IMPACT OF RAS & RAP CONTENT and MIX AGING ON PROJECTED MIX PERFORMANCE

Investigations performed by

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MTE SERVICES, INC.

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PORTSMOUTH, NH

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SOME PRELIMINARY INFORMATION ON TESTS THAT ARE USED TO GENERATE DATA SHOWN IN THIS PRESENTATION

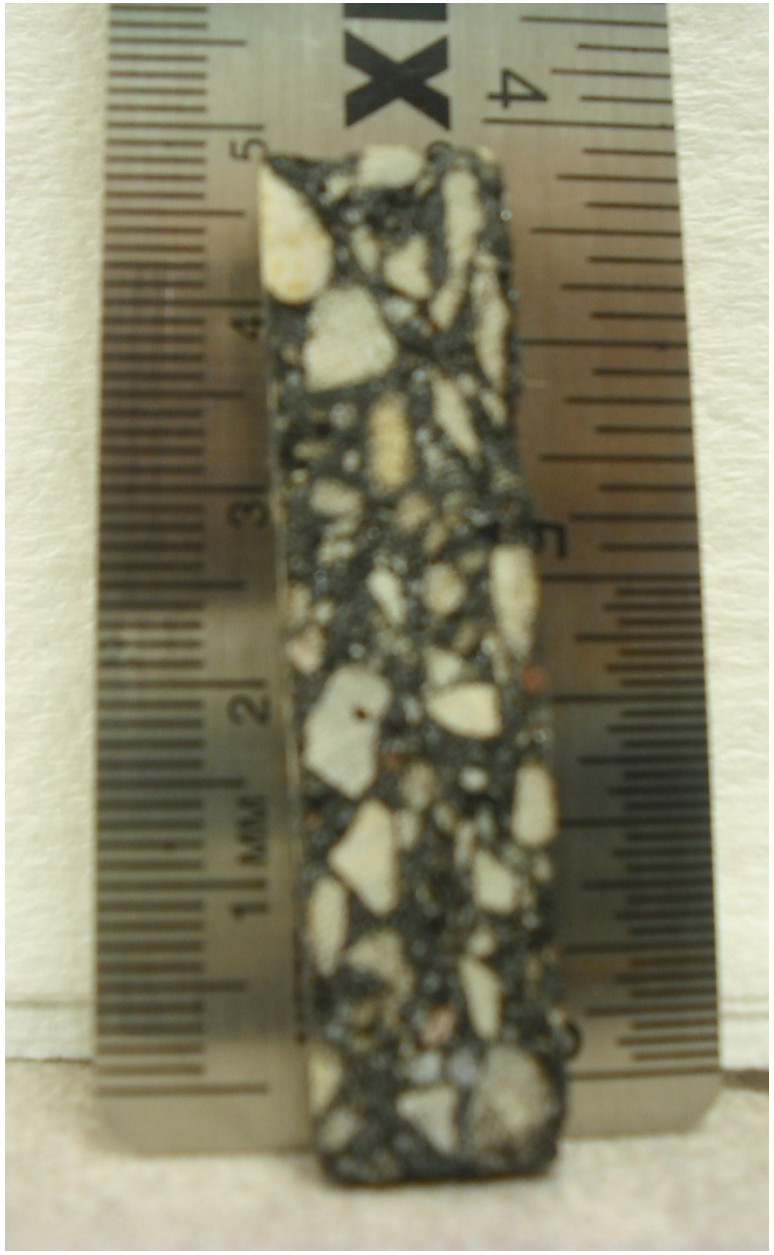
4 mm DSR BINDER TEST

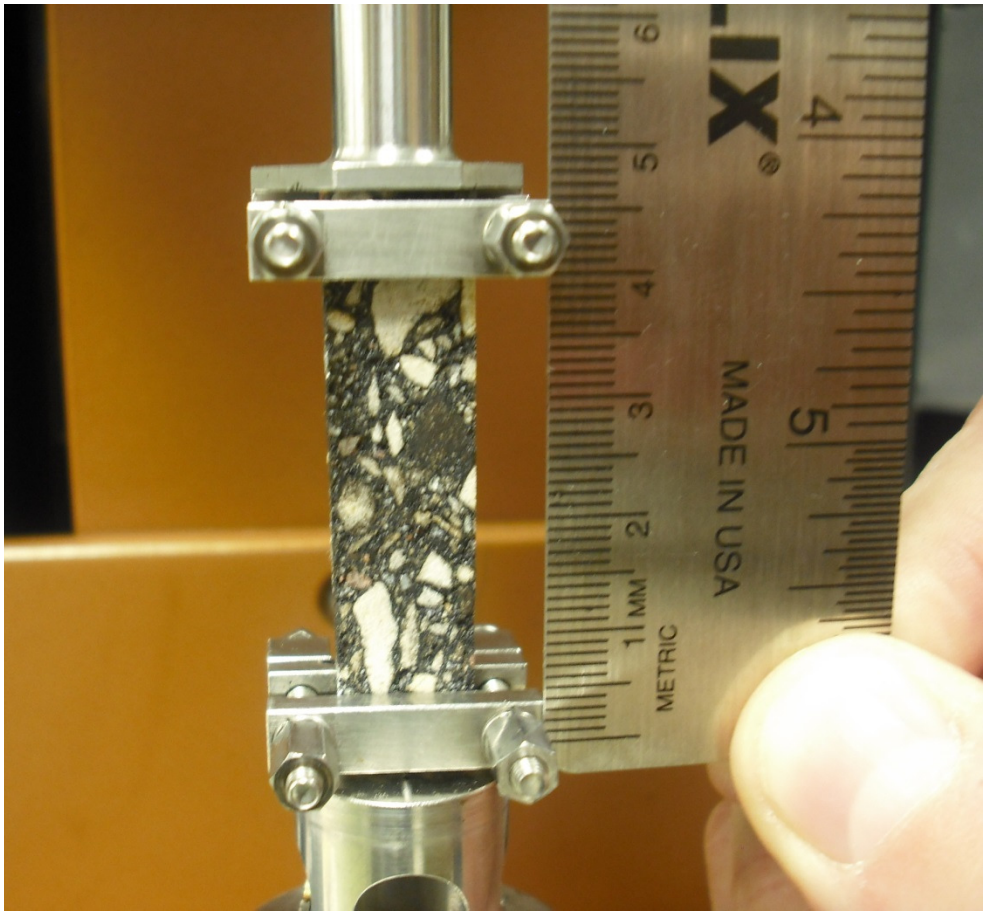
- ✓ Developed by Western Research Institute.
- ✓ TRB talks in 2011 and 2012 by Sui and Farrar, et al
- ✓ AASHTO & ASTM methods submitted

TORSION BAR TESTING OF MIXES

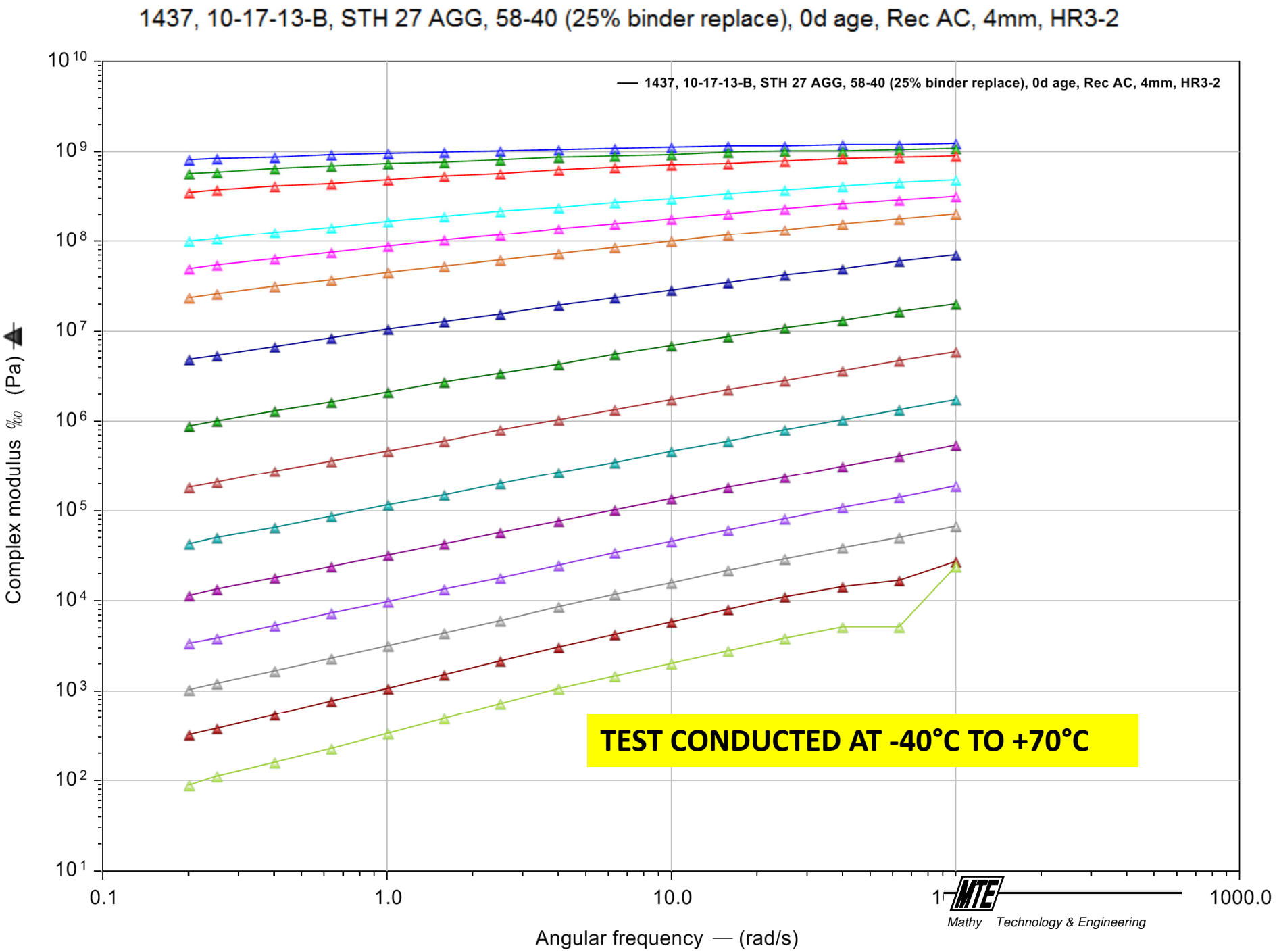
- ✓ Developed at MTE, now ASTM D7522

4 mm DSR test heads. Today all major DSR manufacturers have these test fixtures available. Picture on right shows sample ready to test. Upper geometry should be lock while trimming to prevent material being pulled out from between plates.





