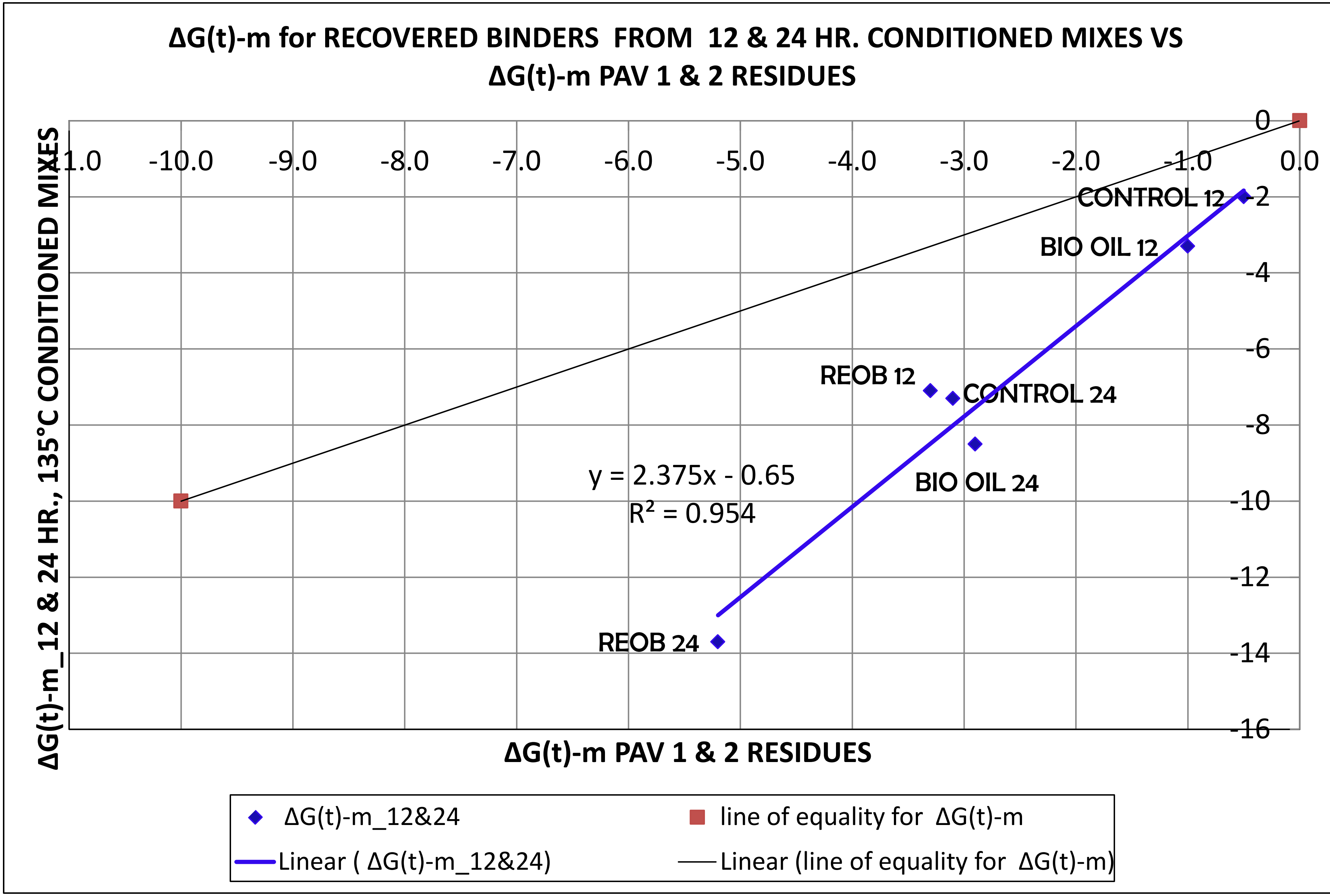

SEE NEXT SLIDE FOR COMMENT ON THIS DATA PLOT

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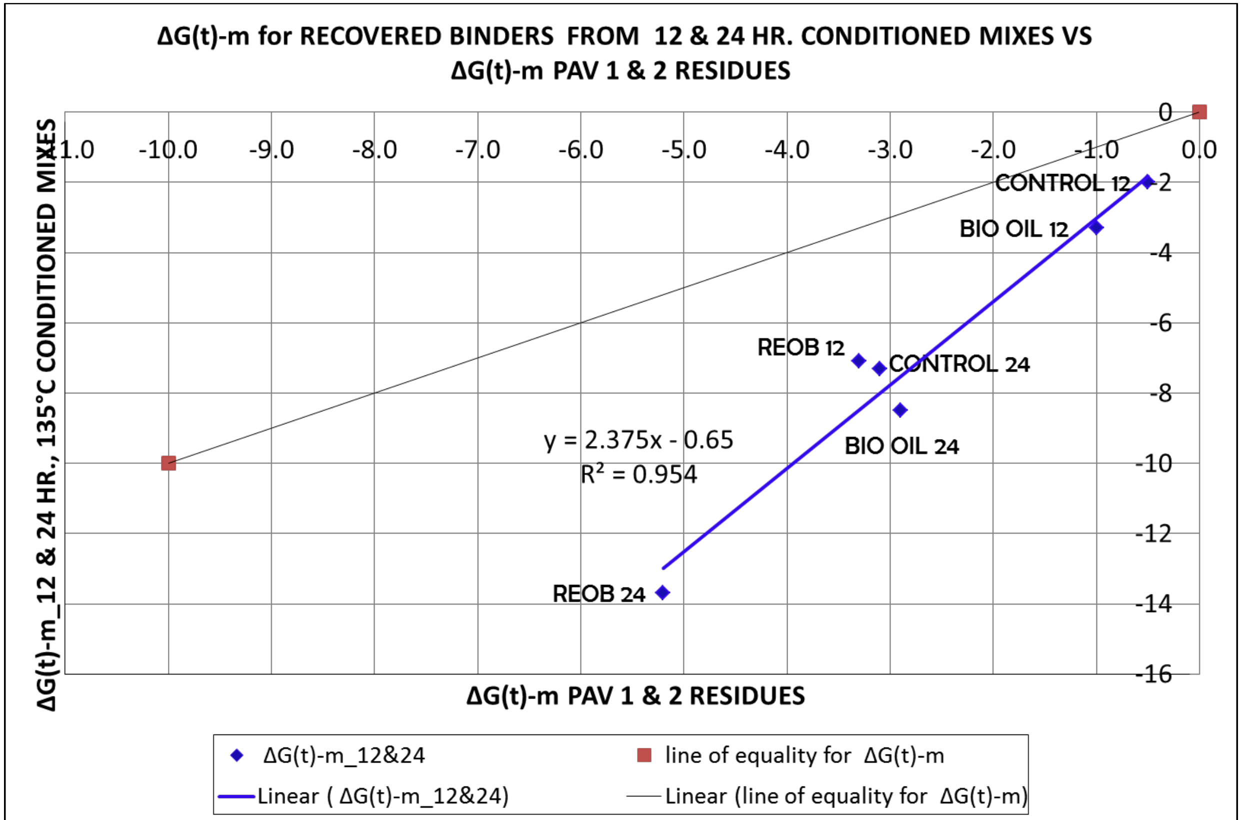

Although Δ G(t)-m for the recovered binders for 12 & 24 hr., 135°C conditioned mixes is more than double the Δ G(t)-m for the PAV 1 & 2 residues the results are highly correlated. This means that the binder aging in the two procedures is affecting the binder chemistry and rheology in the same manner just that the 135°C loose mix aging is more severe. Had the data not been highly correlated I would have expected different mechanisms of aging were taking place.

