SOME PROPERTIES OF BINDERS WITH AND WITHOUT REOB WITH RAP &RAP+RAS NHDOT & DATA FROM VERMONT CORES

BINDER ETG MEETING

SEPTEMBER 15, 2015, OKLAHOMA CITY

WITH THANKS TO

JO DANIEL—UNH

BERAN BLACK—NH DOT

BILL AHEARN—VT DOT

BACKGROUND

- Study originally conceived by UNH and NH DOT to investigate comparative aging behavior of binders in mixtures produced in a hot mix plant and mixtures produced in a laboratory and aged in a controlled setting
- All mixtures were sent to NH DOT for extraction and recovery followed by PAV aging of the recovered binders
  - 3 recovered binders were also RTFO aged prior to PAV aging—those mixtures were reproduced as will be noted in this discussion

BACKGROUND

- With two exceptions all mixtures were produced as matched pairs of samples produced at the NH DOT Lab and an “identical” mix produced by a local HMA contractor

BACKGROUND--mixture compositions

Binder grade/source	NM aggregate	% RAP binder replacement	% RAS binder replacement	Comments Odd # =DOT mix Even #=Contractor HMA mix
PG 58-28-A	½ inch	18.9%		Mix S19/S20 **(1/2)**
PG 52-34-A	½ inch	18.9%		Mix S21/S22 S3/S4
PG 58-28-A	½ inch	28.3%		Mix S23&S5/S6
PG 52-34-A	½ inch	28.3%		S7/S8
PG 58-28-A	½ inch	27.8%		HMA Plant S9
PG 52-34-A	½ inch	7.4%	11.1%	HMA Plant S10
PG 58-28-B	¾ inch	31.9%		S11/S12
PG 52-34-B	¾ inch	31.9%		S13/S14
PG 58-28-B	¾ inch	8.3%	12.5%	S15/S16
PG 52-34-B	¾ inch	8.3%	12.5%	S17/S18

BACKGROUND—Binder Source Comments

- Crude source on binders is not known to me
  - PG 58-28-A is so designated because the binder from that supplier was only used for ½ inch mixes
  - PG 52-34-A is so designated because the binder from that supplier was only used for ½ inch mixes; there is evidence based on zinc level that this sample could have contained ≈2-3% REOB

BACKGROUND—Binder Source Comments

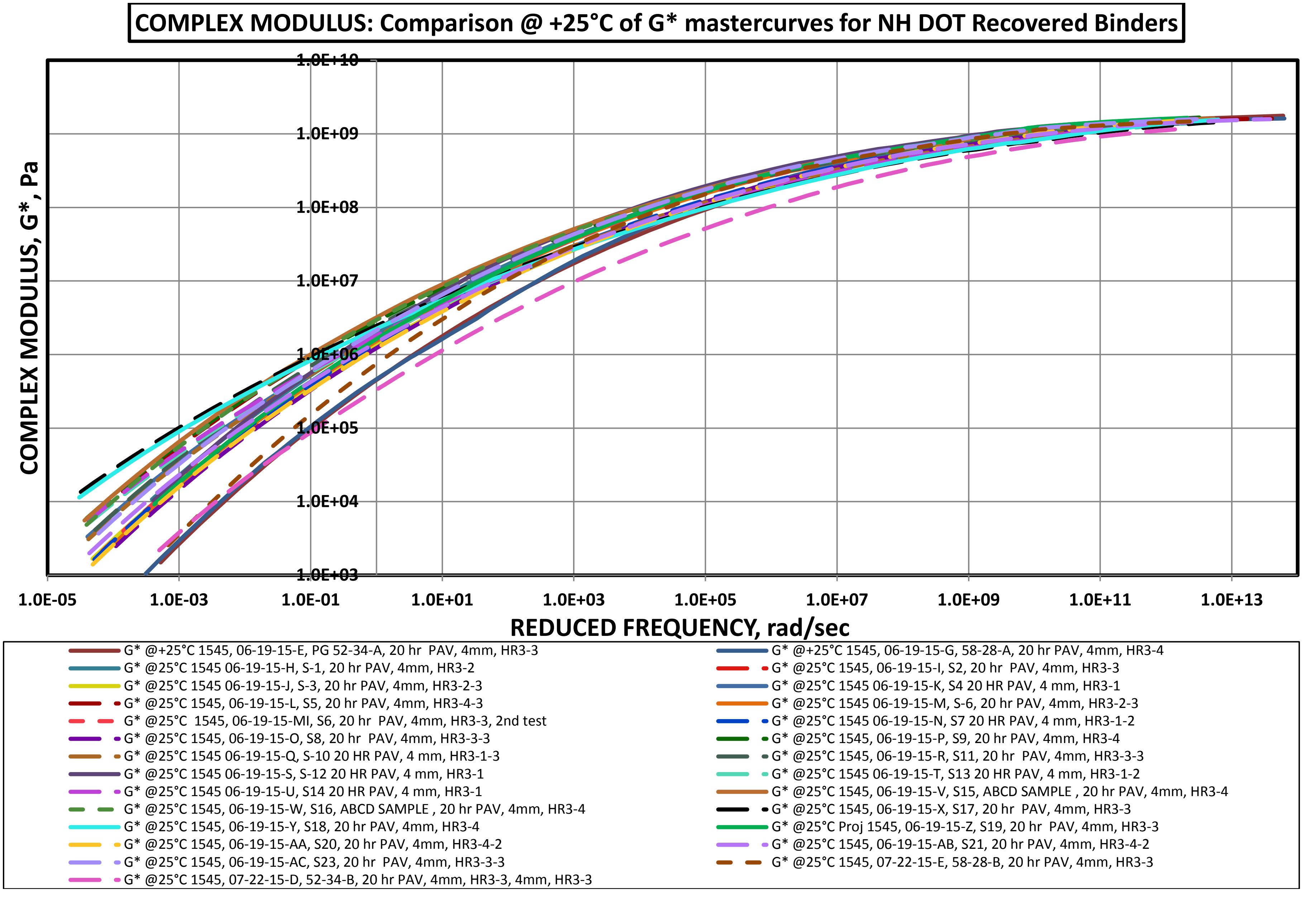
- Crude source on binders is not known to me
  - PG 52-34-B is so designated because the binder from that supplier was only used for ¾ inch mixes; there is evidence based on zinc level that this sample could have contained ≈5% REOB

TESTING PERFORMED

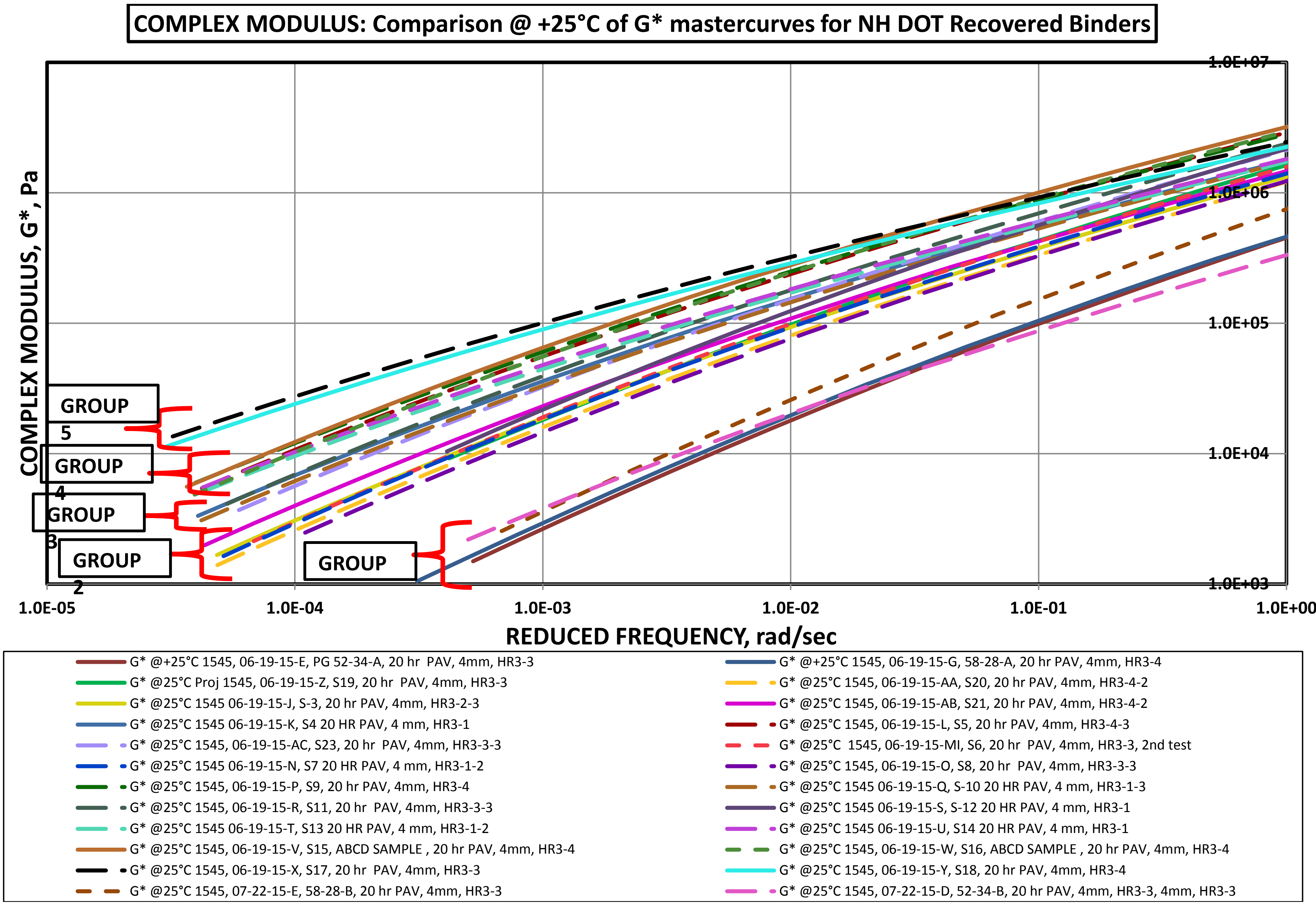
- NH DOT LAB HAD PERFORMED HIGH TEMPERATURE DSR TESTING OF RECOVERED BINDERS AS WELL AS BBR TESTING AND ABCD TESTING FOR LOW TEMPERATURE CRACKING GRADE
- MTE WAS ASKED TO RUN 4 mm DSR TESTING TO DETERMINE THE COMPLEX MODULUS MASTERCURVES FOR THESE BINDERS
- ADDITIONALLY ONCE WE HAD THE 4 mm DATA WE DETERMINED R-VALUE AND THE LOW TEMPERATURE STIFFNESS AND m-VALUE EQUIVALENTS BASED ON THE 4 mm RESULTS

TESTING PERFORMED

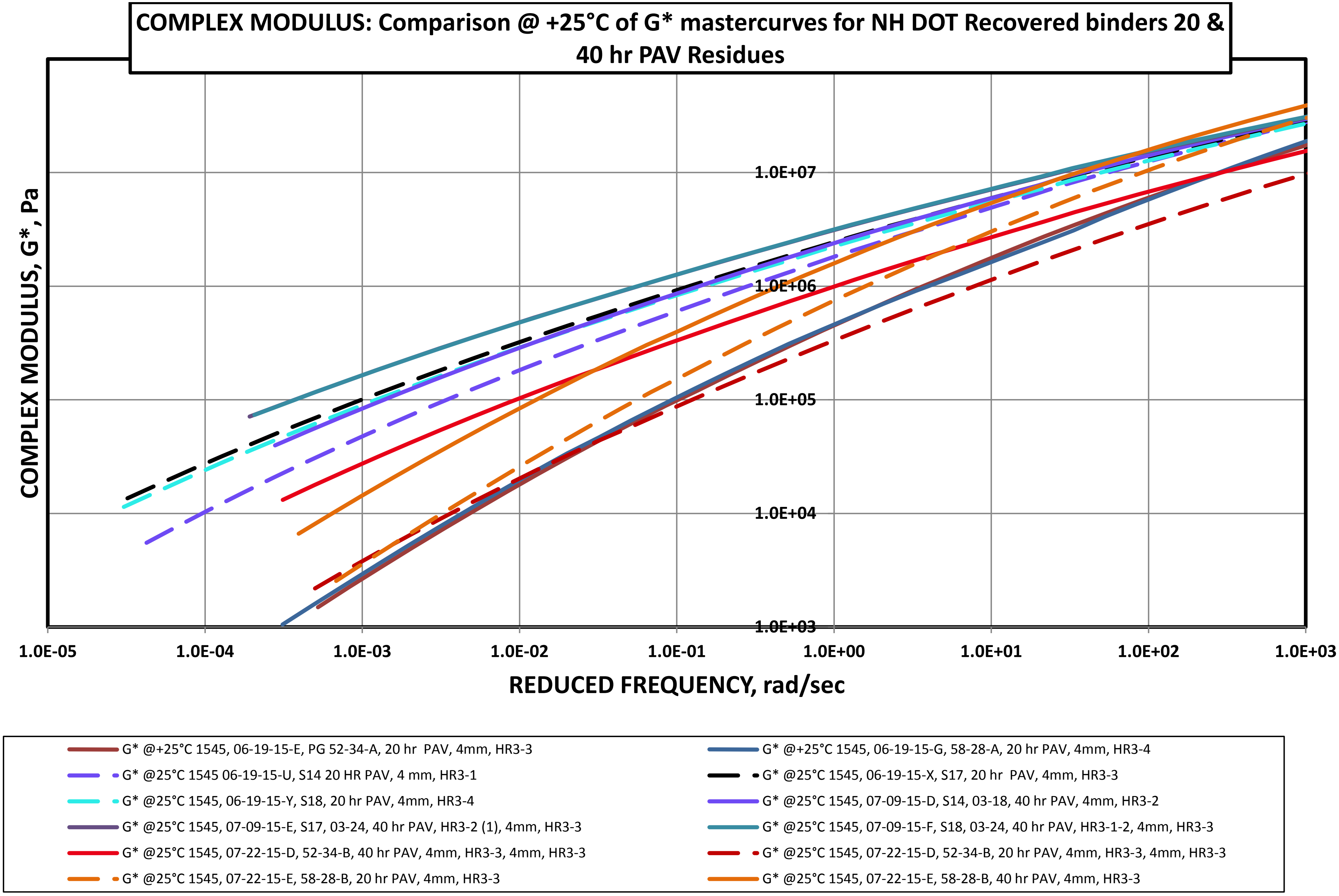
- MTE ALSO LOOKED AT 20 AND 40 HOUR PAV AGING OF THE ORIGINAL BINDERS
- FOR SELECTED RECOVERED MIX BINDERS WE PERFORMED AN ADDITIONAL 20 HOURS OF PAV AGING AT THE REQUEST OF NH DOT



