FURTHER INVESTIGATIONS INTO THE IMPACT OF REOB & PARAFFINIC OILS ON THE PERFORMANCE OF BITIUMINOUS MIXTURES

BY

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BINDER ETG MEETING

APRIL 9, 2015

FALL RIVER, MA

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

ETG MEETING SEPTEMBER 2014, BATON ROUGE

[illegible]
ALEX ENGSTLER, SCOTT VEGLAHN,
ANDREW HANZ, GERALD REINKE
MATHY TECHNOLOGY AND ENGINEERING SERVICES, INC
JOHN JORGENSON, CHAD LEWIS OF MATHY CONSTRUCTION MIXTURE LAB

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MANY SUBJECTS COVERED

1. Impact of REOB, bio derived oil, paraffinic base oil on ΔTc (S critical temp-m critical temp) after mix aging or after 20 & 40 hr. PAV aging of binders
2. Impact of REOB and bio derived oils blended with PG binders + commercially recovered binder from tear off shingles followed by 20 & 40 hr. PAV aging

MANY SUBJECTS COVERED

A great deal of information was presented, if interested I suggest obtaining a copy of the presentation from FHWA or from me.

3\.

4\. Investigation into mixture performance of Comparative Crude Source test sections in Olmsted County, MN and correlations to 40 hr. PAV residue ΔTc properties of binders used to construct those test sections (one of which contained REOB)

What Has Happened Since Sept 2014

1. October 2014 MTE commissioned a distress survey of the 5 test sections of Olmsted County Highway 112
   a. Same person who conducted previous surveys
   b. Cores were taken from each test section, binder extracted for characterization
2. Sufficient binder aged for 20 & 40 hr. PAV to conduct DENT tests
   a. Asphalt Institute conducted DENT testing
   b. MTE determined ΔTc using 4 mm DSR

What Has Happened Since Sept 2014

3. Evaluated blends using asphalt pitch, PG 64-22 and REOB or paraffinic base oil
4. Blends made with PG 64-22 and commercial motor oils to achieve low temperature grade change.
   a. Mobil 1 10w-40
   b. Valvoline 10w-40
   c. Blend Base variable

What Has Happened Since Sept 2014

5. Discussion with Sandy Brown, AI Canadian Engineer prompted investigation of impact of REOB when used in PMA blends
    a. Since REOB is not compatible with some PMA blends that incorporate PPA, paraffinic base oil was substituted
    b. Sufficient data has been generated to show that paraffinic base oils have impact similar to REOB

What Has Happened Since Sept 2014

6. MN DOT raised the question as to whether or not REOB was used in comparative binder investigation on MnROAD in 1999
    a. 3 binders-PG 58-28, PG 58-34, PG 58-40
    b. Constructed in Sept 1999, monitored until April 2007
    c. PG 58-40 exhibited significantly more cracking than other sections
    d. MTE had binder samples from project and an investigation followed

OLMSTED COUNTY, MN REVISITED

Results related to distress survey in October 2014, analysis of cores and recovered binder, and DENT testing of 20 & 40 hr. PAV residue

WHAT WAS DONE & WHY

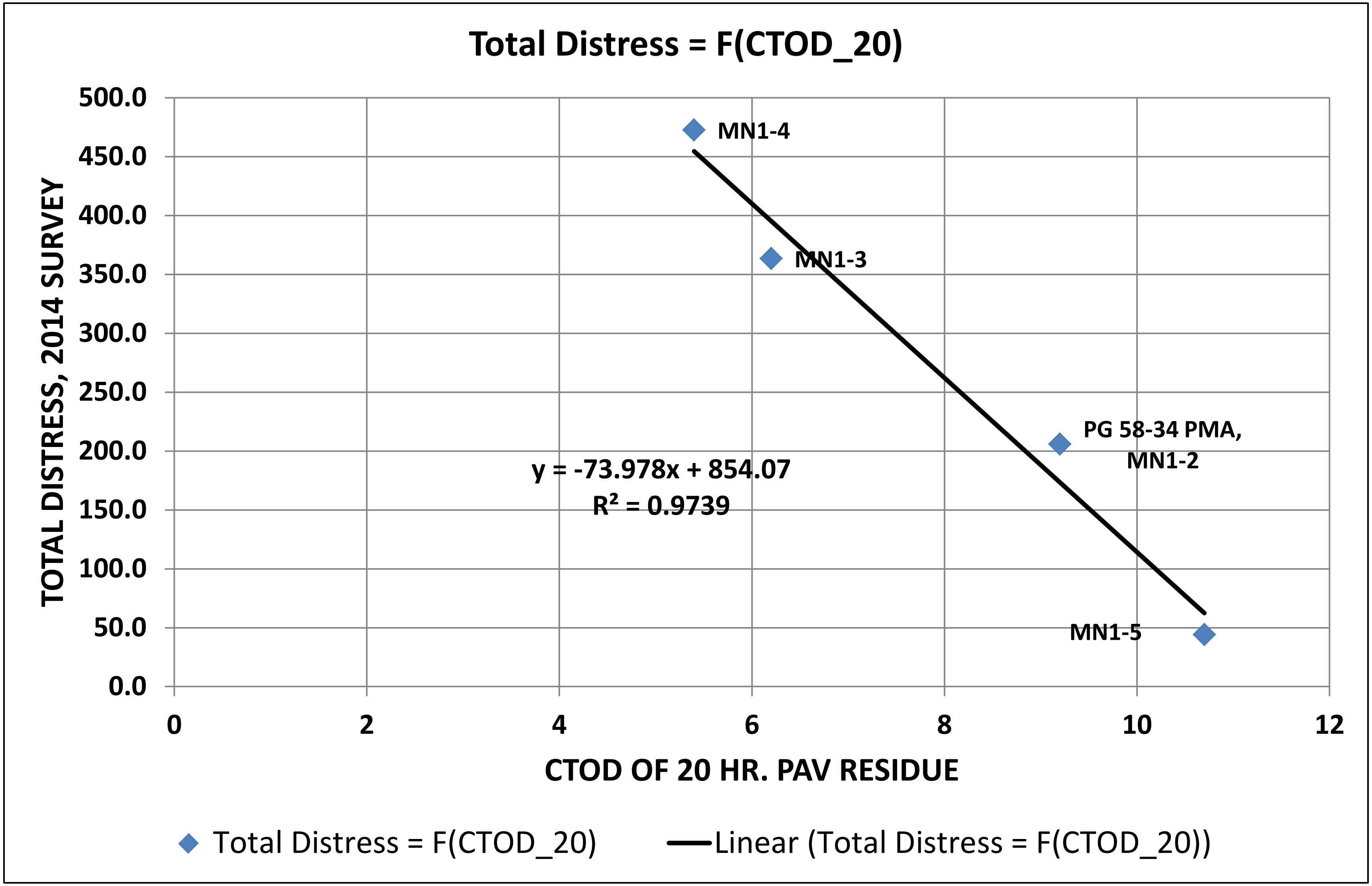
1. Previous work made clear that there was a strong correlation between the 40 hr. PAV ΔTc values and the pavement distress as determined in 2012
2. Current investigation
   a. Update the distress data
   b. Generate DENT data on 20 & 40 hr. PAV residues to correlate against current distress. Tested by Asphalt Institute
   c. Core pavement, recover binder, determine ΔTc for comparison to 20 & 40 hr. PAV ΔTc as a metric of performance prediction
   d. Compare ΔTc from 8 year field core binder to DENT
   e. Is there a more practical indicator of binder impact on mix performance than the DENT procedure

DISTRESS DATA FROM OCTOBER 2014 PAVEMENT SURVEY

Olmsted Cty 112	Transverse (m)	Fatigue (m^2)	Longitudinal (m) Non-Centerline	Centerline (m)	Total_Distress
MN 1-2 PMA 58-34	13.5	0	113.6	78.8	205.9
MN 1-3 Canadian blend 58-28	19.5	18.8	251.8	73.3	363.4
MN 1-4 Kirkuk blend with REOB 58-28	51.2	39.2	300.0	82.2	472.6
MN 1-5 Venezuelan 58-28	19.5	0	12.3	12.3	44.1

Total Distress is simply a summation of all the distress values. This means that fatigue in meters^2 was added to the other values in units of meters. Also centerline cracking was part of Total Distress.

There could be objections to this approach but since there were sections with no generalized areas of fatigue cracking it seemed to the only practical means of including that distress element. Since there were variations in the extent of centerline cracking, esecially for MN1-5 that distress parameter also seemed to be related to the binder characteristics especially since the same mix was used and was placed by the same crew over a 2 day time period.



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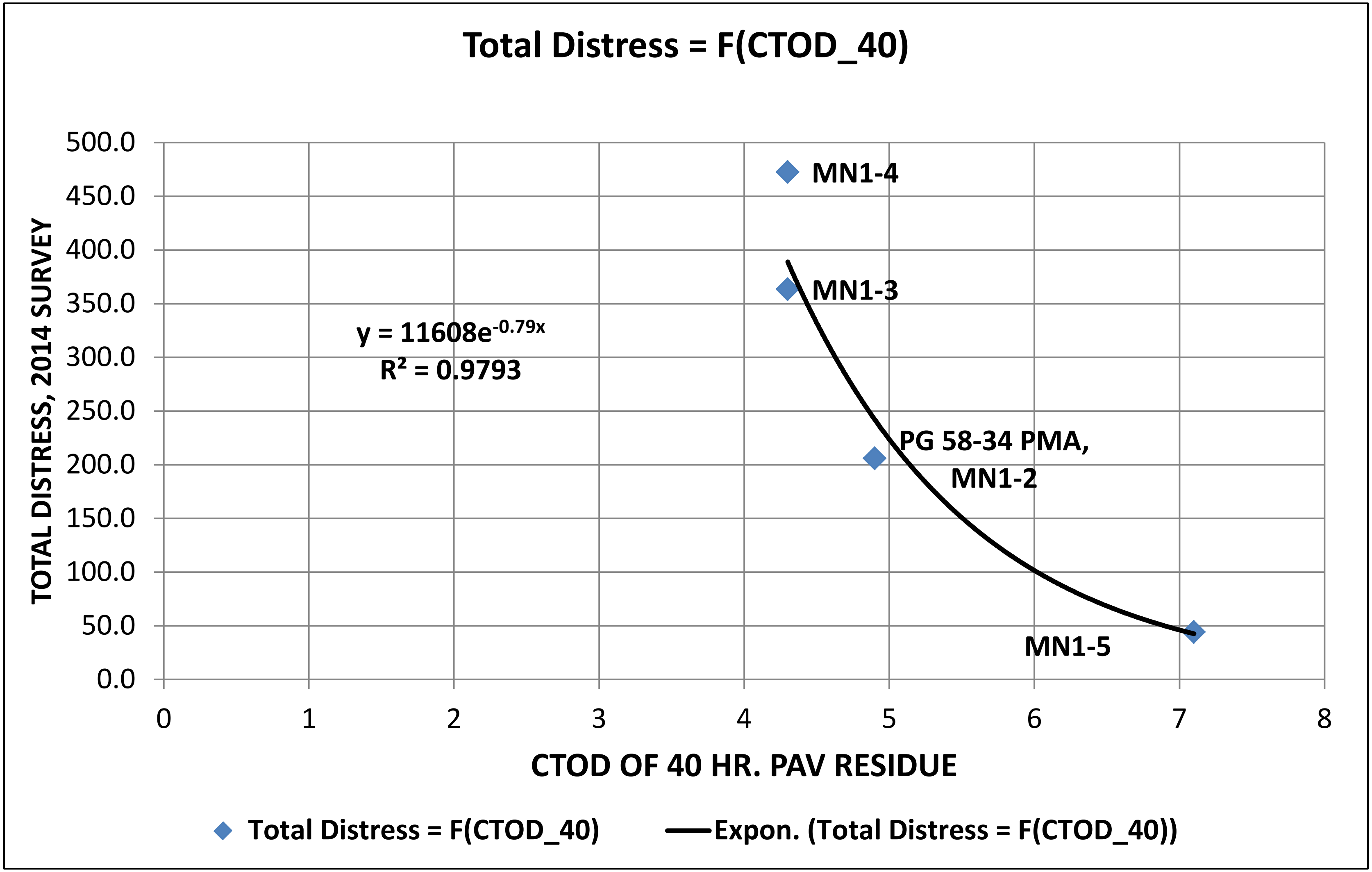

Two individuals from Canada informed me that CTOD values of 3-4 are generally the lowest values measured. I think that is if a CTOD of 3 when tested at 15°C is a lower limiting value that could account for the CTOD values of the 40 hr. PAV residues of MN1-3 an MN1-4 being the same and hence the power law function could be an appropriate fit of the data.

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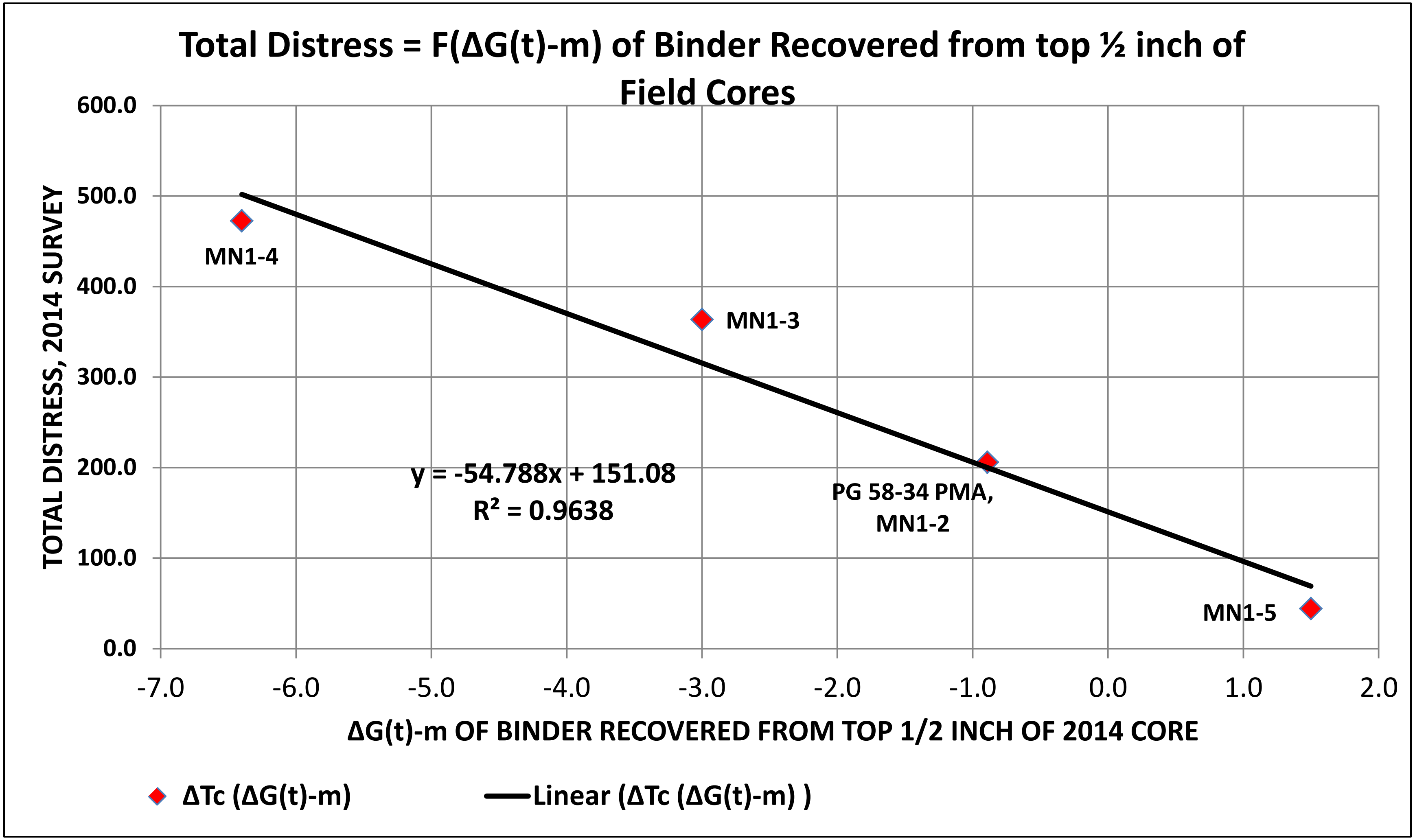
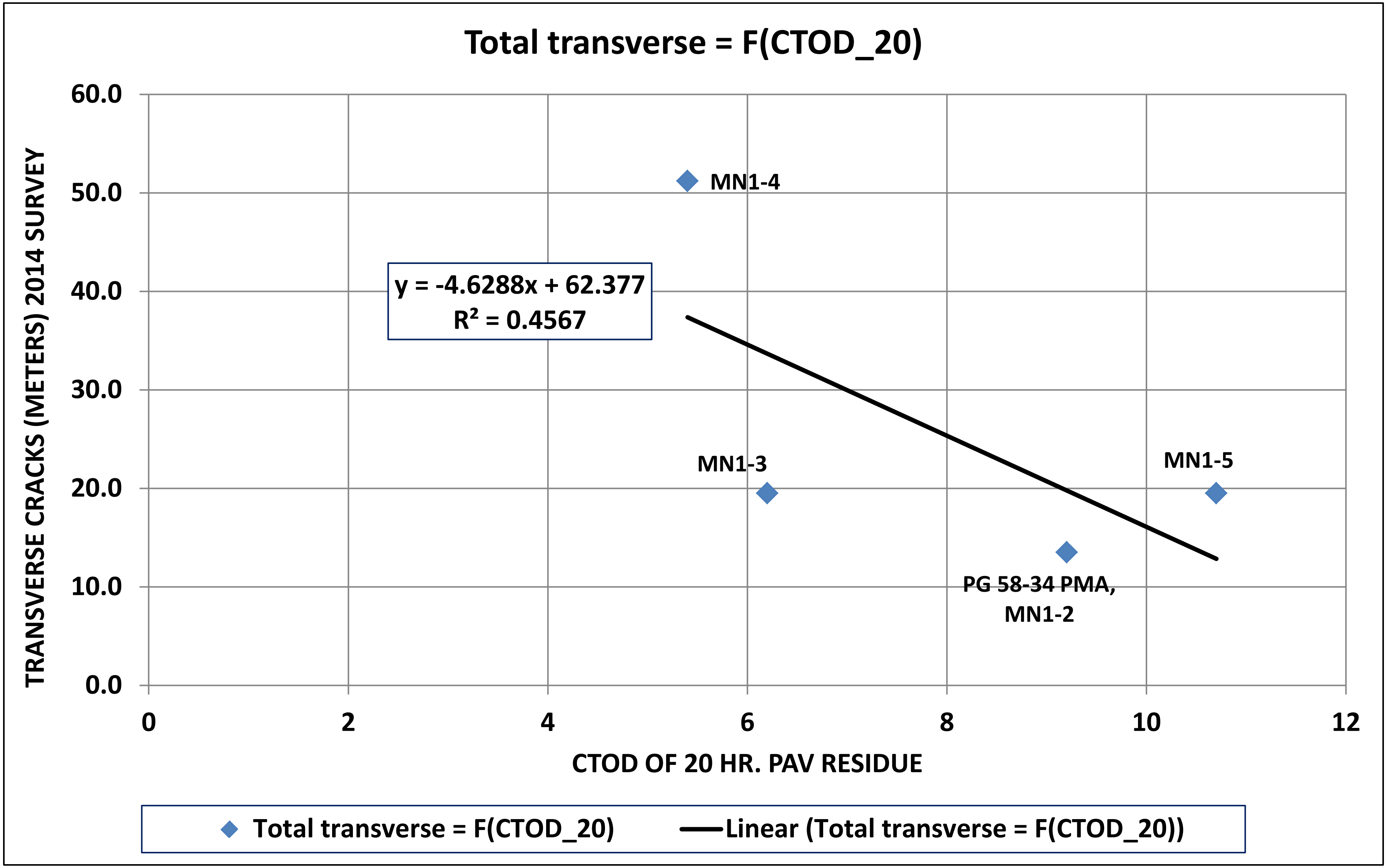
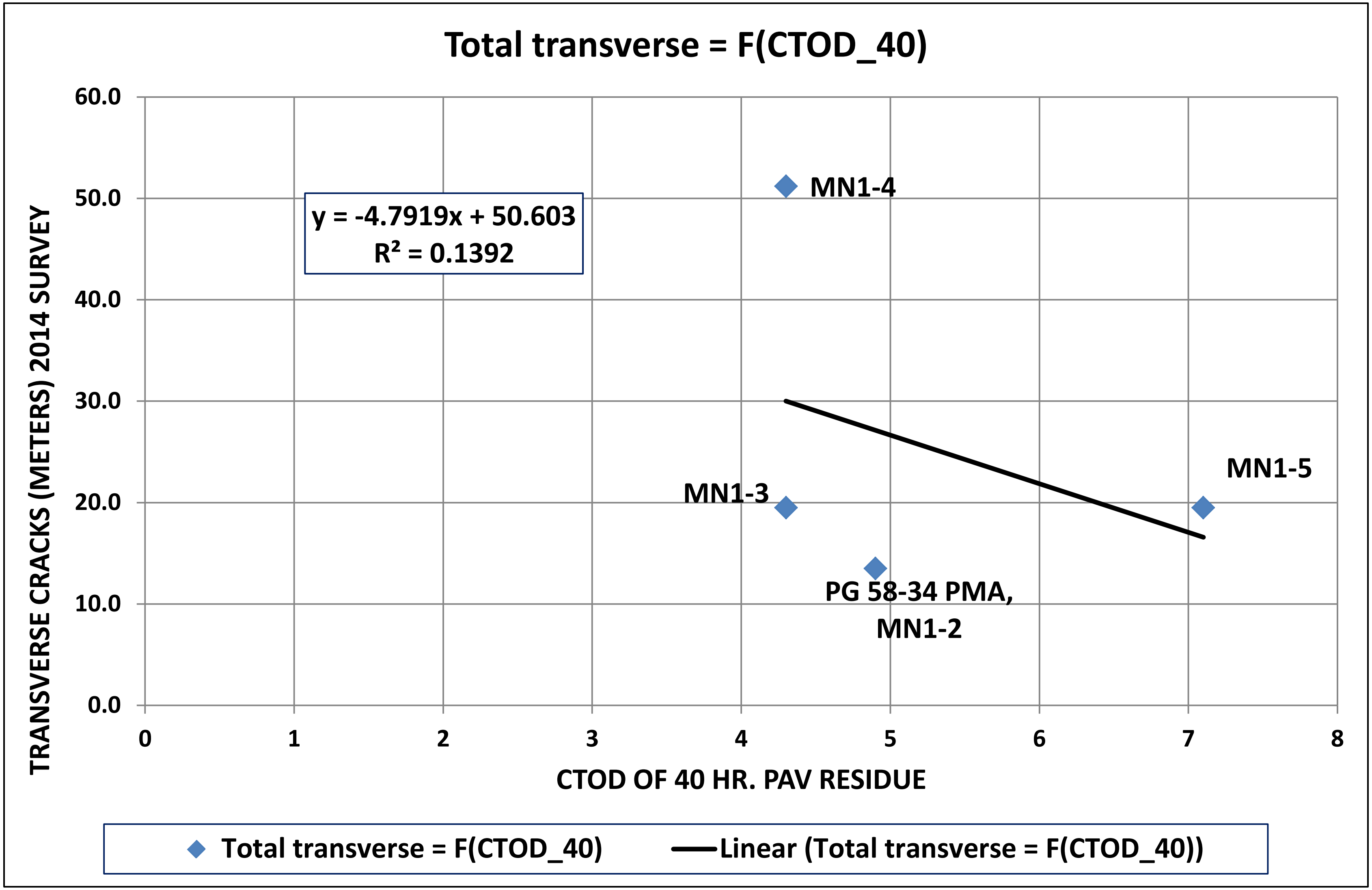