COMPARATIVE CRUDE SOURCE STUDY

- In August of 2006 Mathy constructed at the request of MNDOT and in cooperation with WRI 5 test sections near 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

COMPARATIVE CRUDE SOURCE STUDY

- Binders selected were from St. Paul, MN a blend of Canadian crudes
- A binder from New Jersey using a Venezuelan crude
- A binder from Texas using Arab heavy/Arab medium/Kirkuk blend
- The PG 58-34 was produced from a PG 52-34 based on a blend of Canadian crudes

COMPARATIVE CRUDE SOURCE STUDY

- Several reports have been issued by WRI over the intervening years
- Periodically WRI staff members have visited the site and performed crack surveys and have taken cores
- The most recent survey was conducted in Sept of 2012
- At the time of construction MTE conducted IDT low temperature testing and other low temperature characterization of the mixes
- WRI also conducted similar investigations

COMPARATIVE CRUDE SOURCE STUDY

- In the summer of 2014 Mathy was told by sales representative of the Texas asphalt supplier that they produce PG 58-28 by adding REOB material to their PG 64-22
- MTE just happened to have on hand 5 gallon pails of each of the binders from 2006
- XRF analysis for zinc confirmed the presence of 321 ppm zinc in the PG 58-28 from Texas
  - Only background levels of ~ 11 ppm were detected in the PG 58-28 from St. Paul and New Jersey

COMPARATIVE CRUDE SOURCE STUDY

- Subsequent to confirming the potential for REOB additives in one of the test sections MTE performed an analysis of all 3 of the PG 58-28 binders that were the basis of the comparative crude source study
- The cracking report from 2012 was used as the basis for this comparative investigation
- Rheological testing of unaged, RTFO, PAV1 and PAV 2 residues was initiated, as was Iatroscan evaluation of binders from those aging conditions

RESULTS FOR PAV 1

BINDER SOURCE	S_critical	m_critical_temp	ΔG(t)-m	ASPHALTENE	Colloidal_Index	R_Value
MN1-4	-35.5	-30.7	-4.8	23.9	2.344	2.967
MN1-3	-31.9	-31.8	-0.2	22.2	2.493	2.416
MN1-5	-30.5	-32.2	1.7	19.8	2.788	1.877
MN1-2	-35.5	-36.3	0.8	23.3	2.254	2.687

RESULTS FOR PAV 2

BINDER SOURCE	S_critical	m_critical_temp	ΔG(t)-m	ASPHALTENE	Colloidal_Index	R_Value
MN1-4	-35.2	-27.6	-7.6	25.5	1.889	3.281
MN1-3	-31.8	-28.1	-3.7	25.4	2.115	2.872
MN1-5	-29.3	-30.1	0.8	21.8	2.497	2.162
MN1-2	-34.6	-34.3	-0.3	25.1	2.015	3.061

All low temperature data from 4 mm DSR test

BINDER SOURCE	AGE CONDITION	Stiffness critical temp	m value critical temp	ΔG(t)-m	ASPHALTENE	Colloidal Index	R Value
PG 64-22 (2014) from refinery source for MN1-4	unaged	-32.3	-35.0	2.7	13.2	4.400	1.691
	RTFO	-30.0	-32.6	2.5	16.1	3.673	1.939
	PAV 1	-28.2	-28.7	0.5	21.4	2.846	2.382
	PAV 2	-26.8	-23.7	-3.1	24.6	2.359	2.609
PG 64-22 (2014) + 9% REOB	unaged	-37.4	-37.0	-0.4	13.0	4.097	1.831
Zinc content	RTFO	-35.5	-34.1	-1.3	15.6	3.444	2.169
381 ppm	PAV 1	-33.4	-29.5	-3.9	20.3	2.623	2.688
PG 61.9	PAV 2	-33.2	-28.1	-5.1	21.9	2.370	3.015
MN1-4 (2006 sample)	unaged	-38.3	-38.9	0.6	18.4	2.806	2.037
Zinc content	RTFO	-37.6	-36.3	-1.3	19.8	2.581	2.465
321 ppm	PAV 1	-35.5	-30.7	-4.8	23.9	2.344	2.967
PG 61.1	PAV 2	-35.2	-27.6	-7.6	25.5	1.889	3.281

To gain some insight into the nature of the PG 64-22 base used in 2006 we investigated the aging properties of a 2014 sample of PG 64-22 from the supplier of MN1-4. Also we blended 9% REOB into the 2014 sample of the PG 64-22 to make a PG 58-28 comparable in rheological properties to the 2006 sample. As these data show the 2014 PG 64-22 is a different composition than the 2006 PG 64-22 base. The resulting PG 58-28 does not show the same spread between S & m nor does it exhibit the same data for Colloidal index and R Value with aging mainly because the initial values of those two parameters are better.