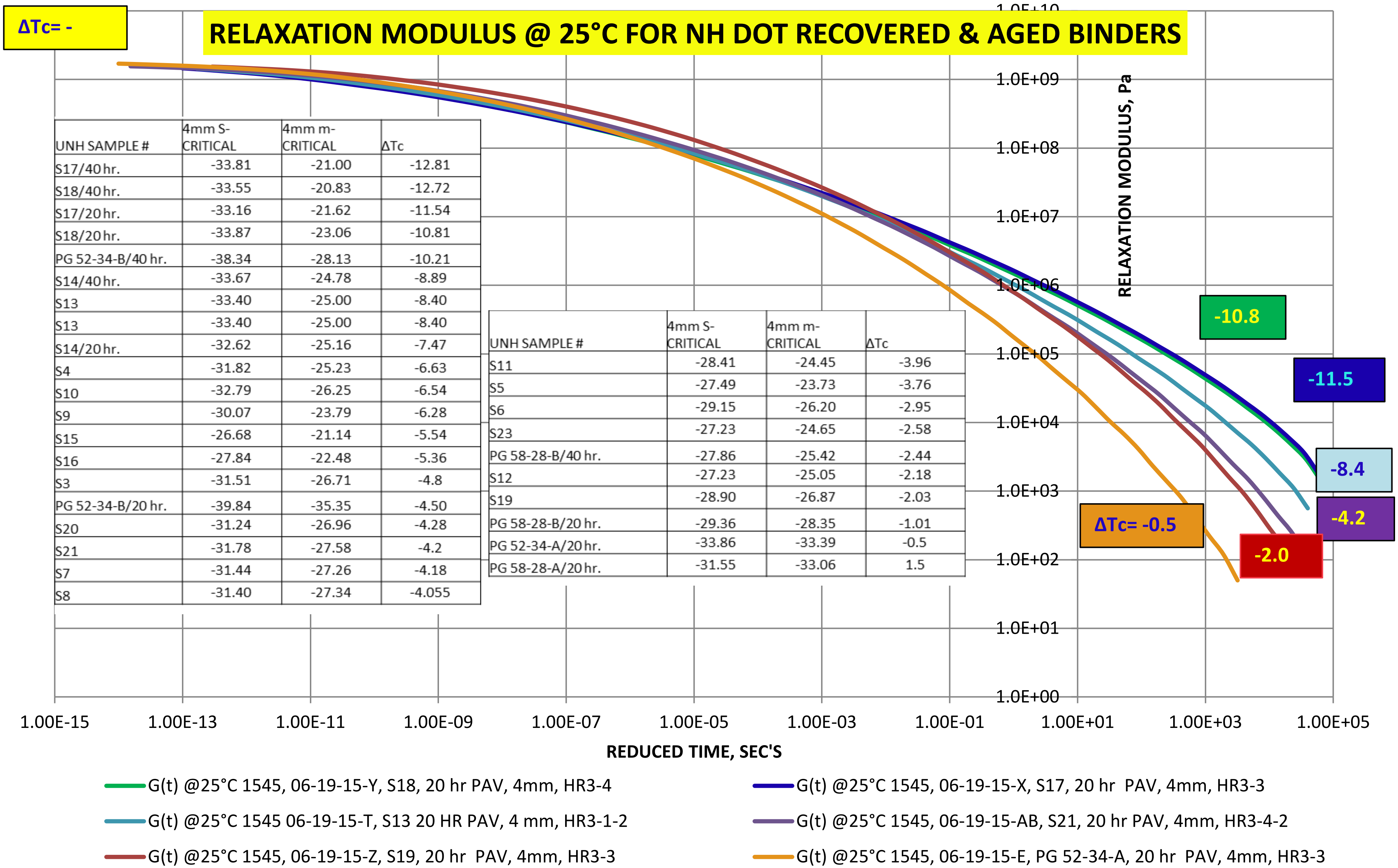
COMPLEX MODULUS: Comparison @ +25°C of G* mastercurves for NH DOT Recovered Binders
COMPLEX MODULUS, G*, Pa
1.0E+10
1.0E+09
1.0E+08
1.0E+07
1.0E+06
1.0E+05
1.0E+04
1.0E+03
1.0E-05
1.0E-03
1.0E-01
1.0E+01
1.0E+03
1.0E+05
1.0E+07
1.0E+09
1.0E+11
1.0E+13
REDUCED FREQUENCY, rad/sec
G* @+25°C 1545, 06-19-15-E, PG 52-34-A, 20 hr PAV, 4mm, HR3-3
G* @+25°C 1545, 06-19-15-G, 58-28-A, 20 hr PAV, 4mm, HR3-4
G* @25°C 1545 06-19-15-H, S-1, 20 hr PAV, 4mm, HR3-2
G* @25°C 1545, 06-19-15-I, S2, 20 hr PAV, 4mm, HR3-3
G* @25°C 1545 06-19-15-J, S-3, 20 hr PAV, 4mm, HR3-2-3
G* @25°C 1545 06-19-15-K, S4 20 HR PAV, 4 mm, HR3-1
G* @25°C 1545, 06-19-15-L, S5, 20 hr PAV, 4mm, HR3-4-3
G* @25°C 1545 06-19-15-M, S-6, 20 hr PAV, 4mm, HR3-2-3
G* @25°C 1545, 06-19-15-MI, S6, 20 hr PAV, 4mm, HR3-3, 2nd test
G* @25°C 1545 06-19-15-N, S7 20 HR PAV, 4 mm, HR3-1-2
G* @25°C 1545, 06-19-15-O, S8, 20 hr PAV, 4mm, HR3-3-3
G* @25°C 1545, 06-19-15-P, S9, 20 hr PAV, 4mm, HR3-4
G* @25°C 1545 06-19-15-Q, S-10 20 HR PAV, 4 mm, HR3-1-3
G* @25°C 1545, 06-19-15-R, S11, 20 hr PAV, 4mm, HR3-3-3
G* @25°C 1545 06-19-15-S, S-12 20 HR PAV, 4 mm, HR3-1
G* @25°C 1545 06-19-15-T, S13 20 HR PAV, 4 mm, HR3-1-2
G* @25°C 1545 06-19-15-U, S14 20 HR PAV, 4 mm, HR3-1
G* @25°C 1545, 06-19-15-V, S15, ABCD SAMPLE , 20 hr PAV, 4mm, HR3-4
G* @25°C 1545, 06-19-15-W, S16, ABCD SAMPLE , 20 hr PAV, 4mm, HR3-4
G* @25°C 1545, 06-19-15-X, S17, 20 hr PAV, 4mm, HR3-3
G* @25°C 1545, 06-19-15-Y, S18, 20 hr PAV, 4mm, HR3-4
G* @25°C Proj 1545, 06-19-15-Z, S19, 20 hr PAV, 4mm, HR3-3
G* @25°C 1545, 06-19-15-AA, S20, 20 hr PAV, 4mm, HR3-4-2
G* @25°C 1545, 06-19-15-AB, S21, 20 hr PAV, 4mm, HR3-4-2
G* @25°C 1545, 06-19-15-AC, S23, 20 hr PAV, 4mm, HR3-3-3
G* @25°C 1545, 07-22-15-E, 58-28-B, 20 hr PAV, 4mm, HR3-3
G* @25°C 1545, 07-22-15-D, 52-34-B, 20 hr PAV, 4mm, HR3-3, 4mm, HR3-3



COMPLEX MODULUS: Comparison @ +25°C of G* mastercurves for NH DOT Recovered Binders
COMPLEX MODULUS, G*, Pa
1.0E+07
1.0E+06
1.0E+05
1.0E+04
1.0E+03
GROUP 5
GROUP 4
GROUP 3
GROUP 2
GROUP
1.0E-05
1.0E-04
1.0E-03
1.0E-02
1.0E-01
1.0E+00
REDUCED FREQUENCY, rad/sec
G* @+25°C 1545, 06-19-15-E, PG 52-34-A, 20 hr PAV, 4mm, HR3-3
G* @+25°C 1545, 06-19-15-G, 58-28-A, 20 hr PAV, 4mm, HR3-4
G* @25°C Proj 1545, 06-19-15-Z, S19, 20 hr PAV, 4mm, HR3-3
G* @25°C 1545, 06-19-15-AA, S20, 20 hr PAV, 4mm, HR3-4-2
G* @25°C 1545 06-19-15-J, S-3, 20 hr PAV, 4mm, HR3-2-3
G* @25°C 1545, 06-19-15-AB, S21, 20 hr PAV, 4mm, HR3-4-2
G* @25°C 1545 06-19-15-K, S4 20 HR PAV, 4 mm, HR3-1
G* @25°C 1545, 06-19-15-L, S5, 20 hr PAV, 4mm, HR3-4-3
G* @25°C 1545, 06-19-15-AC, S23, 20 hr PAV, 4mm, HR3-3-3
G* @25°C 1545, 06-19-15-MI, S6, 20 hr PAV, 4mm, HR3-3, 2nd test
G* @25°C 1545 06-19-15-N, S7 20 HR PAV, 4 mm, HR3-1-2
G* @25°C 1545, 06-19-15-O, S8, 20 hr PAV, 4mm, HR3-3-3
G* @25°C 1545, 06-19-15-P, S9, 20 hr PAV, 4mm, HR3-4
G* @25°C 1545 06-19-15-Q, S-10 20 HR PAV, 4 mm, HR3-1-3
G* @25°C 1545, 06-19-15-R, S11, 20 hr PAV, 4mm, HR3-3-3
G* @25°C 1545 06-19-15-S, S-12 20 HR PAV, 4 mm, HR3-1
G* @25°C 1545 06-19-15-T, S13 20 HR PAV, 4 mm, HR3-1-2
G* @25°C 1545 06-19-15-U, S14 20 HR PAV, 4 mm, HR3-1
G* @25°C 1545, 06-19-15-V, S15, ABCD SAMPLE , 20 hr PAV, 4mm, HR3-4
G* @25°C 1545, 06-19-15-W, S16, ABCD SAMPLE , 20 hr PAV, 4mm, HR3-4
G* @25°C 1545, 06-19-15-X, S17, 20 hr PAV, 4mm, HR3-3
G* @25°C 1545, 06-19-15-Y, S18, 20 hr PAV, 4mm, HR3-4
G* @25°C 1545, 07-22-15-E, 58-28-B, 20 hr PAV, 4mm, HR3-3
G* @25°C 1545, 07-22-15-D, 52-34-B, 20 hr PAV, 4mm, HR3-3, 4mm, HR3-3


COMPLEX MODULUS: Comparison @ +25°C of G* mastercurves for NH DOT Recovered binders 20 & 40 hr PAV Residues
COMPLEX MODULUS, G*, Pa
1.0E+07
1.0E+06
1.0E+05
1.0E+04
1.0E+03
1.0E-05
1.0E-04
1.0E-03
1.0E-02
1.0E-01
1.0E+00
1.0E+01
1.0E+02
1.0E+03
REDUCED FREQUENCY, rad/sec
G* @+25°C 1545, 06-19-15-E, PG 52-34-A, 20 hr PAV, 4mm, HR3-3
G* @+25°C 1545, 06-19-15-G, 58-28-A, 20 hr PAV, 4mm, HR3-4
G* @25°C 1545 06-19-15-U, S14 20 HR PAV, 4 mm, HR3-1
G* @25°C 1545, 06-19-15-X, S17, 20 hr PAV, 4mm, HR3-3
G* @25°C 1545, 06-19-15-Y, S18, 20 hr PAV, 4mm, HR3-4
G* @25°C 1545, 07-09-15-D, S14, 03-18, 40 hr PAV, 4mm, HR3-2
G* @25°C 1545, 07-09-15-E, S17, 03-24, 40 hr PAV, HR3-2 (1), 4mm, HR3-3
G* @25°C 1545, 07-09-15-F, S18, 03-24, 40 hr PAV, HR3-1-2, 4mm, HR3-3
G* @25°C 1545, 07-22-15-D, 52-34-B, 40 hr PAV, 4mm, HR3-3, 4mm, HR3-3
G* @25°C 1545, 07-22-15-D, 52-34-B, 20 hr PAV, 4mm, HR3-3, 4mm, HR3-3
G* @25°C 1545, 07-22-15-E, 58-28-B, 20 hr PAV, 4mm, HR3-3
G* @25°C 1545, 07-22-15-E, 58-28-B, 40 hr PAV, 4mm, HR3-3

RELAXATION MODULUS @ 25°C FOR NH DOT RECOVERED & AGED BINDERS

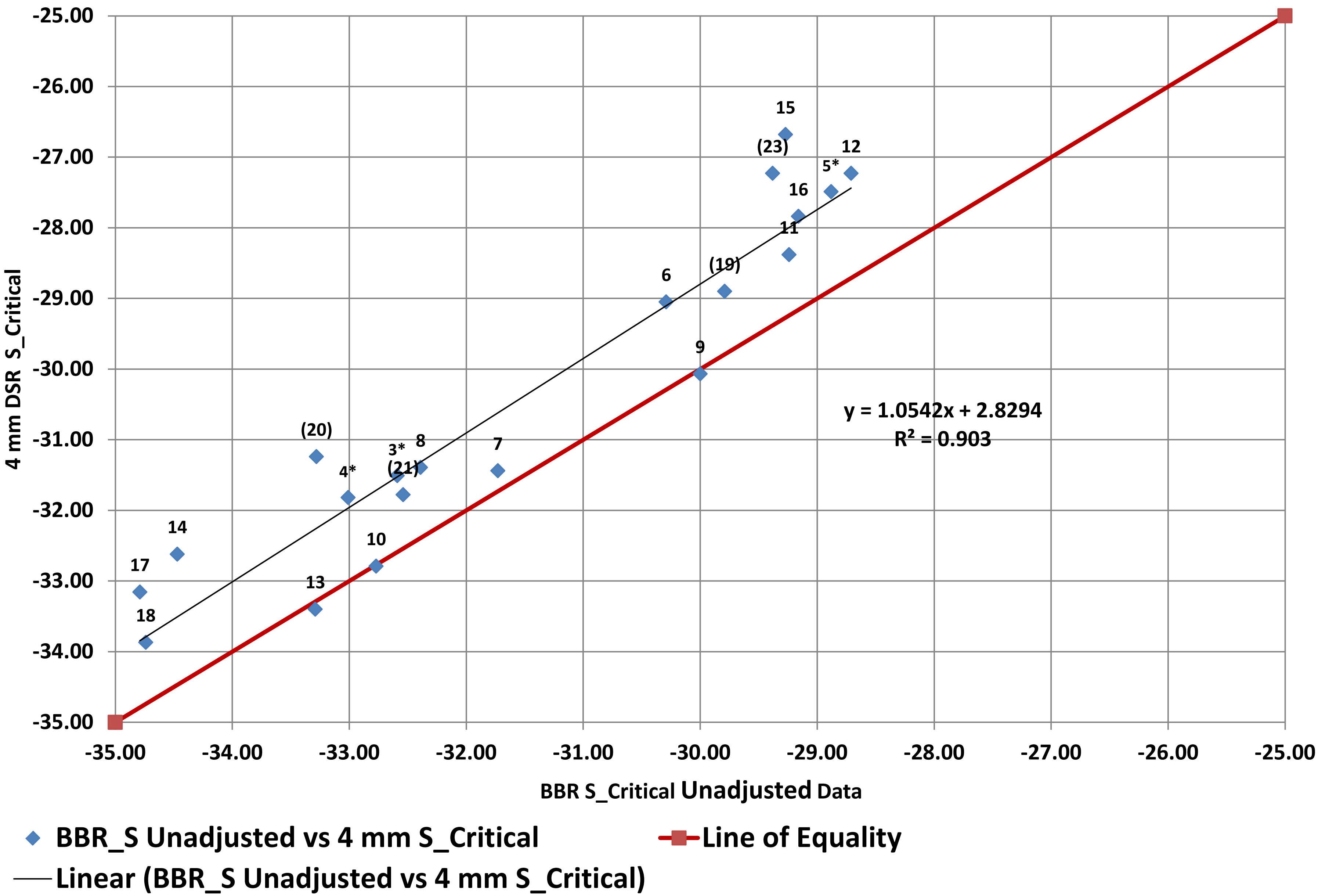


UNH SAMPLE #	4mm S-CRITICAL	4mm m-CRITICAL	ΔTc
S17/40 hr.	-33.81	-21.00	-12.81
S18/40 hr.	-33.55	-20.83	-12.72
S17/20 hr.	-33.16	-21.62	-11.54
S18/20 hr.	-33.87	-23.06	-10.81
PG 52-34-B/40 hr.	-38.34	-28.13	-10.21
S14/40 hr.	-33.67	-24.78	-8.89
S13	-33.40	-25.00	-8.40
S13	-33.40	-25.00	-8.40
S14/20 hr.	-32.62	-25.16	-7.47
S4	-31.82	-25.23	-6.63
S10	-32.79	-26.25	-6.54
S9	-30.07	-23.79	-6.28
S15	-26.68	-21.14	-5.54
S16	-27.84	-22.48	-5.36
S3	-31.51	-26.71	-4.8
PG 52-34-B/20 hr.	-39.84	-35.35	-4.50
S20	-31.24	-26.96	-4.28
S21	-31.78	-27.58	-4.2
S7	-31.44	-27.26	-4.18
S8	-31.40	-27.34	-4.055