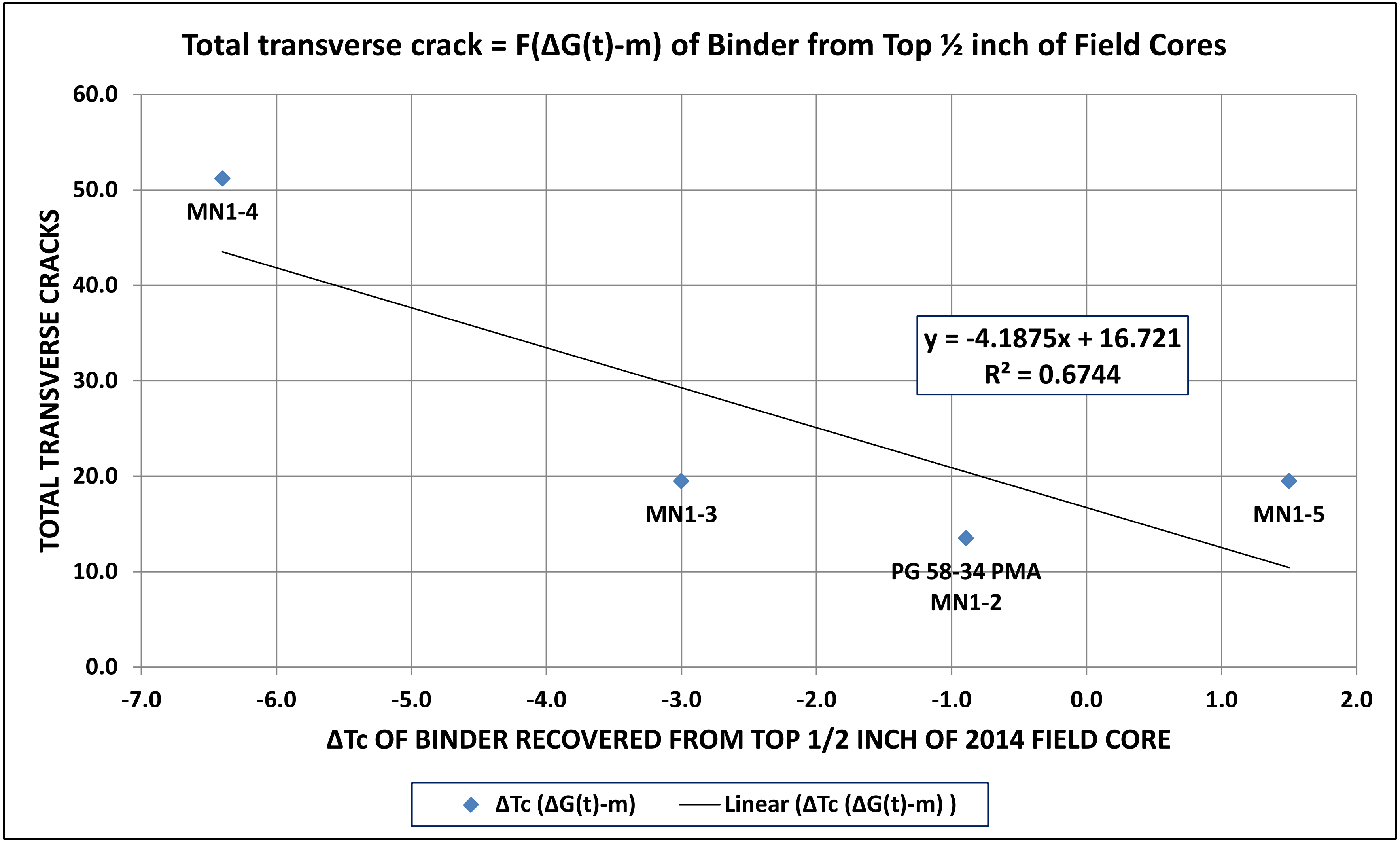
The previous 2 slides show that Total Distress is well correlated to CTOD for the 20 and 40 hr. PAV residues. This slide shows that Total Distress is also well correlated to the ΔT_c (the difference between the Stiffness critical temperature and the m (creep value) critical temperature for the binder recovered from the top ½ inch of the 8 year old field cores



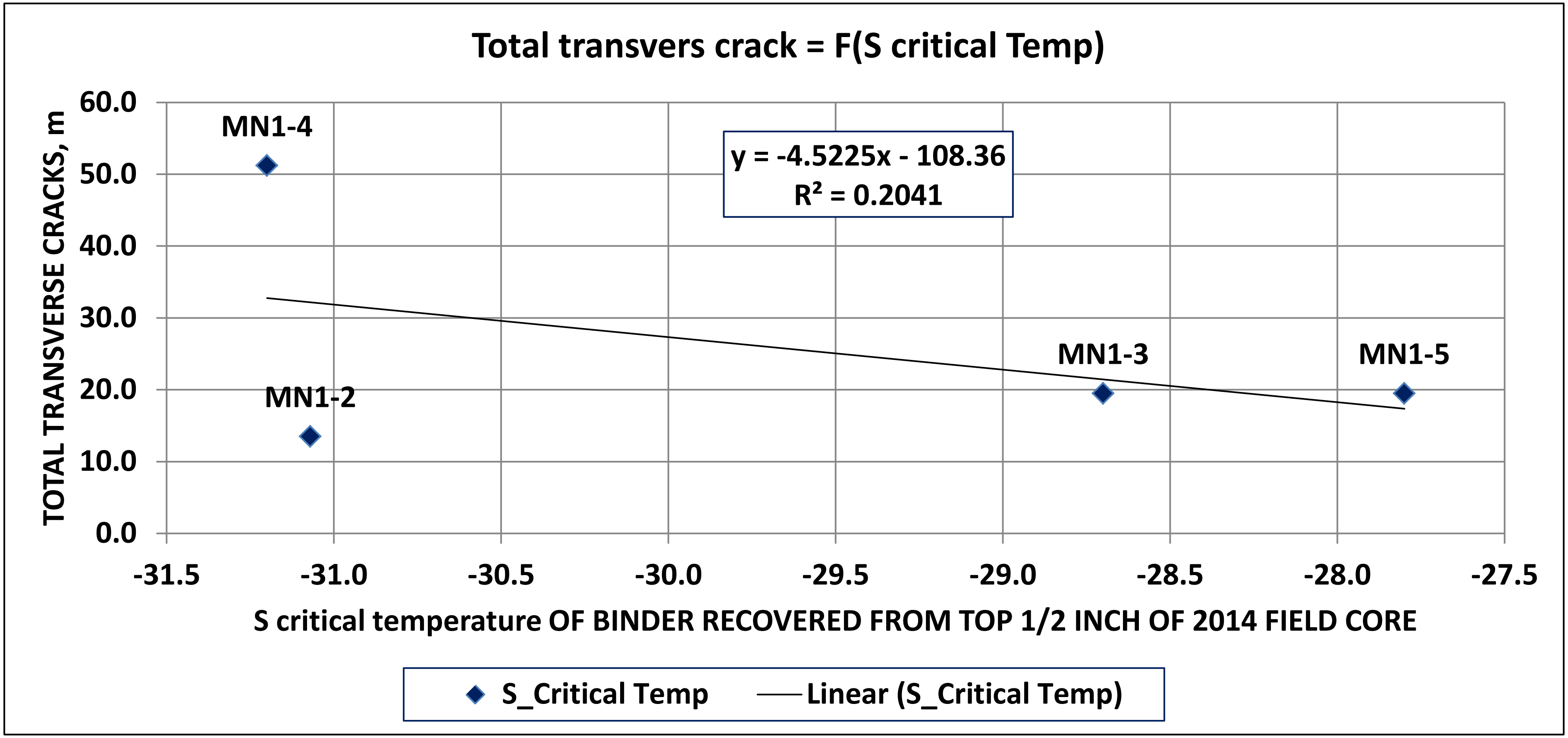
Transverse cracking, generally assumed to be a cold weather distress related to binder stiffness at low temperatures is not well correlated to the CTOD of the 20 hr. PAV residue



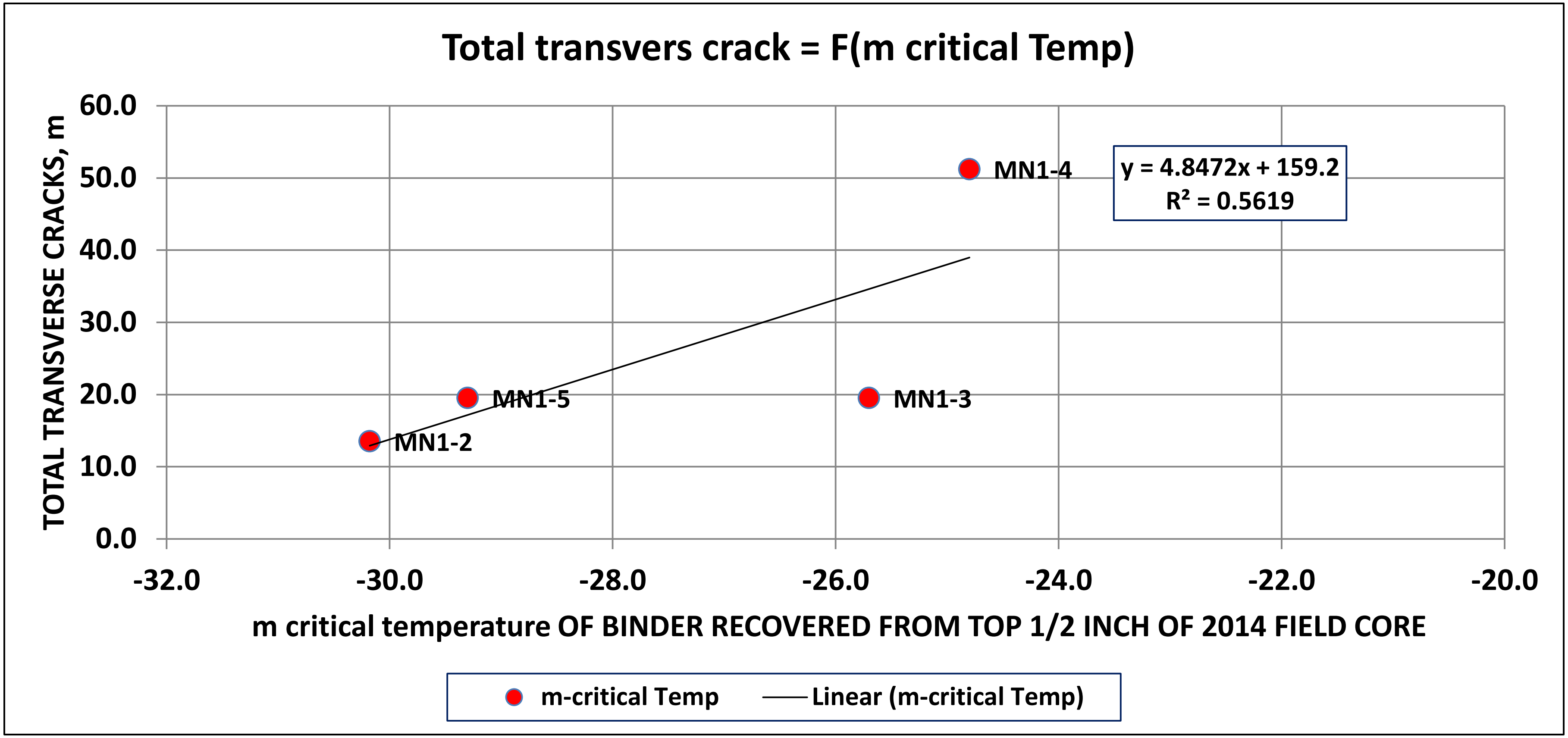
Transverse cracking, generally assumed to be a cold weather distress related to binder stiffness at low temperatures is also not well correlated to the CTOD of the 40 hr. PAV residue. This calls into question whether the binder characteristic being identified by the DENT test is a low temperature problem or some other issue.



ΔTc is better correlated to the transverse cracking, but the fit is still not great.