MIX TORSION BAR TEST
≈50 mm X 12 mm X 7 mm
TESTED AT -40°C TO +40-80° DEPENDING ON MIX STIFFNESS


1437, 10-17-13-B, STH 27 AGG, 58-40 (25% binder replace), 0d age, Rec AC, 4mm, HR3-2
1437, 10-17-13-B, STH 27 AGG, 58-40 (25% binder replace), 0d age, Rec AC, 4mm, HR3-2
Complex modulus ‰ (Pa)
Angular frequency — (rad/s)
0.1
1.0
10.0
1000.0
TEST CONDUCTED AT -40°C TO +70°C
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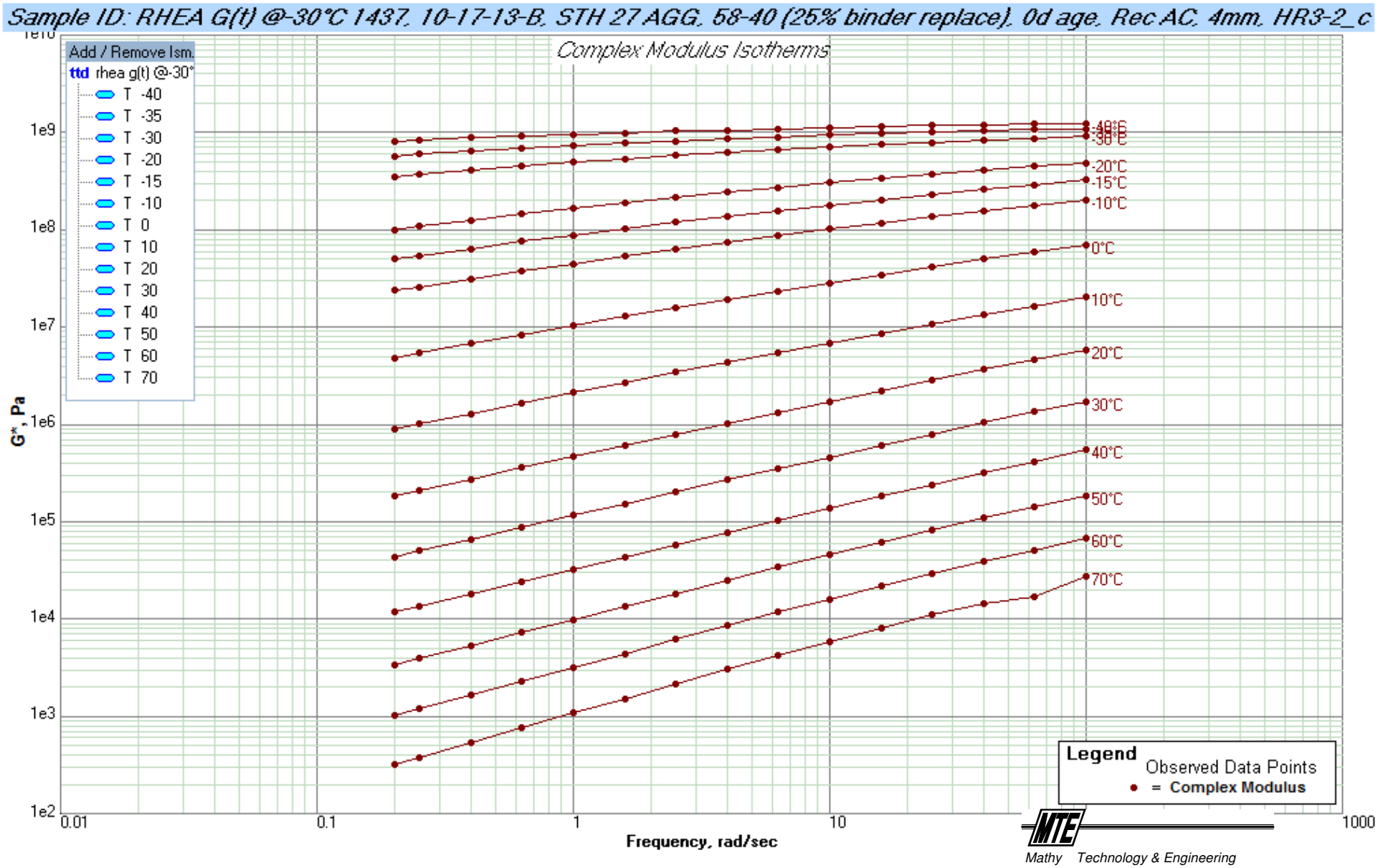
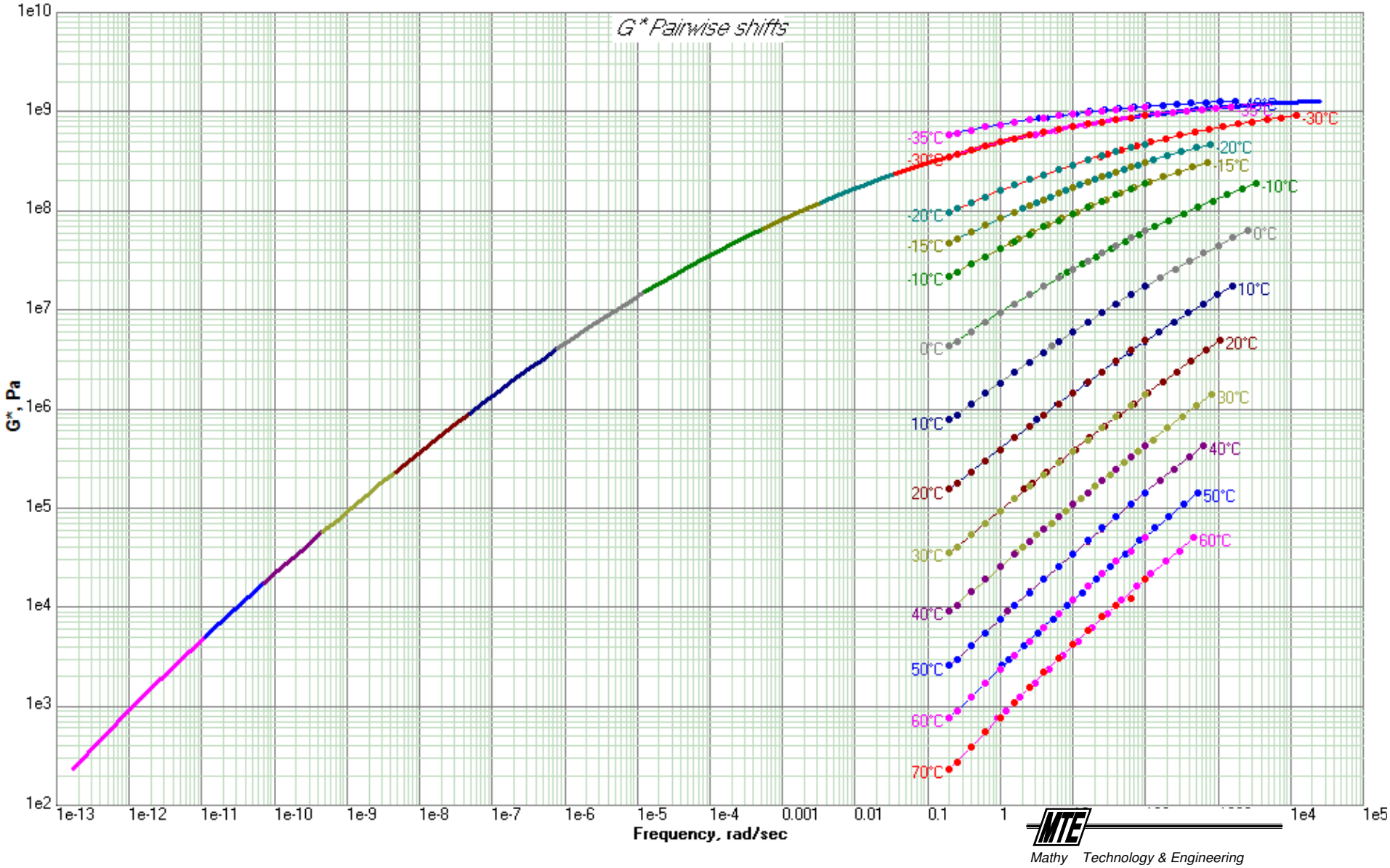
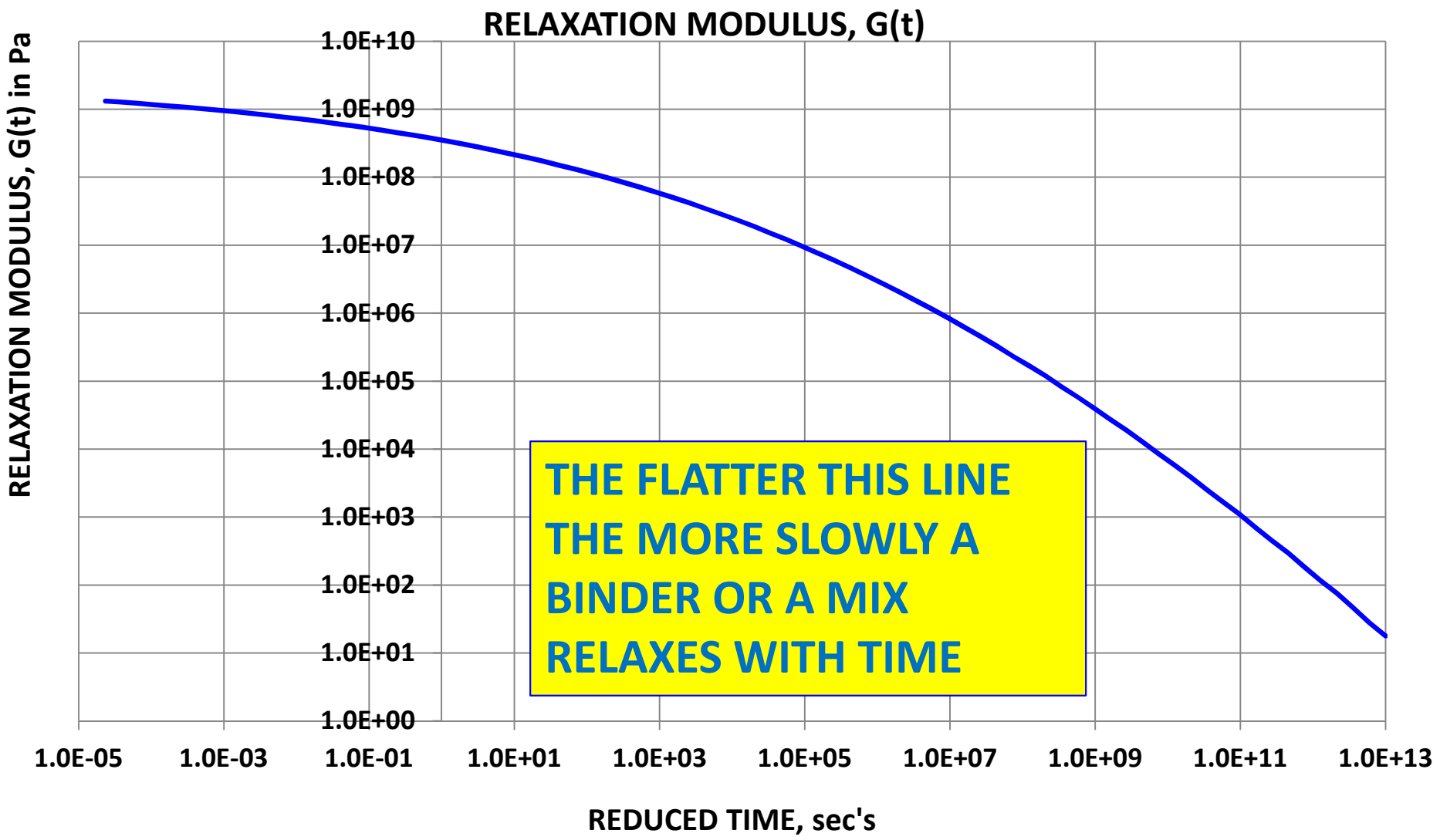
DATA IS TRANSFERRED TO ABATECH ® SOFTWARE FOR ANALYSIS



MASTERCURVE AT ANY TEMPERATURE WITHIN THE TESTED RANGE IS POSSIBLE
BELOW IS THE MASTERCURVE AT -30°C



OR THE DATA CAN BE INTERCONVERTED INTO A RELAXATION MODULUS PLOT



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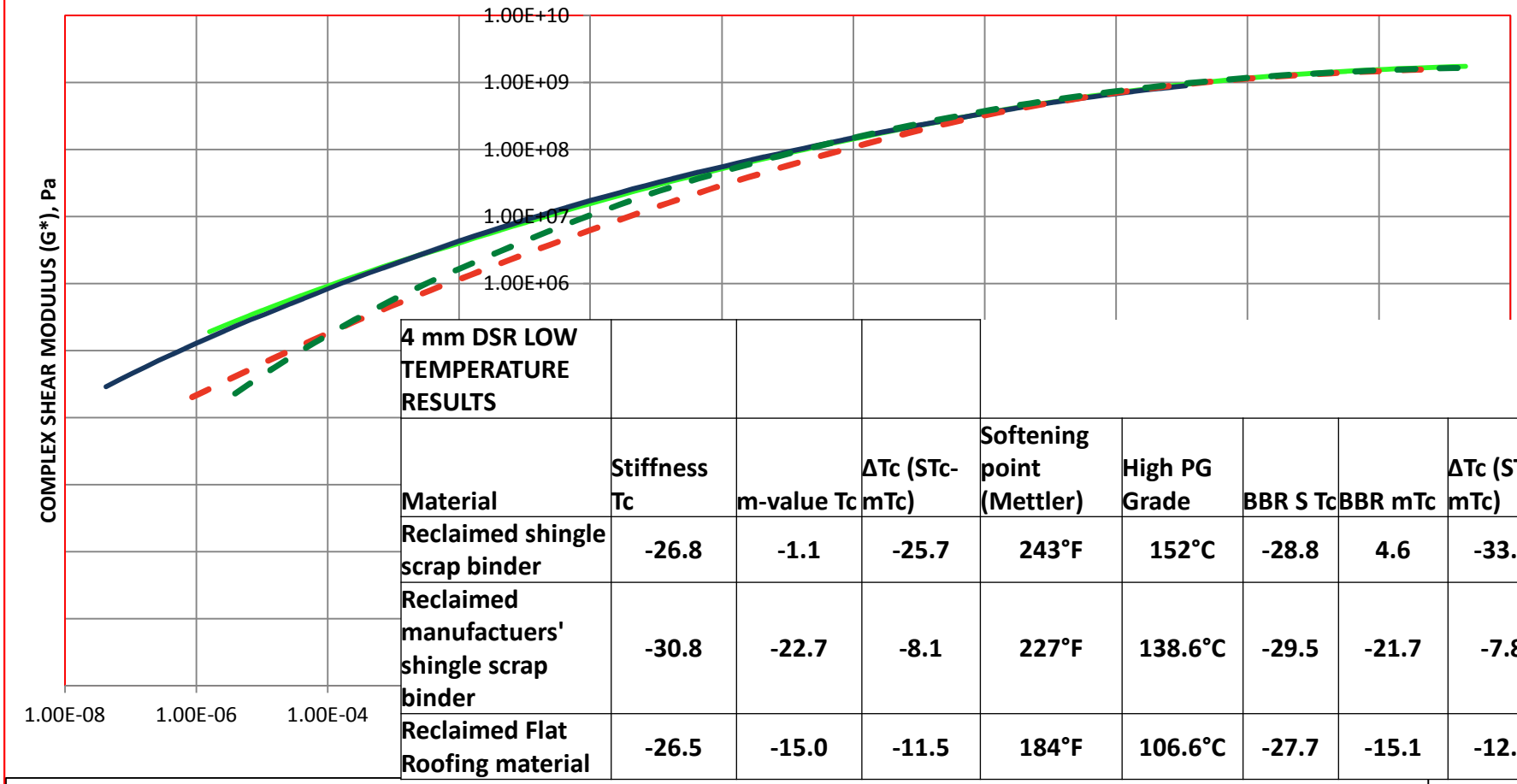
DATA ON THE PROPERTIES OF THE ADDITIVES WE ARE TALKING ABOUT



4 mm DSR LOW TEMPERATURE RESULTS								
Material	Stiffness Tc	m-value Tc	ΔTc (STc-mTc)	Softening point (Mettler)	High PG Grade	BBR S Tc	BBR mTc	ΔTc (STc-mTc)
Reclaimed shingle scrap binder	-26.8	-1.1	-25.7	243°F	152°C	-28.8	4.6	-33.4
Reclaimed manufactuers' shingle scrap binder	-30.8	-22.7	-8.1	227°F	138.6°C	-29.5	-21.7	-7.8
Reclaimed Flat Roofing material	-26.5	-15.0	-11.5	184°F	106.6°C	-27.7	-15.1	-12.6

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Background Information

- ✓ Rising cost of liquid asphalt has motivated agencies, contractors, HMA plant manufacturers, additive suppliers to increase the level of RAP and RAS materials in paving mixes
- ✓ Previous levels were pegged at 15-20% binder replacement of reclaimed binder
  - This usage level generally required no change to the PG grade of the binder used in the mix

Background Information

- ✓ Research reported by NCAT has suggested that higher binder replacement levels can be used without concern
- ✓ Some entities are suggesting that 50% or more binder replacement can be used of which a significant amount can be RAS
  - ➢ Softening of binder grade is recommended
  - ➢ I have some reservations as to whether that will solve the problem

Background Information

- ✓ Our concerns—mainly center around RAS
  - RAS can contain upwards of 30% bitumen (20-27% more typical)
  - Material is highly oxidized
    - Poor m-values, wide variation between S & m-value
      - BUR tear off low temp grade S=-27.8, m= +11.9 (4 mm DSR)
    - Softening points 223°F to 270°F
    - High temp PG grades 118-150
    - Very flat relaxation modulus mastercurves
- ✓ Mixes made with 20% RAS binder replacement look OK initially, but based on our data reported here, fatigue properties seem to deteriorate rapidy
- ✓ Fatigue of these mixes is a significant concern

WHICH BRINGS ME TO THE QUESTION

Do we Rejuvenate RAS?

1. Rejuvenate- to make young again; restore to youthful vigor, appearance, etc
2. To restore to a former state; make fresh or new again

OR

Do we Resuscitate It?