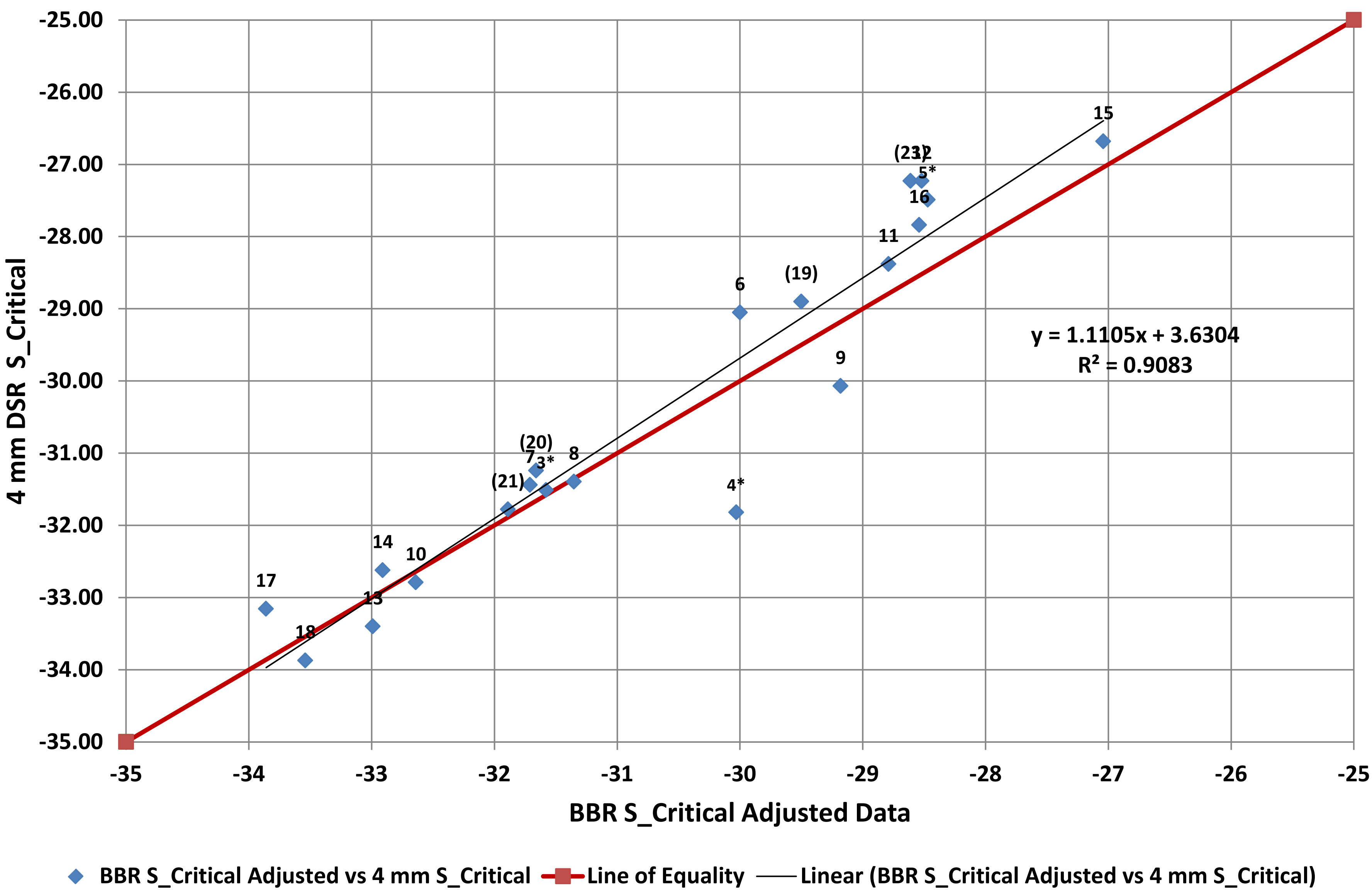
UNH SAMPLE #	4mm S-CRITICAL	4mm m-CRITICAL	ΔTc
S11	-28.41	-24.45	-3.96
S5	-27.49	-23.73	-3.76
S6	-29.15	-26.20	-2.95
S23	-27.23	-24.65	-2.58
PG 58-28-B/40 hr.	-27.86	-25.42	-2.44
S12	-27.23	-25.05	-2.18
S19	-28.90	-26.87	-2.03
PG 58-28-B/20 hr.	-29.36	-28.35	-1.01
PG 52-34-A/20 hr.	-33.86	-33.39	-0.5
PG 58-28-A/20 hr.	-31.55	-33.06	1.5

COMPARISON OF BBR & 4 mm RESULTS

- BBR tests @ NH DOT Lab were generally performed at -18°C and -12°C so that m-value always bracketed 0.300. ∴ S-value never bracketed 300 MPa, was always < 300 MPa
- 4 mm tested from -36°C to +50°C and low temperature calculate to bracket both stiffness and relaxation target values.
- BBR S critical temperatures and 4 mm results calculated to predict BBR S did not match nor did the respective m-value calculated results



-25.00
-26.00
-27.00
-28.00
-29.00
-30.00
-31.00
-32.00
-33.00
-34.00
-35.00
4 mm DSR S_Critical
-35.00
-34.00
-33.00
-32.00
-31.00
-30.00
-29.00
-28.00
-27.00
-26.00
-25.00
BBR S_Critical Unadjusted Data
15
(23)
12
5*
16
11
(19)
6
9
y = 1.0542x + 2.8294
R² = 0.903
(20)
3*
8
7
4*
(21)
14
10
17
13
18
BBR_S Unadjusted vs 4 mm S_Critical
Line of Equality
Linear (BBR_S Unadjusted vs 4 mm S_Critical)


4 mm DSR S_Critical
BBR S_Critical Adjusted Data
-25.00
-26.00
-27.00
-28.00
-29.00
-30.00
-31.00
-32.00
-33.00
-34.00
-35.00
-35
-34
-33
-32
-31
-30
-29
-28
-27
-26
-25
15
(23)
12
5*
16
11
(19)
6
9
(20)
7
3*
8
(21)
4*
14
10
17
13
18
y = 1.1105x + 3.6304
R² = 0.9083
BBR S_Critical Adjusted vs 4 mm S_Critical
Line of Equality
Linear (BBR S_Critical Adjusted vs 4 mm S_Critical)

ADJUSTMENT PROCEDURE

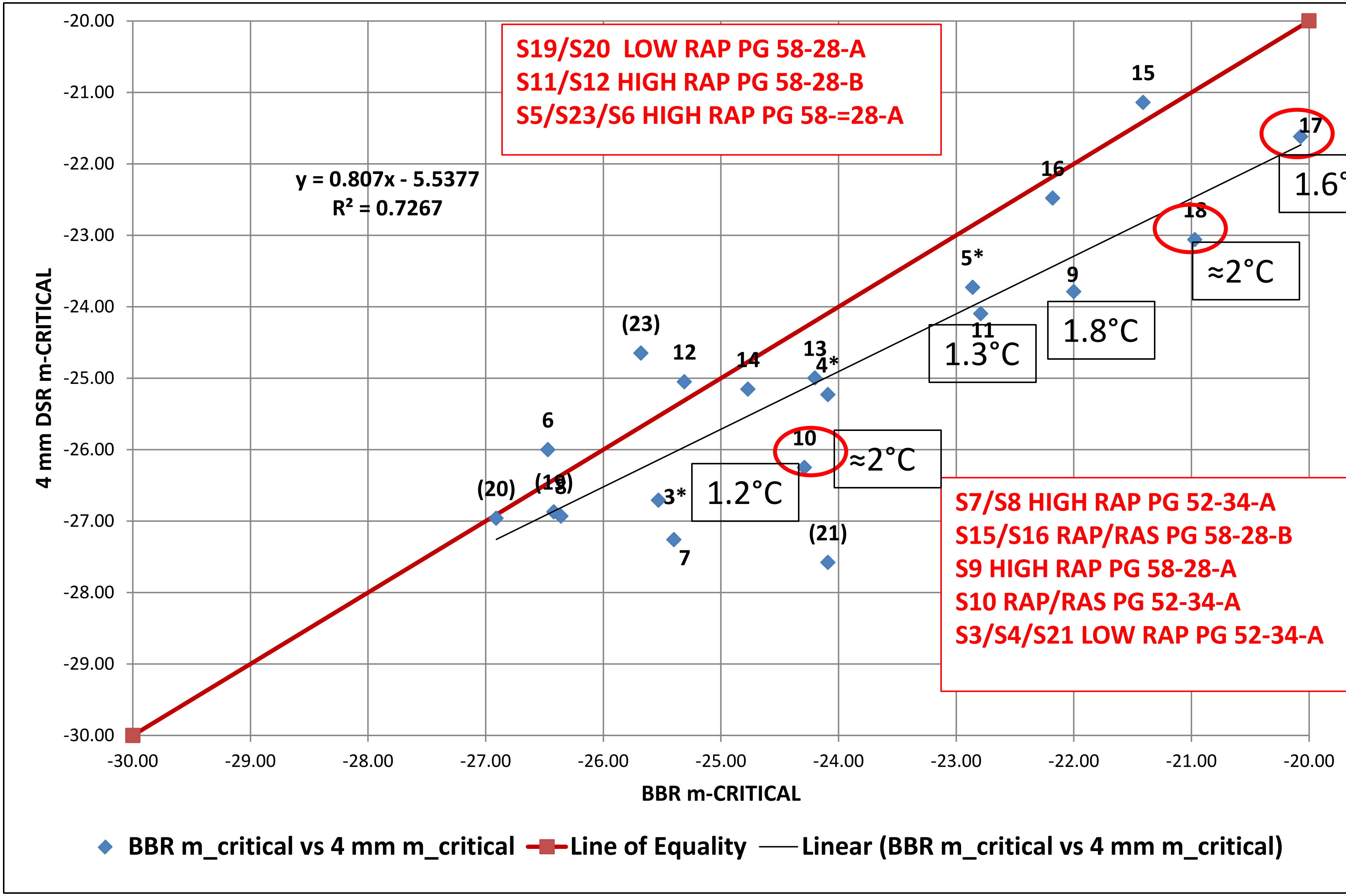
FOR S20 BBR AT -12C = 90 MPa & AT -18C = 178 MPa. RELAXATION MODULUS OF 4 mm TEST AT -24C =198.9 Mpa.

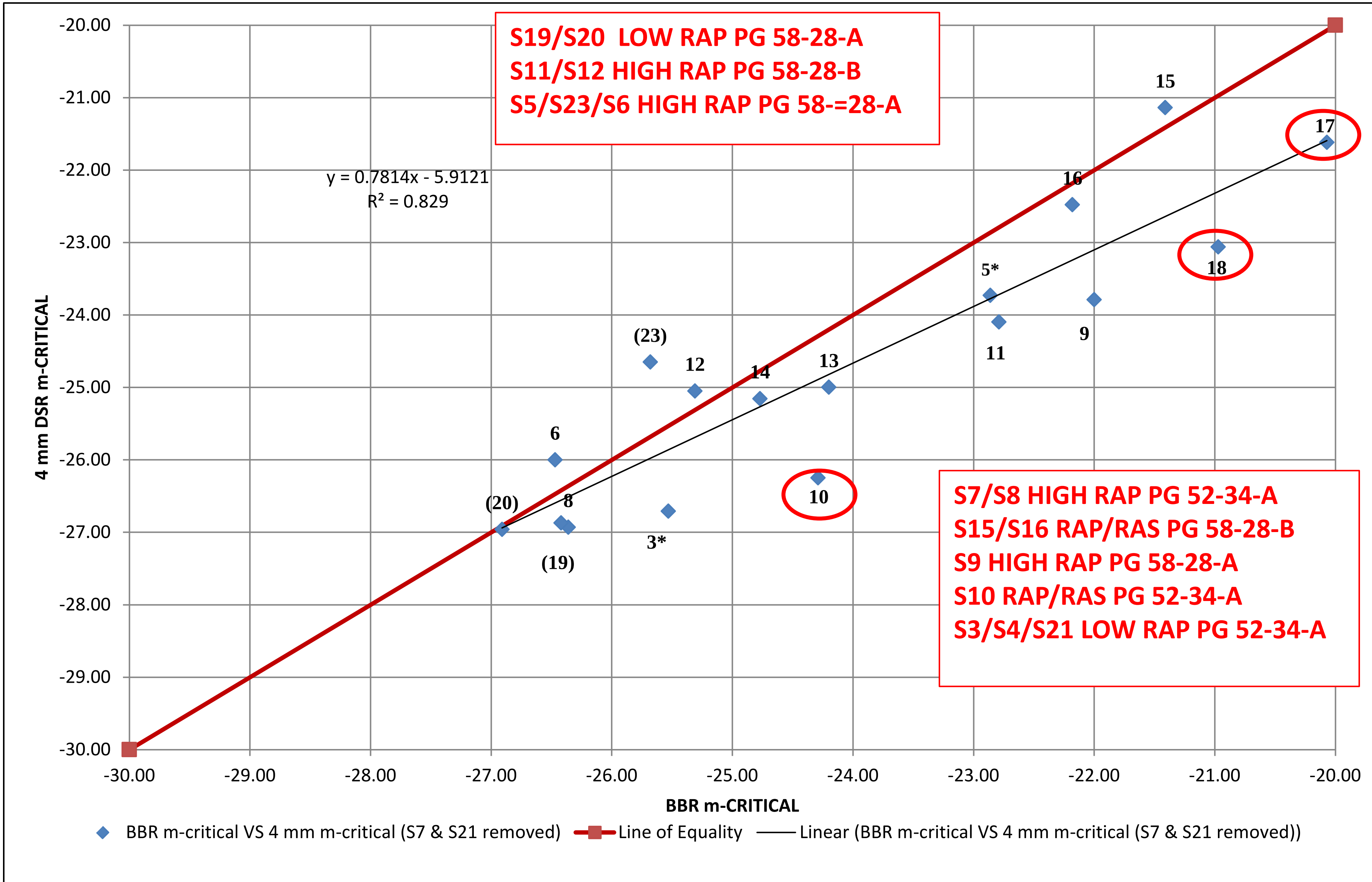
EQUIVALENT RELAXATION MODULUS TO MATCH STIFFNESS MODULUS OF 300 MPa IS 143 MPa. THEREFORE THE CALCULATION TO MAKE THE BBR ADJUSTMENT IS