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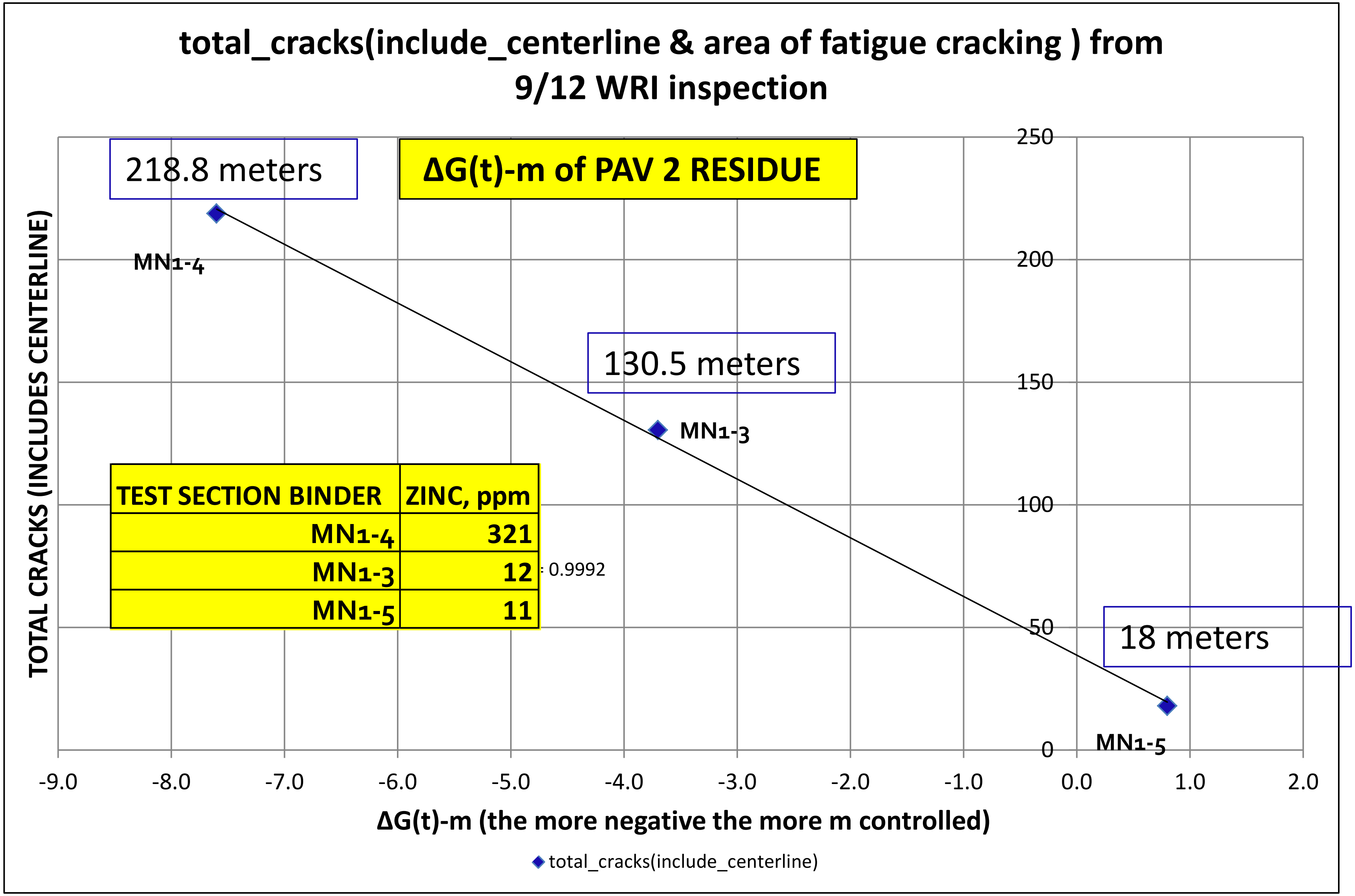
BINDER SOURCE	AGE CONDITION	Stiffness critical temp	m value critical temp	ΔG(t)-m	ASPHALTENE	Colloidal Index	R Value
MN1-4 (2006 sample)	unaged	-38.3	-38.9	0.6	18.4	2.806	2.037
Zinc content	RTFO	-37.6	-36.3	-1.3	19.8	2.581	2.465
321 ppm	PAV 1	-35.5	-30.7	-4.8	23.9	2.344	2.967
PG 61.1	PAV 2	-35.2	-27.6	-7.6	25.5	1.889	3.281

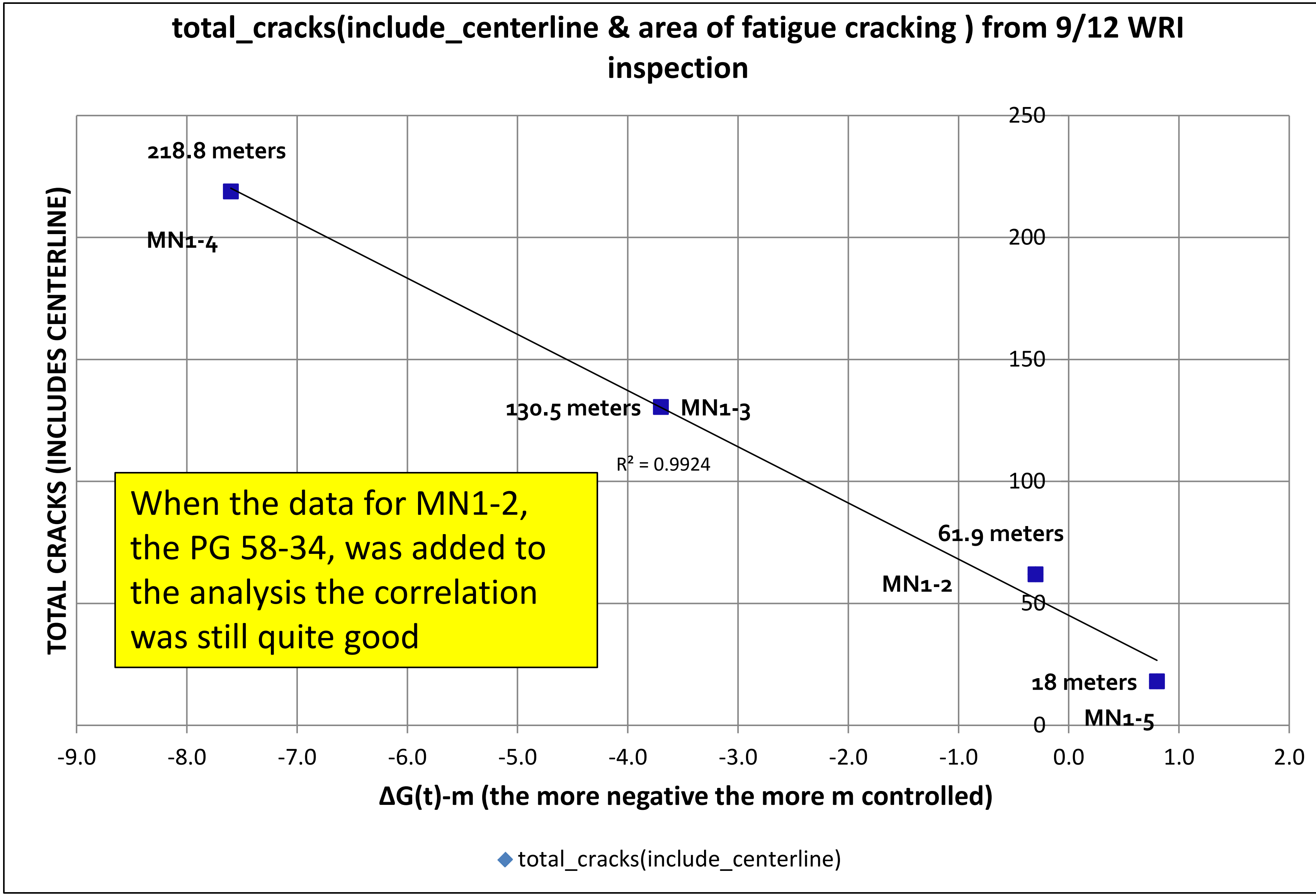
MN1-4 (2006 sample)	BBR RESULTS FOR PAV 1 & PAV 2			
Zinc content				
321 ppm	PAV 1	-36.1	-31.5	-4.7
PG 61.1	PAV 2	-35.9	-28.1	-7.8

Because of the importance of the Δ G(t)-m parameter for the MN1-4 test section we determined the precise low temperature grade of the PAV 1 and PAV 2 samples using the BBR. The Stiffness and m value critical temperatures are within the range of variability we typically see when comparing 4 mm DSR results to BBR results. More importantly for the purposes of this work the Δ G(t)-m values are nearly identical between the two test procedures.