Resuscitate—to revive, especially from apparent death or from unconsciousness

Based on our investigations of RAS containing mixes I would say

There is no fountain of youth for aged shingle binder

Several Studies

1. Lab study
   a) Impact of 20% RAS Binder Replacement on Short Term & 5 Day Aged Mixture Properties
   b) Evaluation of additives to improve RAS performance
      1) Initial properties and after mix aging
2. USH 14 in Winona Cty., MN mix on shoulders
   a) Four test sections place-initial testing
   b) Follow-up testing after 1 year

Design of Experiment

1. Shingle source chosen with ≈ 250°F softening point
2. Sufficient shingle binder (SB) extracted & recovered to make test specimens for study
3. Binder replacement was chosen at 22%
4. This afforded two mixes where we knew 100% blending of shingle binder and virgin binder had taken place

Design of Experiment

1. Mixes produced
   1) PG 58-28 virgin control
   2) PG 58-28 + 22% recovered shingle binder
   3) PG 58-28 + 5% RAS (=22% binder replacement)
   4) PG 58-28 + 5% RAS + 0.5% warm mix additive
   5) PG 58-28 + 5% RAS treated with 5% oil added by wt of binder in the RAS
   6) PG 52-34 + 22% recovered shingle binder
   7) PG 58-28 + 5% RAS (=22% binder replacement)
   8) PG 52-34 + 5% RAS treated with 5% oil added by wt of binder in the RAS
2. Mix was Wisconsin E-3 (3 million ESAL)
3. Limestone aggregate

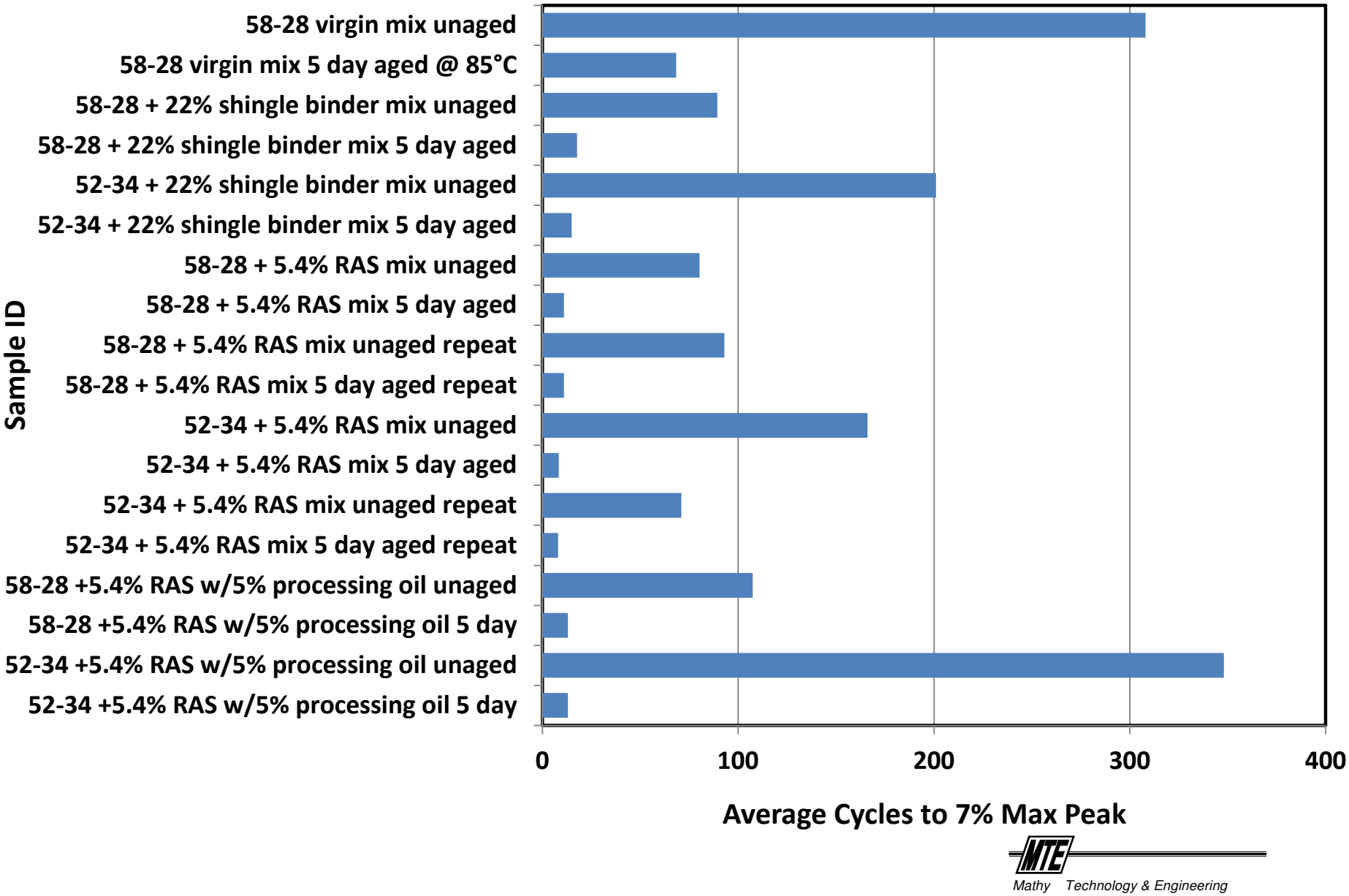
Design of Experiment

1. Treatment of mixes
   1) All mixes produced at 135°C (275°F)
   2) Short term conditioned for 2 hrs at 135°C (275°F)
   3) Compacted at 135°C (275°F)
2. One set of specimens tested at 0 day
3. One set of specimens conditioned for 5 days at 85°C

Testing Performed

1. Hamburg wet (50°C) and dry (58°C) but only in the 0 day aged condition
2. Overlay test (triplicate) conducted at 20°C both 0 day and 5 day conditioned
3. **Torsion bars tested at -40°C to +60°C** in 10°C increments from 100 to 0.5 radians/sec for complex modulus and relaxation modulus for both 0 day and 5 day conditioned
4. **Binder recovered from 0 day and 5 day** conditioned mix (only the 22% preblend), **4 mm DSR tested at -40°C to +60°C** for determination of low temp grade and relaxation modulus at +20°C

Average Cycles to 7% Max Load



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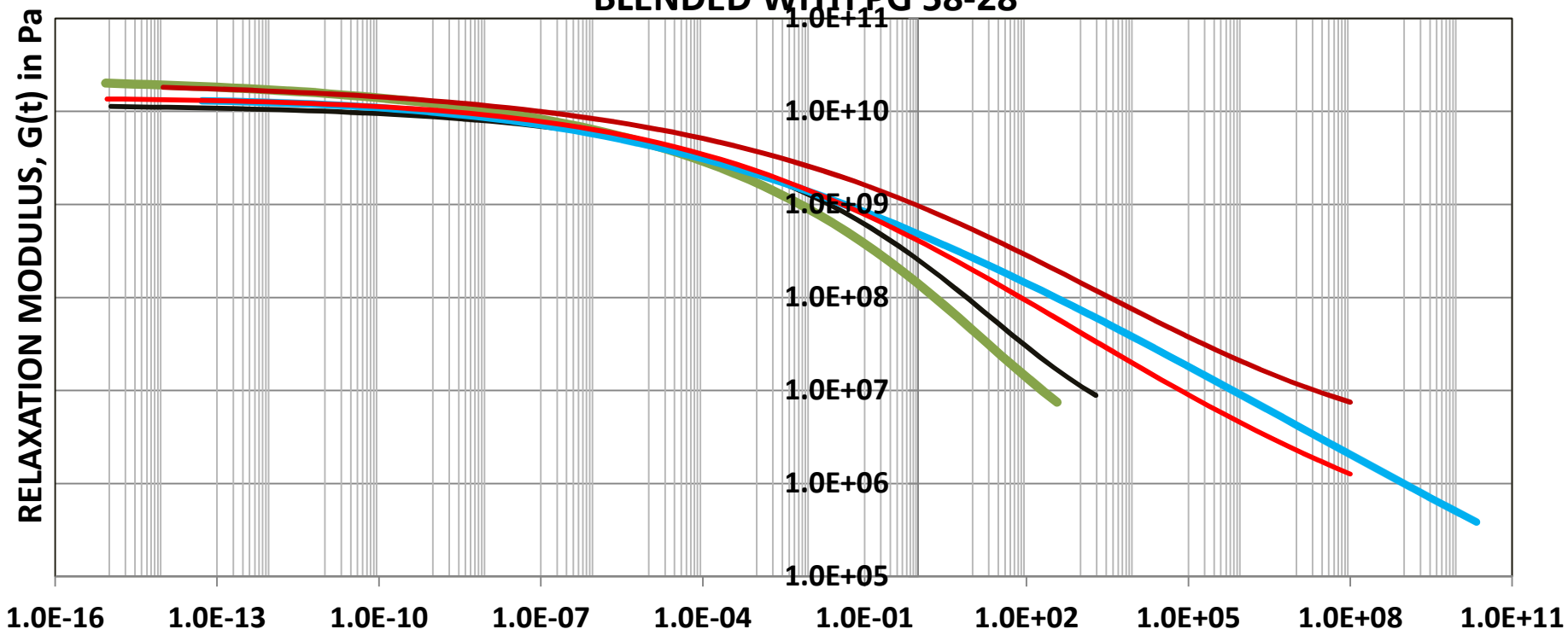
TORSION BAR RELAXATION MODULUS AT +20°C OF PG 58-28 CONTROL MIX, MIX CONTAINING 5% RAS, MIX WHERE 22% SHINGLE BINDER WAS BLENDED WITH PG 58-28



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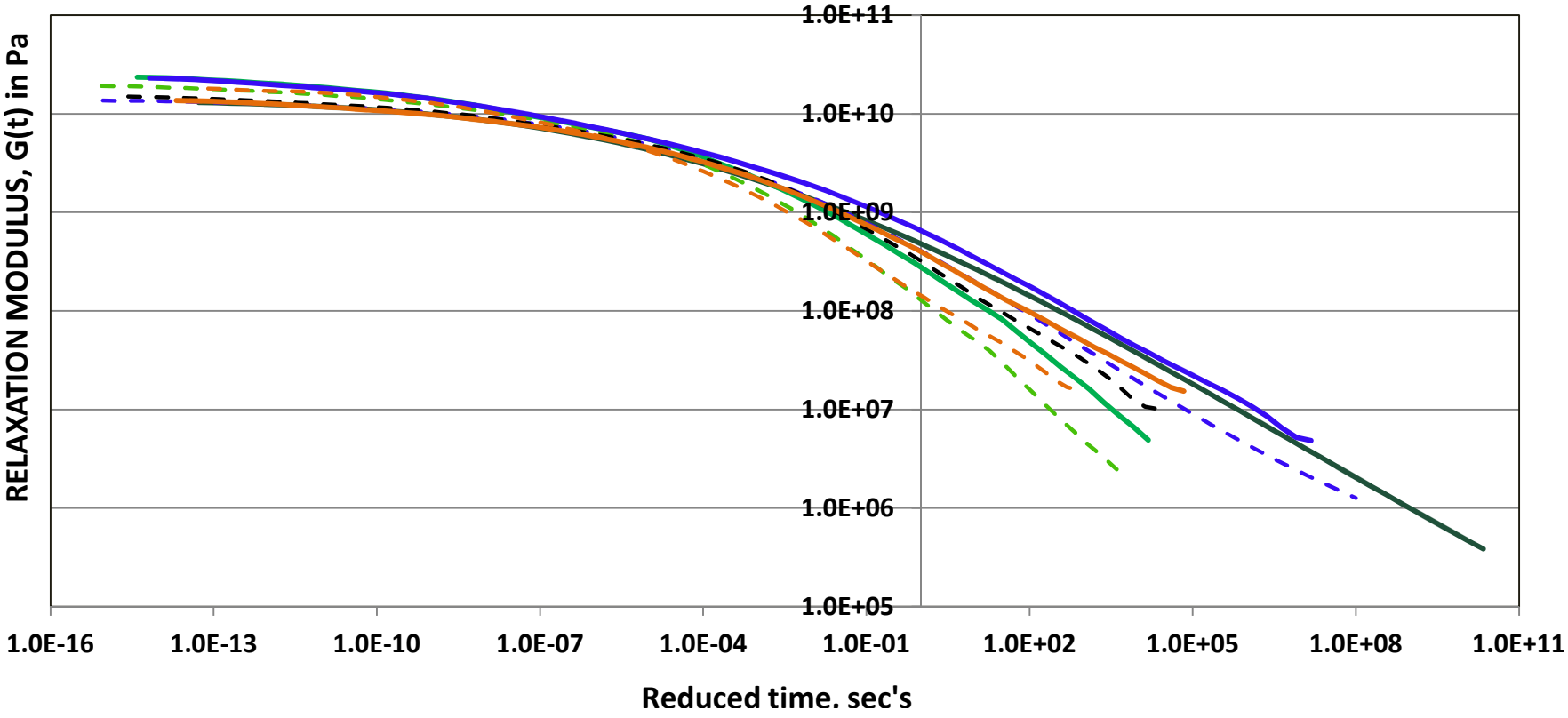
Relaxation Modulus (G(t)) as function of Reduced Time



- G(t) @ +20C 1309, 02-28-12-H, 58-28, 5% Shingles, 5d aged, HR-3
- G(t) @ +20C 1309, 02-28-12-C, 58-28, 22% SB, 0d aged HR-3 #1
- MODEL: G(t) @ +20 1309, 02-28-12-B, 58-28 control, 5d aged, tmp-frq, HR3-1
- G(t) @ 20 1309, 02-28-12-A, 58-28 control, 0d aged, tmp-frq, HR3-1
- G(t) @20°C 1309, 02-28-12-D, 58-28, 22% SB, 5d aged, HR-3
- G(t) @20°C 1309, 02-28-12-G, 58-28, 5% Shingles, 0d aged, AR-2
- G(t) @20°C 1309, 02-28-12-F, 52-34, 22% SB, 5d aged, AR-2-0002o
- MODEL: G(t) @20°C 1309, 02-28-12-E, 52-34, 22% SB, 0d aged, tmp-frq, HR-3-3