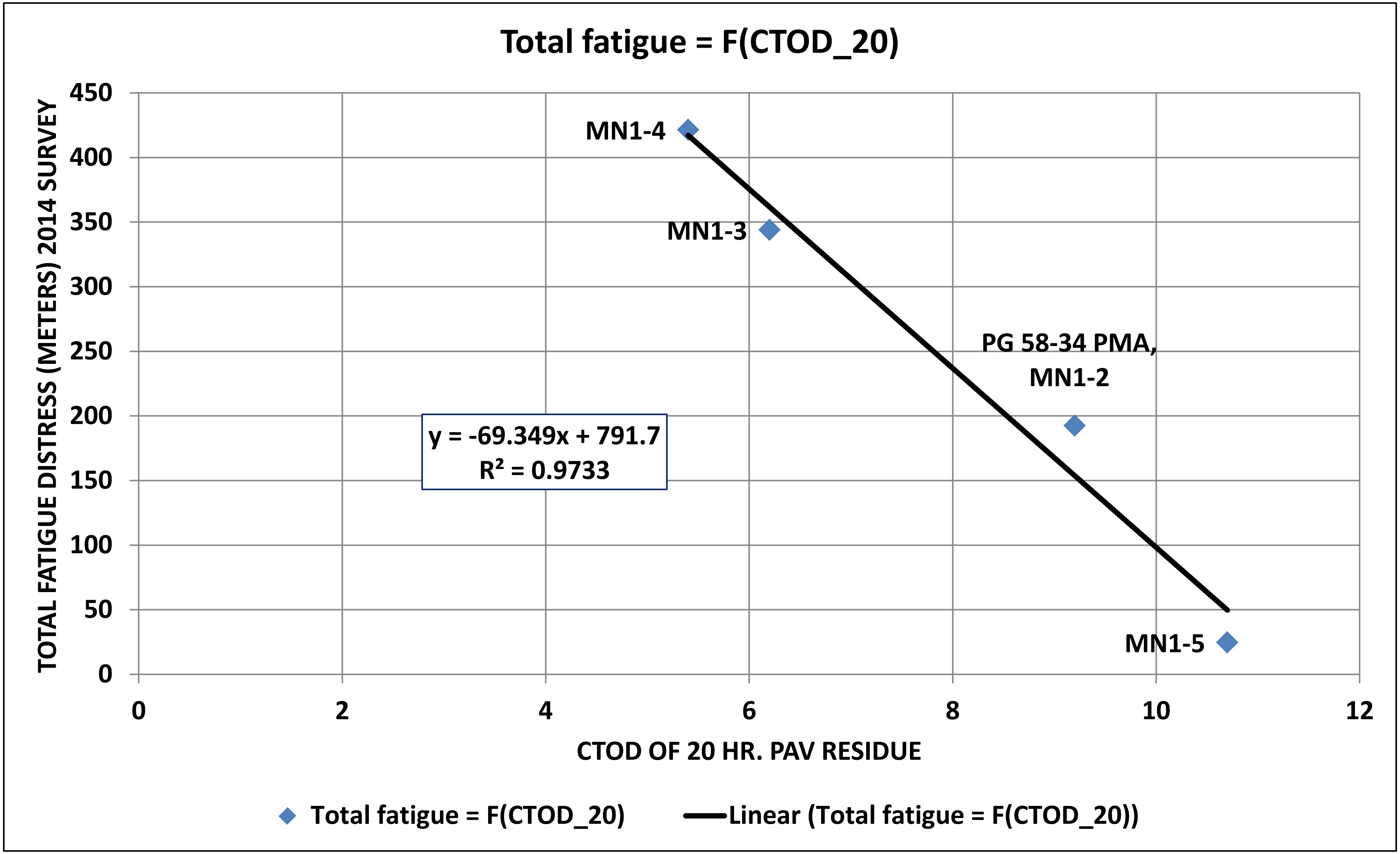


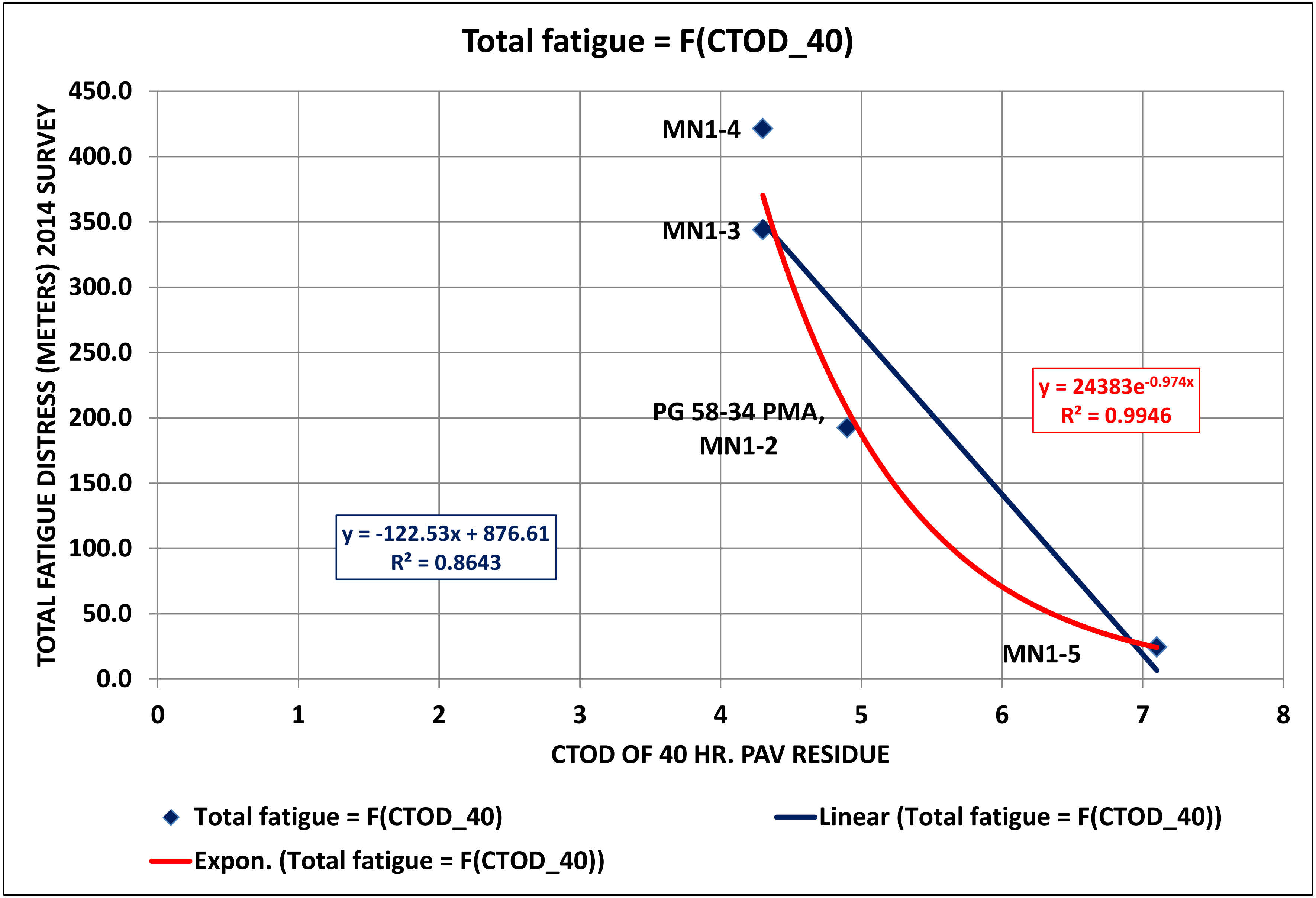
The fit of S critical temperature for the top ½ inch recovered binder is directionally wrong. The two PG 58-28 binders (MN1-3 & MN1-5) with the warmest S critical temperatures had fewer transverse cracks than MN1-4 with the lowest S critical temperature had the largest amount of transverse cracks. MN1-2 was a PMA PG 58-34.

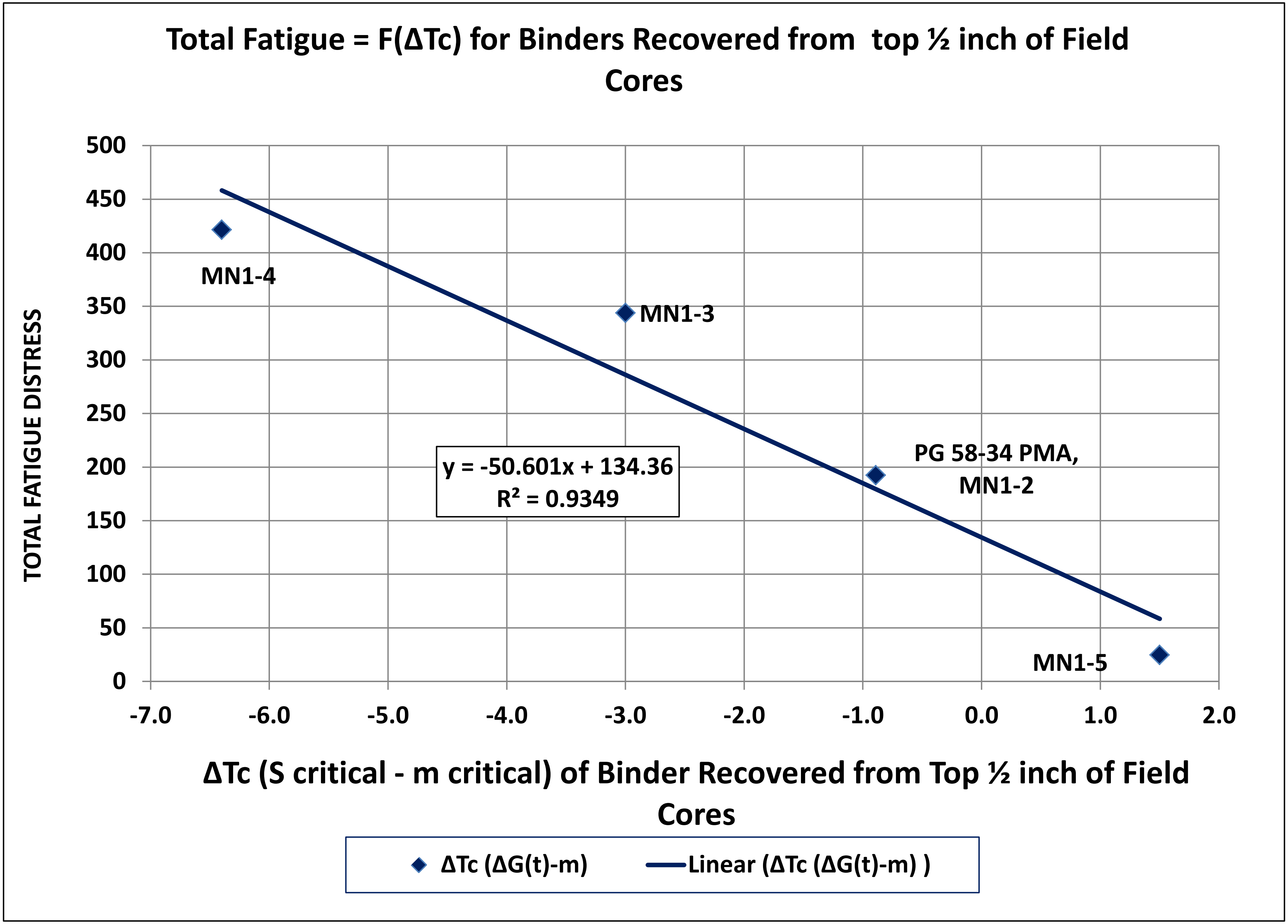


The relationship between the m critical temperature and transverse cracking is still not well correlated but at least the directional trend is more logical. Other than MN1-3 the recovered binders m critical temperatures tracks the amount of transverse cracking

As a result of the previous 3 slides I would say that single event thermal cracking as represented by transverse cracking is not the main problem caused by REOB on this project.


Total fatigue = F(CTOD_20)
TOTAL FATIGUE DISTRESS (METERS) 2014 SURVEY
CTOD OF 20 HR. PAV RESIDUE
0
50
100
150
200
250
300
350
400
450
0
2
4
6
8
10
12
MN1-4
MN1-3
PG 58-34 PMA, MN1-2
MN1-5
y = -69.349x + 791.7
R² = 0.9733
◆ Total fatigue = F(CTOD_20)
Linear (Total fatigue = F(CTOD_20))


Total fatigue = F(CTOD_40)
TOTAL FATIGUE DISTRESS (METERS) 2014 SURVEY
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
0
1
2
3
4
5
6
7
8
CTOD OF 40 HR. PAV RESIDUE
MN1-4
MN1-3
PG 58-34 PMA, MN1-2
MN1-5
y = 24383e^-0.974x
R² = 0.9946
y = -122.53x + 876.61
R² = 0.8643
Total fatigue = F(CTOD_40)
Linear (Total fatigue = F(CTOD_40))
Expon. (Total fatigue = F(CTOD_40))



Total Fatigue = F(ΔTc) for Binders Recovered from top ½ inch of Field Cores

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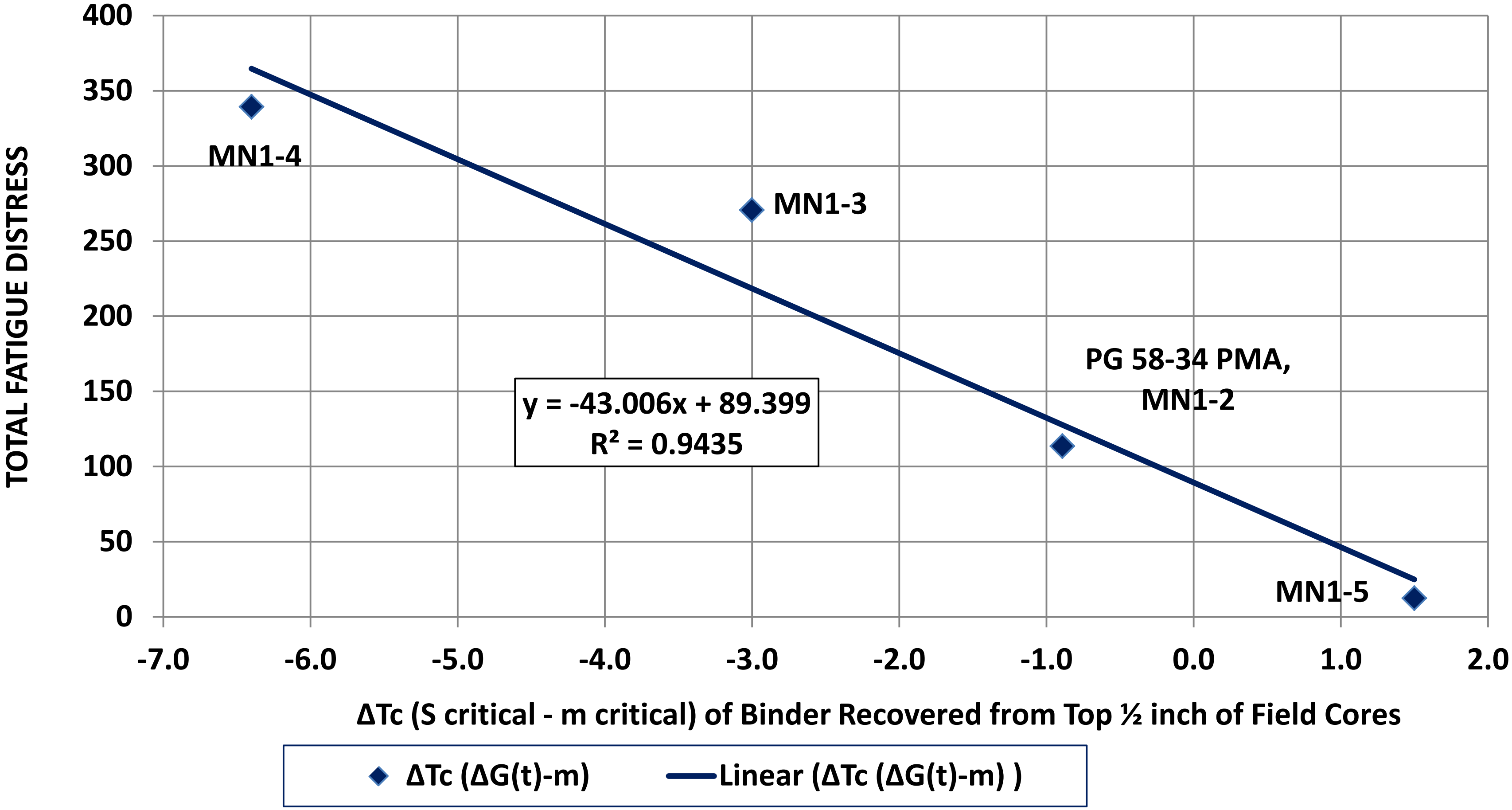
Non-Centerline Fatigue = F(ΔTc) for Binders Recovered from top ½ inch of Field Cores