BINDER SOURCE	AGE CONDITION	Stiffness critical temp	m value critical temp	ΔG(t)-m
MN1-4	unaged	-38.5	-37	-1.5
MN1-3	unaged	-35.3	-38.5	3.2
MN1-5	unaged	-34.2	-37.7	3.5
MN1-2	unaged	-38.7	-41.5	2.8
MN1-4	RTFO	-38.3	-36.4	-1.9
MN1-3	RTFO	-34.4	-36.7	2.3
MN1-5	RTFO	-32	-34.8	2.8
MN1-2	RTFO	-37.7	-39.6	1.9
MN1-4	PAV 1	-35.5	-30.7	-4.8
MN1-3	PAV 1	-31.9	-31.8	-0.2
MN1-5	PAV 1	-30.5	-32.2	1.7
MN1-2	PAV 1	-35.5	-36.3	0.8
MN1-4	PAV 2	-35.2	-27.6	-7.6
MN1-3	PAV 2	-31.8	-28.1	-3.7
MN1-5	PAV 2	-29.3	-30.1	0.8
MN1-2	PAV 2	-34.6	-34.3	-0.3



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



MN1-4	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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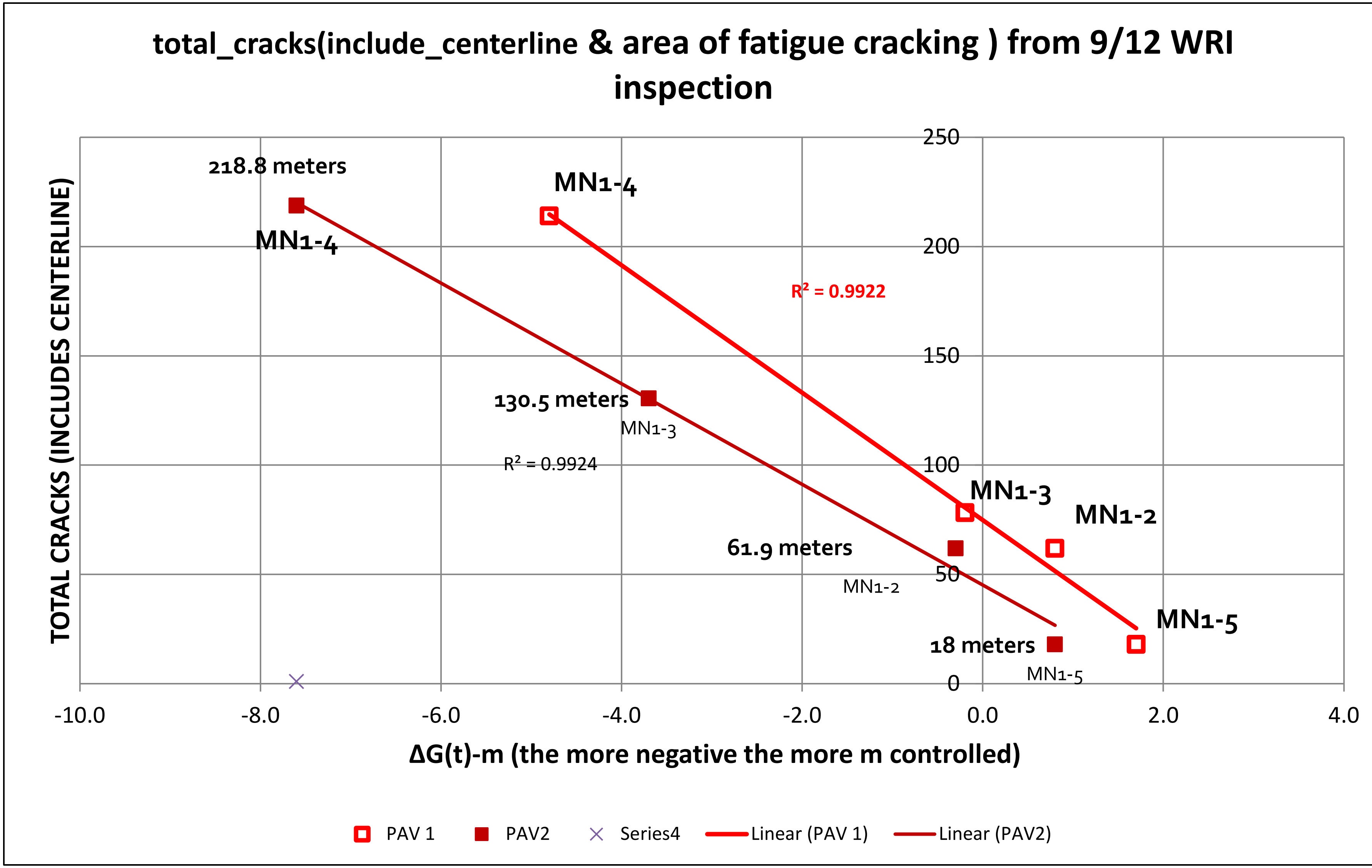

MN1-4	PG 58-28 Arab heavy/Arab medium/Kirkuk blend
MN1-3	PG 58-28 Canadian blend
MN1-5	PG 58-28 Venezuelan blend
MN1-2	PG 58-34 PMA based on Canadian blend