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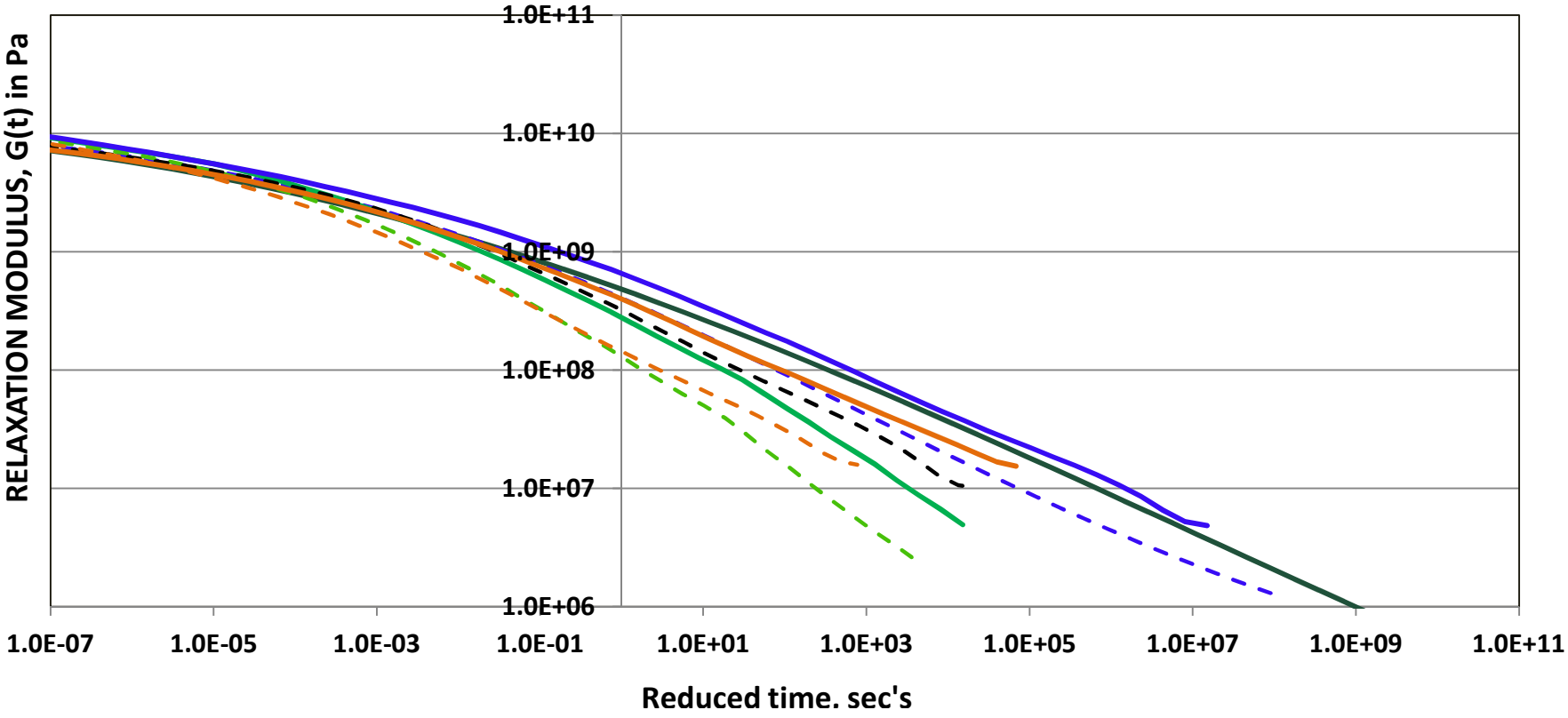
Relaxation Modulus (G(t)) as function of Reduced Time



- G(t) @ +20C 1309, 02-28-12-H, 58-28, 5% Shingles, 5d aged, HR-3
- G(t) @ +20C 1309, 02-28-12-C, 58-28, 22% SB, 0d aged HR-3 #1
- MODEL: G(t) @ +20 1309, 02-28-12-B, 58-28 control, 5d aged, tmp-frq, HR3-1
- G(t) @ 20 1309, 02-28-12-A, 58-28 control, 0d aged, tmp-frq, HR3-1
- G(t) @20°C 1309, 02-28-12-D, 58-28, 22% SB, 5d aged, HR-3
- G(t) @20°C 1309, 02-28-12-G, 58-28, 5% Shingles, 0d aged, AR-2
- G(t) @20°C 1309, 02-28-12-F, 52-34, 22% SB, 5d aged, AR-2-0002o
- MODEL: G(t) @20°C 1309, 02-28-12-E, 52-34, 22% SB, 0d aged, tmp-frq, HR-3-3

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Several Studies

1. Lab study
   a) Impact of 20% RAS Binder Replacement on Short Term & 5 Day Aged Mixture Properties
   b) Evaluation of additives to improve RAS performance
      1) Initial properties and after mix aging
2. USH 14 in Winona Cty., MN mix on shoulders
   a) Four test sections place-initial testing
   b) Follow-up testing after 1 year

Several Studies-US Hwy 14

1. Field study US Hwy 14 in Winona County, MN mixes place on shoulders
   a) PG 58-28, 6% RAS (22% binder replacement) , 11% RAP (12% binder replacement)
   b) PG 52-34, 6% RAS (22% binder replacement) , 11% RAP (12% binder replacement)
   c) PG 58-28, 0% RAS, 31% RAP (32% binder replacement)
   d) PG 58-28, 0% RAS, 20% RAP (21% binder replacement-this was the original job mix

Several Studies-US Hwy 14

1. **Mix was place in September 2012**
2. FHWA trailer was on project to collect mix and obtain samples to characterize mix as placed.
3. **November 2012 three cores taken from each test section**
   a) 1 unaged core cut into **torsion bars** for mix modulus testing @ -40°C(-35°C) to +60°C
   b) After this testing binder extracted for **4 mm DSR** testing @ -40°C(-35°C) to +60°C

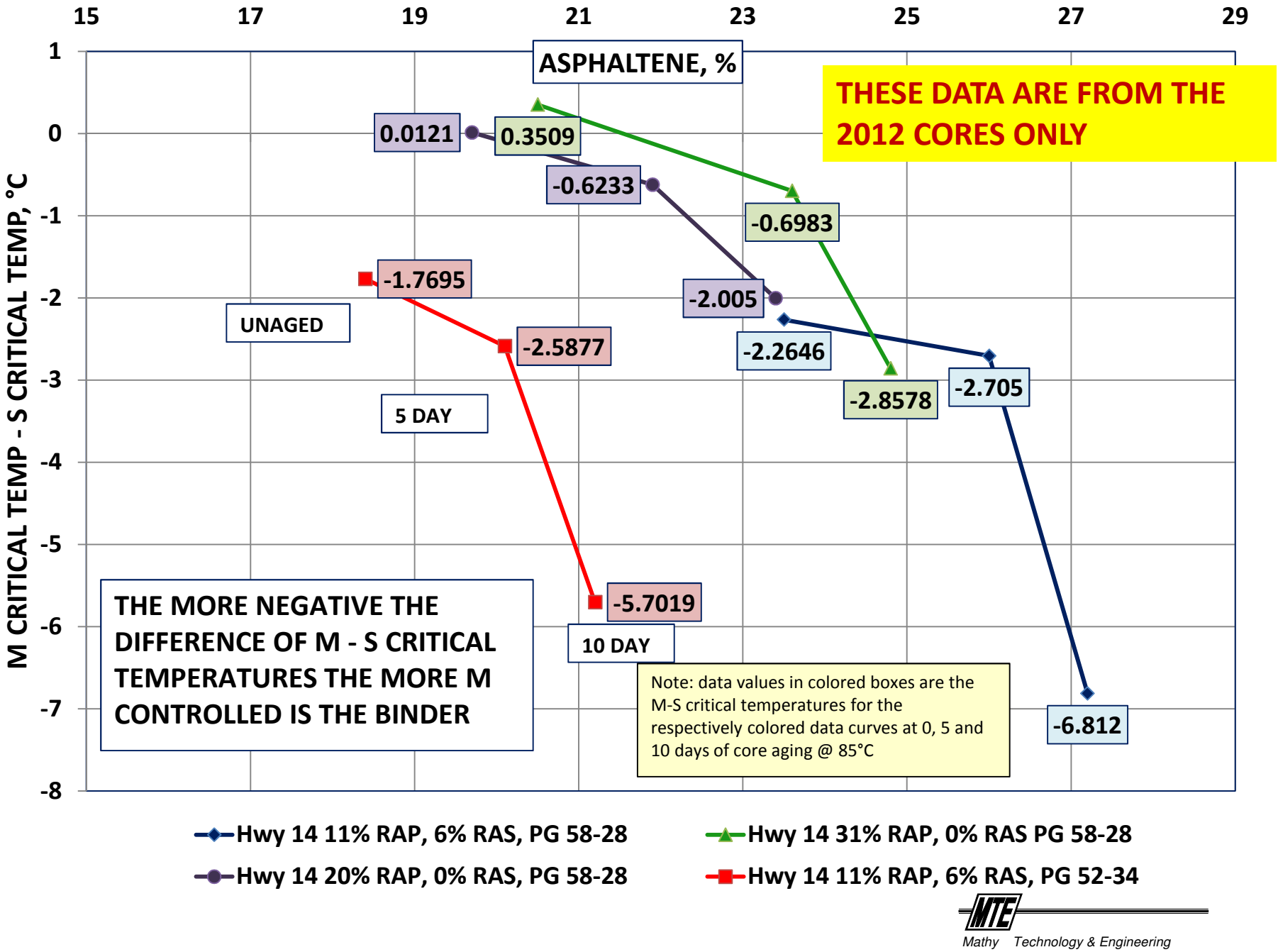
Several Studies—US Hwy 14

a) Additional field cores aged 5 & 10 days @ 85°C

1) Torsion bars for mix modulus testing @ -40°C(-35°C) to +60°C
2) After this testing binder extracted for 4 mm DSR testing @ -40°C(-35°C) to +60°C
3) **Iatroscan data collected on all recovered binders (asphaltenes + 3 other fractions determined)**

b) New Cores taken 1 year after placement

1) Top 12 mm and 2nd 12 mm layers of each mix were tested for
2) Mix stiffness using torsion bars
3) Recovered binder properties using 4 mm DSR



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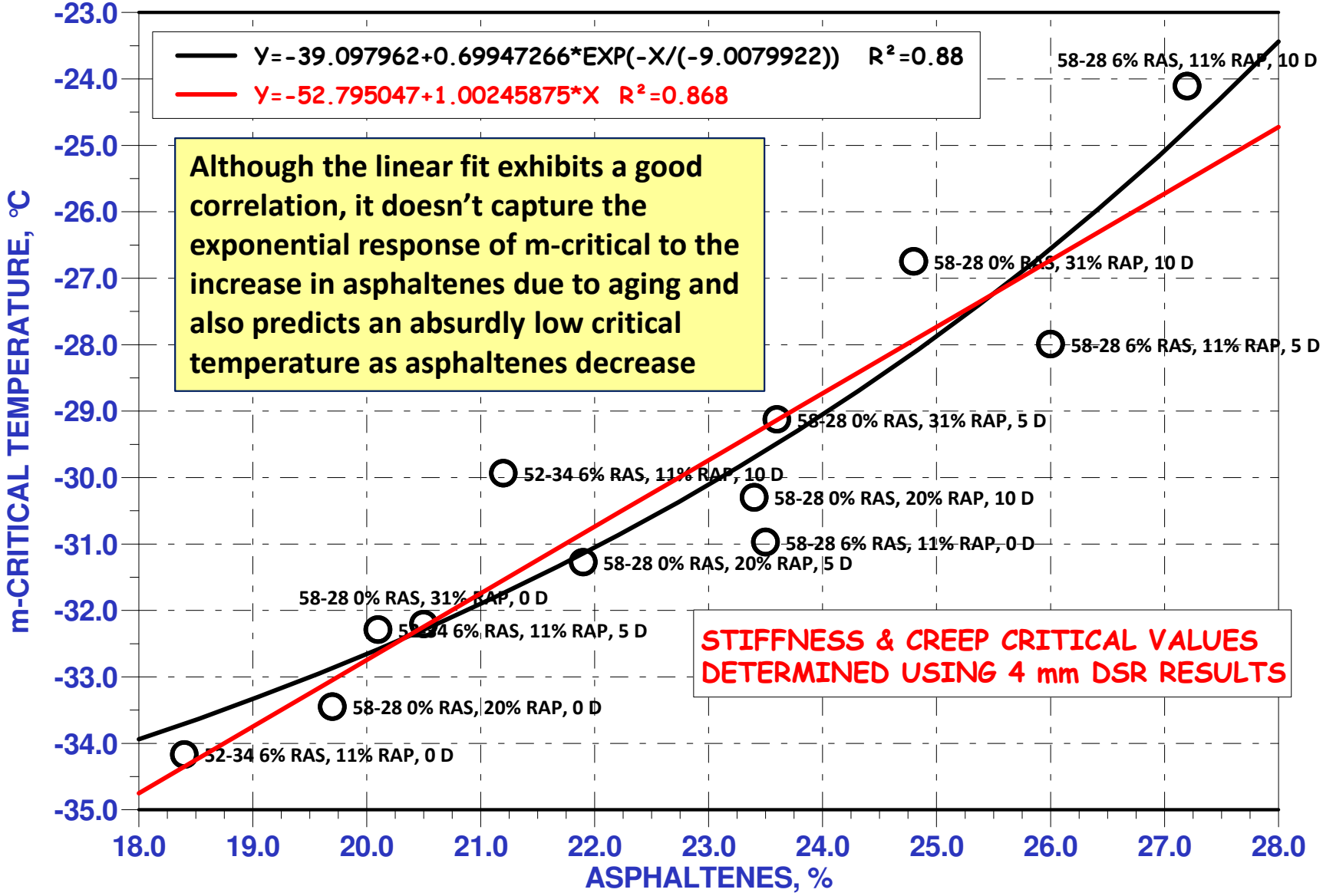
PLOT OF M-CRITICAL AS FUNCTION OF % ASPHALTENES