$\frac{\mathbf{198.90}}{\mathbf{143}} = \frac{\boldsymbol{x}}{\mathbf{300}}$ AND x = 417.3

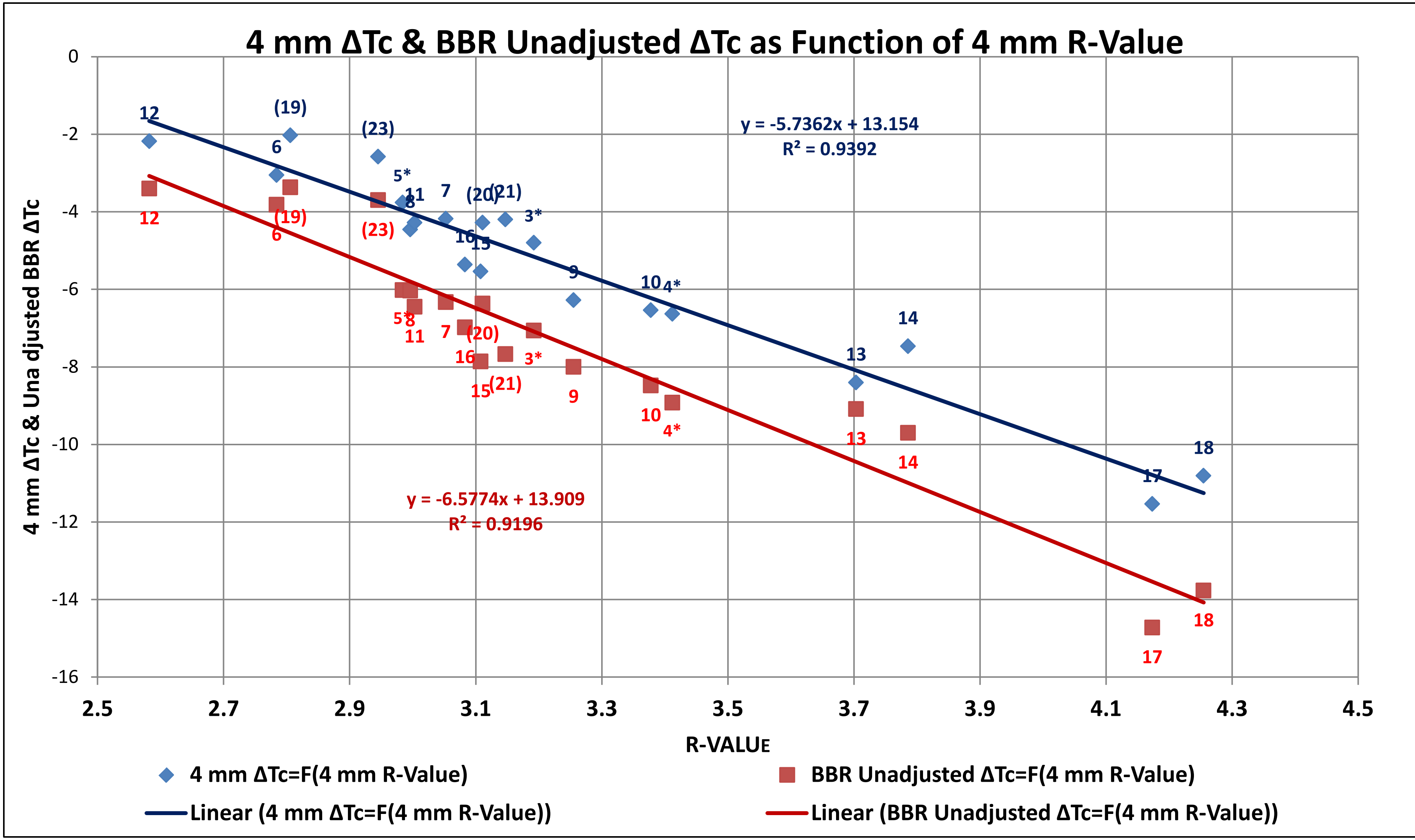
THE ORIGINAL S VALUE GRADE WAS CALCULATED AT -33.28 AND THE ADJUSTED S VALUE GRADE BECOMES -31.68

THE CLOSER THE STIFFNESS VALUE AT -18C IS TO 300 THE LOWER THE ADJUSTMENT.

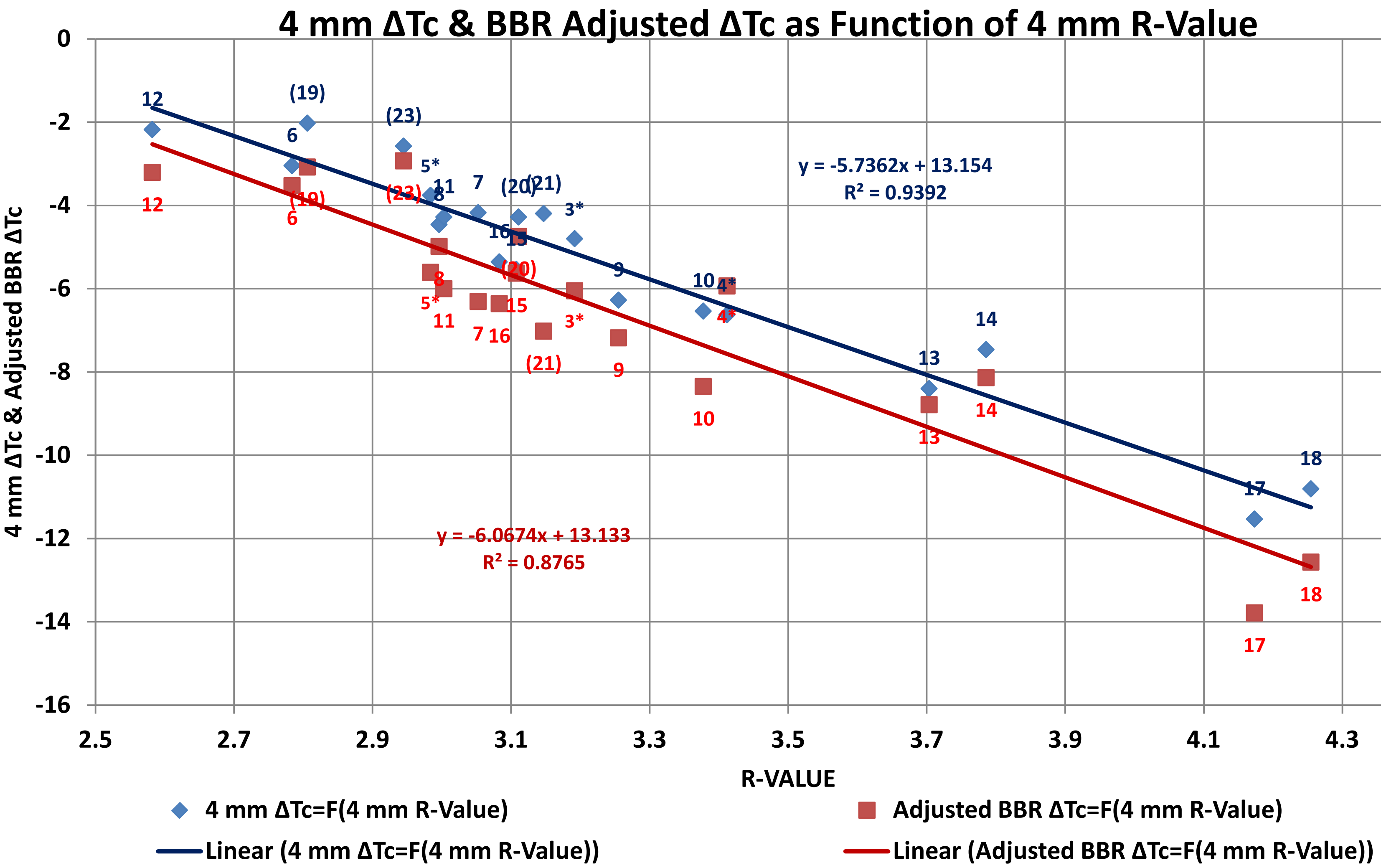

S19/S20 LOW RAP PG 58-28-A
S11/S12 HIGH RAP PG 58-28-B
S5/S23/S6 HIGH RAP PG 58-=28-A
y = 0.807x - 5.5377
R² = 0.7267
1.6°C
≈2°C
1.8°C
1.3°C
≈2°C
1.2°C
S7/S8 HIGH RAP PG 52-34-A
S15/S16 RAP/RAS PG 58-28-B
S9 HIGH RAP PG 58-28-A
S10 RAP/RAS PG 52-34-A
S3/S4/S21 LOW RAP PG 52-34-A
4 mm DSR m-CRITICAL
BBR m-CRITICAL
BBR m_critical vs 4 mm m_critical
Line of Equality
Linear (BBR m_critical vs 4 mm m_critical)



S19/S20 LOW RAP PG 58-28-A
S11/S12 HIGH RAP PG 58-28-B
S5/S23/S6 HIGH RAP PG 58-=28-A
S7/S8 HIGH RAP PG 52-34-A
S15/S16 RAP/RAS PG 58-28-B
S9 HIGH RAP PG 58-28-A
S10 RAP/RAS PG 52-34-A
S3/S4/S21 LOW RAP PG 52-34-A
y = 0.7814x - 5.9121
R² = 0.829
4 mm DSR m-CRITICAL
BBR m-CRITICAL
-20.00
-21.00
-22.00
-23.00
-24.00
-25.00
-26.00
-27.00
-28.00
-29.00
-30.00
-30.00
-29.00
-28.00
-27.00
-26.00
-25.00
-24.00
-23.00
-22.00
-21.00
-20.00
15
17
16
18
5*
9
11
(23)
12
14
13
6
10
(20)
8
3*
(19)
BBR m-critical VS 4 mm m-critical (S7 & S21 removed)
Line of Equality
Linear (BBR m-critical VS 4 mm m-critical (S7 & S21 removed))