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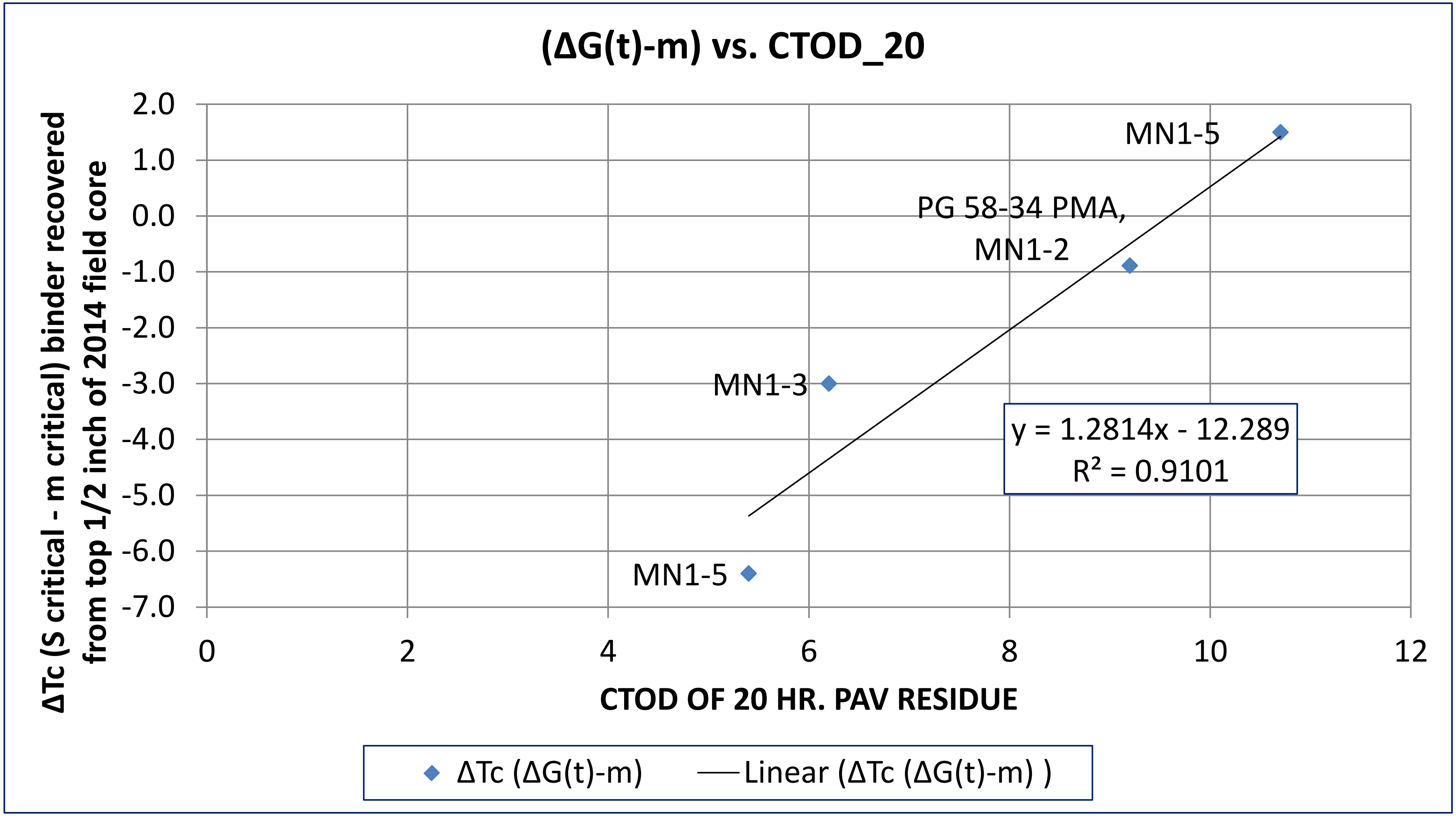
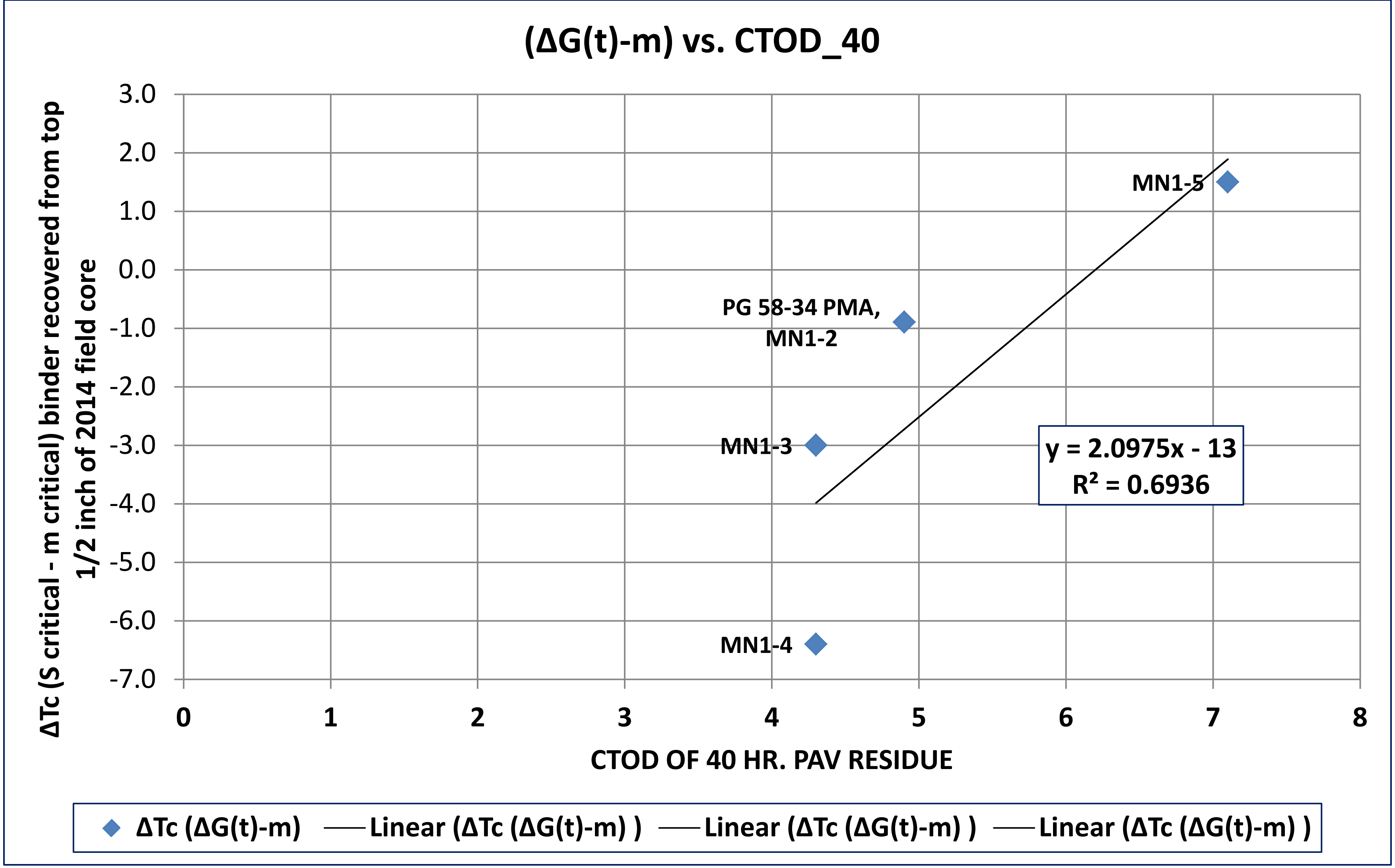
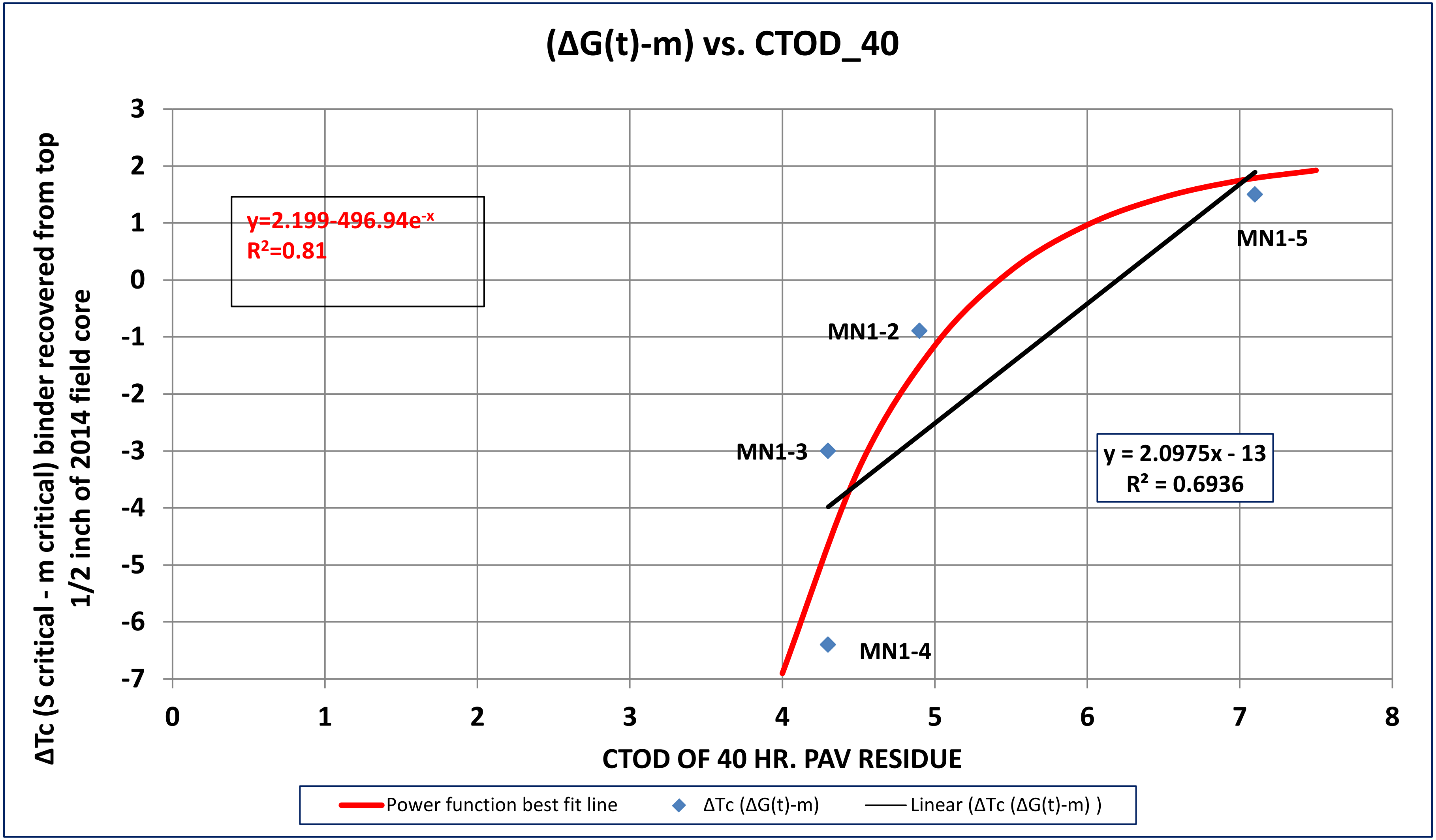
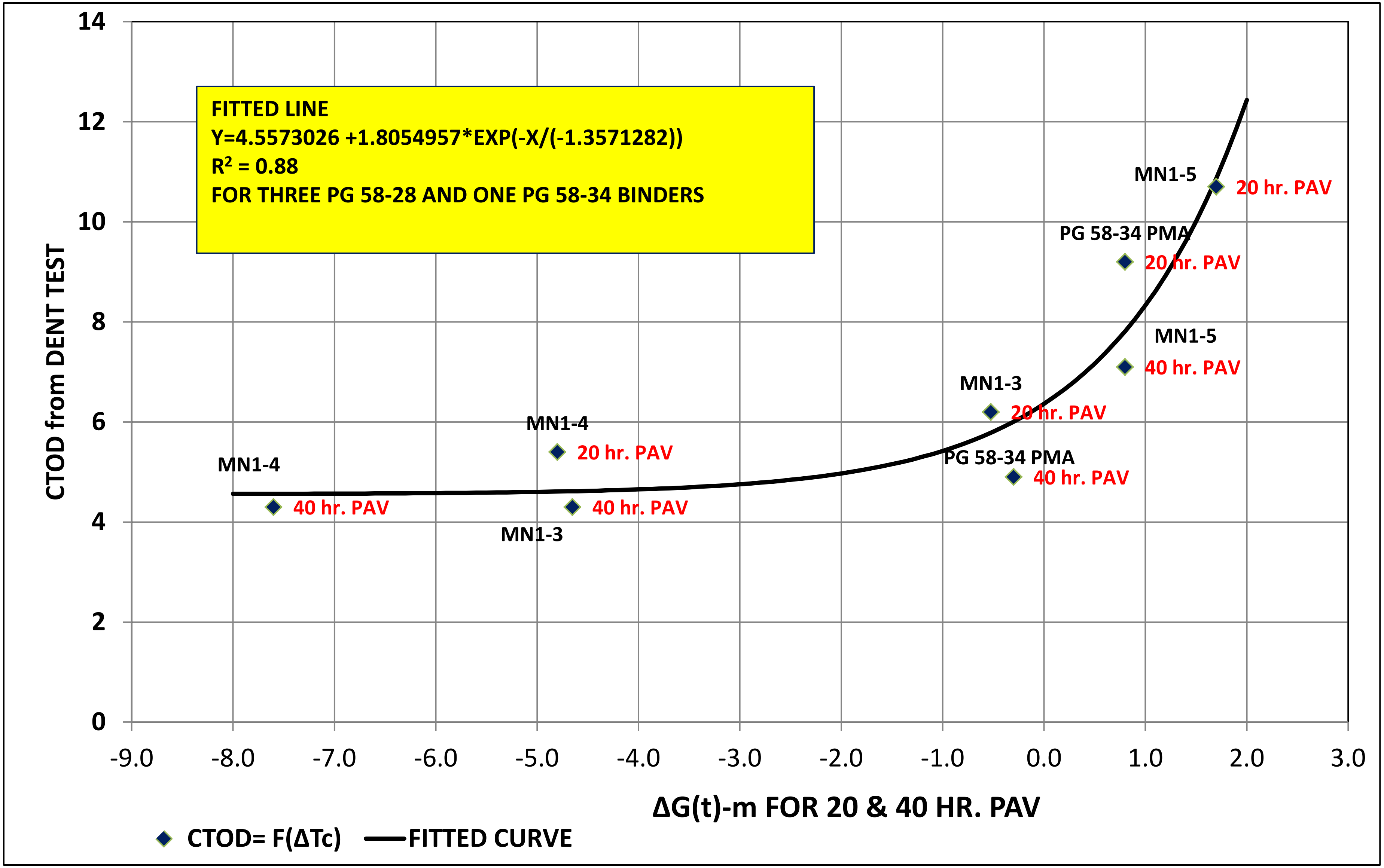

(ΔG(t)-m) vs. CTOD_20
ΔTc (S critical - m critical) binder recovered from top 1/2 inch of 2014 field core
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
-7.0
0
2
4
6
8
10
12
CTOD OF 20 HR. PAV RESIDUE
MN1-5
PG 58-34 PMA, MN1-2
MN1-3
MN1-5
y = 1.2814x - 12.289
R² = 0.9101
◆ ΔTc (ΔG(t)-m)
Linear (ΔTc (ΔG(t)-m))



The fit for the 40 PAV CTOD to the ΔTc of the binder recovered from the top ½ inch of the field cores is not very good, but once again I think the trending of the CTOD data to a limiting value may be part of the reason. A suggestion was to look at a power function fit and that is shown on the next slide.



I doubt the power function is the correct fit for the data. I think the fact that CTOD data has what amounts to a lower limiting value of around 3 is the most likely reason why the linear fit is not better.



FITTED LINE
Y=4.5573026 +1.8054957*EXP(-X/(-1.3571282))
R^2 = 0.88
FOR THREE PG 58-28 AND ONE PG 58-34 BINDERS

I think the take away here is that ΔTc has no limiting value whereas the data shows a trend for the CTOD to a value around 4

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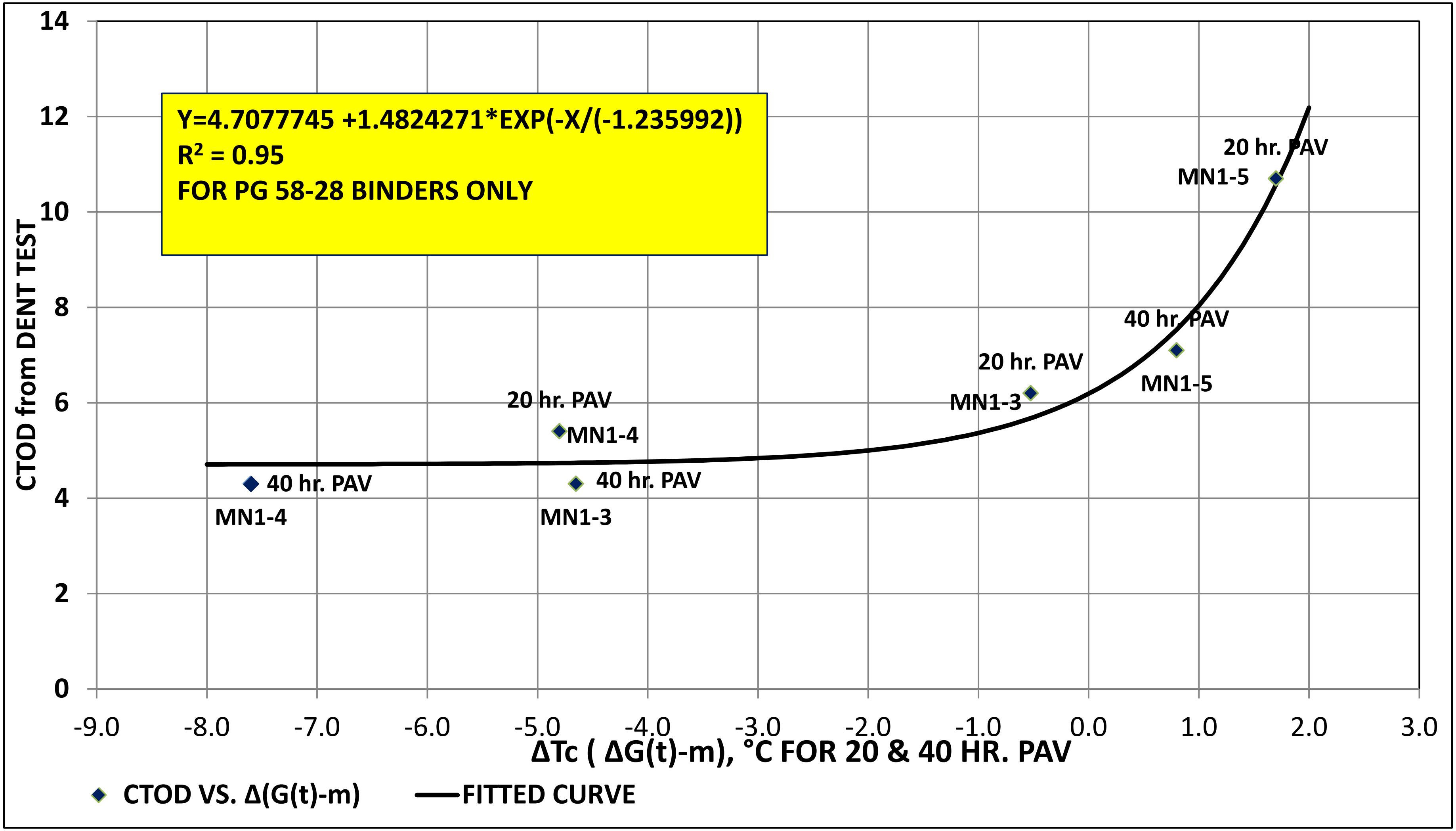
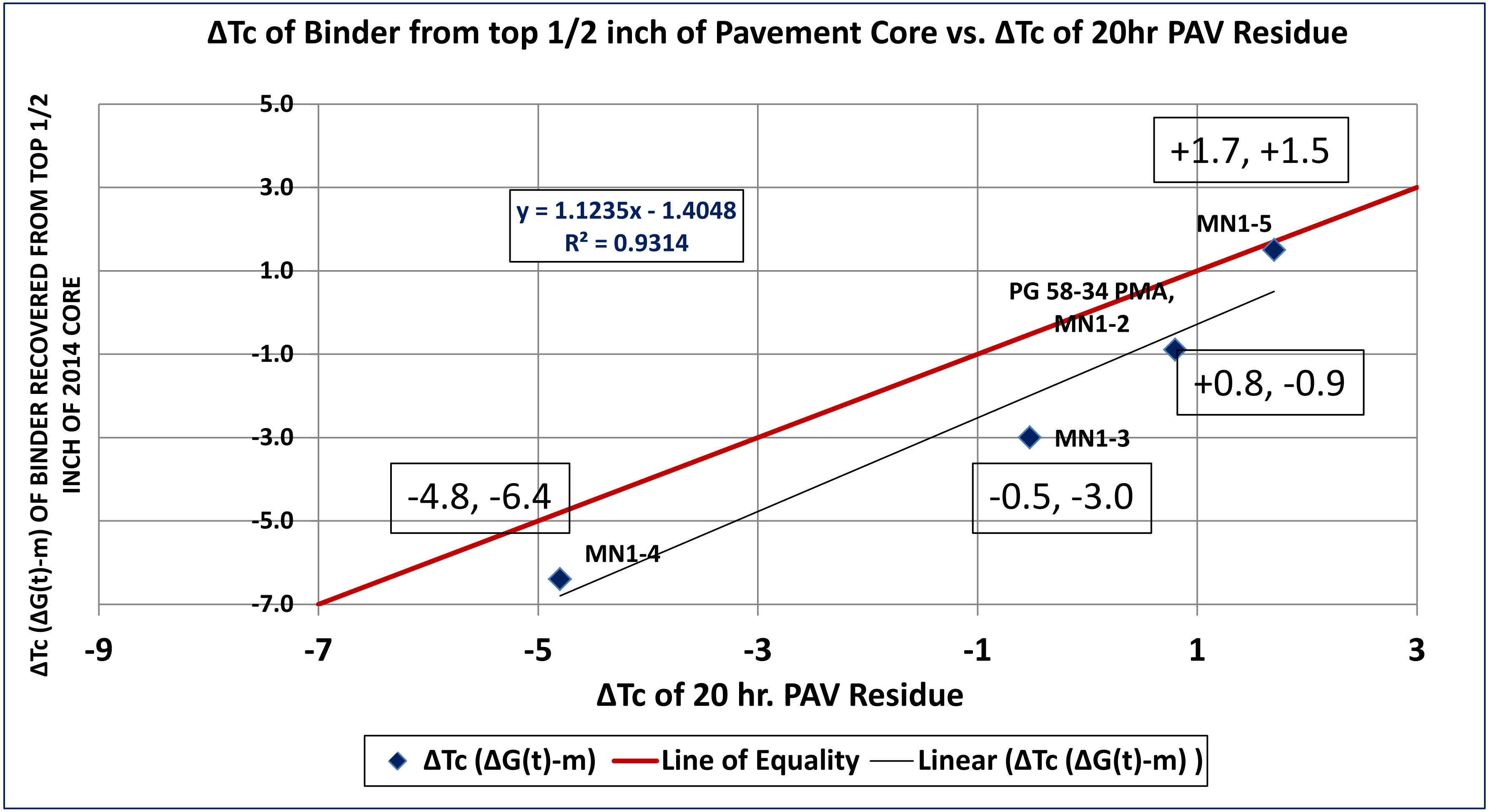
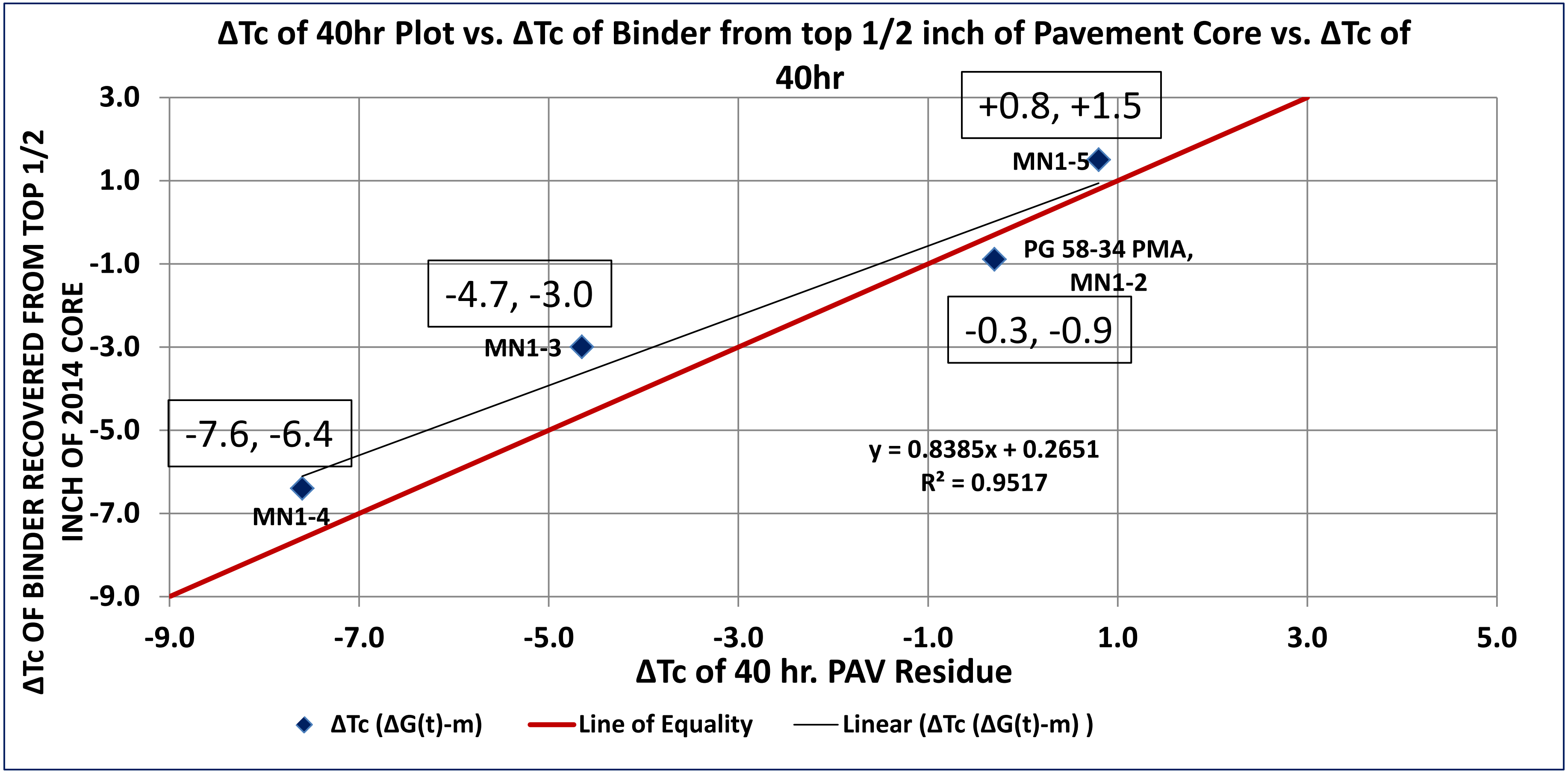