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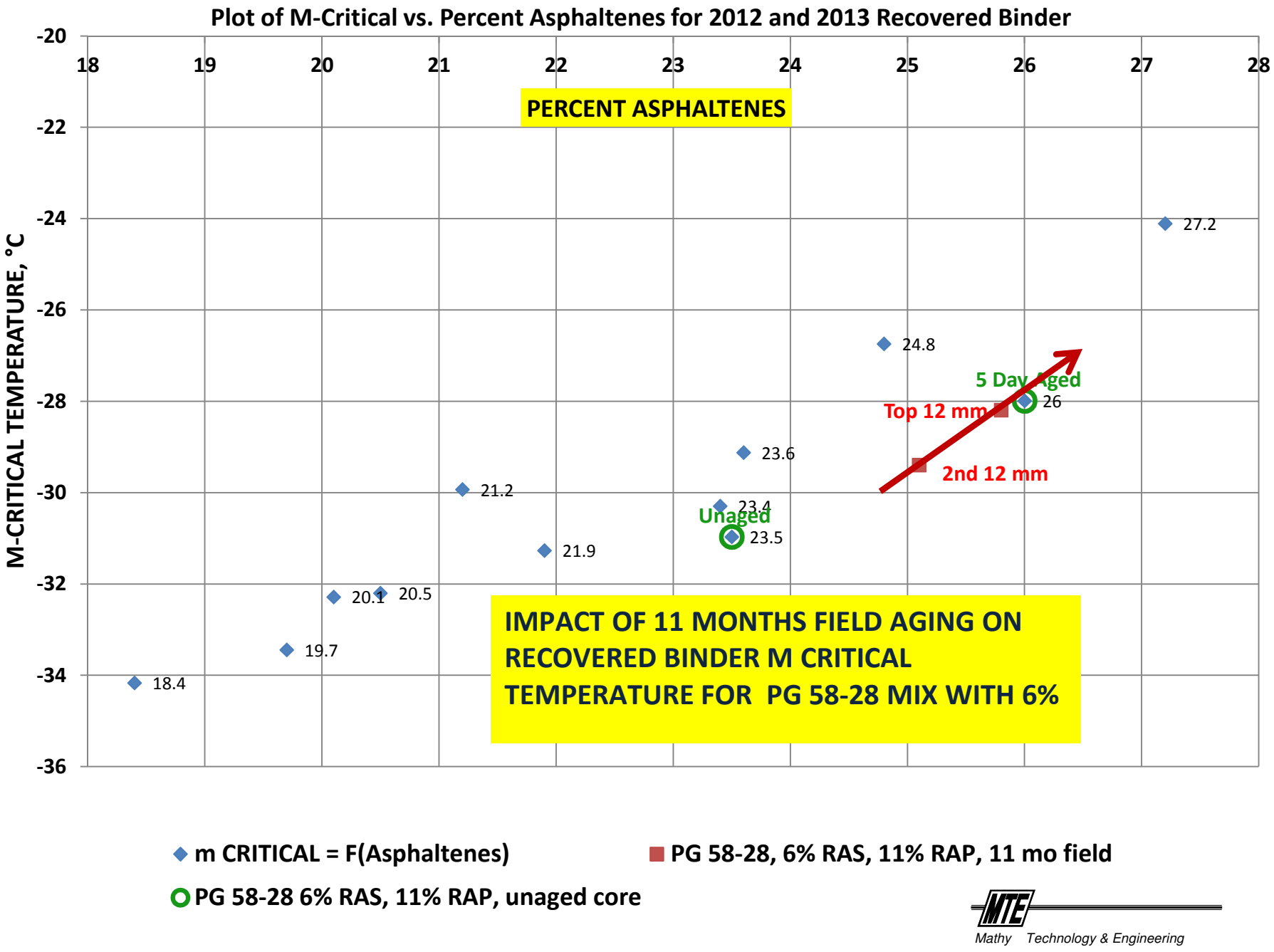
03/23/13 21:37:14 C:\DRIVE_E\2010 DATA\Proj 1376 - Hwy 14 High RAP & RAS Shoulder Test Sections\PLOTIT PLOT M CRTIICAL = F(ASPHALTENES).spf

IMPACT AFTER 1 YEAR OF FIELD AGING



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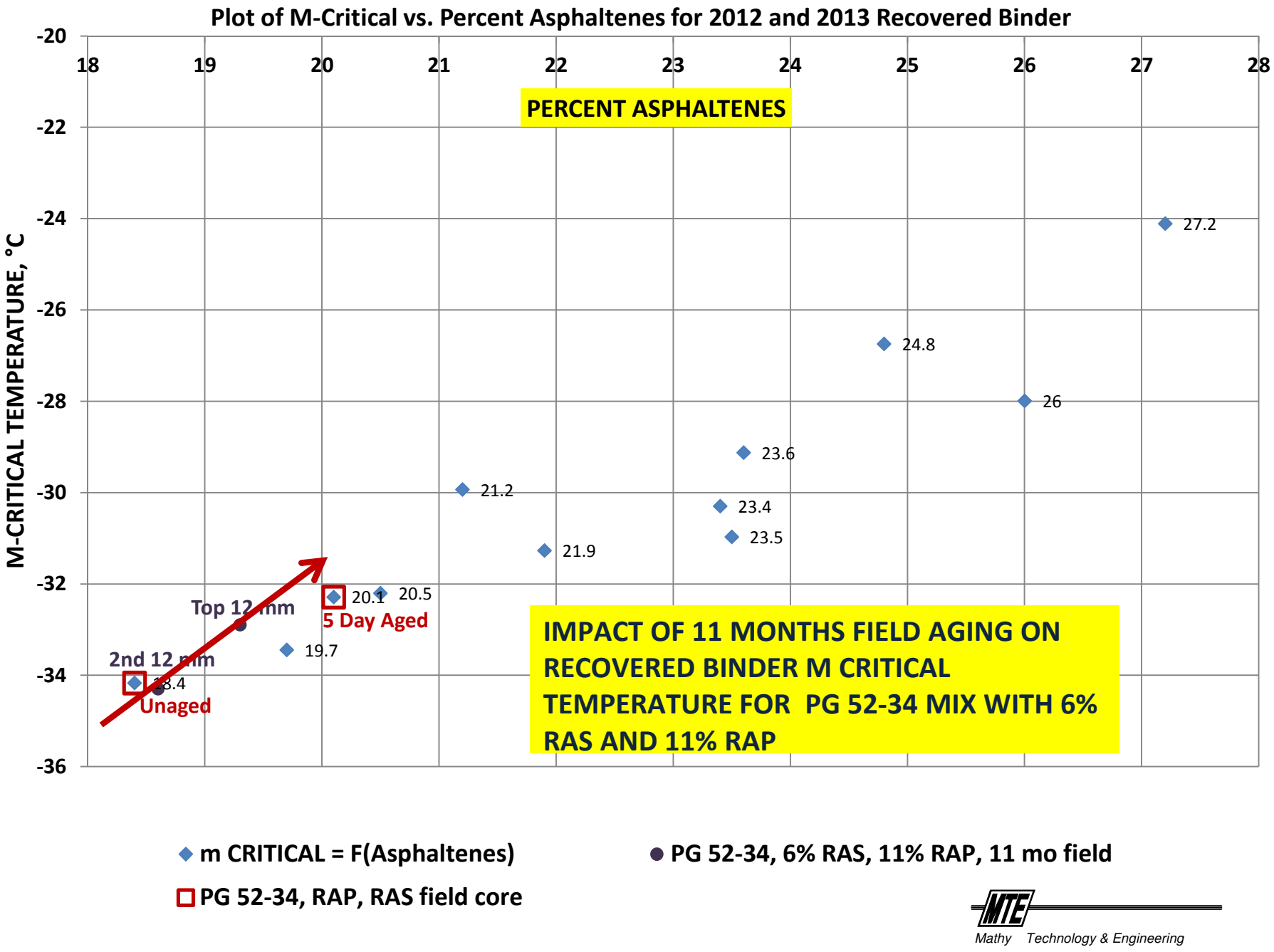
Plot of M-Critical vs. Percent Asphaltenes for 2012 and 2013 Recovered Binder
M-CRITICAL TEMPERATURE, °C
-20
-22
-24
-26
-28
-30
-32
-34
-36
18
19
20
21
22
23
24
25
26
27
28
PERCENT ASPHALTENES
27.2
24.8
26
23.6
21.2
23.4
23.5
21.9
20.1
20.5
19.7
Top 12 mm
5 Day Aged
2nd 12 mm
Unaged
IMPACT OF 11 MONTHS FIELD AGING ON RECOVERED BINDER M CRITICAL TEMPERATURE FOR PG 52-34 MIX WITH 6% RAS AND 11% RAP
m CRITICAL = F(Asphaltenes)
PG 52-34, 6% RAS, 11% RAP, 11 mo field
PG 52-34, RAP, RAS field core
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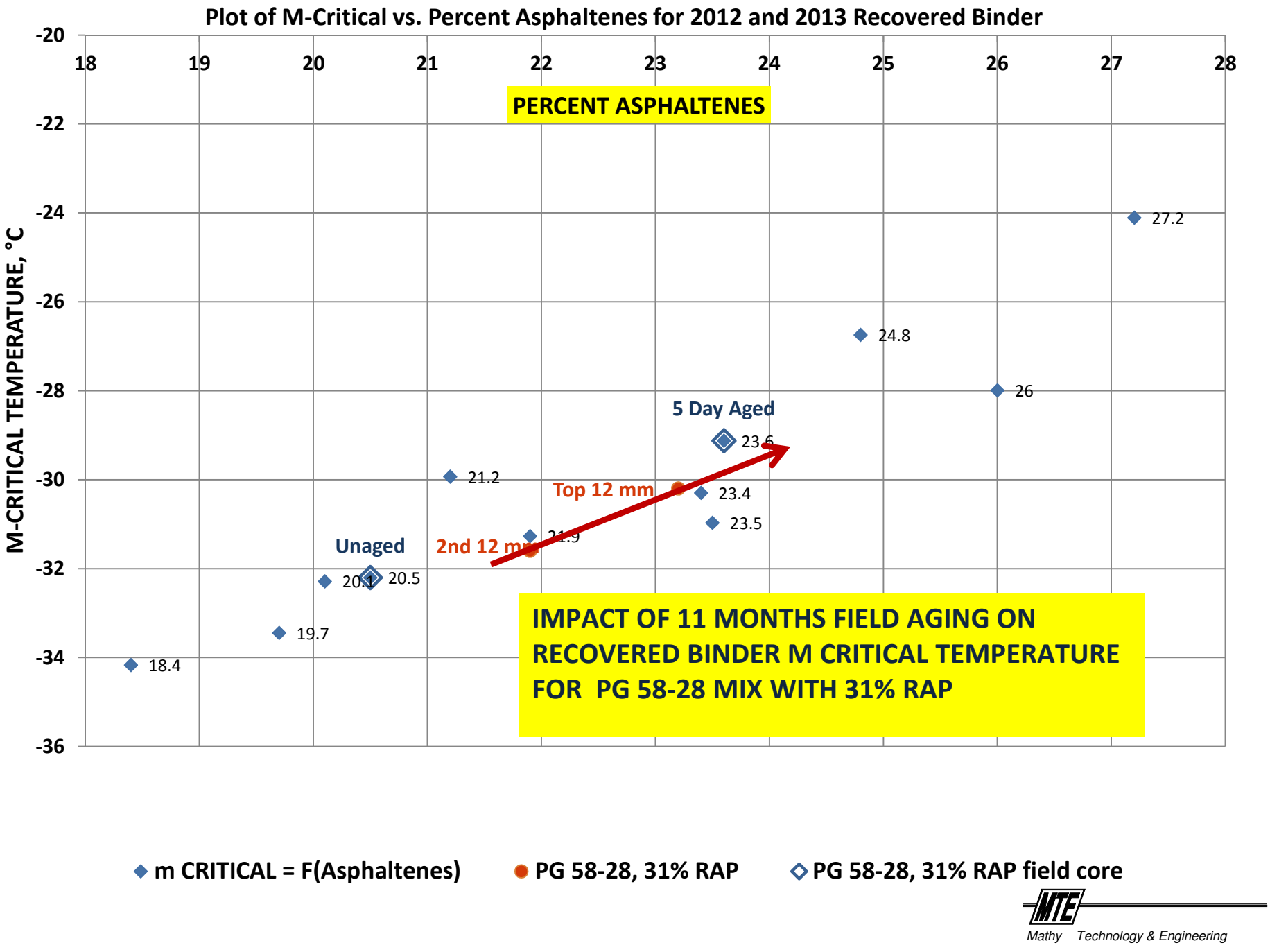

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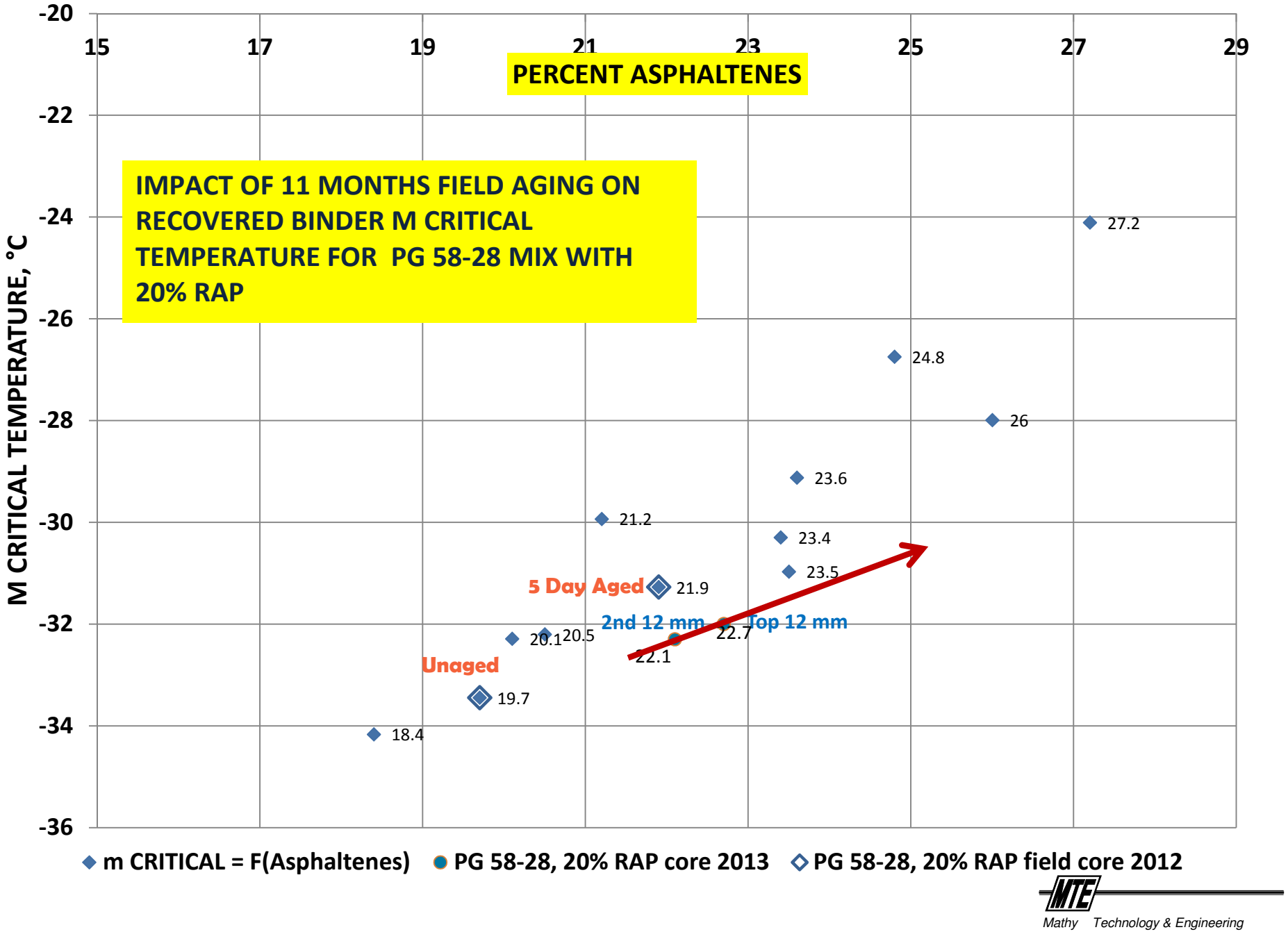