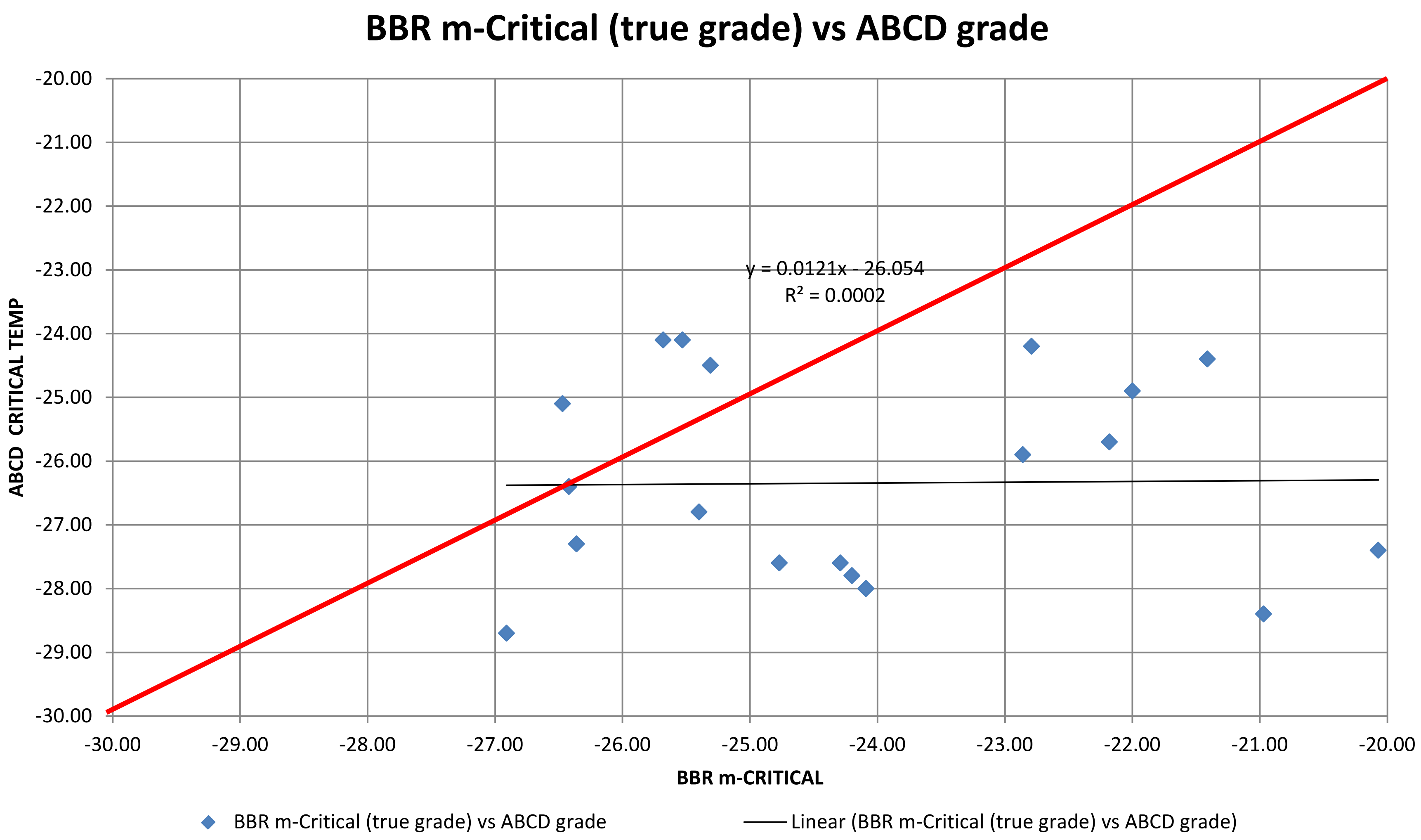
R VALUE DATA WAS DERIVED FROM 4 mm DSR MODULUS RESULTS

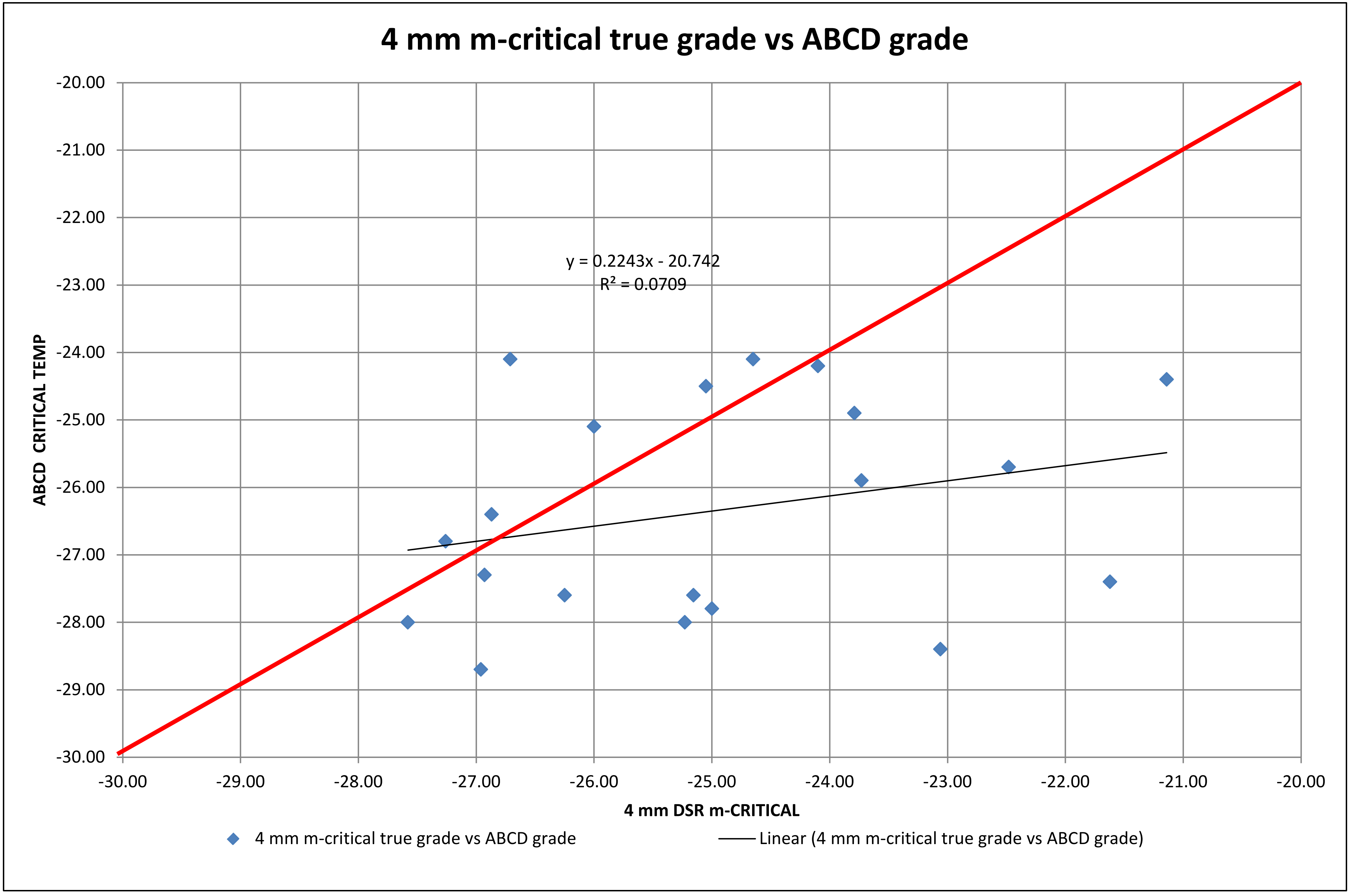


USING ADJUSTED BBR RESULTS DIFFERENCE IN ΔTc IS 1°-1.5°C FOR A GIVEN R VALUE

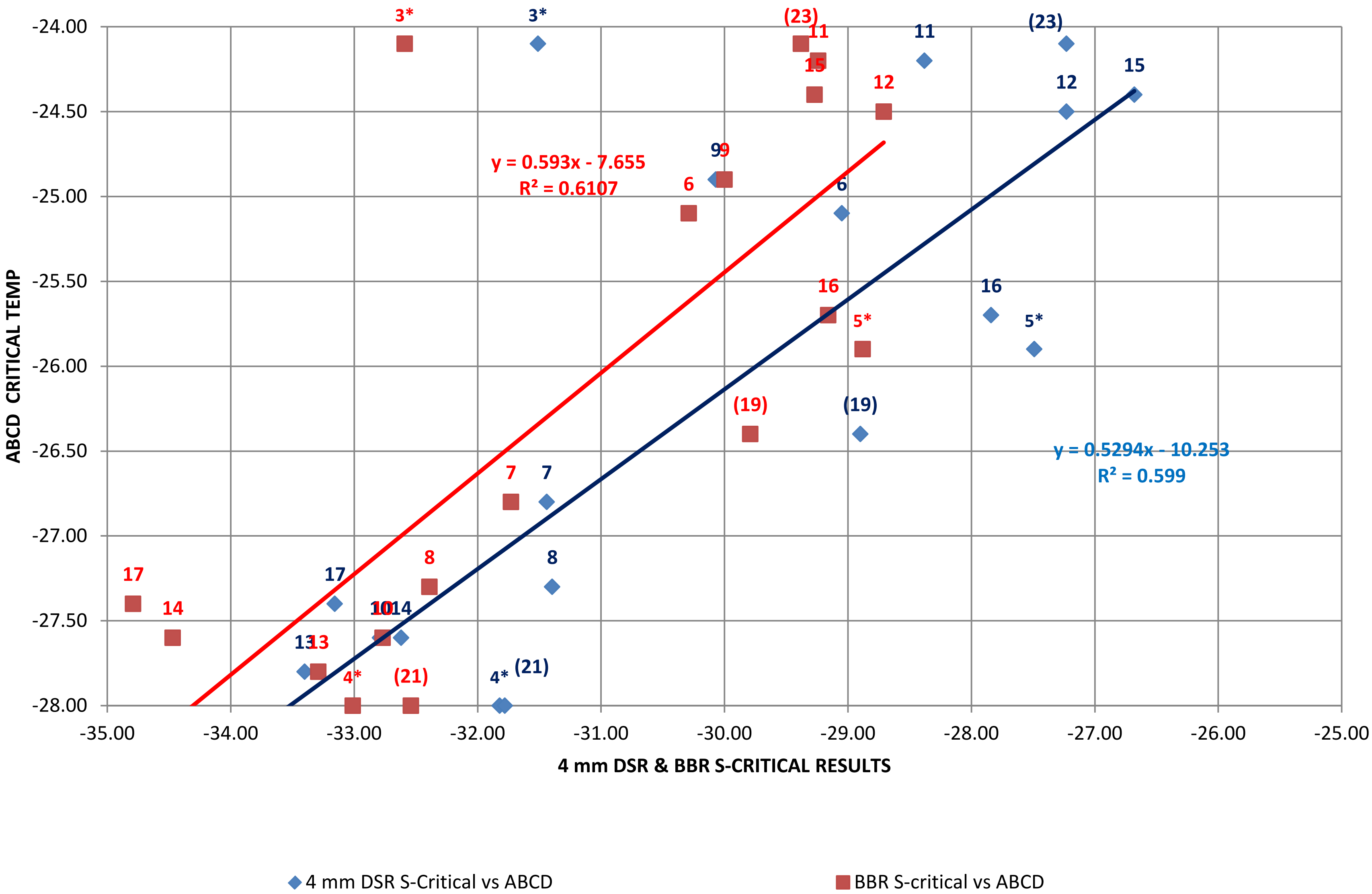
ABCD TEST RESULTS

- NH DOT performed ABCD testing on all recovered and PAV aged binder samples.

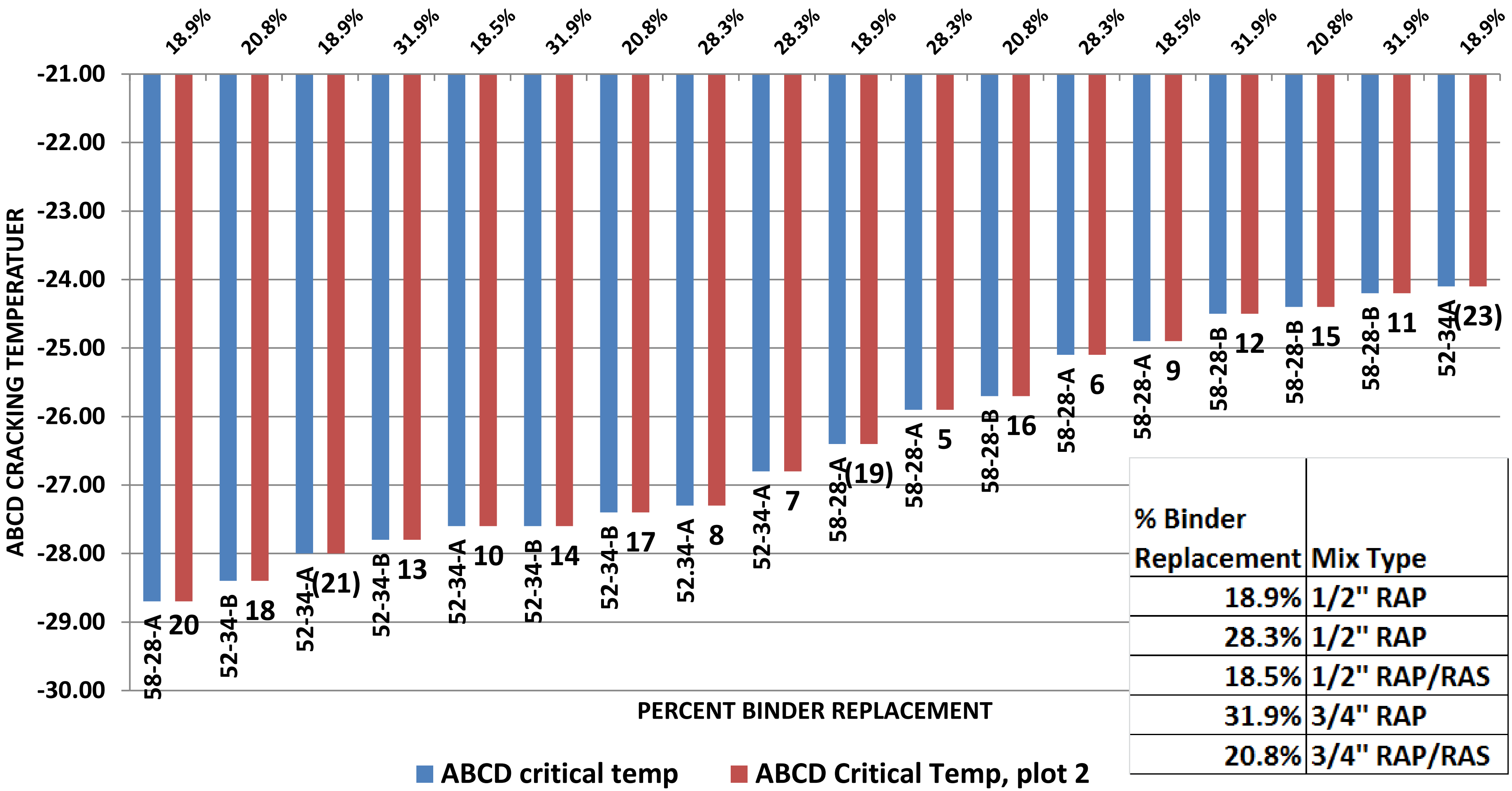

BBR m-Critical (true grade) vs ABCD grade
ABCD CRITICAL TEMP
-20.00
-21.00
-22.00
-23.00
-24.00
-25.00
-26.00
-27.00
-28.00
-29.00
-30.00
-30.00
-29.00
-28.00
-27.00
-26.00
-25.00
-24.00
-23.00
-22.00
-21.00
-20.00
BBR m-CRITICAL
y = 0.0121x - 26.054
R² = 0.0002
BBR m-Critical (true grade) vs ABCD grade
Linear (BBR m-Critical (true grade) vs ABCD grade)



4 mm m-critical true grade vs ABCD grade
y = 0.2243x - 20.742
R² = 0.0709
ABCD CRITICAL TEMP
4 mm DSR m-CRITICAL
-20.00
-21.00
-22.00
-23.00
-24.00
-25.00
-26.00
-27.00
-28.00
-29.00
-30.00
-30.00
-29.00
-28.00
-27.00
-26.00
-25.00
-24.00
-23.00
-22.00
-21.00
-20.00
4 mm m-critical true grade vs ABCD grade
Linear (4 mm m-critical true grade vs ABCD grade)

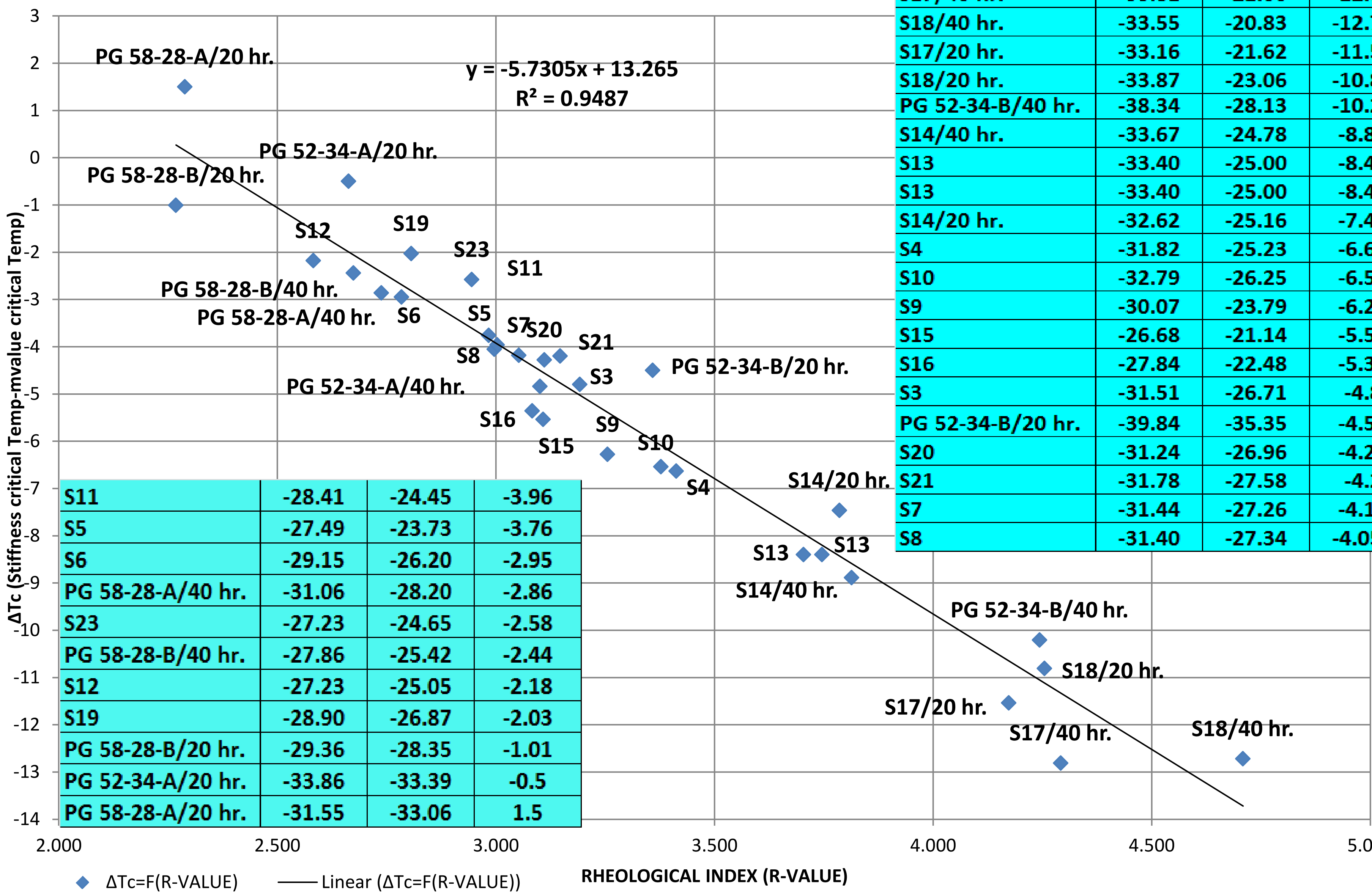


ABCD CRITICAL TEMP
4 mm DSR & BBR S-CRITICAL RESULTS
y = 0.593x - 7.655
R² = 0.6107
y = 0.5294x - 10.253
R² = 0.599
-24.00
-24.50
-25.00
-25.50
-26.00
-26.50
-27.00
-27.50
-28.00
-35.00
-34.00
-33.00
-32.00
-31.00
-30.00
-29.00
-28.00
-27.00
-26.00
-25.00
3*
(23)
11
15
12
9
6
16
5*
(19)
7
8
17
14
10
13
4*
(21)
4 mm DSR S-Critical vs ABCD
BBR S-critical vs ABCD