It is plausible that trying to correlate binder parameters for non-polymer modified and polymer modified binders will be less than perfect. The relationship between CTOD and ΔTc for the binders of this investigation , even with the inclusion of the PMA data are reasonable.


ΔTc of Binder from top 1/2 inch of Pavement Core vs. ΔTc of 20hr PAV Residue

The ΔTc of the 20 hr. PAV residue under predicts (i.e. is warmer) the actual ΔTc of the binder recovered from the top ½ of the field cores with the exception of the MN1-5 binder. The under prediction for the test sections with the greatest distress is on the order of 1.6°C for MN1-4, 2.5°C for MN1-3 and 1.7°C for the PMA (MN1-2).



The ΔTc of the 40 hr. PAV residue over predicts (i.e. is colder) the actual ΔTc of the binder recovered from the top ½ of the field cores with the exception of the PMA (MN1-2) binder. The prediction for the PMA and MN1-5 binders are quite close to the line of equality. The over prediction for the test sections with the greatest distress is 1.2°C for MN1-4 and 1.7°C for MN1-3. The binder recovered from the 8 year old field cores is closer to the aging predicted by the 40 hr. PAV residue but is somewhere between those two PAV aging conditions

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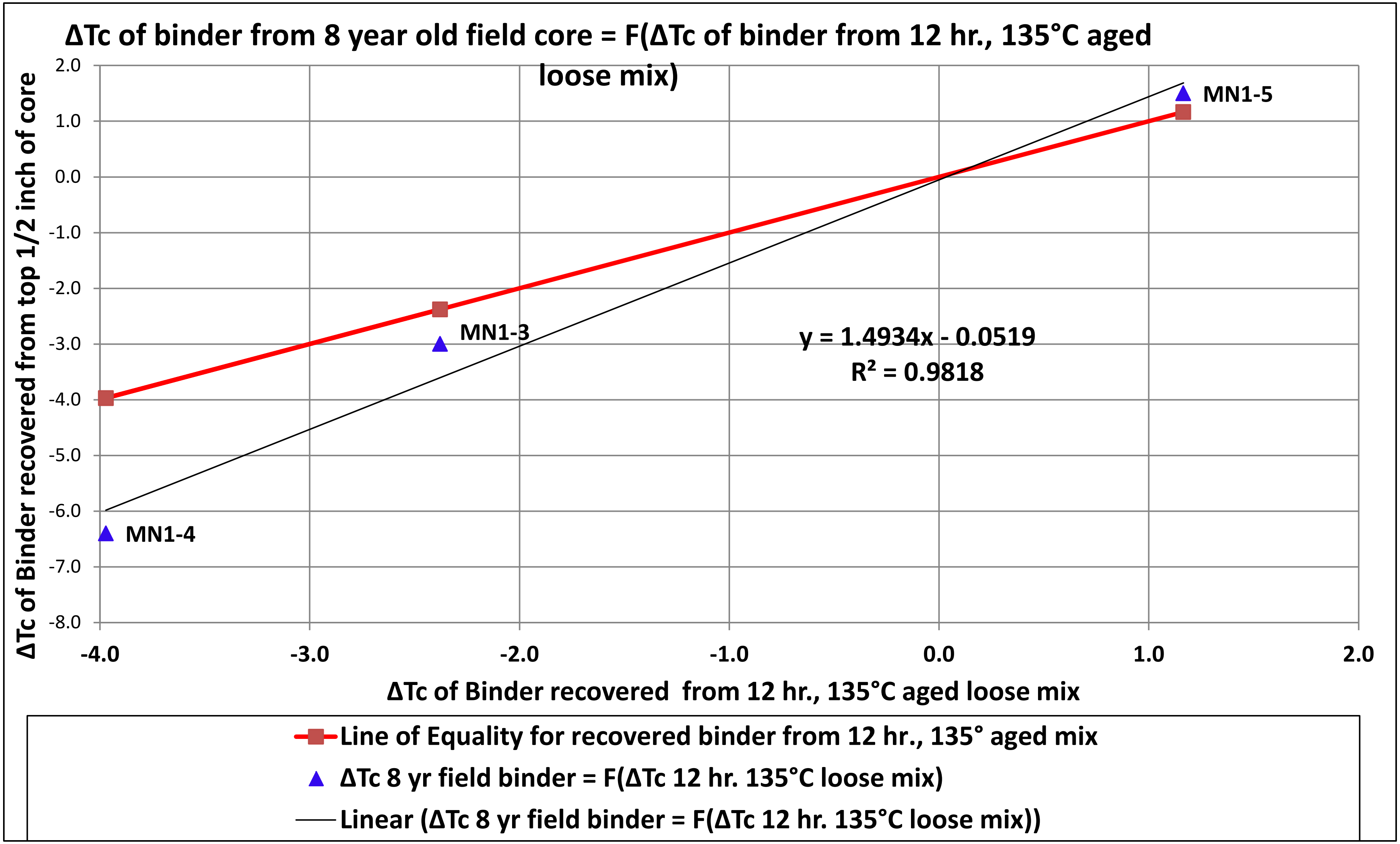
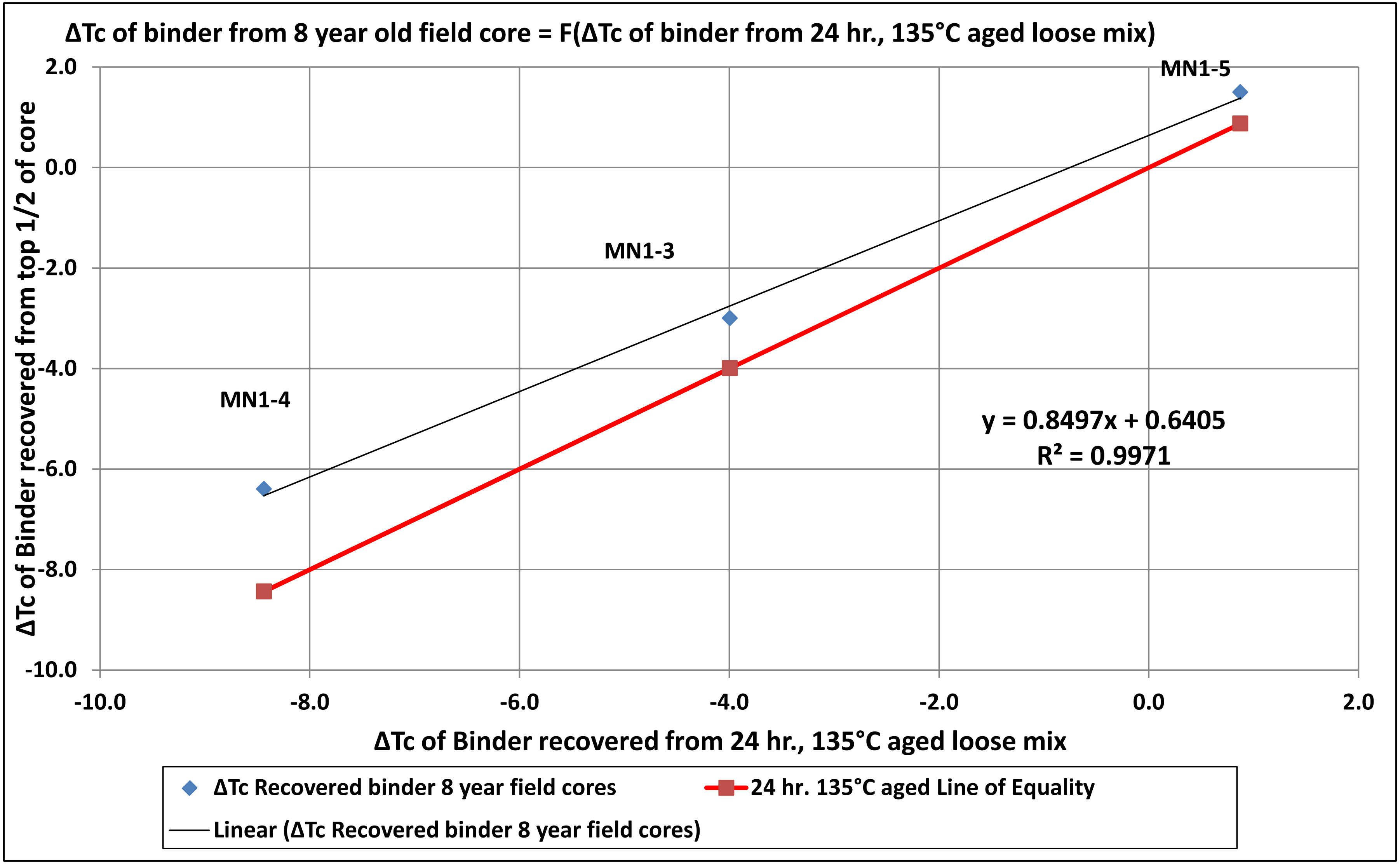


Loose mix from the 3 PG 58-28 test sections was aged @ 135°C for 12 and 24 hrs. and then compacted for mix testing. The binder was extracted from the mix specimens. The binder from the 12 hr., 135°C aged mix does not age the binder with the most severe ΔTc as much as the field.

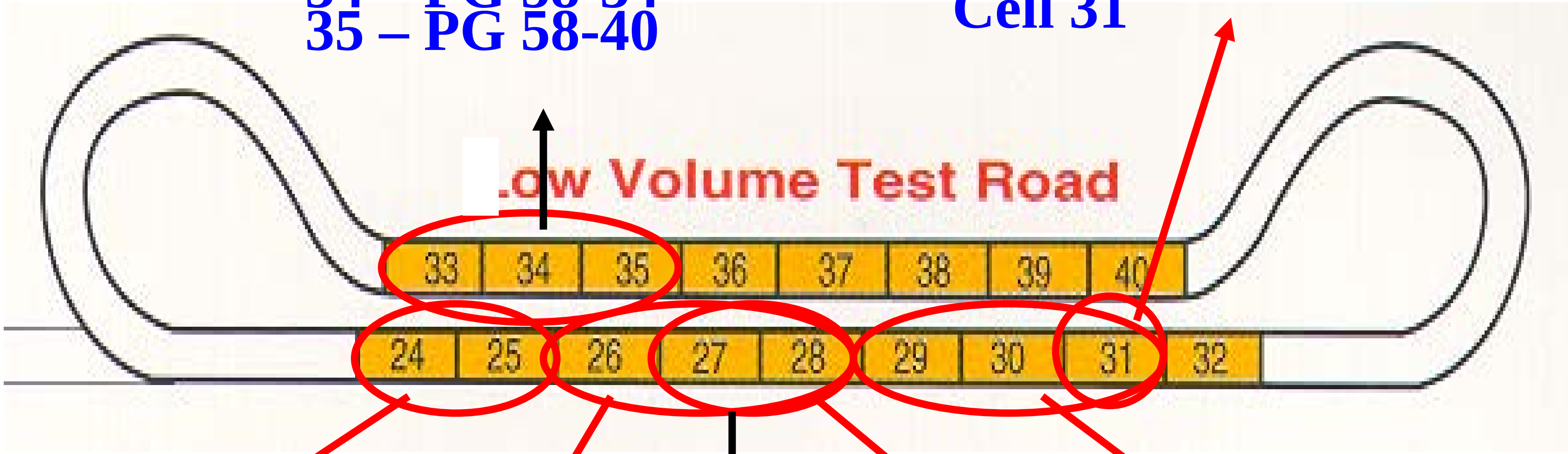


The binder recovered from the 24 hr., 135°C aged mix is uniformly more severe than the aging of the binder in the top ½ of the field cores.

MnROAD TEST OF 3 BINDERS

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

Low Volume Road Events



1999 SuperPave Cells
33 – PG 58-28
34 – PG 58-34
35 – PG 58-40

2004 Mesabi Hard Rock

Cell 31

Cells 29-31
Original – Clay Subgrad

Cells 24-25
Sand Subgrade

Cell 26
Full Depth
Clay Subgrade

Cells 27-28
3” HMA
Clay Subgrade

1999 – 2000 Oil Gravel
26 Reclaimed HMA Base
27-28 Crushed Stone Base

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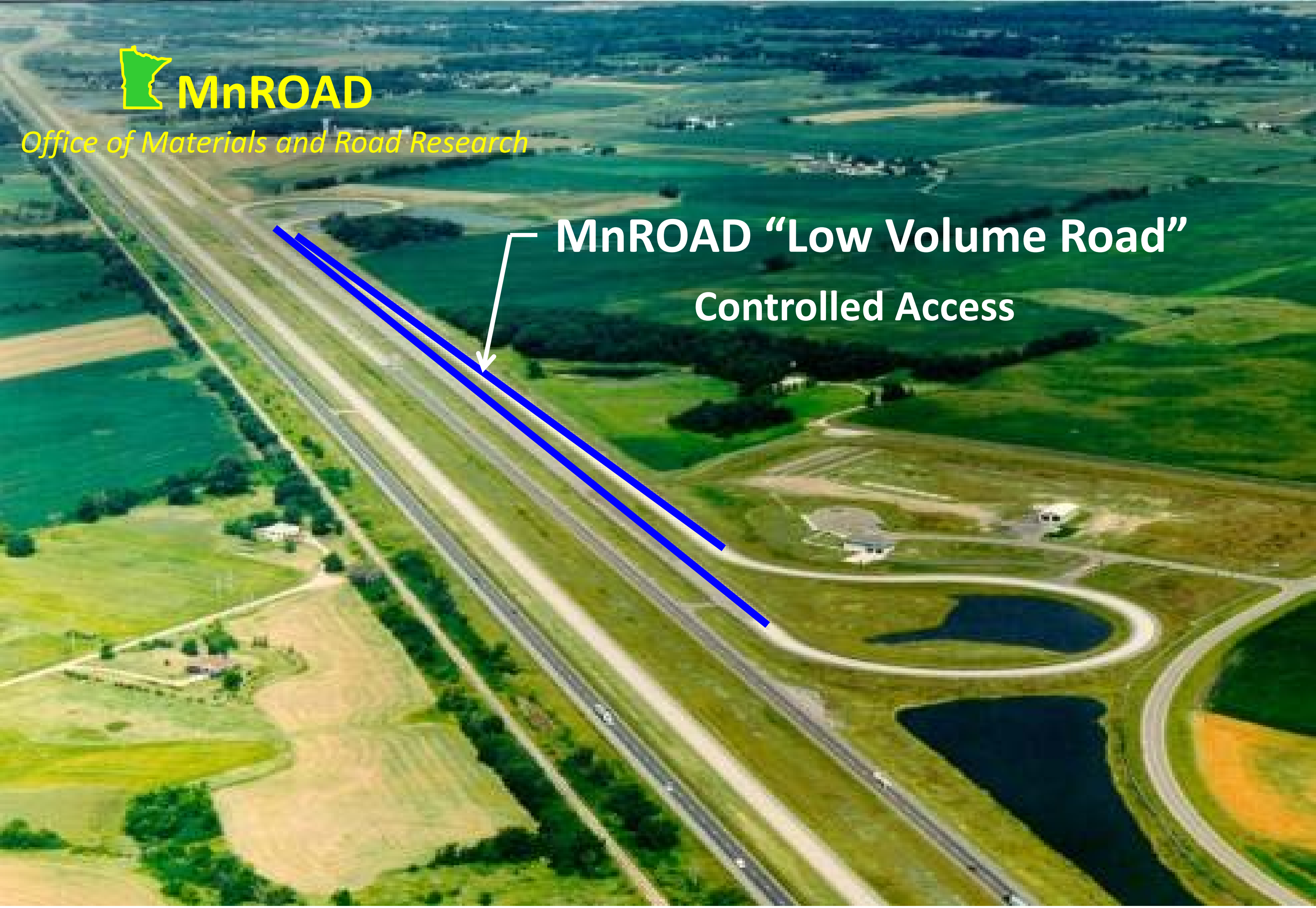