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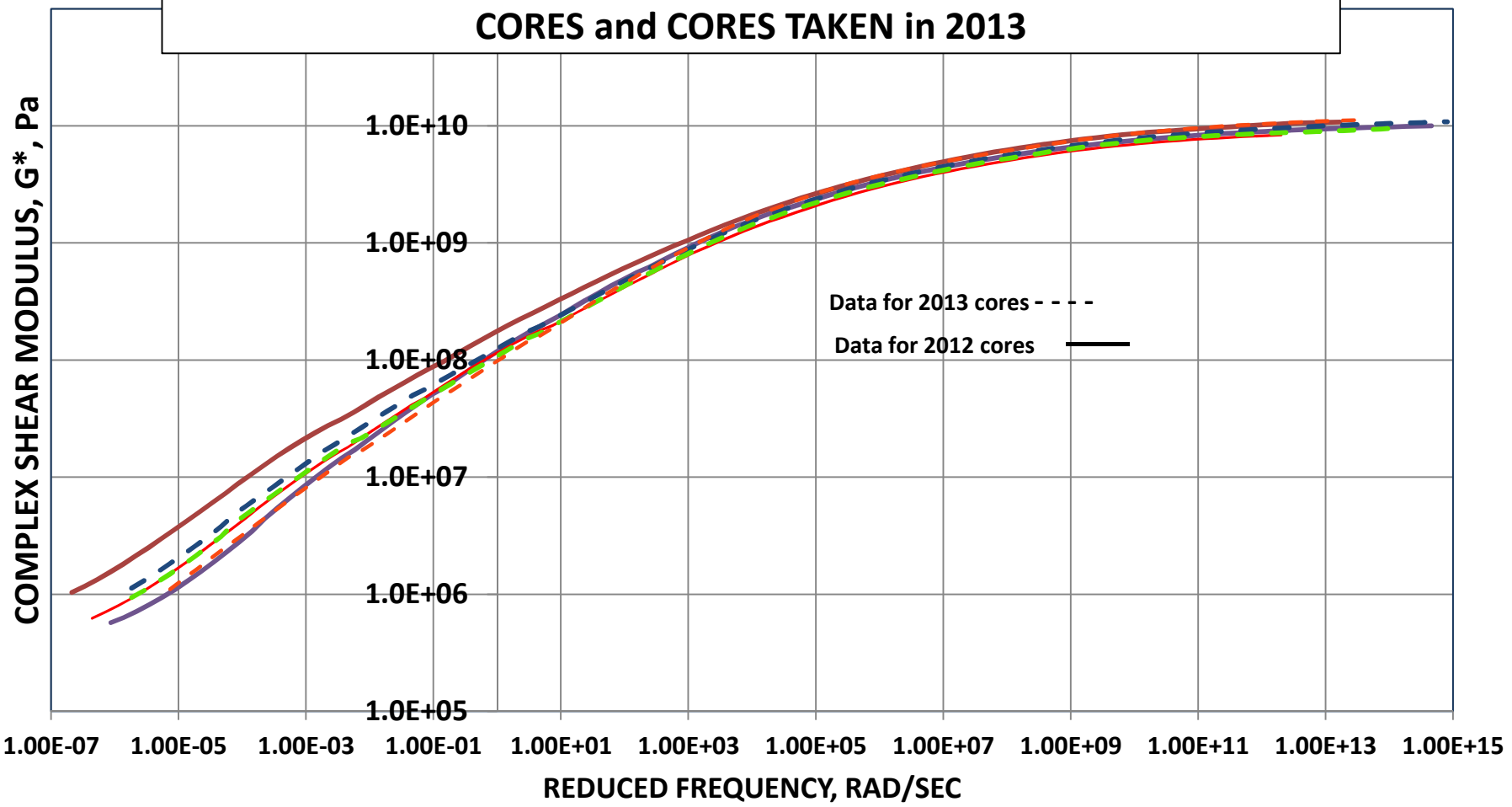
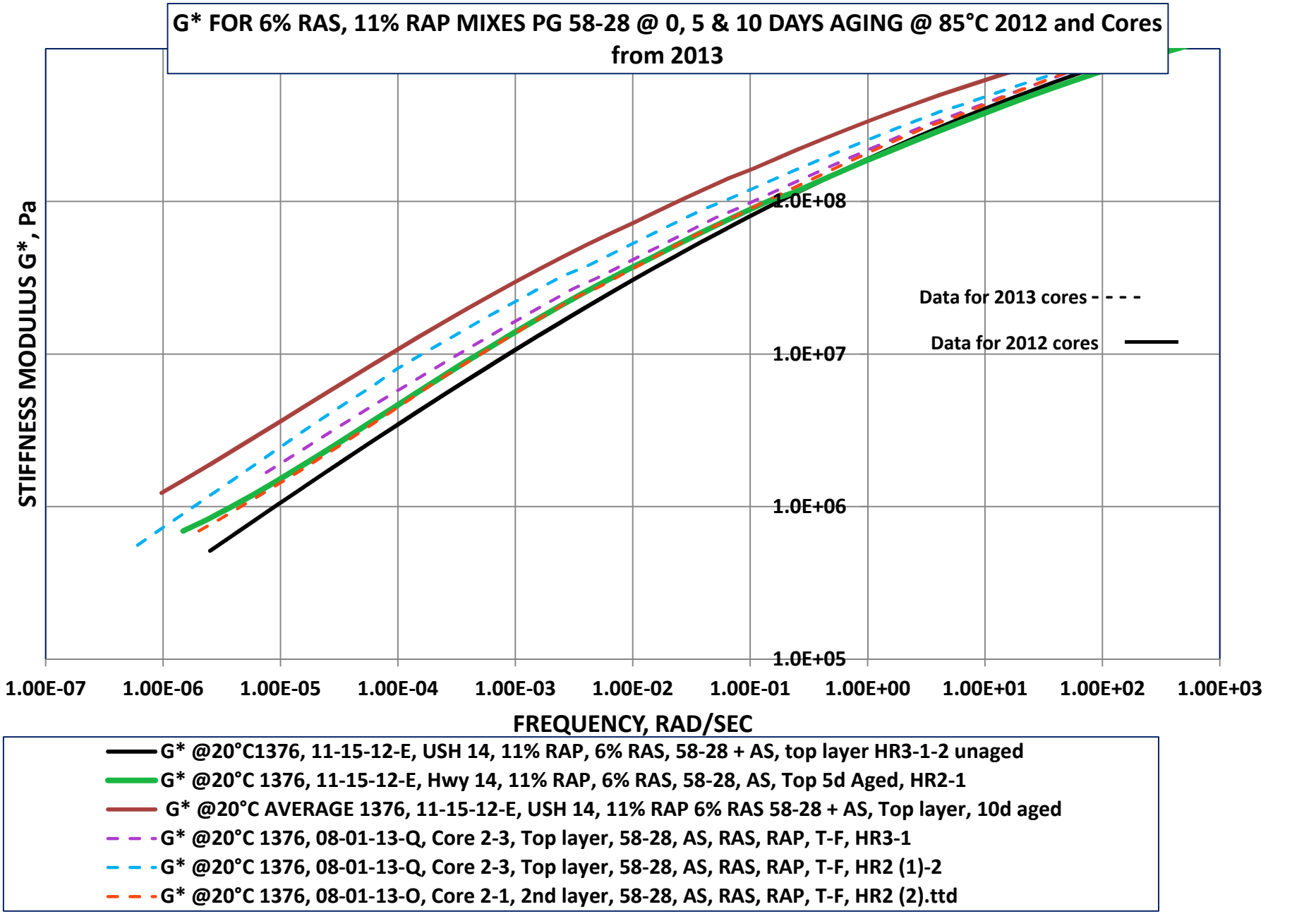
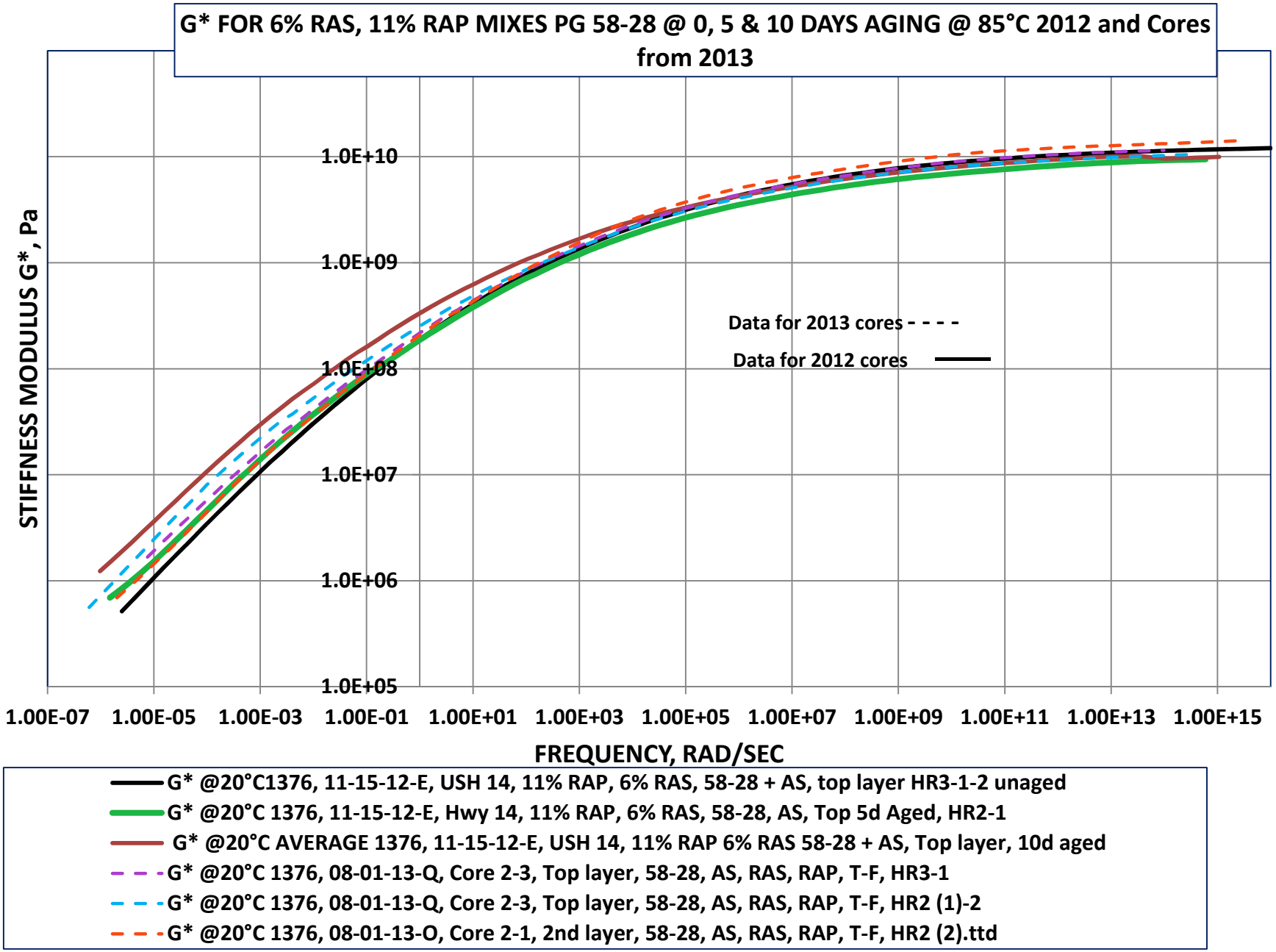
Mix type	Days of 85°C core aging (or as noted in Table)	Asphaltenes	m-critical Temp, °C (mcT)	S-critical Temp, °C (ScT)	ΔTc (S-Critical - m-critical)
Sec 1 52-34	0	18.4	-34.2	-35.9	-1.8
6%RAS	5	20.1	-32.3	-34.9	-2.6
11% RAP	10	21.2	-29.9	-35.6	-5.7
Top 12 mm	11 months field	19.3	-32.9	-35.7	-2.8
2nd 12 mm	11 months field	18.6	-34.3	-35.9	-1.6
Sec 2 58-28	0	23.5	-31.0	-33.2	-2.3
6%RAS	5	26	-28.0	-30.7	-2.7
11% RAP	10	27.2	-24.1	-30.9	-6.8
Top 12 mm	11 months field	25.8	-28.2	-30.8	-2.6
2nd 12 mm	11 months field	25.1	-29.4	-31.3	-1.9
Sec 3 58-28	0	20.5	-32.2	-31.9	0.4
0%RAS	5	23.6	-29.1	-29.8	-0.7
31% RAP	10	24.8	-26.7	-29.6	-2.9
Top 12 mm	11 months field	23.2	-30.2	-31.3	-1.1
2nd 12 mm	11 months field	21.9	-31.6	-31.4	+0.2
Sec 4 58-28	0	19.7	-33.4	-33.4	0.0
0%RAS	5	21.9	-31.3	-31.9	-0.6
21% RAP	10	23.4	-30.3	-32.3	-2.0
Top 12 mm	11 months field	22.7	-32.0	-32.2	-0.2
2nd 12 mm	11 months field	22.1	-32.3	-31.9	+0.4