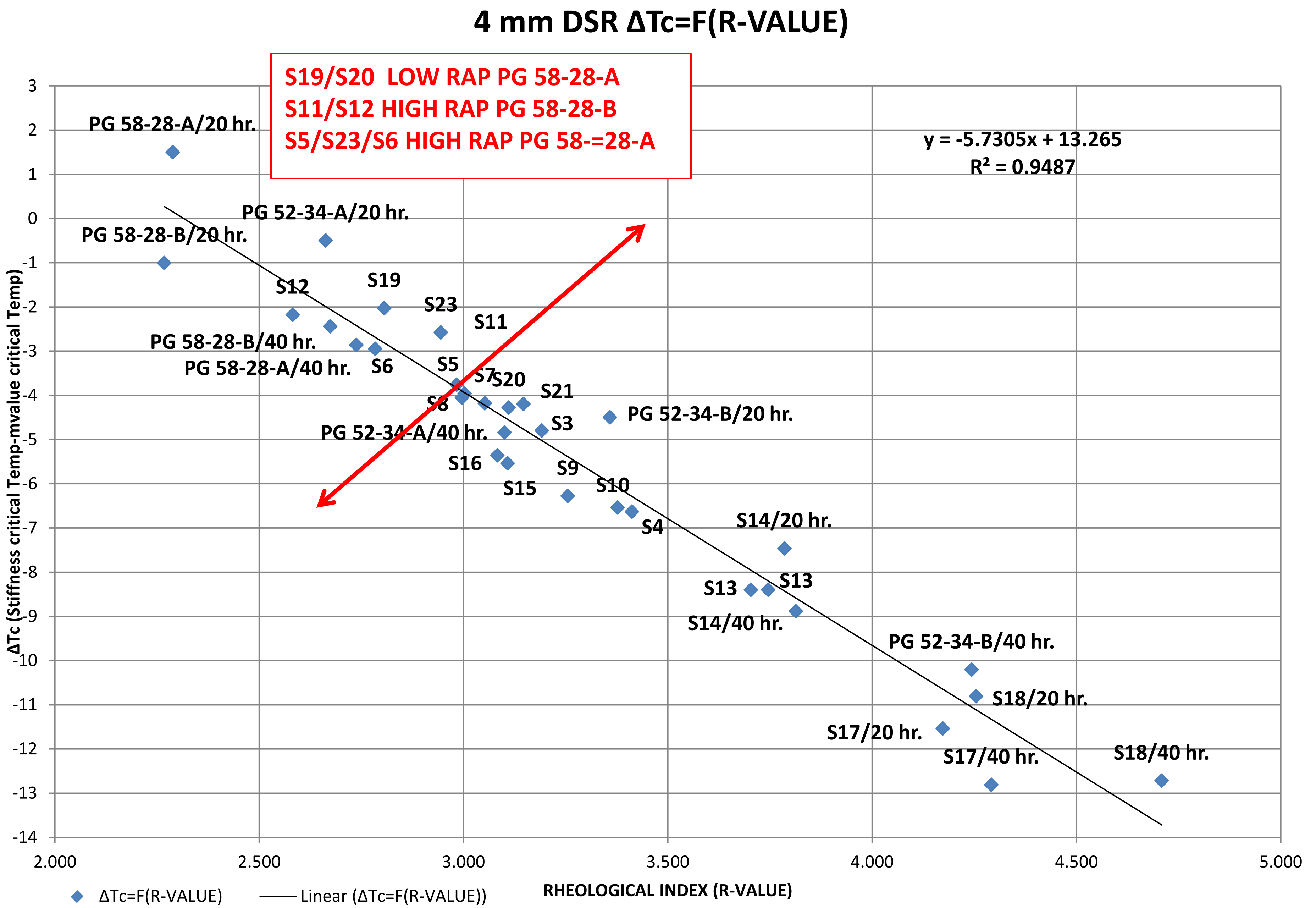
% Binder Replacement	Mix Type
18.9%	1/2" RAP
28.3%	1/2" RAP
18.5%	1/2" RAP/RAS
31.9%	3/4" RAP
20.8%	3/4" RAP/RAS

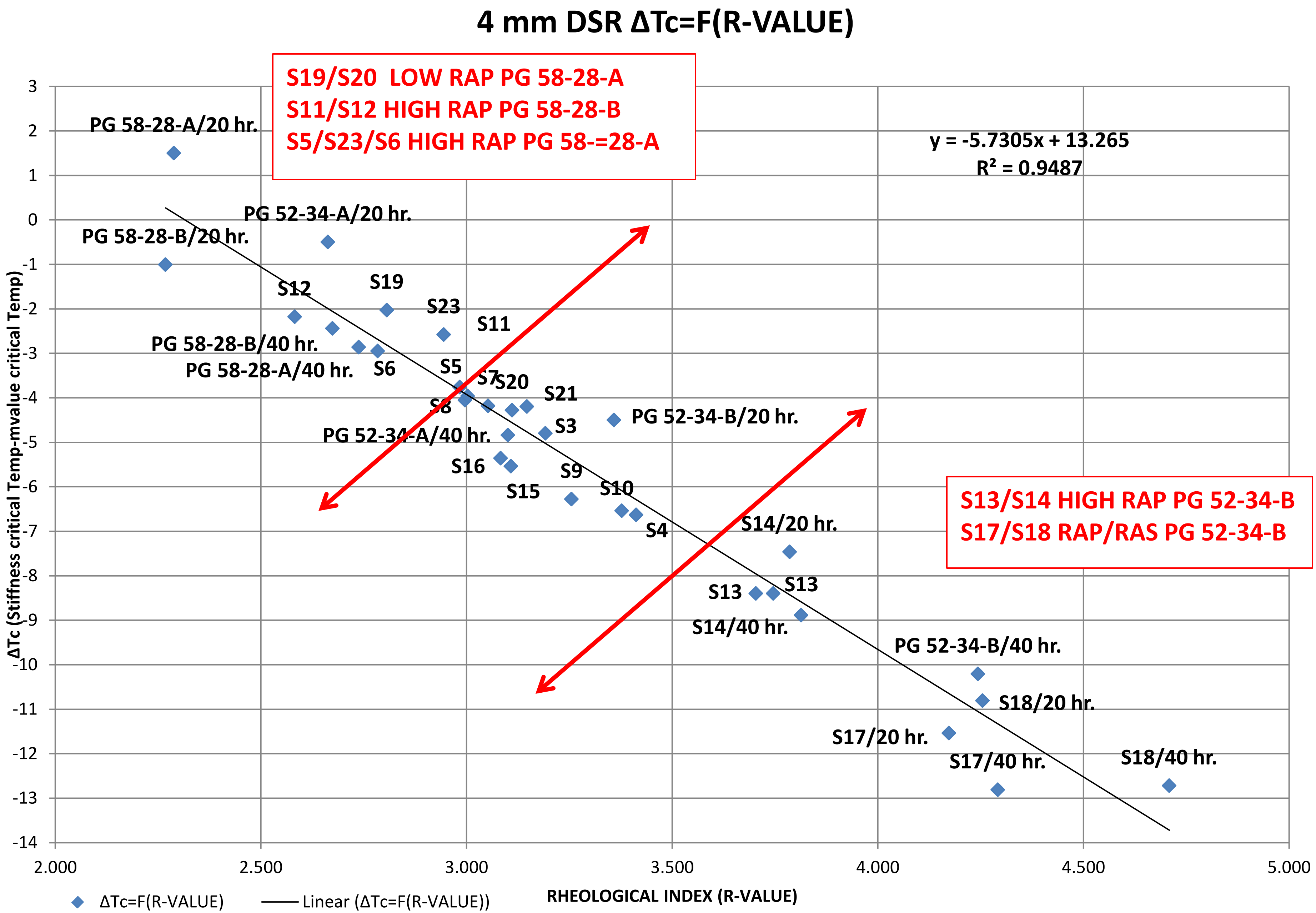
4 mm DSR ΔTc=F(R-VALUE



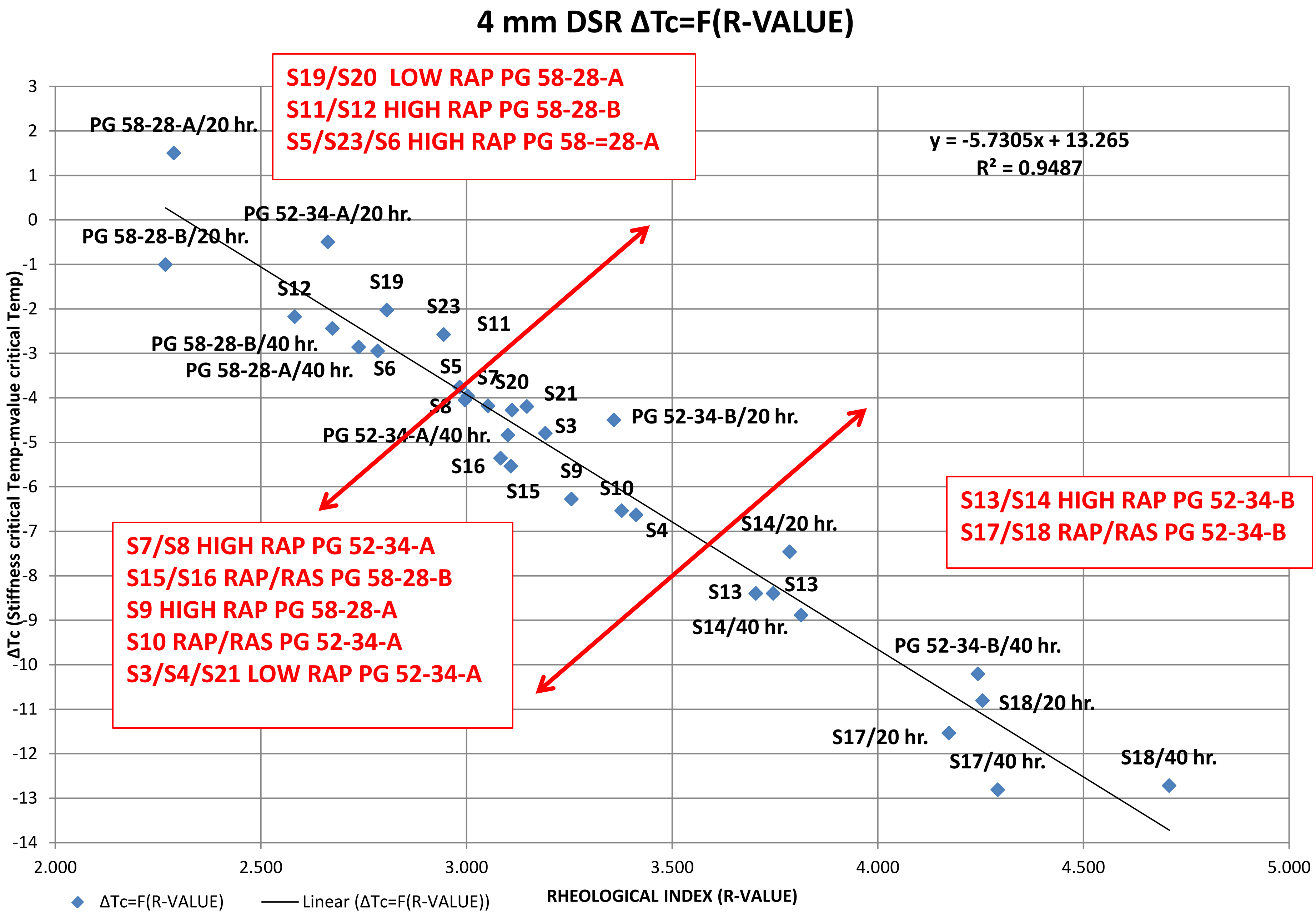
UNH SAMPLE #	4mm S-CR	4mm m-CI	ΔTc
S17/40 hr.	-33.81	-21.00	-12.81
S18/40 hr.	-33.55	-20.83	-12.72
S17/20 hr.	-33.16	-21.62	-11.54
S18/20 hr.	-33.87	-23.06	-10.81
PG 52-34-B/40 hr.	-38.34	-28.13	-10.21
S14/40 hr.	-33.67	-24.78	-8.89
S13	-33.40	-25.00	-8.40
S13	-33.40	-25.00	-8.40
S14/20 hr.	-32.62	-25.16	-7.47
S4	-31.82	-25.23	-6.63
S10	-32.79	-26.25	-6.54
S9	-30.07	-23.79	-6.28
S15	-26.68	-21.14	-5.54
S16	-27.84	-22.48	-5.36
S3	-31.51	-26.71	-4.8
PG 52-34-B/20 hr.	-39.84	-35.35	-4.50
S20	-31.24	-26.96	-4.28
S21	-31.78	-27.58	-4.2
S7	-31.44	-27.26	-4.18
S8	-31.40	-27.34	-4.055

S11	-28.41	-24.45	-3.96
S5	-27.49	-23.73	-3.76
S6	-29.15	-26.20	-2.95
PG 58-28-A/40 hr.	-31.06	-28.20	-2.86
S23	-27.23	-24.65	-2.58
PG 58-28-B/40 hr.	-27.86	-25.42	-2.44
S12	-27.23	-25.05	-2.18
S19	-28.90	-26.87	-2.03
PG 58-28-B/20 hr.	-29.36	-28.35	-1.01
PG 52-34-A/20 hr.	-33.86	-33.39	-0.5
PG 58-28-A/20 hr.	-31.55	-33.06	1.5