MnROAD

Office of Materials and Road Research

MnROAD “Low Volume Road”

Controlled Access

Binder grade	BBR Data from 20 hr. PAV tests performed in 2000			20 hr. PAV	20 hr. PAV	20 hr. PAV
	S critical from BBR	m critical from BBR	ΔTc (S grade - m grade)	S_critical from 4 mm DSR	m_critical_temp from 4 mm DSR	ΔTc (S grade - m grade)
58-28	-30.9	-30.3	-0.6	-31.3	-30.5	-0.8
58-34	-34.8	-35.98	1.2	-35.6	-35.4	-0.2
58-40	-44.3	-42.9	-1.4	-44.4	-42.0	-2.4

Binder grade	40 hr. PAV	40 hr. PAV	40 hr. PAV	60 hr. PAV	60 hr. PAV	60 hr. PAV
	S_critical from 4 mm DSR	m_critical_temp from 4 mm DSR	ΔTc (S grade - m grade)	S_critical from 4 mm DSR	m_critical_temp from 4 mm DSR	ΔTc (S grade - m grade)
58-28	-29.5	-26.7	-2.8	-28.5	-22.7	-5.8
58-34	-34.9	-32.4	-2.5	-33.1	-27.6	-5.5
58-40	-42.9	-34.6	-8.3	-42.9	-30.5	-12.4

Binder grade	sulfur, %	phosphorus, %	molybdenum, ppm	zinc, ppm
58-28	4.896	0.001	9	19
58-34	4.374	0.001	8	10
58-40	3.969	0.059	18	925

The data below summarizes the low temp results and shows the spread between S critical and m critical temperatures and also shows the ΔG(t)-m which is referred to in the rest of the slides as ΔTc (difference between the critical temperature values for each grade. Also show are the asphaltene , the colloidal index and the R-Value for each PAV residue and which I will discuss later

	20 hr. PAV	20 hr. PAV	20 hr. PAV	20 hr. PAV	20 hr. PAV	20 hr. PAV
BINDER SOURCE	S_critical from 4 mm DSR	m_critical_temp from 4 mm DSR	ΔG(t)-m	ASPHALTENE	Colloidal_Index	R_Value
Cell 33 PG 58-28	-31.3	-30.5	-0.8	21.9	2.559	2.456
Cell 34 PG 58-34	-35.6	-35.4	-0.2	24.3	1.994	2.601
Cell 35 PG 58-40	-44.4	-42.0	-2.4	25.5	1.681	3.347

	40 hr. PAV	40 hr. PAV	40 hr. PAV	40 hr. PAV	40 hr. PAV	40 hr. PAV
BINDER SOURCE	S_critical temp 4 mm DSR	m_critical_temp 4 mm DSR	ΔG(t)-m	ASPHALTENE	Colloidal_Index	R_Value
Cell 33 PG 58-28	-29.5	-26.7	-2.8	25.6	2.135	2.896
Cell 34 PG 58-34	-34.9	-32.4	-2.5	27.1	1.833	2.901
Cell 35 PG 58-40	-42.9	-34.6	-8.3	27.2	1.577	3.951

	60 hr. PAV	60 hr. PAV	60 hr. PAV	60 hr. PAV	60 hr. PAV	60 hr. PAV
BINDER SOURCE	S_critical temp 4 mm DSR	m_critical_temp 4 mm DSR	ΔG(t)-m	ASPHALTENE	Colloidal_Index	R_Value
Cell 33 PG 58-28	-28.5	-22.7	-5.8	27.7	1.944	3.153
Cell 34 PG 58-34	-33.1	-27.6	-5.5	29.2	1.650	3.475
Cell 35 PG 58-40	-42.9	-30.5	-12.4	28.3	1.506	[illegible]

DISTRESS DATA FROM SURVEYS CONDUCTED IN YEARS 3 AND 4

paved		9/15/1999					
3 year		12/26/2002					
BINDER SOURCE	Total transverse_cracks, ft	fatigue area	Long WP, ft	Long NWP, ft	Center line, ft	total crack length, ft (Transverse, WP & NWP)	total crack length, ft (Transverse, WP & NWP+CL)
Cell 33 PG 58-28	0	0	0	0	0	0	0
Cell 34 PG 58-34	0	0	0	0	0	0	0
Cell 35 PG 58-40	0	17	0	12	48	12	60

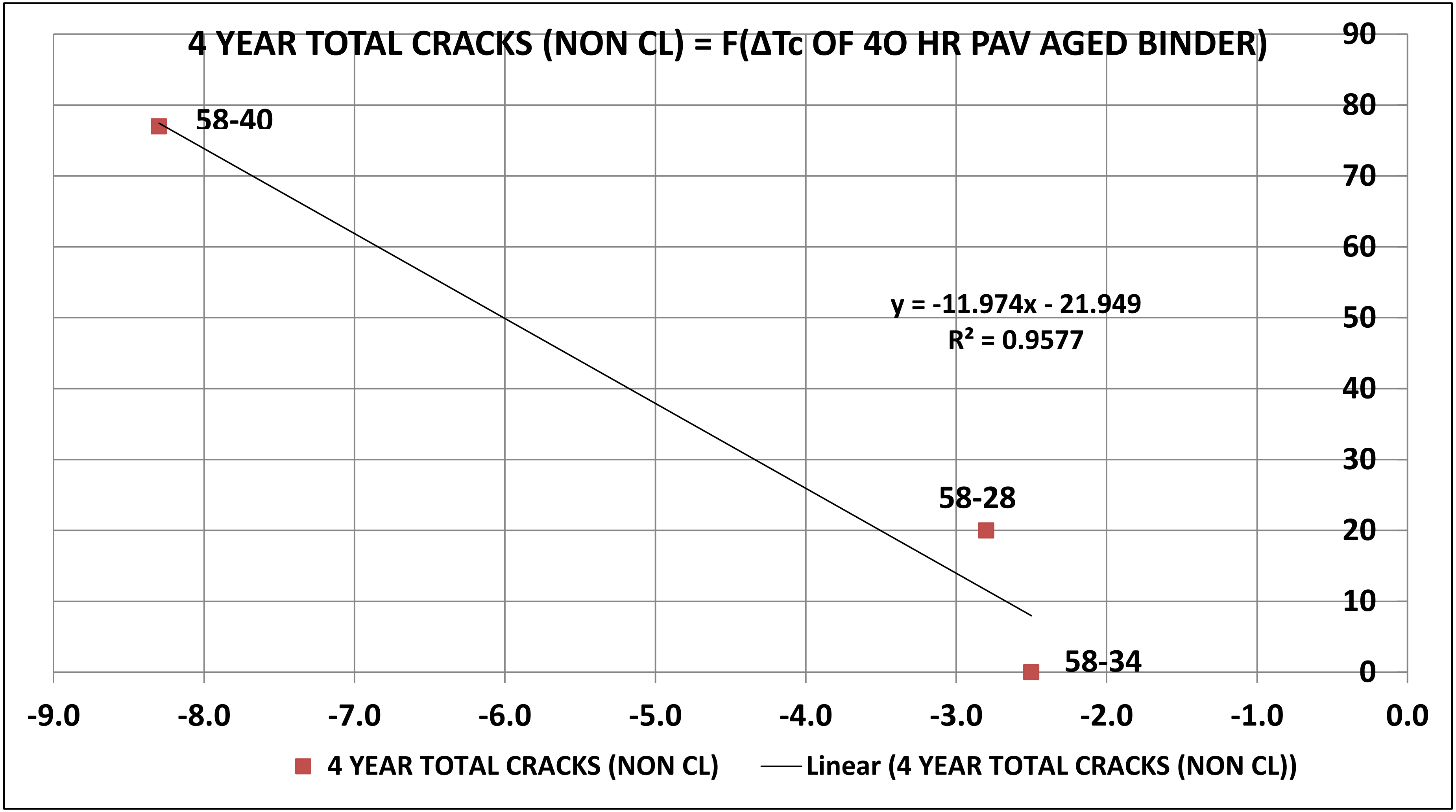
paved		9/15/1999					
4 year		10/15/2003					
BINDER SOURCE	Total transverse_cracks	fatigue area	Long WP	Long NWP	Center line	total cracks (Transverse, WP & NWP)	total cracks (Transverse, WP & NWP+CL)
Cell 33 PG 58-28	20	0	0	0	0	20	20
Cell 34 PG 58-34	0	0	0	0	0	0	0
Cell 35 PG 58-40	41	17	36	0	476	77	553

DISTRESS DATA FROM SURVEYS CONDUCTED 5.5 AND 7.5 YEARS

paved		9/15/1999					
5.5 year		5/17/2005					
BINDER SOURCE	Total transverse_ cracks	fatigue area	Long WP	Long NWP	Center line	total cracks (Transverse, WP & NWP)	total cracks (Transverse, WP & NWP+CL)
Cell 33 PG 58-28	126	0	0	0	171	126	297
Cell 34 PG 58-34	10	0	0	3	0	13	13
Cell 35 PG 58-40	555	106	362	7	492	924	1416

paved		9/15/1999					
7.5 year		4/16/2007					
BINDER SOURCE	Total transverse_ cracks	fatigue area	Long WP	Long NWP	Center line	total cracks (Transverse, WP & NWP)	total cracks (Transverse, WP & NWP+CL)
Cell 33 PG 58-28	149	24	3	0	223	152	375
Cell 34 PG 58-34	20	0	6	0	0	26	26
Cell 35 PG 58-40	1050	281	651	12	492	1713	2205

CRACKING AFTER 4 YEARS OF SERVICE DOESN’T LOOK TOO OMINOUS



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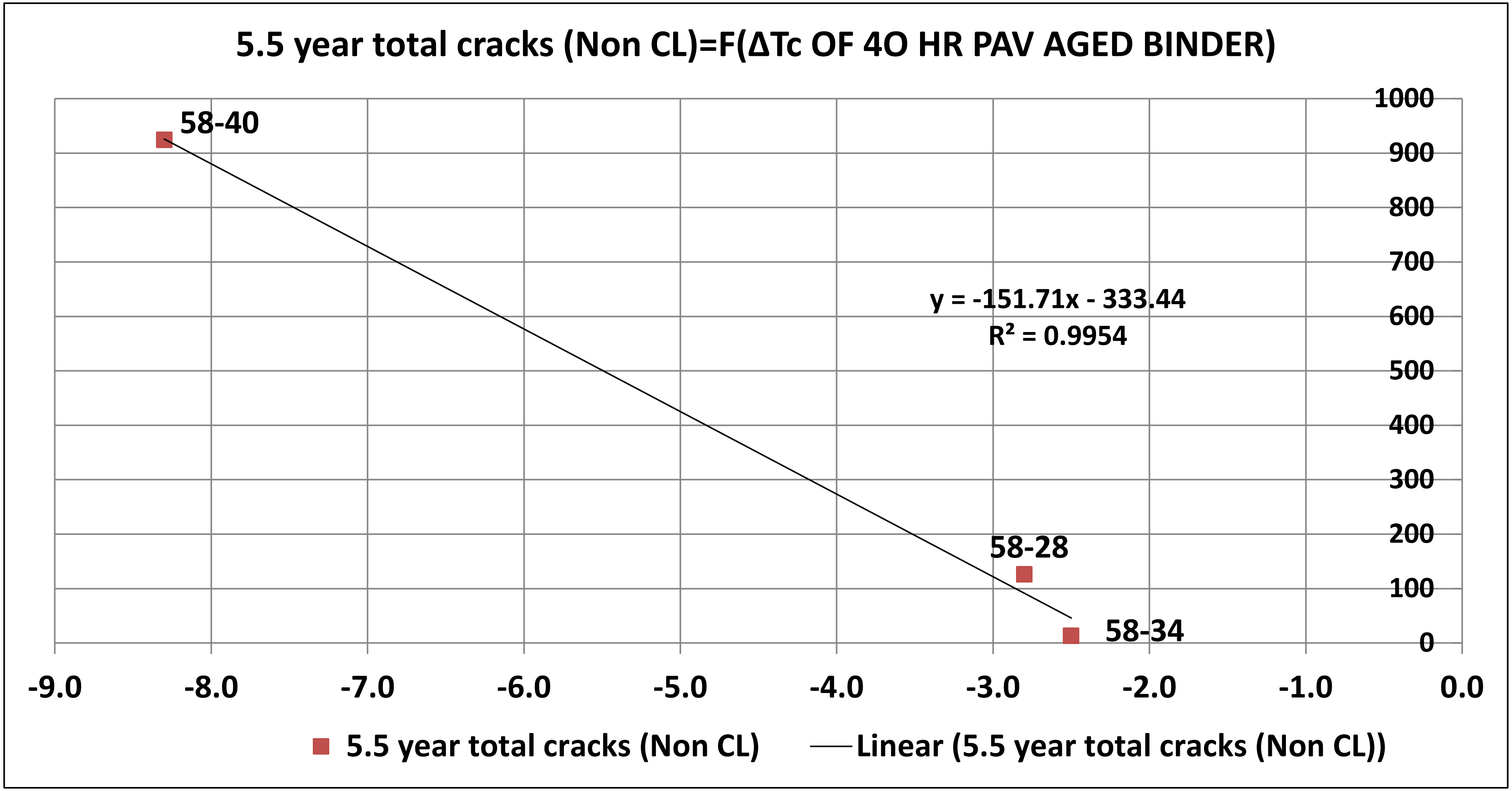
BY YEAR 5.5 THINGS HAVE GOTTEN WORSE