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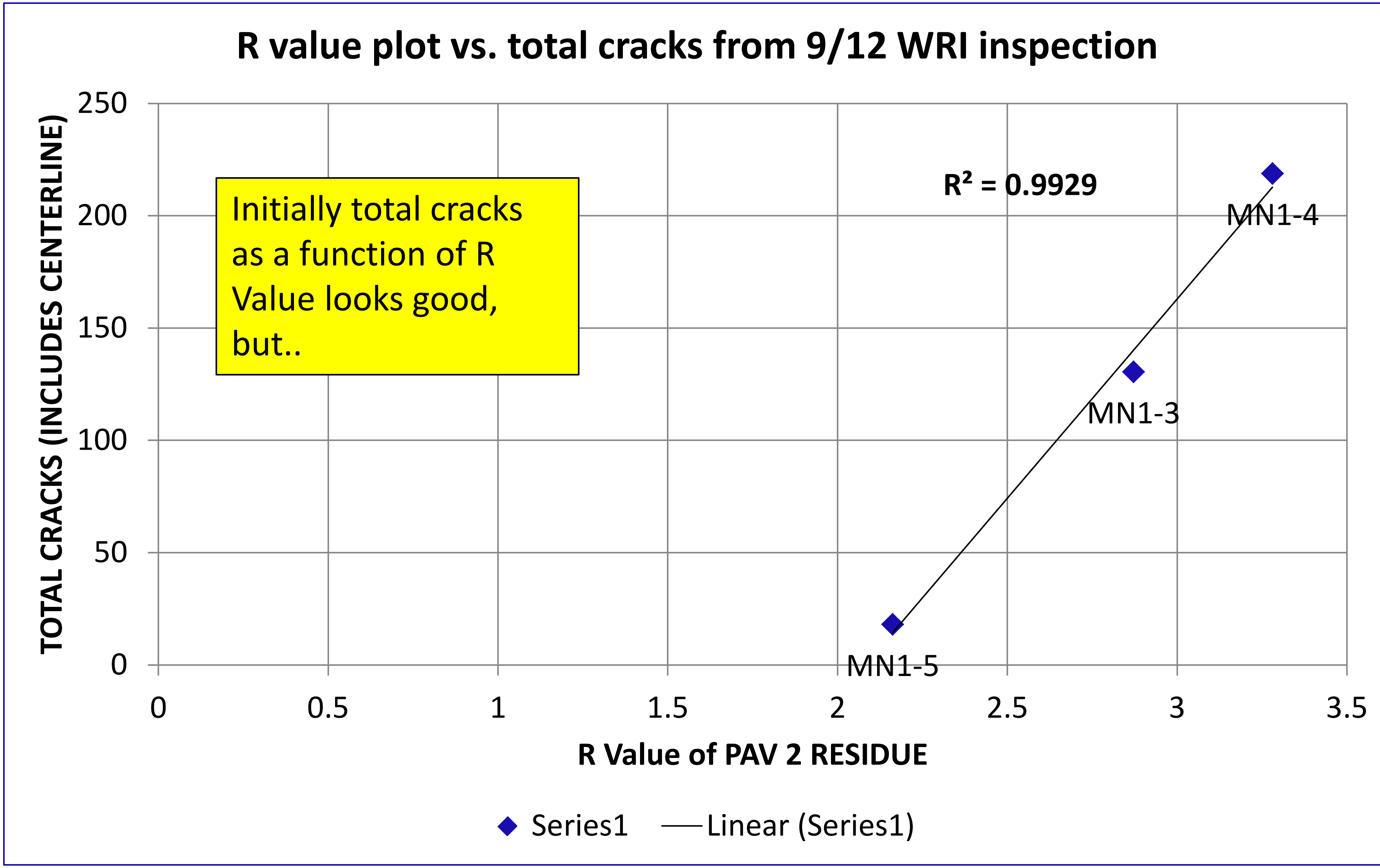

MN1-4	PG 58-28 Arab heavy/Arab medium/Kirkuk blend
MN1-3	PG 58-28 Canadian blend
MN1-5	PG 58-28 Venezuelan blend

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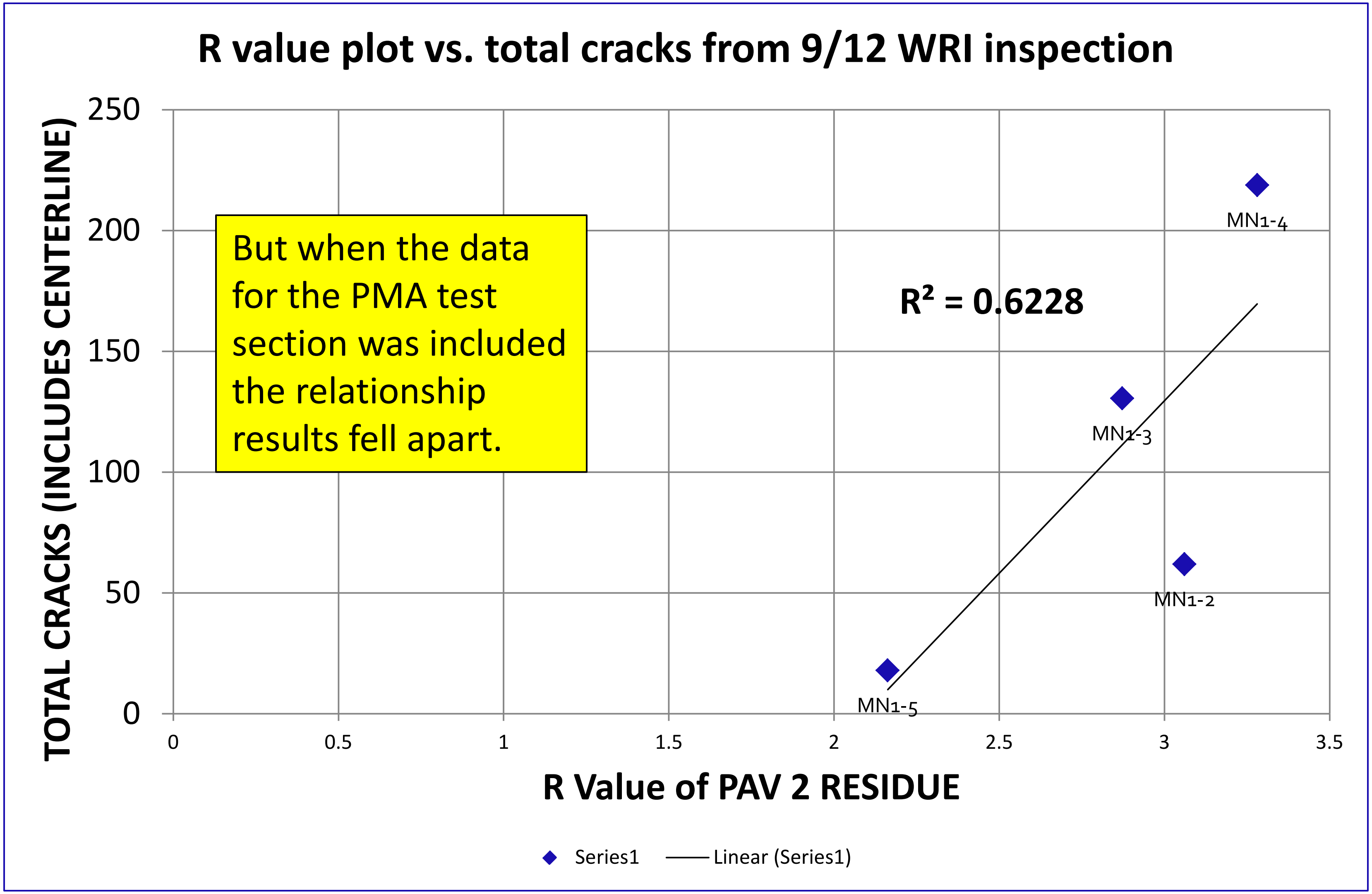

MN1-4	PG 58-28 Arab heavy/Arab medium/Kirkuk blend
MN1-3	PG 58-28 Canadian blend
MN1-5	PG 58-28 Venezuelan blend
MN1-2	PG 58-34 PMA based on Canadian blend