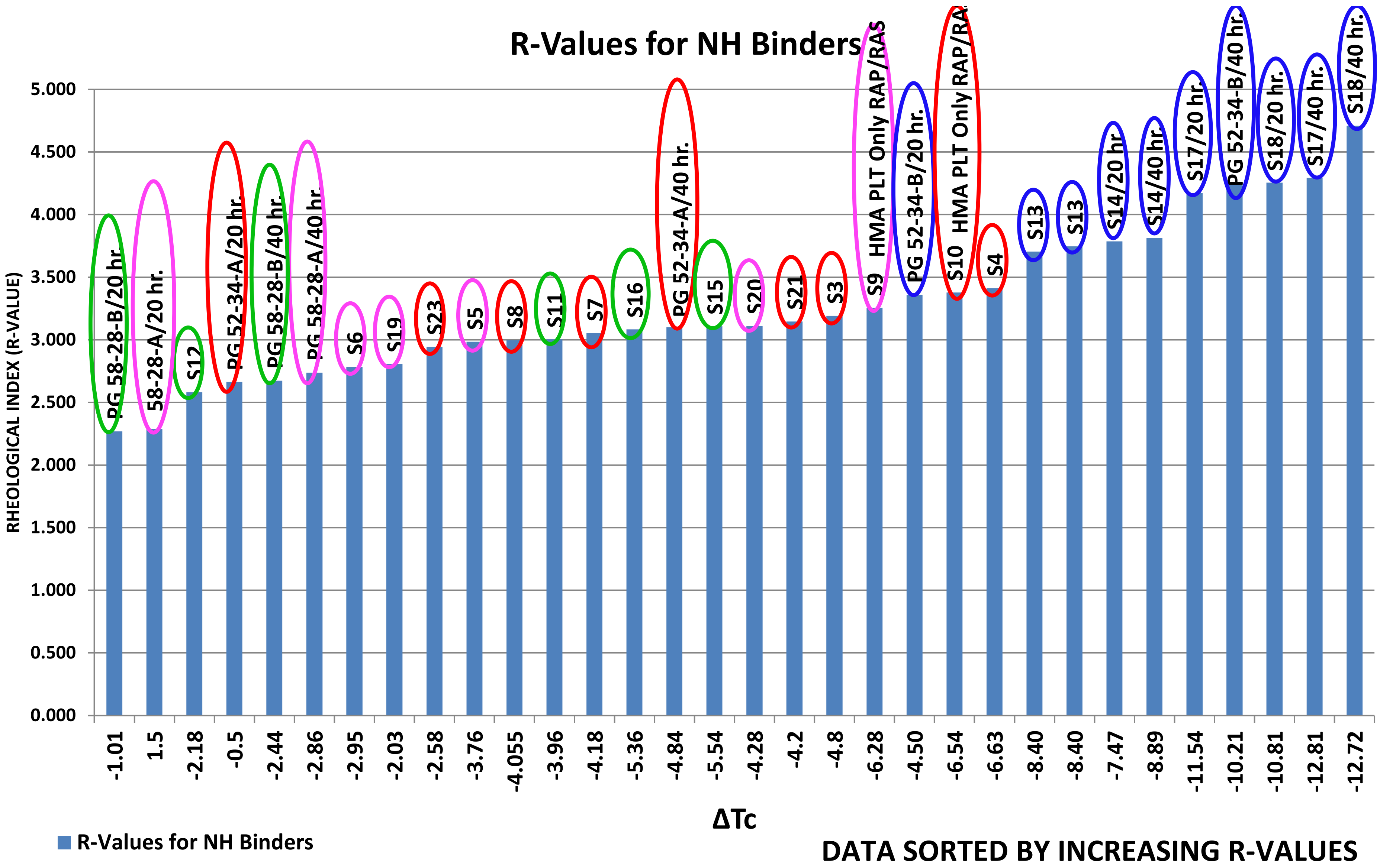

4 mm DSR ΔTc=F(R-VALUE)
S19/S20 LOW RAP PG 58-28-A
S11/S12 HIGH RAP PG 58-28-B
S5/S23/S6 HIGH RAP PG 58-=28-A
y = -5.7305x + 13.265
R² = 0.9487
PG 58-28-A/20 hr.
PG 52-34-A/20 hr.
PG 58-28-B/20 hr.
S12
S19
S23
S11
PG 58-28-B/40 hr.
PG 58-28-A/40 hr.
S6
S5
S7
S20
S21
S8
PG 52-34-B/20 hr.
S3
PG 52-34-A/40 hr.
S16
S9
S15
S10
S4
S14/20 hr.
S13
S13
S14/40 hr.
PG 52-34-B/40 hr.
S18/20 hr.
S17/20 hr.
S17/40 hr.
S18/40 hr.
ΔTc (Stiffness critical Temp-mvalue critical Temp)
RHEOLOGICAL INDEX (R-VALUE)
ΔTc=F(R-VALUE)
Linear (ΔTc=F(R-VALUE))
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
2.000
2.500
3.000
3.500
4.000
4.500
5.000



4 mm DSR ΔTc=F(R-VALUE)
S19/S20 LOW RAP PG 58-28-A
S11/S12 HIGH RAP PG 58-28-B
S5/S23/S6 HIGH RAP PG 58-=28-A
S13/S14 HIGH RAP PG 52-34-B
S17/S18 RAP/RAS PG 52-34-B
y = -5.7305x + 13.265
R² = 0.9487
PG 58-28-A/20 hr.
PG 52-34-A/20 hr.
PG 58-28-B/20 hr.
S12
S19
S23
S11
PG 58-28-B/40 hr.
PG 58-28-A/40 hr.
S6
S5
S7
S20
S8
S21
PG 52-34-B/20 hr.
S3
PG 52-34-A/40 hr.
S16
S9
S15
S10
S4
S14/20 hr.
S13
S13
S14/40 hr.
PG 52-34-B/40 hr.
S18/20 hr.
S17/20 hr.
S17/40 hr.
S18/40 hr.
ΔTc (Stiffness critical Temp-mvalue critical Temp)
RHEOLOGICAL INDEX (R-VALUE)
ΔTc=F(R-VALUE)
Linear (ΔTc=F(R-VALUE))



4 mm DSR ΔTc=F(R-VALUE)
S19/S20 LOW RAP PG 58-28-A
S11/S12 HIGH RAP PG 58-28-B
S5/S23/S6 HIGH RAP PG 58-=28-A
y = -5.7305x + 13.265
R² = 0.9487
PG 58-28-A/20 hr.
PG 52-34-A/20 hr.
PG 58-28-B/20 hr.
S12
S19
S23
S11
PG 58-28-B/40 hr.
PG 58-28-A/40 hr.
S6
S5
S7
S20
S21
S8
PG 52-34-B/20 hr.
S3
PG 52-34-A/40 hr.
S16
S9
S15
S10
S4
S13/S14 HIGH RAP PG 52-34-B
S17/S18 RAP/RAS PG 52-34-B
S7/S8 HIGH RAP PG 52-34-A
S15/S16 RAP/RAS PG 58-28-B
S9 HIGH RAP PG 58-28-A
S10 RAP/RAS PG 52-34-A
S3/S4/S21 LOW RAP PG 52-34-A
S14/20 hr.
S13
S13
S14/40 hr.
PG 52-34-B/40 hr.
S18/20 hr.
S17/20 hr.
S17/40 hr.
S18/40 hr.
ΔTc (Stiffness critical Temp-mvalue critical Temp)
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
2.000
2.500
3.000
3.500
4.000
4.500
5.000
RHEOLOGICAL INDEX (R-VALUE)
ΔTc=F(R-VALUE)
Linear (ΔTc=F(R-VALUE))


R-Values for NH Binders
RHEOLOGICAL INDEX (R-VALUE)
5.000
4.500
4.000
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
PG 58-28-B/20 hr.
58-28-A/20 hr.
S12
PG 52-34-A/20 hr.
PG 58-28-B/40 hr.
PG 58-28-A/40 hr.
S6
S19
S23
S5
S8
S11
S7
S16
PG 52-34-A/40 hr.
S15
S20
S21
S3
S9 HMA PLT Only RAP/RAS
PG 52-34-B/20 hr.
S10 HMA PLT Only RAP/RAS
S4
S13
S13
S14/20 hr.
S14/40 hr.
S17/20 hr.
PG 52-34-B/40 hr.
S18/20 hr.
S17/40 hr.
S18/40 hr.
-1.01
1.5
-2.18
-0.5
-2.44
-2.86
-2.95
-2.03
-2.58
-3.76
-4.055
-3.96
-4.18
-5.36
-4.84
-5.54
-4.28
-4.2
-4.8
-6.28
-4.50
-6.54
-6.63
-8.40
-8.40
-7.47
-8.89
-11.54
-10.21
-10.81
-12.81
-12.72
ΔTc
R-Values for NH Binders
DATA SORTED BY INCREASING R-VALUES

DISCUSSION

- Imperative that when trying to arrive at a precise low temperature grade that both BBR test results bridge the failure criteria—this can take 3 or maybe 4 test temperatures for BBR
- I have no reason for the lack of comparability between some BBR m-value and 4 mm relaxation value for this data set except to note that some of the samples with largest deviation contained RAP & RAS.

DISCUSSION

- I believe this data once again supports the need to age mixtures and binders sufficiently enough to stress the material to simulate extended aging time in the field
  - Regardless of whether or not REOB is present
  - Impact of high RAP and RAP/RAS binder replacement can result in higher values of ΔTc
  - Those properties can be exacerbated by REOB and possibly other materials.

VERMONT CORE TESTING

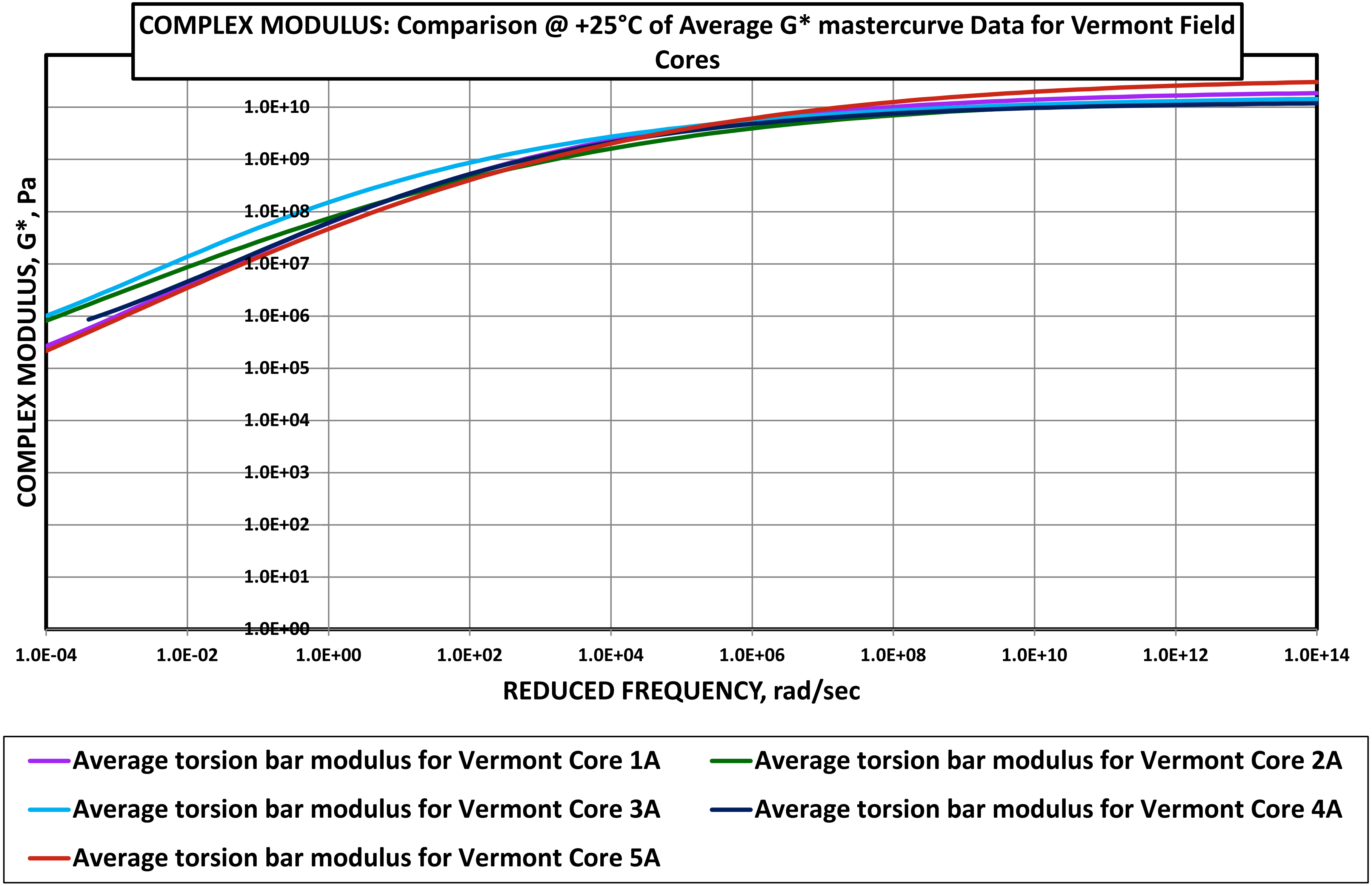
- At Fall River ETG meeting after Bill Ahearn's presentation with respect to REOB, MTE offered to test cores from projects that were considered suspect by VT DOT