RATIO CRACKS IN YEAR 5.5 TO YEAR 4			
BINDER	YEAR 5.5	YEAR 4	RATIO
58-28	126	20	6.3
58-34	13	0	∞
58-40	924	77	12



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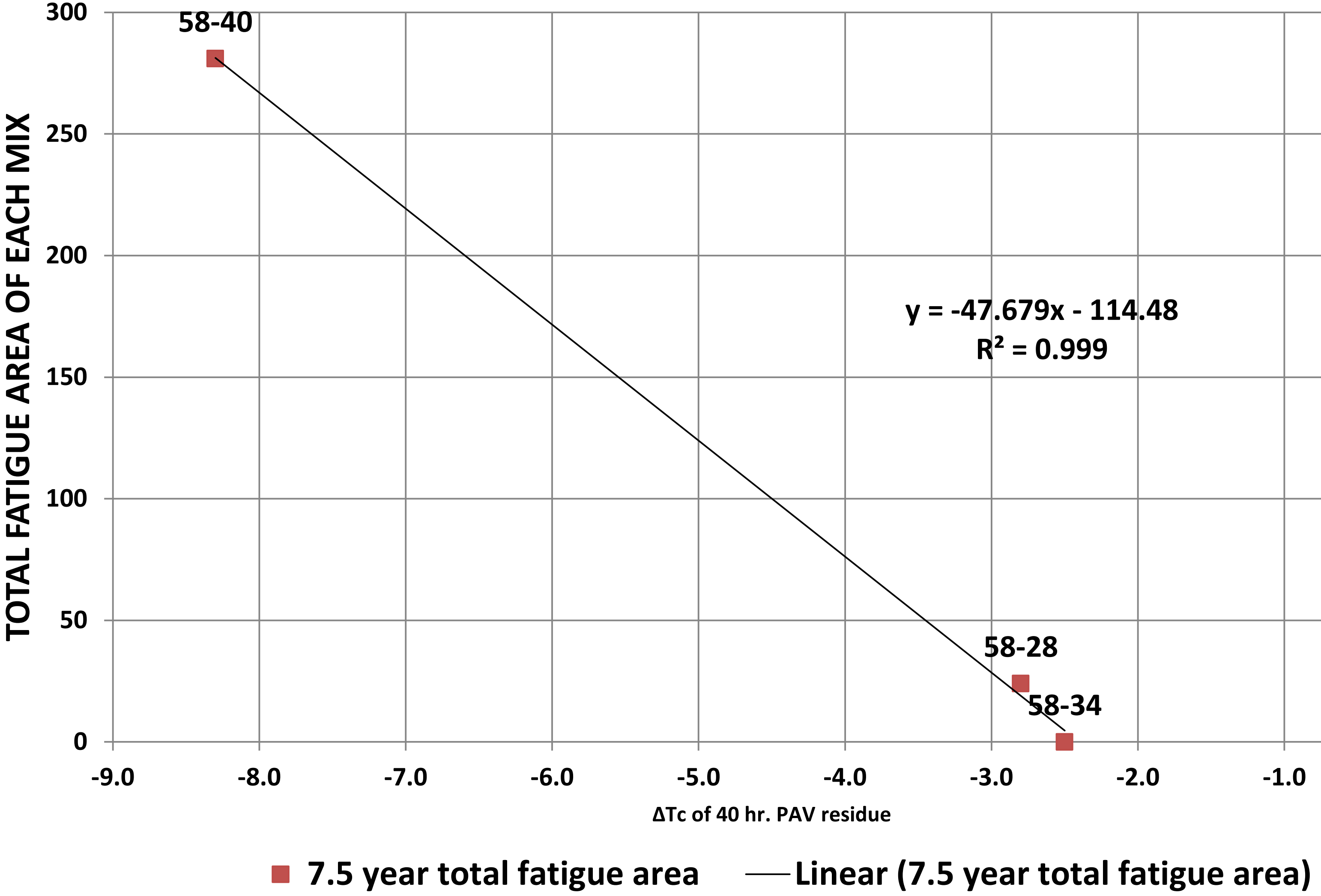
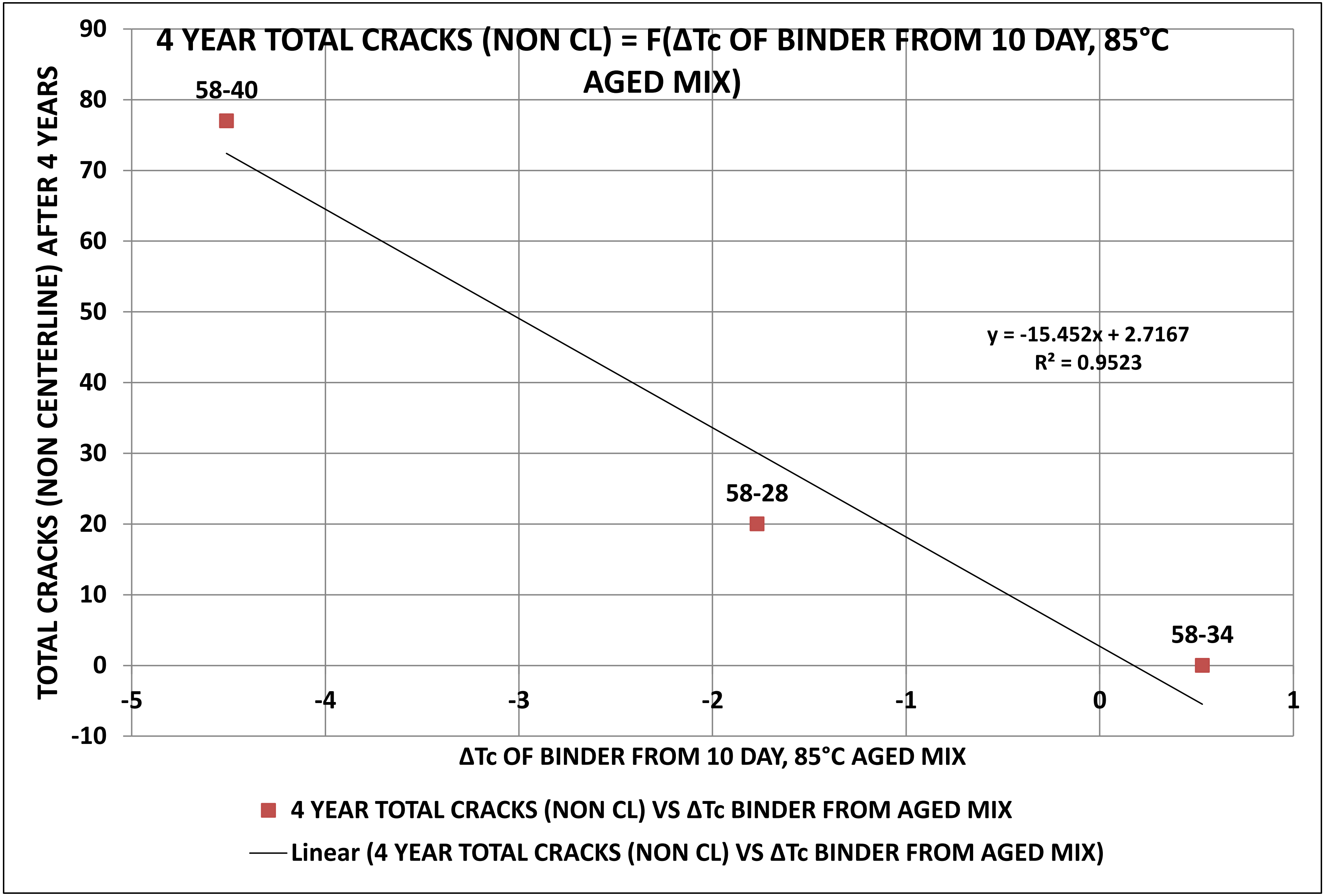
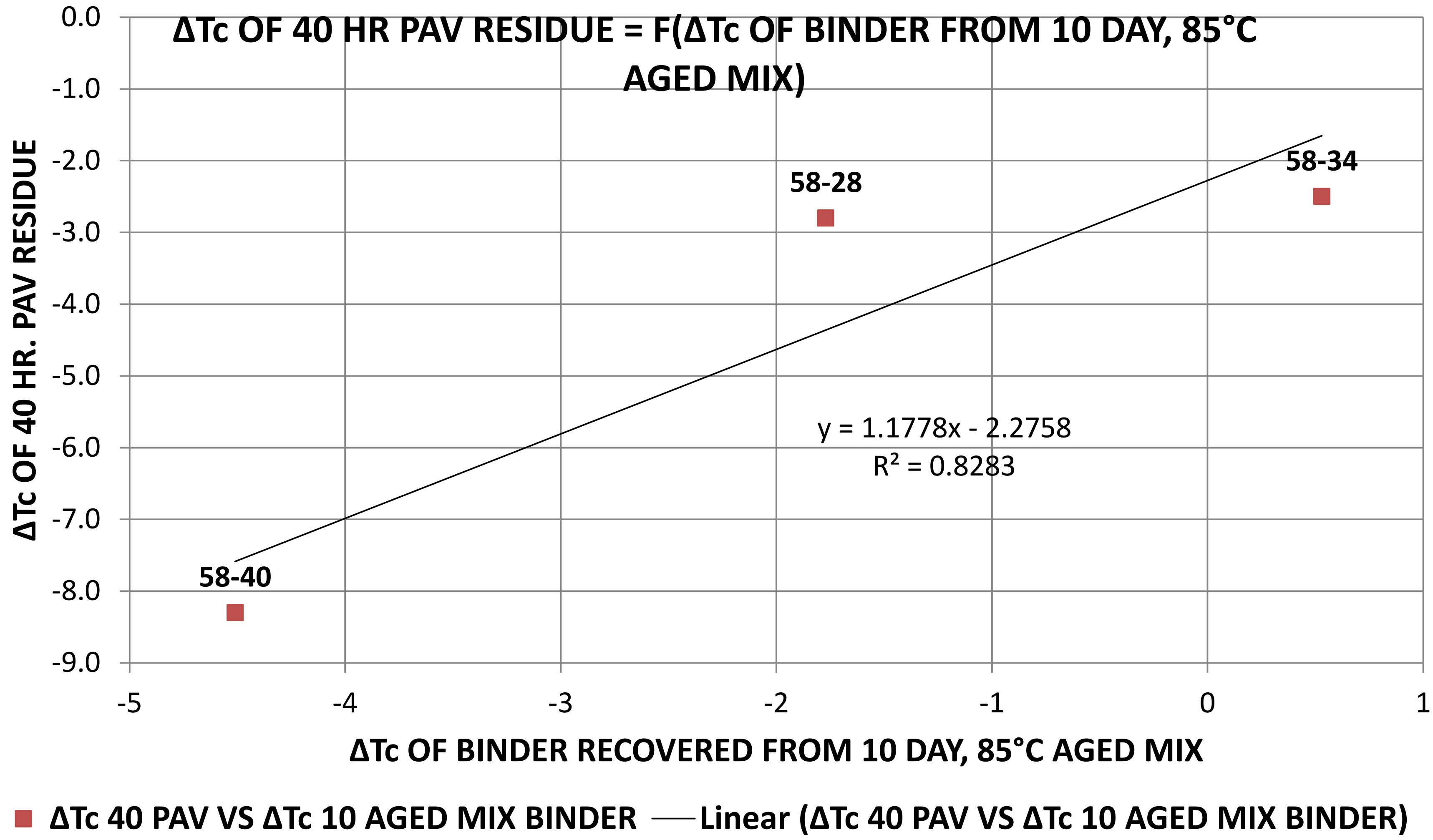
7.5 year total fatigue area= F(ΔTc 40 hr PAV)




4 YEAR TOTAL CRACKS (NON CL) = F(ΔTc OF BINDER FROM 10 DAY, 85°C AGED MIX)
58-40
58-28
58-34
y = -15.452x + 2.7167
R² = 0.9523
TOTAL CRACKS (NON CENTERLINE) AFTER 4 YEARS
90
80
70
60
50
40
30
20
10
0
-10
-5
-4
-3
-2
-1
0
1
ΔTc OF BINDER FROM 10 DAY, 85°C AGED MIX
4 YEAR TOTAL CRACKS (NON CL) VS ΔTc BINDER FROM AGED MIX
Linear (4 YEAR TOTAL CRACKS (NON CL) VS ΔTc BINDER FROM AGED MIX)



In the winter of 2000 MTE performed 5 and 10 day aging of compacted specimens @ 85°C and then performed IDT low temperature cracking tests. We also extracted binder from both sets of aged specimens and determined low temperature S & m on the BBR. The ΔTc values were calculated for this presentation.

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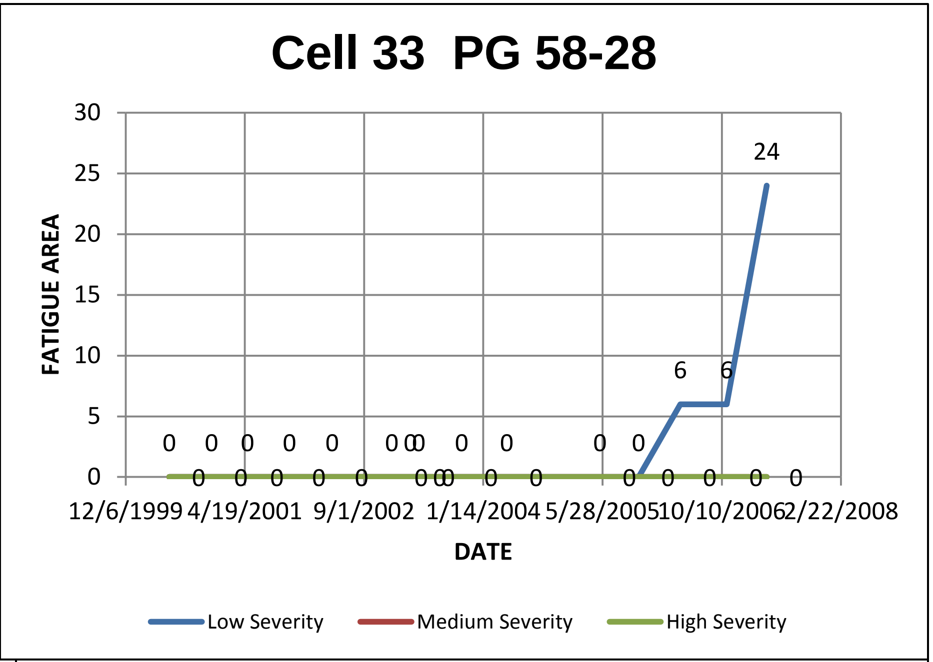

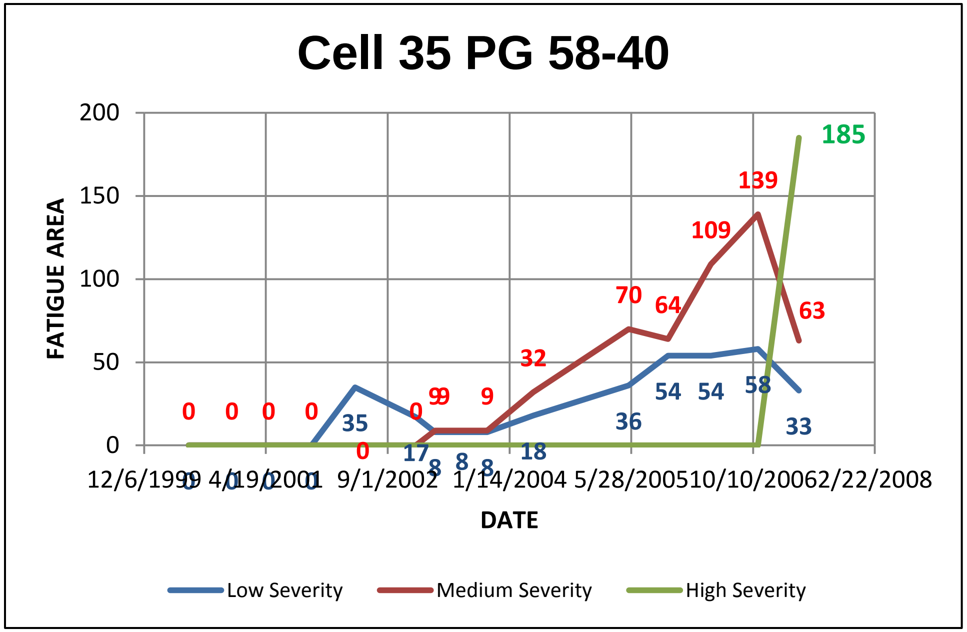

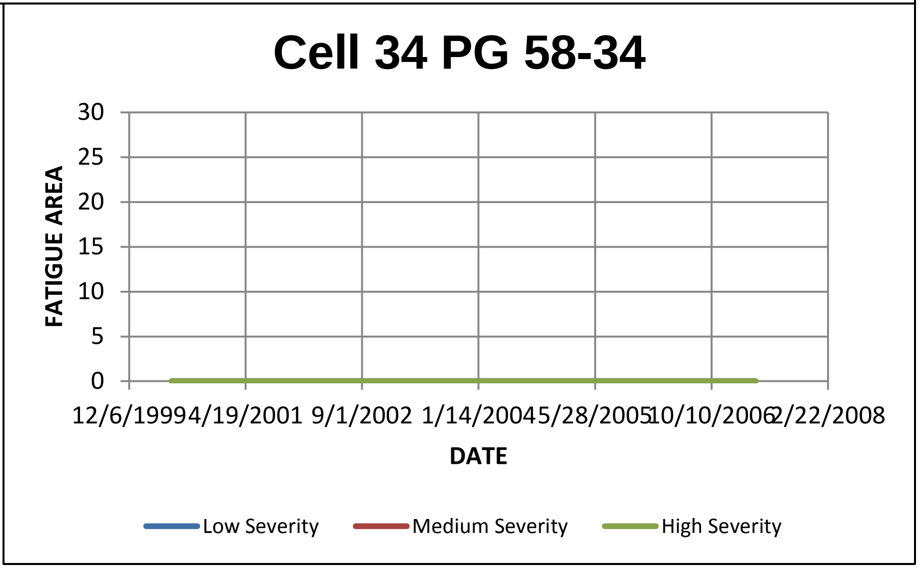

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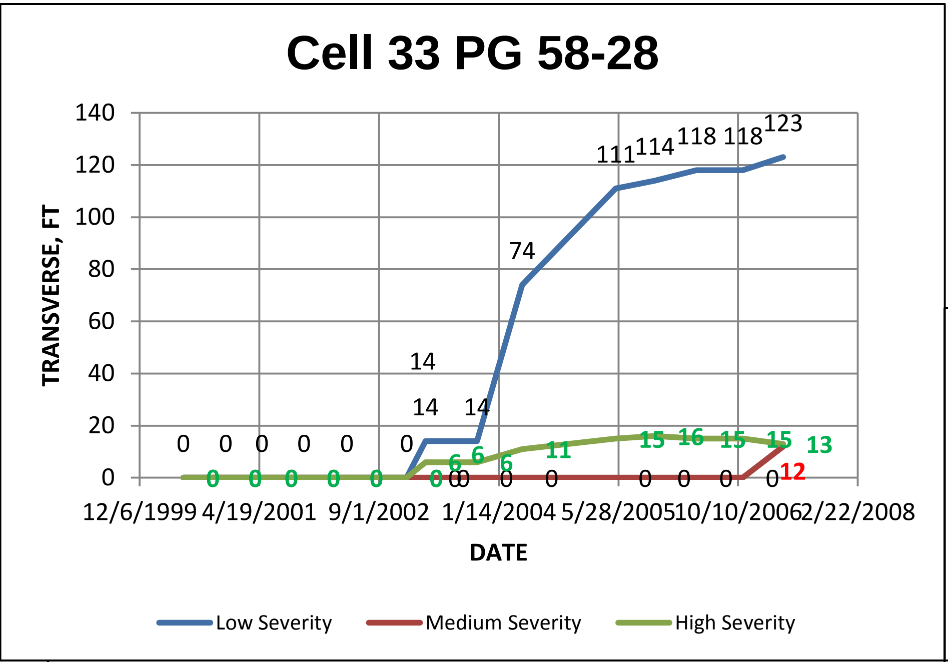

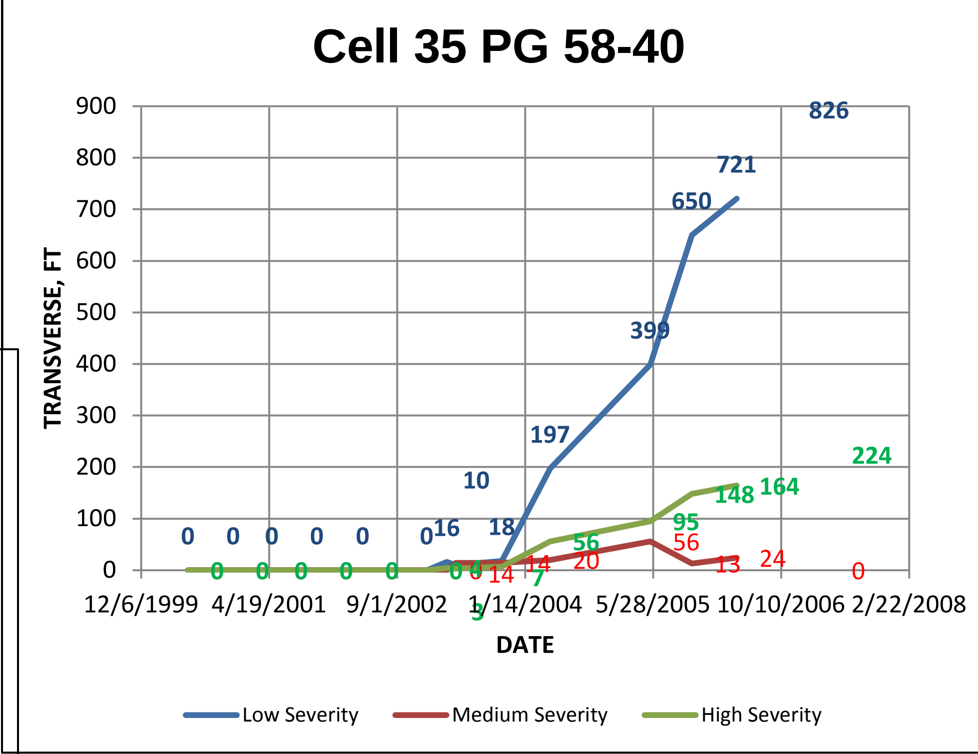

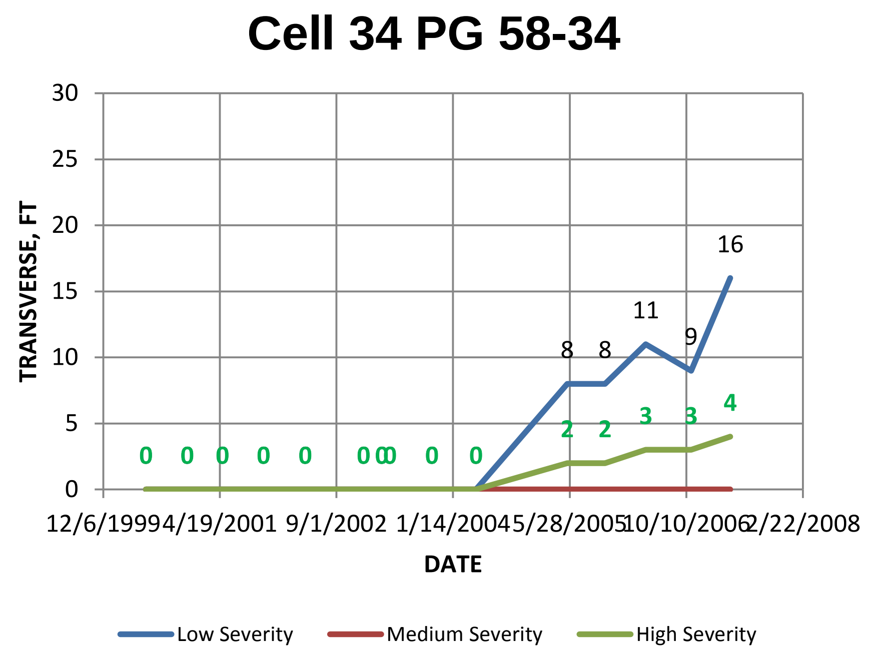

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CRACK MAPPING OF MnROAD TEST SECTIONS

SUMMARY OF ΔTc RESULTS ON SEVERAL DIFFERENT BLENDS

1. COMMERCIAL MOTOR OILS,

2 REOB SOURCES

3. IMPACT OF DIFFERENT BINDER SOURCES WITH REOB

SUMMARY OF ΔTc RESULTS ON SEVERAL DIFFERENT BLENDS

COMMERCIAL MOTOR OILS, ~~2 REOB SOURCES, AND IMPACT OF DIFFERENT BINDER SOURCES WITH REOB~~

Blend	TRUE GRADE	UNAGED	ΔTc	RTFO	ΔTc	20 HR. PAV	ΔTc	40 HR. PAV	ΔTc
PG 64-22 base	PG 66.3-27.1	S=-32.2, m=-35.3	+3.1	S=-29.5, m=-31.8	+2.3	S=-27.3, m=-27.1	-0.2	S=-26.8, m=-25.7	-1.2
92% 64-22, 8% Valvoline 10W-40	PG 55.2-33.6	S=-41.3, m=-43.1	+1.8	S=-38.4, m=-38.9	+0.5	S=-36.0, m=-33.6	-2.4	S=-33.7, m=-29.1	-4.6
92% 64-22, 8% Mobil 1 10W-40	PG 55.8-33.7	S=-42.4, m=-44.8	+2.4	S=-37.2, m=-37.9	+0.7	S=-38.0, m=-33.7	-4.3	S=-36.3, m=-29.3	-7.0

These blends were made and tested to make the point that the issue as I see it is not the re-refined engine oil residue, it is inherent in the chemistry of the base oil used to produce the engine oil. We need to focus on the causative factor and come up with a test or tests that will identify when a problem is likely to exist. Mobil 1 might be great oil, but it is not a very good asphalt modifier.