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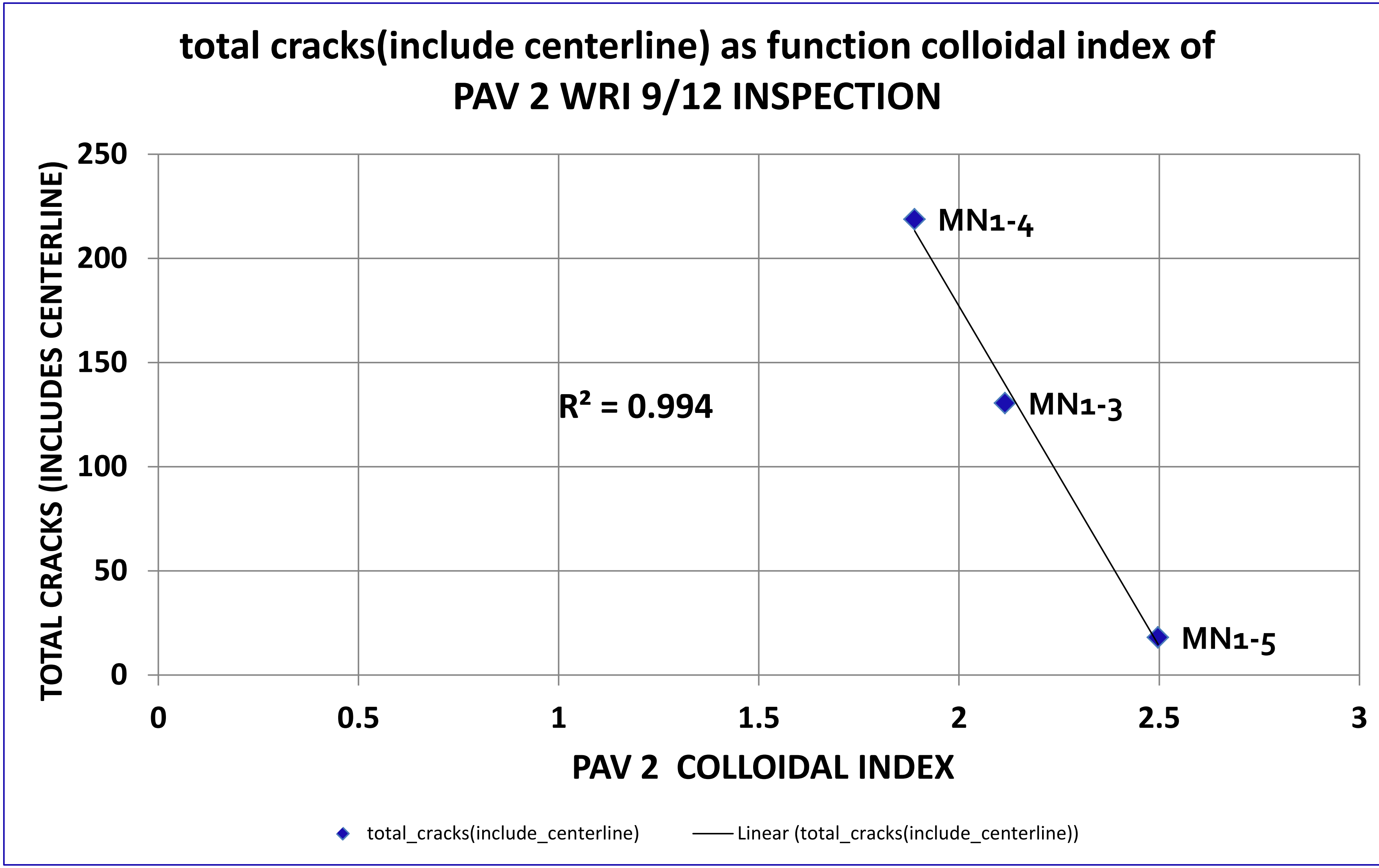

MN1-4	PG 58-28 Arab heavy/Arab medium/Kirkuk blend
MN1-3	PG 58-28 Canadian blend
MN1-5	PG 58-28 Venezuelan blend

MTE
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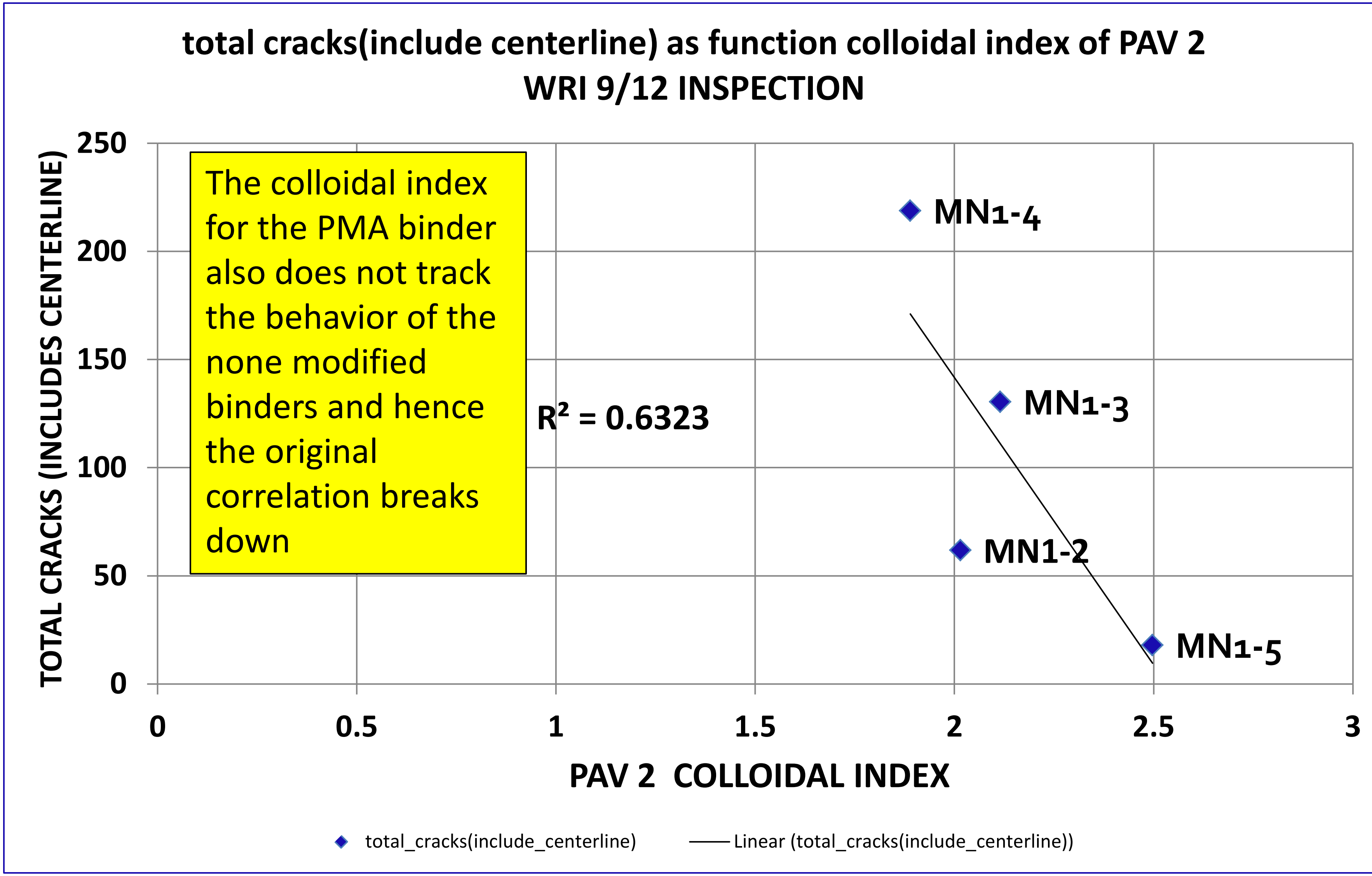