G* for 6% RAS, 11% RAP MIXES PG 52-34 @ 0, 5, 10 DAYS AGING 2012 CORES and CORES TAKEN in 2013

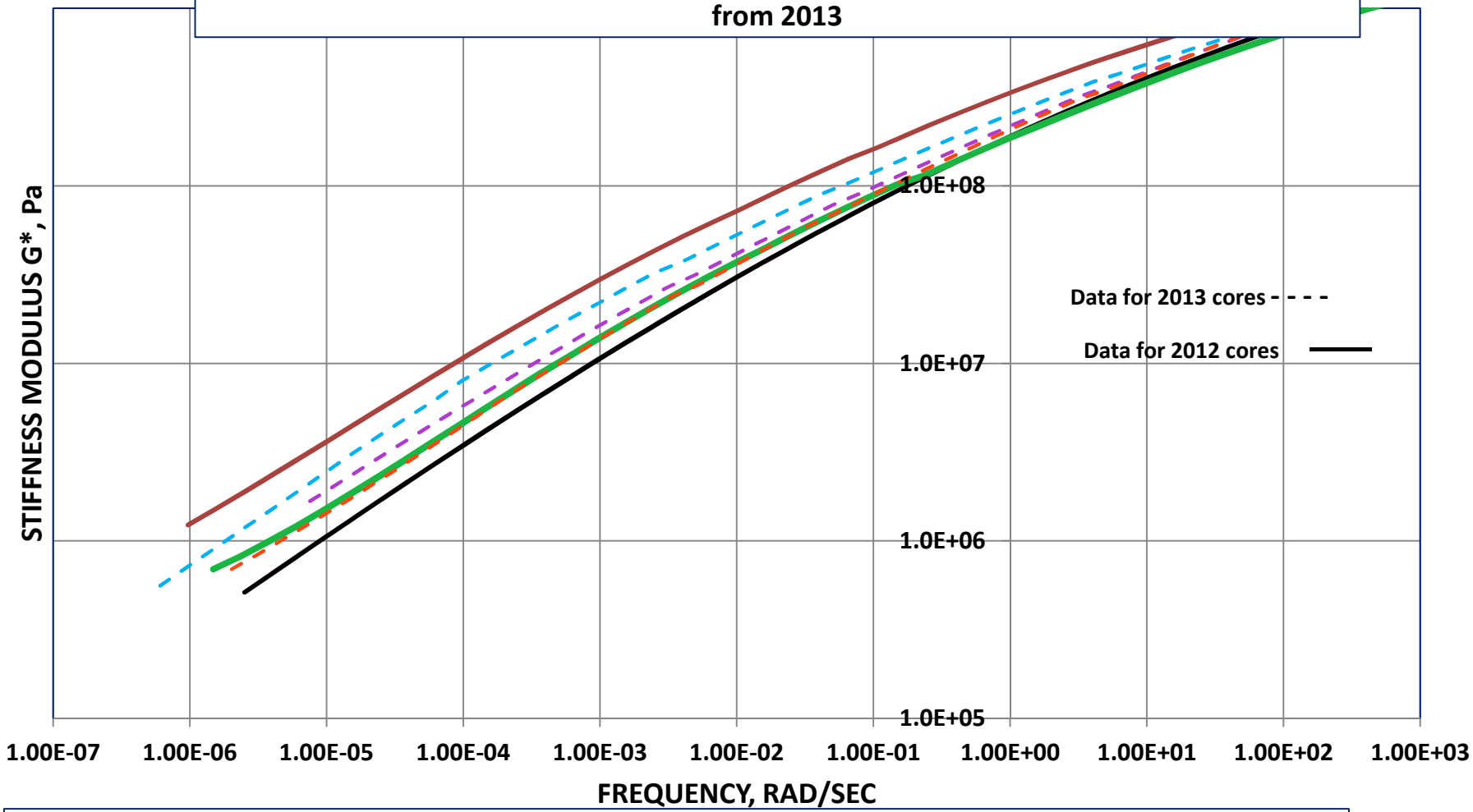


- G* @20°C 1376, 11-15-12-D, Hwy 14 shoulder 11% RAP, 6% RAS, 52-34 top HR3-1-2
- G* @20°C 1376, 11-15-12-D, Hwy 14, 11% RAP, 6% RAS, 52-34, AS, top, 5d HR3-1 (1)
- G* average @20°C 1376, 11-15-12-D, USH 14 , 11% RAP, 6% RAS, 52-34, 2nd 10d HR3 &AR1
- G* @20°C 1376, 08-01-13-K, Core 1-1, Top layer, 52-34, AS. RAS, RAP, T-F, HR3-2 T-F-split
- G* @20°C 1376, 08-01-13-K, Core 1-1, Top layer, 52-34, AS. RAS, RAP, T-F, HR2 T-F-split
- G* @20°C 1376, 08-01-13-K, Core 1-1, 2nd layer, 52-34, AS, RAS, RAP, T-F, HR2 T-F-split


G* FOR 6% RAS, 11% RAP MIXES PG 58-28 @ 0, 5 & 10 DAYS AGING @ 85°C 2012 and Cores from 2013
STIFFNESS MODULUS G*, Pa
1.0E+08
1.0E+07
1.0E+06
1.0E+05
Data for 2013 cores - - - -
Data for 2012 cores
1.00E-07
1.00E-06
1.00E-05
1.00E-04
1.00E-03
1.00E-02
1.00E-01
1.00E+00
1.00E+01
1.00E+02
1.00E+03
FREQUENCY, RAD/SEC
G* @20°C1376, 11-15-12-E, USH 14, 11% RAP, 6% RAS, 58-28 + AS, top layer HR3-1-2 unaged
G* @20°C 1376, 11-15-12-E, Hwy 14, 11% RAP, 6% RAS, 58-28, AS, Top 5d Aged, HR2-1
G* @20°C AVERAGE 1376, 11-15-12-E, USH 14, 11% RAP 6% RAS 58-28 + AS, Top layer, 10d aged
G* @20°C 1376, 08-01-13-Q, Core 2-3, Top layer, 58-28, AS, RAS, RAP, T-F, HR3-1
G* @20°C 1376, 08-01-13-Q, Core 2-3, Top layer, 58-28, AS, RAS, RAP, T-F, HR2 (1)-2
G* @20°C 1376, 08-01-13-O, Core 2-1, 2nd layer, 58-28, AS, RAS, RAP, T-F, HR2 (2).ttd

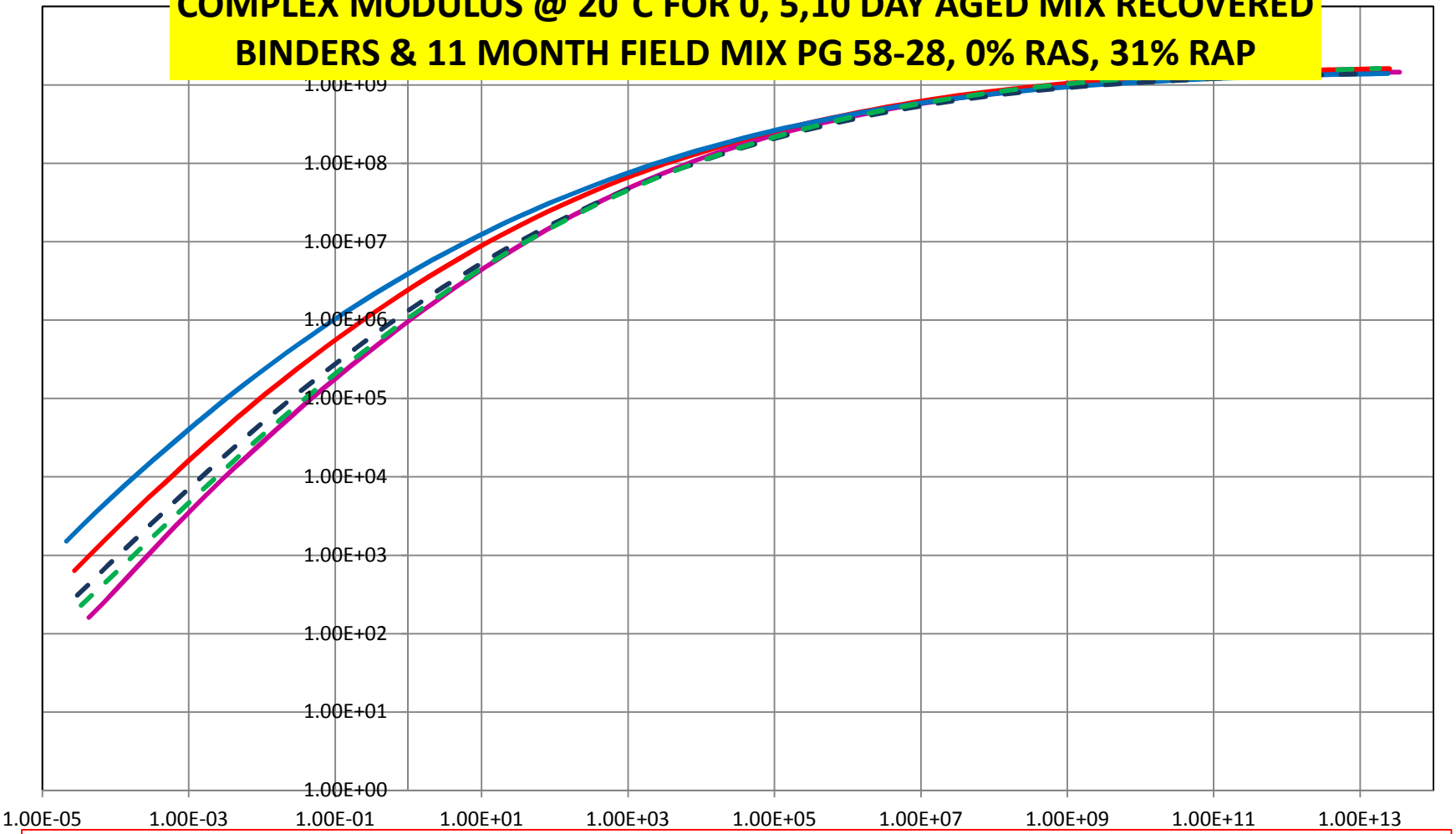

G* FOR 6% RAS, 11% RAP MIXES PG 58-28 @ 0, 5 & 10 DAYS AGING @ 85°C 2012 and Cores from 2013
STIFFNESS MODULUS G*, Pa
1.0E+10
1.0E+09
1.0E+08
1.0E+07
1.0E+06
1.0E+05
Data for 2013 cores - - - -
Data for 2012 cores
1.00E-07
1.00E-05
1.00E-03
1.00E-01
1.00E+01
1.00E+03
1.00E+05
1.00E+07
1.00E+09
1.00E+11
1.00E+13
1.00E+15
FREQUENCY, RAD/SEC
G* @20°C1376, 11-15-12-E, USH 14, 11% RAP, 6% RAS, 58-28 + AS, top layer HR3-1-2 unaged
G* @20°C 1376, 11-15-12-E, Hwy 14, 11% RAP, 6% RAS, 58-28, AS, Top 5d Aged, HR2-1
G* @20°C AVERAGE 1376, 11-15-12-E, USH 14, 11% RAP 6% RAS 58-28 + AS, Top layer, 10d aged
G* @20°C 1376, 08-01-13-Q, Core 2-3, Top layer, 58-28, AS, RAS, RAP, T-F, HR3-1
G* @20°C 1376, 08-01-13-Q, Core 2-3, Top layer, 58-28, AS, RAS, RAP, T-F, HR2 (1)-2
G* @20°C 1376, 08-01-13-O, Core 2-1, 2nd layer, 58-28, AS, RAS, RAP, T-F, HR2 (2).ttd

G* FOR 6% RAS, 11% RAP MIXES PG 58-28 @ 0, 5 & 10 DAYS AGING @ 85°C 2012 and Cores from 2013



- G* @20°C1376, 11-15-12-E, USH 14, 11% RAP, 6% RAS, 58-28 + AS, top layer HR3-1-2 unaged
- G* @20°C 1376, 11-15-12-E, Hwy 14, 11% RAP, 6% RAS, 58-28, AS, Top 5d Aged, HR2-1
- G* @20°C AVERAGE 1376, 11-15-12-E, USH 14, 11% RAP 6% RAS 58-28 + AS, Top layer, 10d aged
- G* @20°C 1376, 08-01-13-Q, Core 2-3, Top layer, 58-28, AS, RAS, RAP, T-F, HR3-1
- G* @20°C 1376, 08-01-13-Q, Core 2-3, Top layer, 58-28, AS, RAS, RAP, T-F, HR2 (1)-2
- G* @20°C 1376, 08-01-13-O, Core 2-1, 2nd layer, 58-28, AS, RAS, RAP, T-F, HR2 (2).ttd

COMPLEX MODULUS @ 20°C FOR 0, 5,10 DAY AGED MIX RECOVERED BINDERS & 11 MONTH FIELD MIX PG 58-28, 0% RAS, 31% RAP



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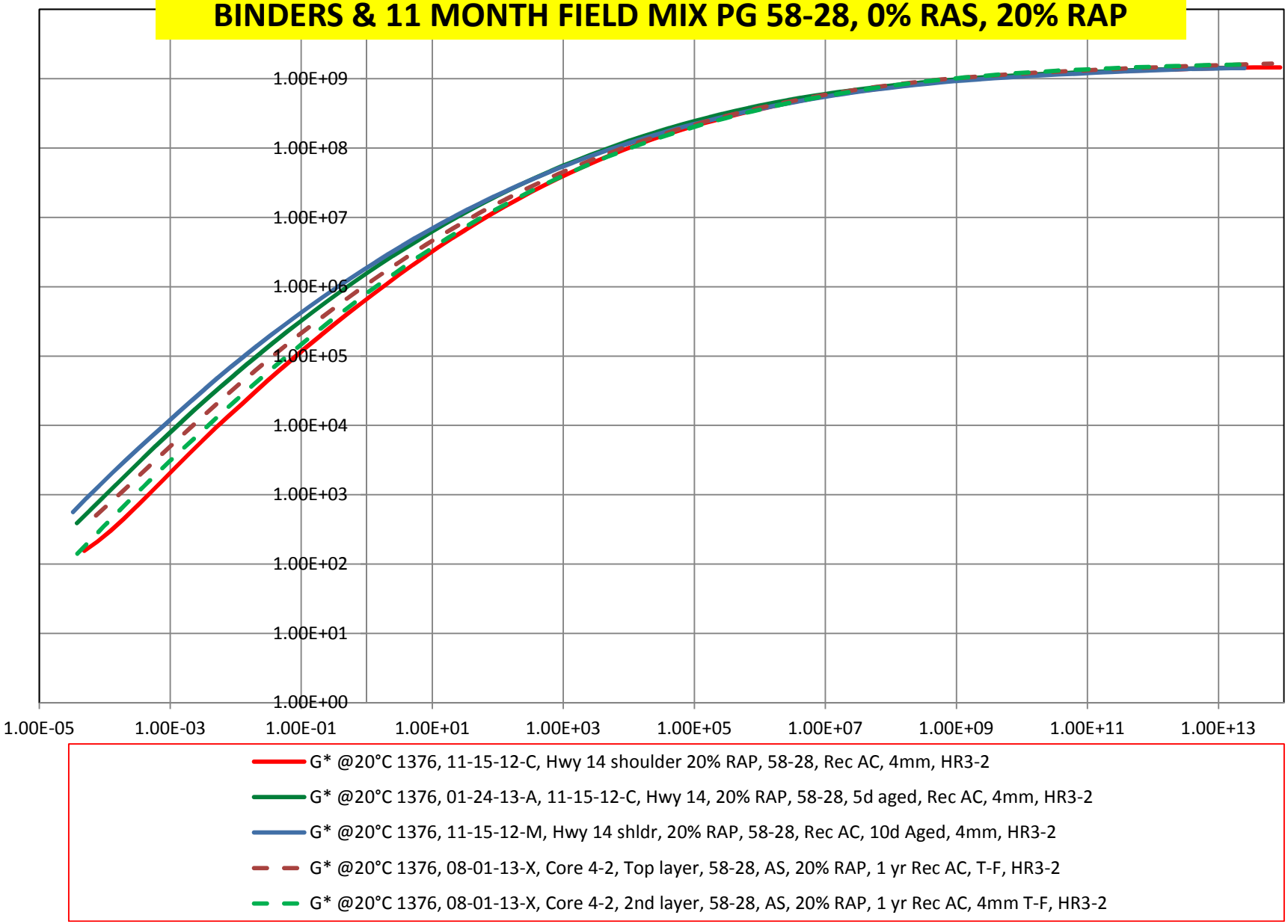
COMPLEX MODULUS @ 20°C FOR 0, 5,10 DAY AGED MIX RECOVERED BINDERS & 11 MONTH FIELD MIX PG 58-28, 0% RAS, 20% RAP