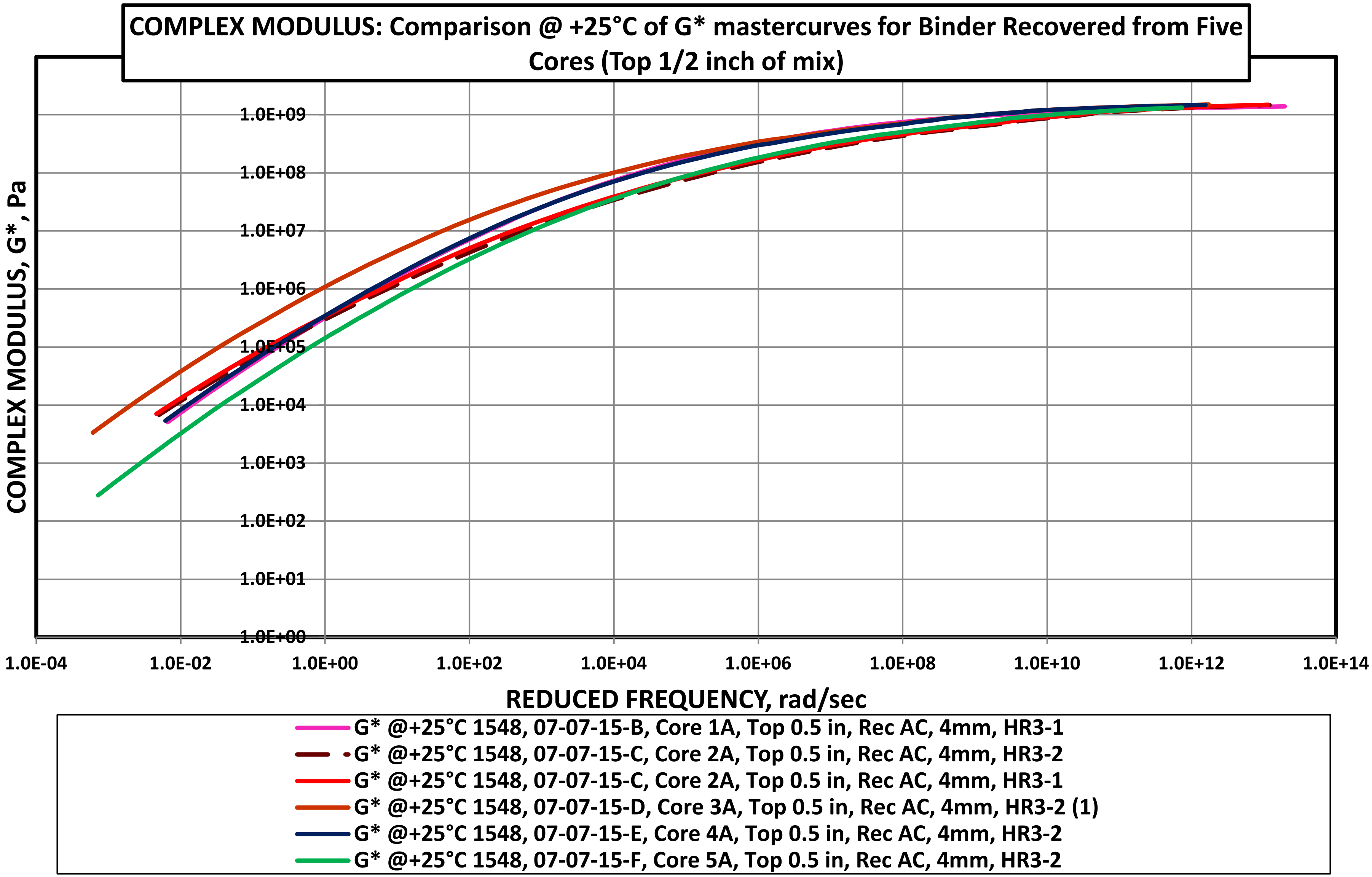
DATA FROM VERMONT CORES

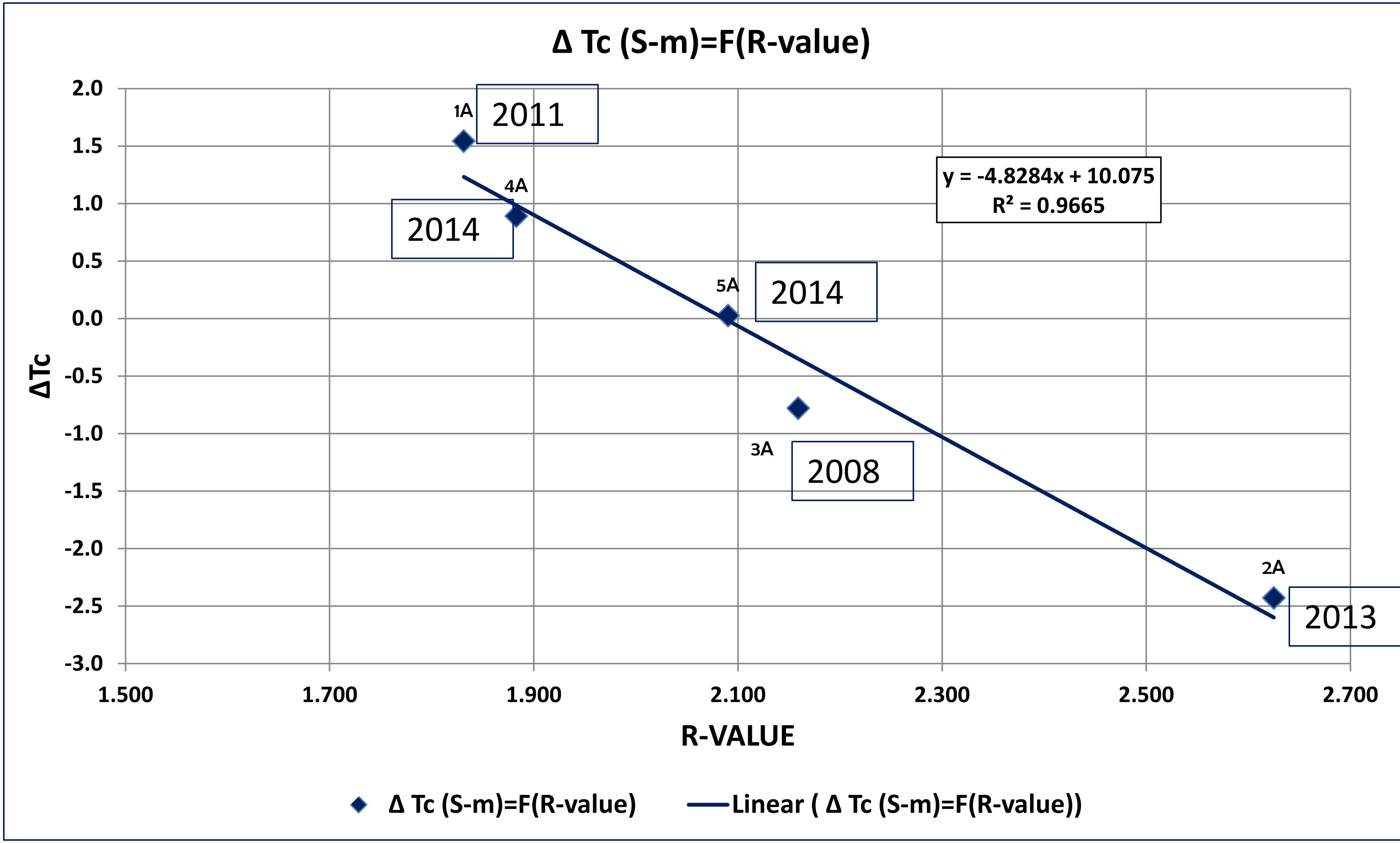
- FIVE CORES SUBMITTED FOR TESTING
  - All mixes produced with PG 58-28 and ≈20% RAP
- TORSION BARS CUT FROM TOP ½ INCH OF CORES
  - FOUR SPECIMENS TESTED AND MODULUS AVERAGE COMPUTED
  - BINDER EXTRACTED FROM TOP ½ INCH MATERIAL
  - 4 mm DSR TESTING PERFORMED

High and Low temperature summary Vermont recovered binder								
MTE Lab #	Core #	Location	Year Placed	High temp grade, 2.2 kPa	Low temp S_Critical	Low temp m_critical	Δ Tc (S-m)	R-Value
07-07-15-B	1A	St. George	2011	66.0	-32.0	-33.5	1.5	1.831
07-07-15-C	2A	Essex	2013	67.6	-37.0	-34.6	-2.4	2.625
07-07-15-D	3A	Westford	2008	74.8	-28.01	-27.23	-0.8	2.159
07-07-15-E	4A	Putney	2014	66.0	-30.6	-31.5	0.9	1.883
07-07-15-F	5A	Weatherfield	2014	59.5	-36.2	-36.2	0.0	2.090

Determination of metals in binders recovered from field cores						
MTE Lab #	Core #	Location	Year Placed	Zinc	Calcium	copper
07-07-15-B	1A	St. George	2011	14	4551	0
07-07-15-C	2A	Essex	2013	21	555	0
07-07-15-D	3A	Westford	2008	30	1259	0
07-07-15-E	4A	Putney	2014	50	184	2
07-07-15-F	5A	Weatherfield	2014	203	380	9


COMPLEX MODULUS: Comparison @ +25°C of Average G* mastercurve Data for Vermont Field Cores
COMPLEX MODULUS, G*, Pa
1.0E+10
1.0E+09
1.0E+08
1.0E+07
1.0E+06
1.0E+05
1.0E+04
1.0E+03
1.0E+02
1.0E+01
1.0E+00
1.0E-04
1.0E-02
1.0E+00
1.0E+02
1.0E+04
1.0E+06
1.0E+08
1.0E+10
1.0E+12
1.0E+14
REDUCED FREQUENCY, rad/sec
Average torsion bar modulus for Vermont Core 1A
Average torsion bar modulus for Vermont Core 2A
Average torsion bar modulus for Vermont Core 3A
Average torsion bar modulus for Vermont Core 4A
Average torsion bar modulus for Vermont Core 5A


COMPLEX MODULUS: Comparison @ +25°C of G* mastercurves for Binder Recovered from Five Cores (Top 1/2 inch of mix)
COMPLEX MODULUS, G*, Pa
1.0E+09
1.0E+08
1.0E+07
1.0E+06
1.0E+05
1.0E+04
1.0E+03
1.0E+02
1.0E+01
1.0E+00
1.0E-04
1.0E-02
1.0E+00
1.0E+02
1.0E+04
1.0E+06
1.0E+08
1.0E+10
1.0E+12
1.0E+14
REDUCED FREQUENCY, rad/sec
G* @+25°C 1548, 07-07-15-B, Core 1A, Top 0.5 in, Rec AC, 4mm, HR3-1
G* @+25°C 1548, 07-07-15-C, Core 2A, Top 0.5 in, Rec AC, 4mm, HR3-2
G* @+25°C 1548, 07-07-15-C, Core 2A, Top 0.5 in, Rec AC, 4mm, HR3-1
G* @+25°C 1548, 07-07-15-D, Core 3A, Top 0.5 in, Rec AC, 4mm, HR3-2 (1)
G* @+25°C 1548, 07-07-15-E, Core 4A, Top 0.5 in, Rec AC, 4mm, HR3-2
G* @+25°C 1548, 07-07-15-F, Core 5A, Top 0.5 in, Rec AC, 4mm, HR3-2



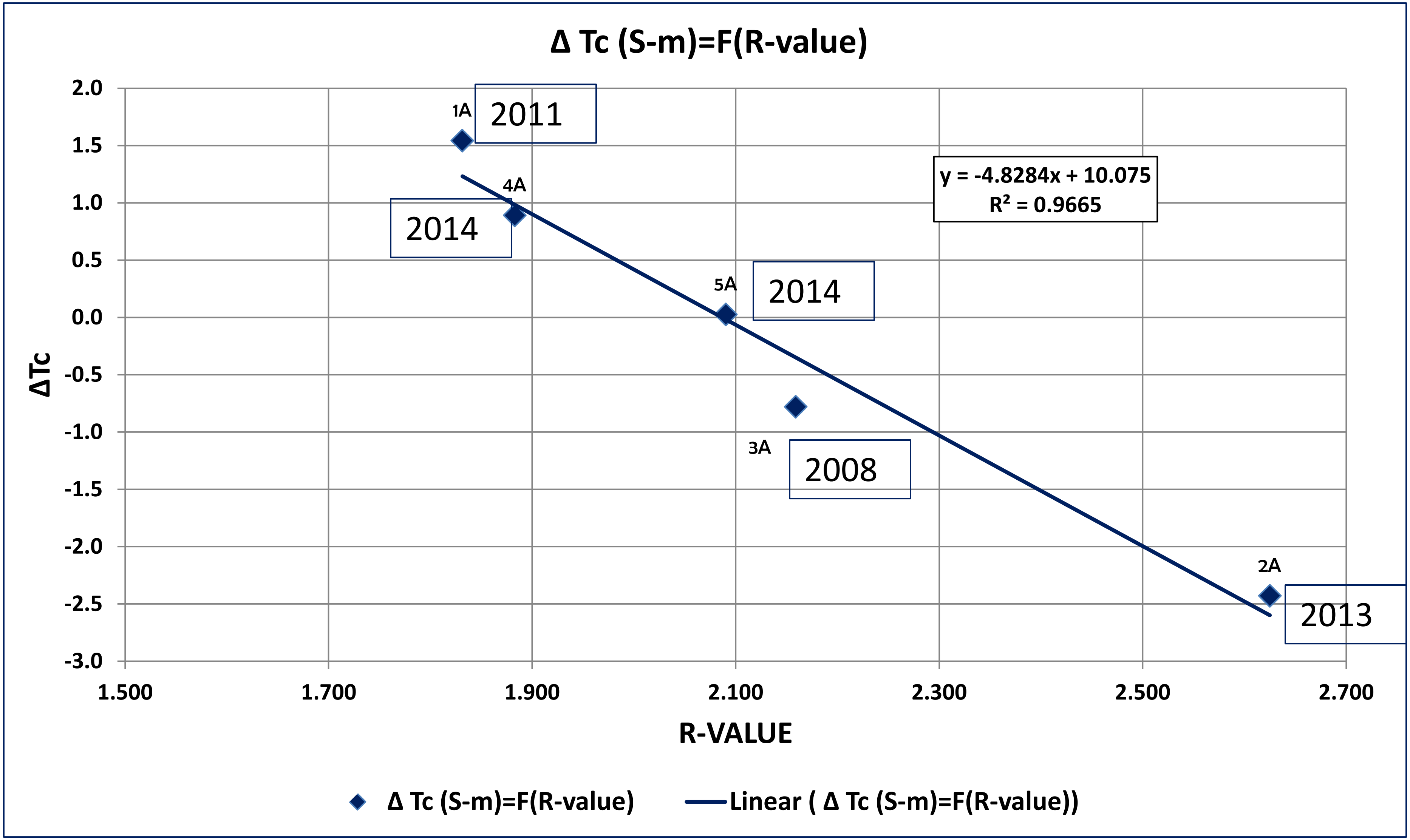
Δ Tc (S-m)=F(R-value)
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
ΔTc
1A
2011
4A
2014
5A
2014
3A
2008
2A
2013
y = -4.8284x + 10.075
R² = 0.9665
1.500
1.700
1.900
2.100
2.300
2.500
2.700
R-VALUE
Δ Tc (S-m)=F(R-value)
Linear (Δ Tc (S-m)=F(R-value))

DISCUSSION

1. St. George project (core 1A) was stated as showing distress, but ΔTc of +1.5 after 4 years and low zinc indicate that REOB is not the issue
2. Oldest project, Westford (Core 3A), after 5 years has a ΔTc of -0.2°C and the highest high temp grade.
3. Core 2A, Essex, is 2 years old and the ΔTc value is -2.1°C could be typical behavior for the particular binder used on the project or for the condition of the RAP binder used on the project, however the low temperature values (S=-37°C, m=-34.6°C) is such that it does not suggest an excessively stiff RAP binder in the mix

DISCUSSION

4. Core 4A is only 1 year old, zinc level is low, low temperature grade is -30.6°C. Binder from core 4A is second stiffest of the five. Interpretation is that the level and stiffness of RAP is the cause
5. Core 5A is 1 year old, level of zinc would indicate ~ 5% REOB. ΔTc at 1 year is 0.0°C. Both S-critical and m-critical grades are -36.2°C & high grade is 59.2°C
6. One year is too short to find "smoking gun" evidence of REOB and/or impact of RAP content
7. Projects should be followed for several years


Δ Tc (S-m)=F(R-value)
ΔTc
R-VALUE
y = -4.8284x + 10.075
R² = 0.9665
1A
2011
4A
2014
5A
2014
3A
2008
2A
2013
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
1.500
1.700
1.900
2.100
2.300
2.500
2.700
Δ Tc (S-m)=F(R-value)
Linear (Δ Tc (S-m)=F(R-value))