MN1-4	PG 58-28 Arab heavy/Arab medium/Kirkuk blend
MN1-3	PG 58-28 Canadian blend
MN1-5	PG 58-28 Venezuelan blend
MN1-2	PG 58-34 PMA based on Canadian blend

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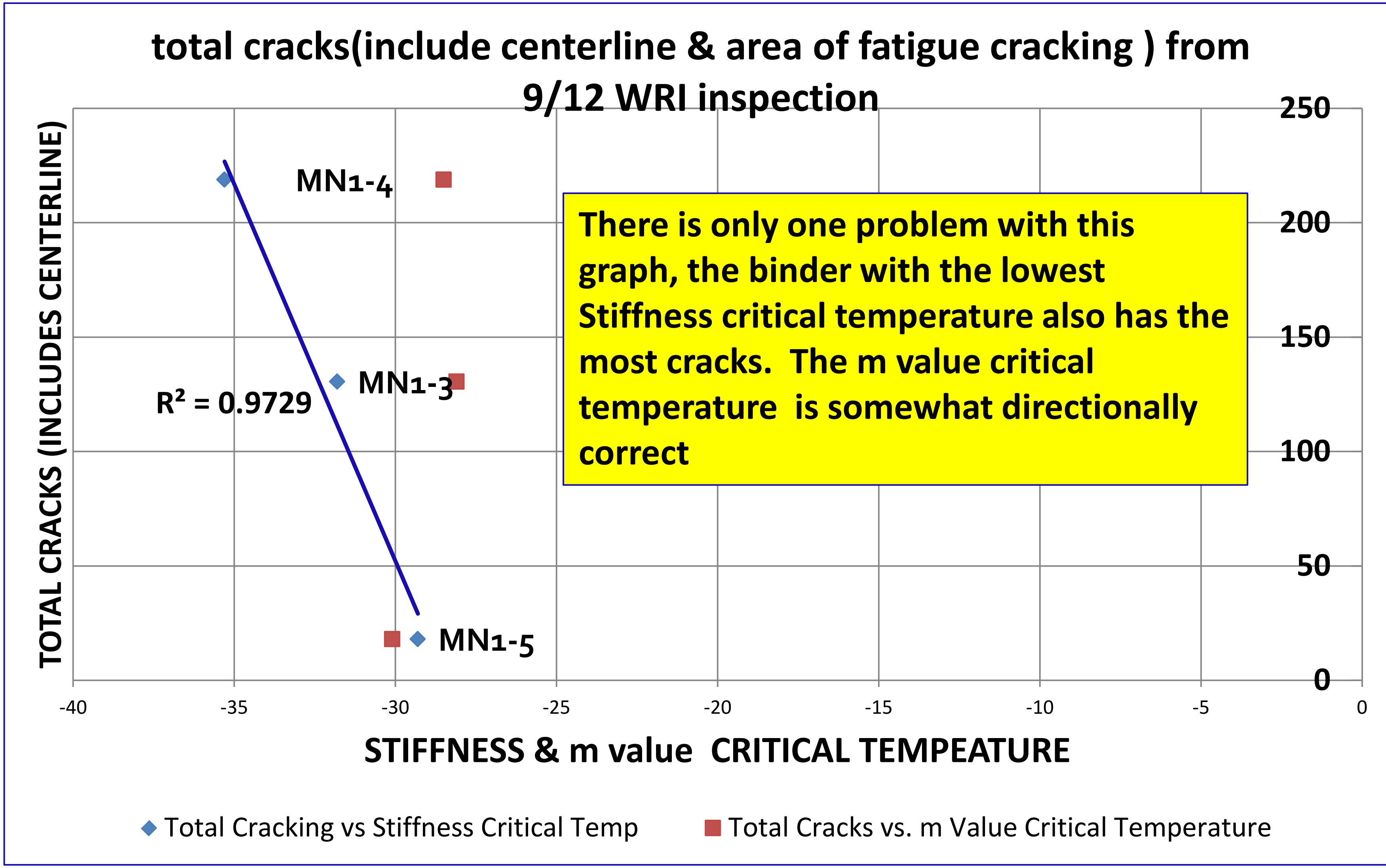

MN1-4	PG 58-28 Arab heavy/Arab medium/Kirkuk blend
MN1-3	PG 58-28 Canadian blend
MN1-5	PG 58-28 Venezuelan blend

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COMMENTS

- ADDITION OF NON ASPHALTIC MATERIALS TO CONVENTIONAL BINDERS DO NOT SEEM TO AGE WELL
  - Just because the softening agent is petroleum derived is no guarantee there will be not be deleterious effect on binder aging
  - Bio derived additive reported here impacted low temperature properties after aging to lesser extent than paraffinic based oils
- REOB *PER SE* IS NOT THE ISSUE, IN MY OPINION
- VIRGIN BASE OILS DISPLAY SAME CHARACTERISTICS IN ASPHALT BINDERS WHEN AGED
  - Main factor i believe is high levels of paraffinic compounds
- THE IMPACT OF NON ASPHALT BLEND COMPONENTS SEEMS TO HAVE MORE OF AN EFFECT ON FATIGUE PROPERTIES THAN LOW TEMPERATURE CRACKING
- THE $\Delta G(t)$-m APPEARS TO RELATE QUITE WELL TO THE INCREASE IN PAVEMENT CRACKING and BASED ON THE COUNTY HWY 112 DATA THE RELATIONSHIP HOLDS FOR PMA AS WELL AS THE ORIGINAL PG 58-28 BINDERS

COMMENTS

- THE USE OF EXCESSIVE LEVELS OF PARAFFINIC OIL DERIVED ADDITIVES PRODUCES PROPERTIES APPEAR TO IMPACT FATIGUE CRACKING PERFORMANCE.
- THE USE OF ADDITIVES CONTAINING 5% AND HIGHER LEVELS OF PARAFFINIC DERIVED OILS APPEAR TO PRODUCE BINDERS WHICH DO NOT AGE WELL AT LOW TEMPERATURES
- THERE IS A NEED TO FIND AGING & TESTING PROTOCOLS BY WHICH THE AMOUNT OF REOB, OTHER PARAFFINIC ADDITIVES OR ANY SO CALLED REJUVENATORS (REGARDLESS OF SOURCE & CHEMISTRY) WHICH RESULT IN POOR LOW TEMPERATURE PROPERTIES AND EXCESSIVELY M CONTROLLED BINDERS CAN BE EVALUATED
  - Aging in mix is preferred, but binder aging as a screening tool would also be useful
- THERE IS A NEED TO FIND A MEANS BY WHICH DRAIN OIL CANNOT BE ADDED TO BITUMEN TO PRODUCE A SPEC GRADE BINDER.
  - Clearly tests such as flash point, RTFO loss and ash % won't work
    - Drain oil has lower ash content than REOB on a mass/mass basis