SUMMARY OF ΔTc RESULTS ON SEVERAL DIFFERENT BLENDS ~~COMMERCIAL MOTOR OILS~~, **2 REOB SOURCES**, ~~AND IMPACT OF DIFFERENT BINDER SOURCES WITH REOB~~

Blend	TRUE GRADE	UNAGED	ΔTc	RTFO	ΔTc	20 HR. PAV	ΔTc	40 HR. PAV	ΔTc
PG 64-22 base	PG 66.3-27.1	S=-32.2, m=-35.3	+3.1	S=-29.5, m=-31.8	+2.3	S=-27.3, m=-27.1	-0.2	S=-26.8, m=-25.7	-1.2
92% 64-22, 8% REOB #1	PG 62.5-28.8	S=-36.5, m=-38.2	+1.7	S=-33.7, m=-33.7	+0.1	S=-32.4, m=-28.8	-3.6	S=-30.9, m=-25.7	-5.1
92% 64-22, 8% REOB #2	PG 60.9-30.6	S=-37.0, m=-37.8	+0.8	S=-35.8, m=-36.4	+0.6	S=-32.7, m=-30.6	-2.2	S=-32.6, m=-27.7	-4.9

[redacted]

Above is data from 2 sources of REOB blended into the same binder at the same loadings. At least for this binder and these sources the ΔTc results are similar, BUT you can see that after 40 hr. PAV aging source #2 better low temperature properties. Note that between the unaged low temperature properties and the RTFO low temperature properties source #1 lost 1.6°C in ΔTc compared to only 0.2°C for source #2. There are differences in these products although in the final analysis those differences may not matter to long term performance

SUMMARY OF ΔTc RESULTS ON SEVERAL DIFFERENT BLENDS ~~COMMERCIAL MOTOR OILS~~, ~~2 REOB SOURCES~~, AND **IMPACT OF DIFFERENT BINDER SOURCES WITH REOB**

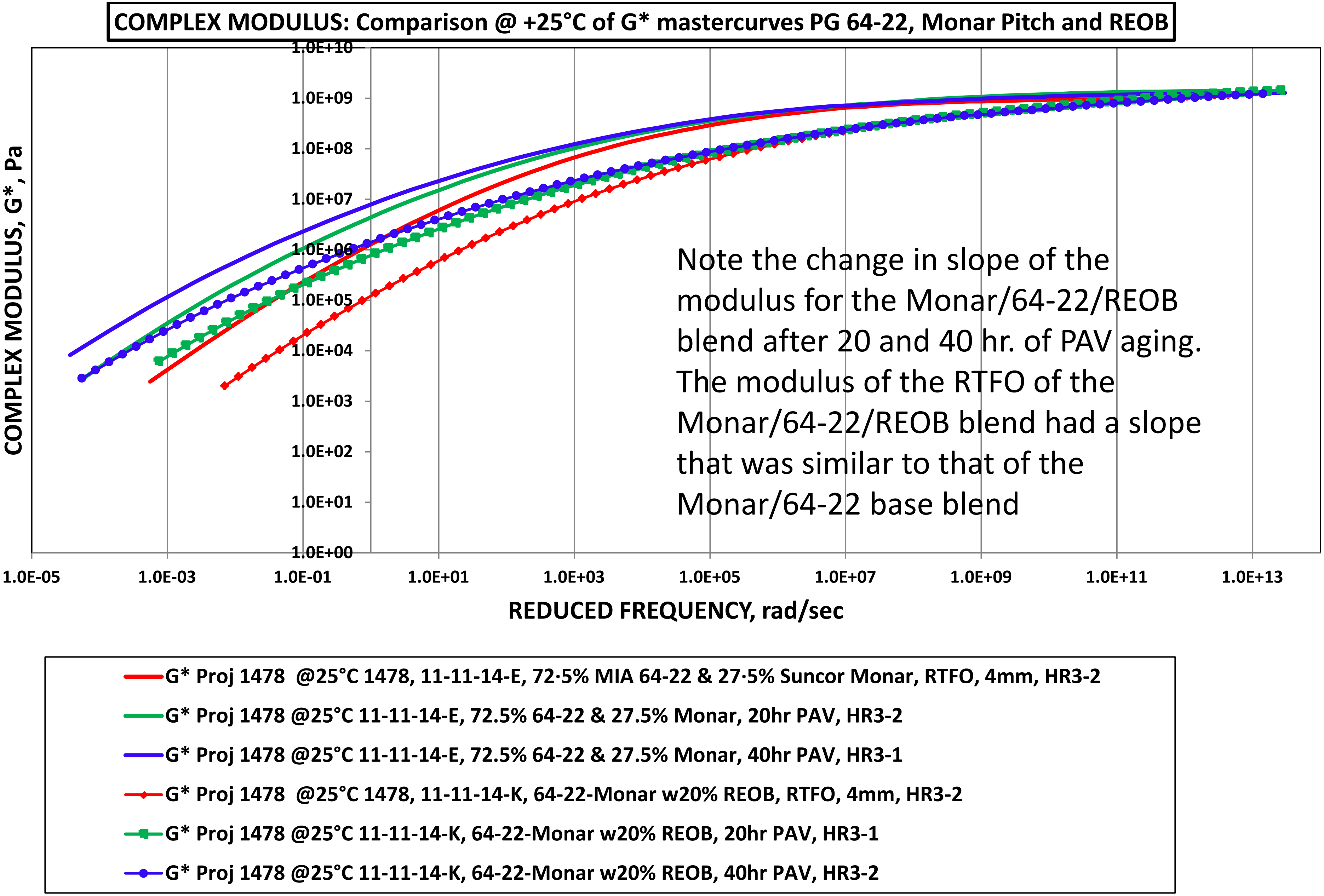
Blend	TRUE GRADE	UNAGED	ΔTc	RTFO	ΔTc	20 HR. PAV	ΔTc	40 HR. PAV	ΔTc
PG 64-22 NEW BARGE	PG 64.3-28.2	S=-31.9, m=-35.1	+3.3	S=-29.0, m=-31.9	+2.9	S=-28.2, m=-28.8	+0.6	S=-26.7, m=-26.0	-0.6
92% PG 64-22 NEW BARGE + 8% REOB #1	PG 60.0-30.8	S=-36.5, m=-39.2	+2.7	S=-34.4, m=-35.5	+1.2	S=-32.7, m=-30.8	-1.9	S=-31.4, m=-28.1	-3.3

The data below is for a different supply of 64-22 compared to the 64-22 of the previous slide. Comparing the ΔTc for this source shows that 40 hr. PAV ΔTc result is better by 1.8°C. You should also note that the ΔTc of the base 64-22 for the new source is better by 0.6°C. The impact of source on performance is a factor that needs to be examined. Hence the need for a test that can identify when there are likely to be issues.

BLEND OF STRAIGHT RUN ASPHALT, ASPHALT PITCH AND REOB TO MAKE A PG 58-28

Sample ID	Description	TRUE GRADE	ΔTc	Asphaltenes	Resins	Cyclics	Saturates	CI
11-11-14-E	20hr PAV, 72.5% 64-22, 27.5% Monar	72.9-20.9	0.0	22.9	36.8	36.0	4.3	2.676
11-11-14-E	40hr PAV, 72.5% 64-22, 27.5% Monar		-1.6	26.1	37.6	31.9	4.4	2.279
11-11-14-K	20hr PAV, 64-22, Monar, 20% REOB	60.0-29.0	-7.6	20.9	39.6	28.8	10.6	2.171
11-11-14-K	40hr PAV, 64-22, Monar, 20% REOB		-12.2	23.8	38.6	26.9	10.7	1.899

Monar is an asphalt pitch resulting from the propane deasphalting of refinery residuum. This pitch that is no longer being produced, but there are other sources of this type of material. Blends of this type have been made in the past and sold as paving grade binders. You will note that this blend successfully yielded a PG 58-28 and only required 72.9% of a straight run asphalt. You will note that the ΔTc of the Monar/64-22 blend did not have excessively negative values of ΔTc.



Note the change in slope of the modulus for the Monar/64-22/REOB blend after 20 and 40 hr. of PAV aging. The modulus of the RTFO of the Monar/64-22/REOB blend had a slope that was similar to that of the Monar/64-22 base blend

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IMPACT OF PARAFFINIC OIL ON PAV PROPERTIES OF PMA BINDERS

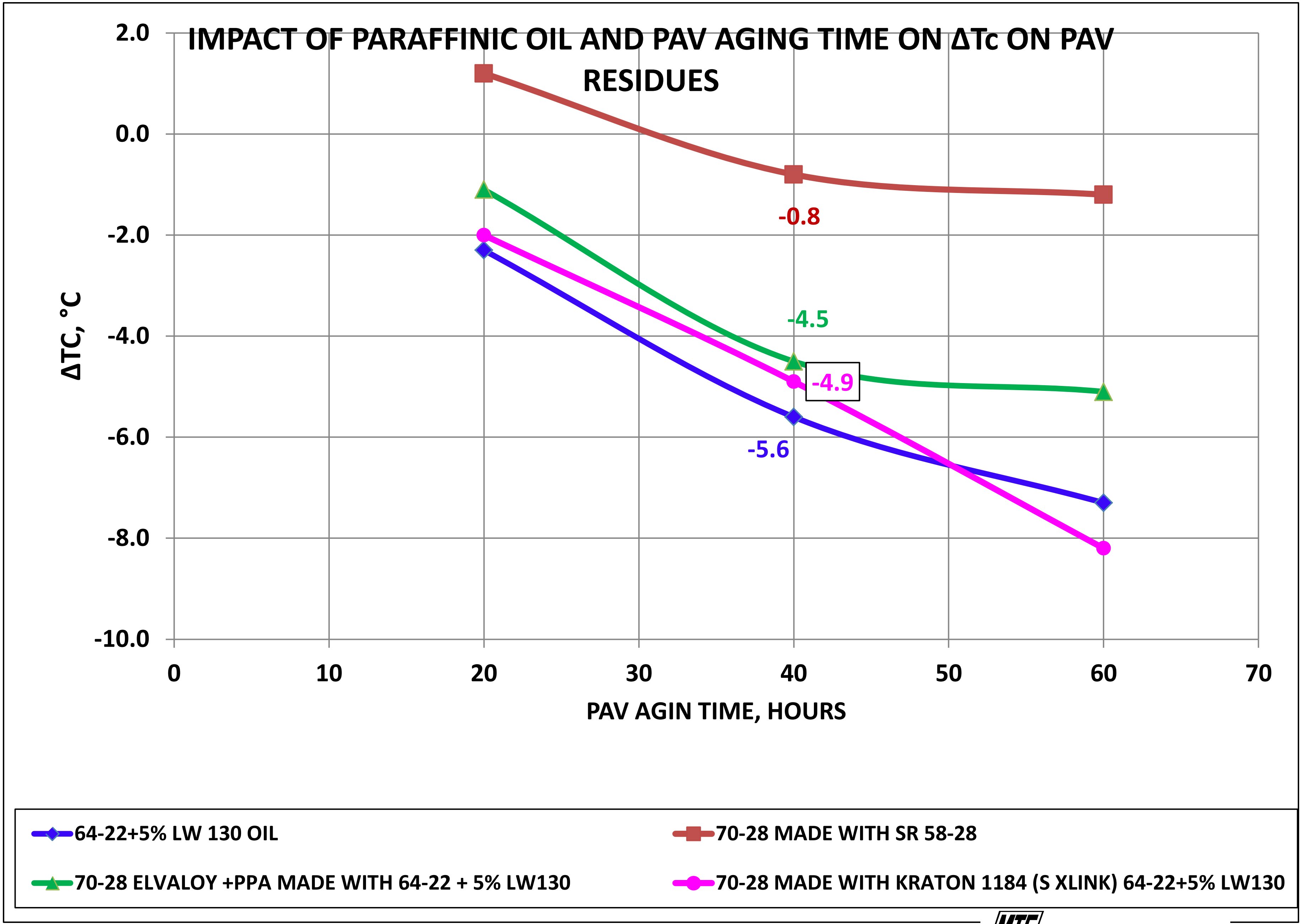
For the following blends we used a paraffinic base oil and not REOB mainly because one of the PMA materials contained PPA and we have previously shown that REOB interferes with PPA chemistry causing a need to use more PPA to achieve desired results.

We have also shown that the paraffinic oils impart similar properties to asphalt binders as does REOB

RESULTS FOR PMA BINDERS PRODUCED FROM PG 64-22 +5% LW 130 PARAFFINIC OIL

	20 HR. PAV			40 HR. PAV			60 HR. PAV		
BINDER	S CRITICAL	m CRITICAL	ΔTc	S CRITICAL	m CRITICAL	ΔTc	S CRITICAL	m CRITICAL	ΔTc
PG 58-28 BLEND (64-22 + 5% LW130 OIL	-33.6	-31.3	-2.3	-32.7	-27.1	-5.6	-32.0	-24.7	-7.3
PG 70-28 USING PG 58-28	-32.5	-33.7	1.2	-30.7	-29.9	-0.8	-30.7	-29.5	-1.2
PG 70-28 MADE FROM PG 58-28 (PG 64-22 + 5% LW 130) ELVALOY + PPA	-34.2	-33.1	-1.1	-33.1	-28.6	-4.5	-32.1	-27	-5.1
PG 70-28 MADE FROM PG 58-28 (PG 64-22 + 5% LW 130)SBS 1184 + SULFUR	-35.6	-33.6	-2.0	-34.7	-29.8	-4.9	-33.1	-24.9	-8.2

A total of 60 hrs. of PAV aging was conducted just to have 3 data points to plot trends. The relevant data is still the ΔTc of the 40 hr. PAV residue



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RECOVERED BINDER FROM WI STH 53, BUILT SEPT 1994, 4 YEAR OLD CORE TEST RESULTS

DATA FROM BINDER RECOVERED FROM WI HWY 53, 4 YEAR OLD PAVEMENT			
BINDER	BBR, S CRITICAL	BBR m CRITICAL	ΔTc
58-28	-34.5	-35.4	0.9
58-34 (58-28 + 3% SUNPAR 300 PARAFFINIC OIL)	-38.1	-33	-5.1
58-40 (58-28 + 5% SUNPAR 300 PARAFFINIC OIL)	-43.1	-34.9	-8.2

I think this effort has told me several things

1. **There are additives that can negatively impact mix performance because of their impact on the extent to which they accelerate the loss of m-value in the binder.**

2. **Based on the performance of binders containing REOB on Olmsted county 112 and at MnROAD I think the link between paraffinic oil modifiers and an accelerated rate of pavement distress, especially after year 4, is clear.**

3. **Even without deleterious additives binders age at different rates as evidenced by the other 3 virgin binders in the Olmsted County 112 study.**

4. **The Olmsted binder MN1-3 PG 58-28 is aging poorly compared to the MN1-5 PG 58-28, but given the superior quality of the crude used to produce the MN1-5 binder perhaps the MN1-3 PG 58-28 is just performing as we would expect an average quality crude source binder to perform.**

5. **The PG 58-40 binder at MnROAD and the blends that our company produced for the WI Hwy 53 PG 58-34 and PG 58-40 are examples of the unintended consequences of not understanding how the chemistry of the blend stocks would impact the long term performance of the mix. Now that we aware of those consequences we should not keep repeating the same mistakes.**

6. We should be able to control the introduction of deleterious additives into binders and if we have a test that can discern this we should use it. That is if REOB or other blend stocks cause a long term aging problem relative to the binder to which the additive is being added why should we be using them?

7. We can’t control the natural aging response of the binder. We have to live with what Mother Nature gives us, but we ought not purposely make it worse with the additives we use. A binder such as the MN1-3 PG 58-28 is an example; it is showing fairly high levels of distress, but we also know that it did not contain any deleterious additives. However with a test such as the ΔTc of the 40 hr. PAV we would at least know that this is a pavement to monitor for signs of deterioration . A judicious monitoring of the rate at which the ΔTc is degrading over time would be a good indicator of how closely we approaching the 40 hr. PAV result.

8. We can’t build every pavement with superior quality binder. There isn’t enough to go around and transportation cost would be prohibitive, but we can monitor the binders we do use for potential problems and make sure we aren’t creating problems through the additives that we use to produce those binders.

QUESTIONS & DISCUSSION