INFORMATION FROM MIKE ANDERSON

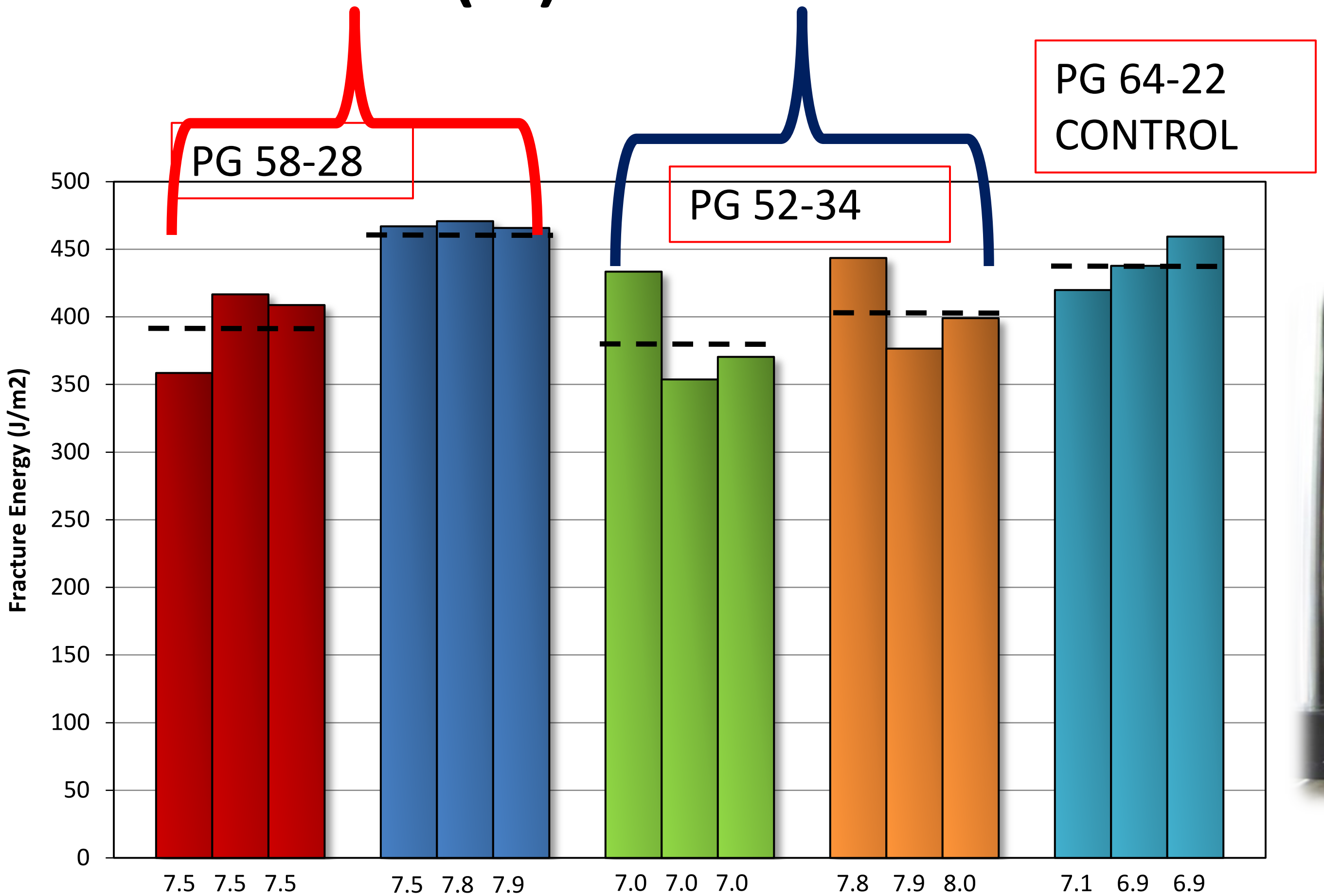
Evaluation of Kentucky RAP-RAS Mixtures

COUNTY	Bullitt	Fleming	Grant	Robertson
MIX COMPOSITION	PG 58-28, 10% RAP, 3% RAS	PG 58-28, 10% RAP, 3% RAS	PG 52-34, 3% RAS	PG 52-34, 3% RAS
BBR S @-24C, MPa	420	143	51	33
BBR m @-24C	0.258	0.273	0.268	0.300
$T_{c,S}$	-31.3	-40	-49	-60.2
$T_{c,m}$	-29.5	-25.7	-28.2	-34.2
ΔT_c	-1.8	**-14.3**	**-20.8**	**-26**
Zinc ppm	11	**1085**	**1748**	**1723**
Asphaltenes	13.1	13.4	11.1	11.4
Resins	23.5	27.7	33.5	35.4
Cyclics	55.2	45.9	37.2	33.7
Saturates	8.1	**12.9**	**18.1**	**19.5**

PAV RESIDUE DATA (BBR S @-24C through ΔT_c)

UNAGED BINDER DATA (Zinc ppm through Saturates)

DC(T) Test Results

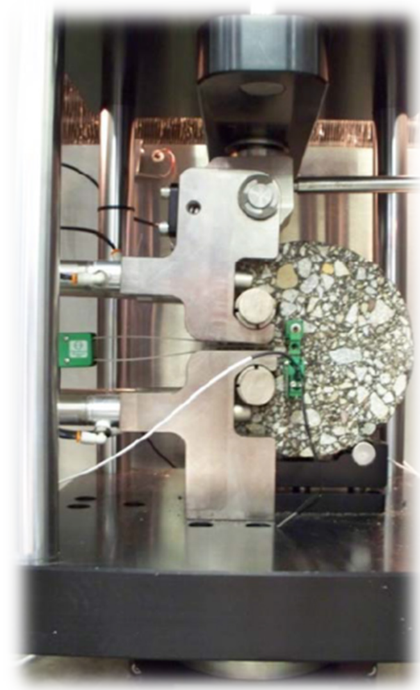


Property	Bullitt	Fleming	Grant	Robertson	Control
RAP, %	10	10	0	10	0
RAS, %	3	3	3	3	0
Effective AC, %	3.5	5.1	5.6	5	4.8
Virgin Asphalt Grade	PG 58-28	PG 58-28	PG 52-34	PG 52-34	PG 64-22

DC(T) Test Results

Fisher's LSD pairwise comparison

Mixture	N	Virgin Binder	Average Fracture Energy (J/m²)	Fisher's Grouping	
Fleming	3	PG 58-28	467.77	A	
Control	3	PG 64-22	438.93	A	B
Robertson	3	PG 52-34	406.33		B
Bullitt	3	PG 58-28	394.60		B
Grant	3	PG 52-34	385.83		B



Mixture Conclusions

- Performance of the mixture with the PG 58-28 virgin binder was comparable to the control mixture.

- Mixtures with PG 52-34:
  - Higher lab fatigue life
  - More compliant, overdesigned
  - Lower fracture energy

Mixture Conclusions

- Adding a binder two grades softer than the target results in a softer mixture, but the mixture is not more resistant to crack growth.
- Hypothesis:
  - The PG 52-34 does not properly blend into the mixture.
  - Brittle spots remain throughout the mixture.