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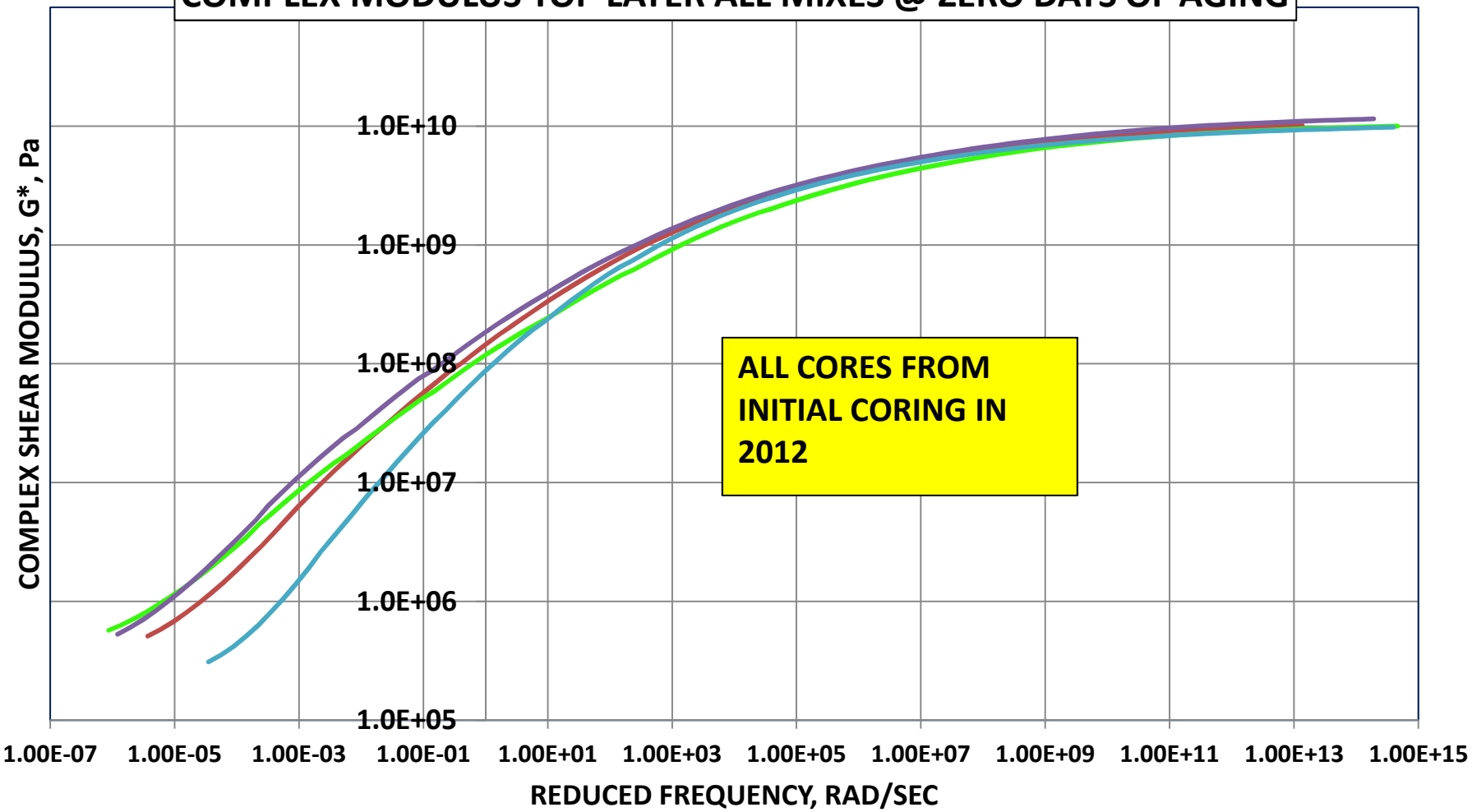
COMPLEX MODULUS TOP LAYER ALL MIXES @ ZERO DAYS OF AGING



- G* @20°C Average 1376, 11-15-12-F, USH 14 31% RAP, top layer, AR3 & HR3-1
- G* @20°C 1376, 11-15-12-D, Hwy 14 shoulder 11% RAP, 6% RAS, 52-34 top HR3-1-2
- G* @20°C 1376, 11-15-12-E, Hwy 14 shoulder, 11% RAP, 6% RAS, 58-28 top HR3-1-2
- G* @20°C Average 1376, 11-15-12-C, USH 14 , 20% RAP, 58-28, Top layer, HR3-1

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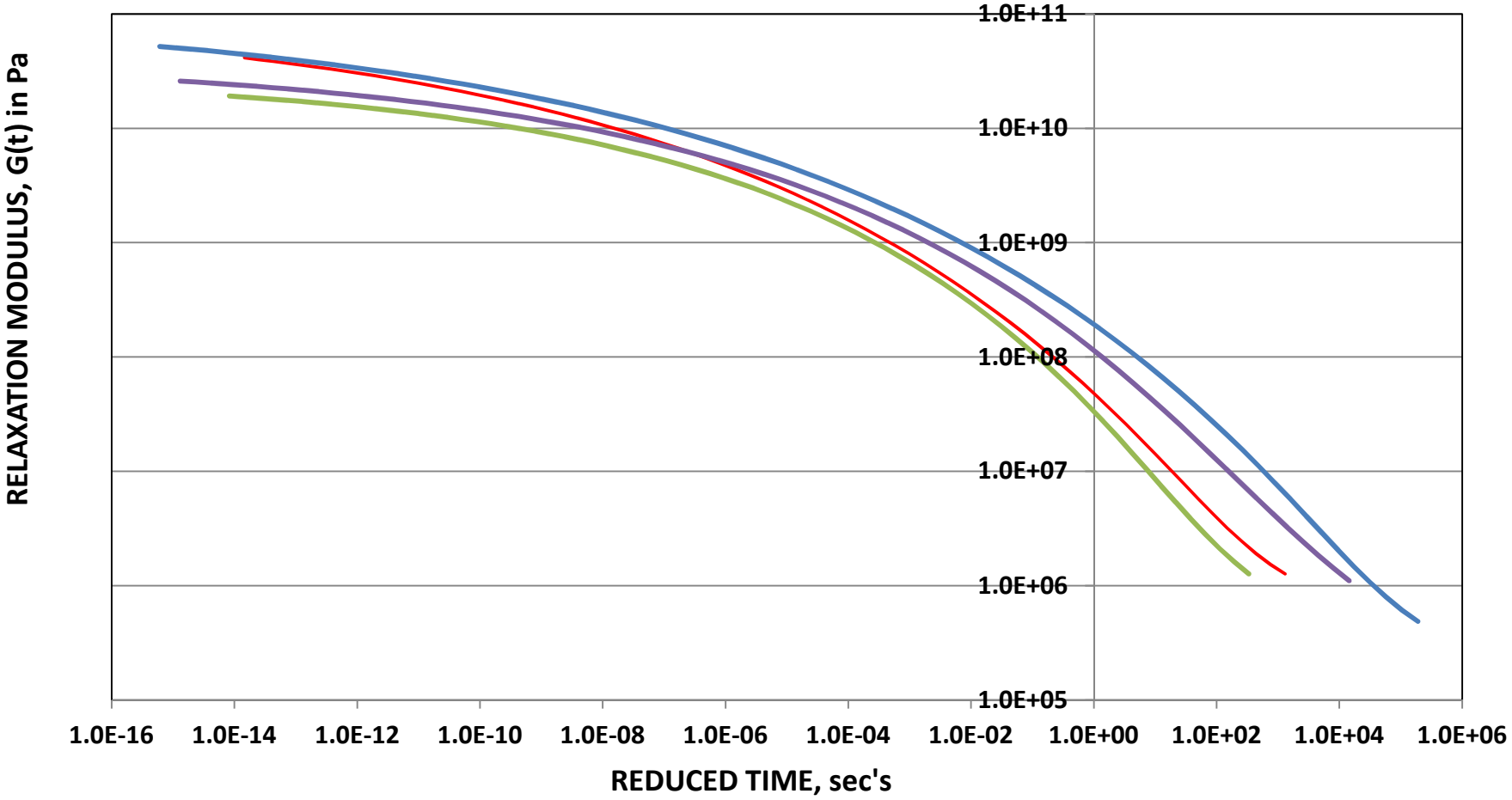
Oil Treated Shingle Mixes

1. Another mix study for fatigue
   1) 15% Cargill bio based oil by weight of asphalt in shingles oil added to shingles
   2) 5% shingles added to mix using PG 58-28 binder
   3) HMA & WMA mixes produced
   4) Tests performed on 0 day aged and 5 day aged
      a) Rut tests @ 58°C (dry) & 50°C (wet) on 0 day aged only
      b) Overlay test @ 20°C
      c) Torsion bars -40 to +60

RELAXATION MODULUS FROM TORSION BAR MIX TESTS OF HMA & WMA MIXES MADE WITH SHINGLES TREATED WITH 15% OIL @ Tref=+20°C

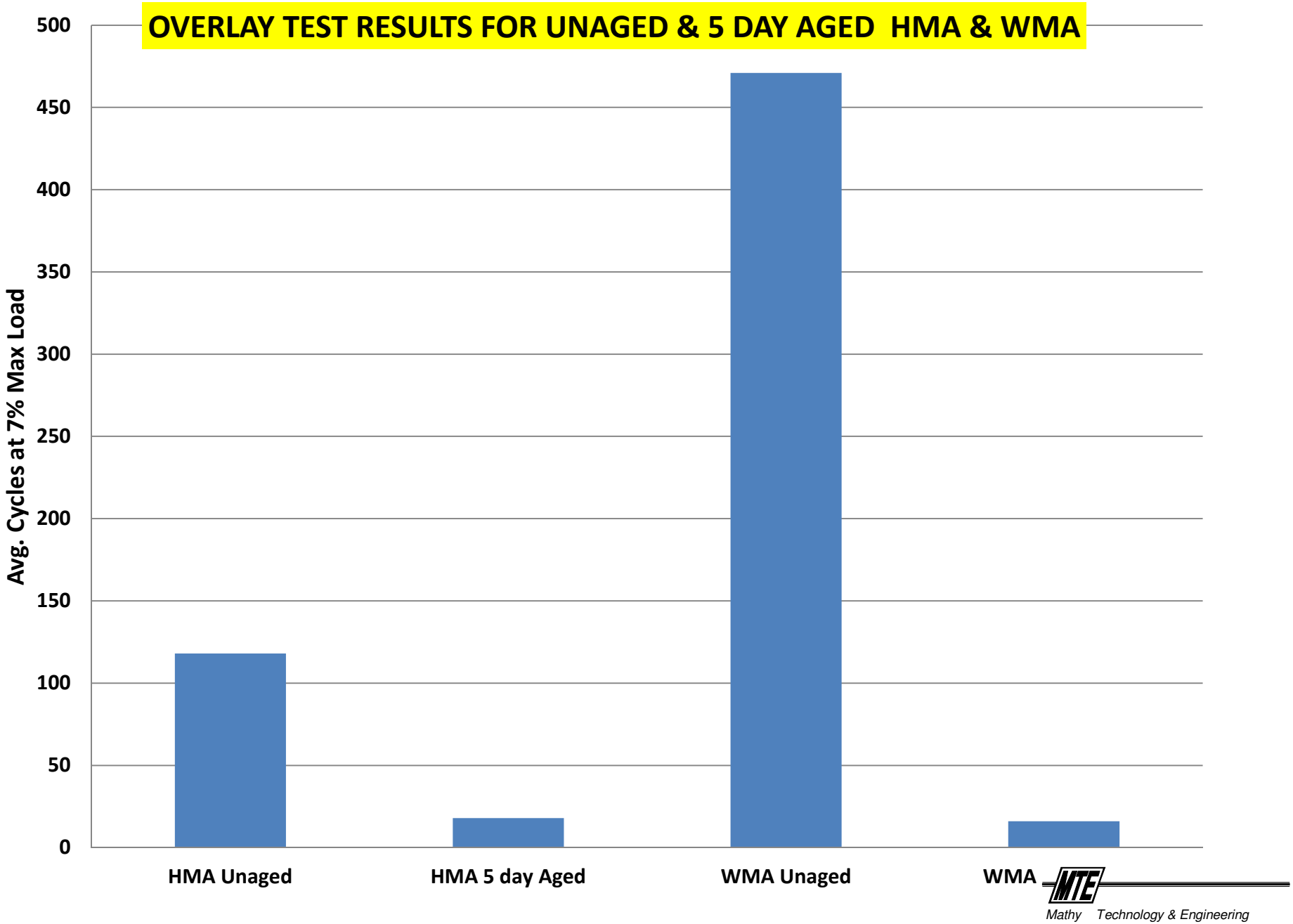


MODEL: G(t) @+20C Proj 1309 07-26-12-K HMA 0 aged 15% 161 oil pre added to shinglesTEMP FREQ TEST HR3-2 (1)

MODEL: G(t) @+20C Proj 1309 07-26-12-L HMA 5 aged 15% 161 oil pre added to shinglesTEMP FREQ TEST HR3-2

MODEL: G(t) @ +20C Proj 1309 07-26-12-R WMA 0 aged 15% 161 oil pre added to shinglesTEMP FREQ TEST HR3-2 (2)

MODEL: G(t) @+20C Proj 1309 07-26-12-S WMA 5 aged 15% 161 oil pre added to shinglesTEMP FREQ TEST HR3-2


OVERLAY TEST RESULTS FOR UNAGED & 5 DAY AGED HMA & WMA
Avg. Cycles at 7% Max Load
500
450
400
350
300
250
200
150
100
50
0
HMA Unaged
HMA 5 day Aged
WMA Unaged
WMA
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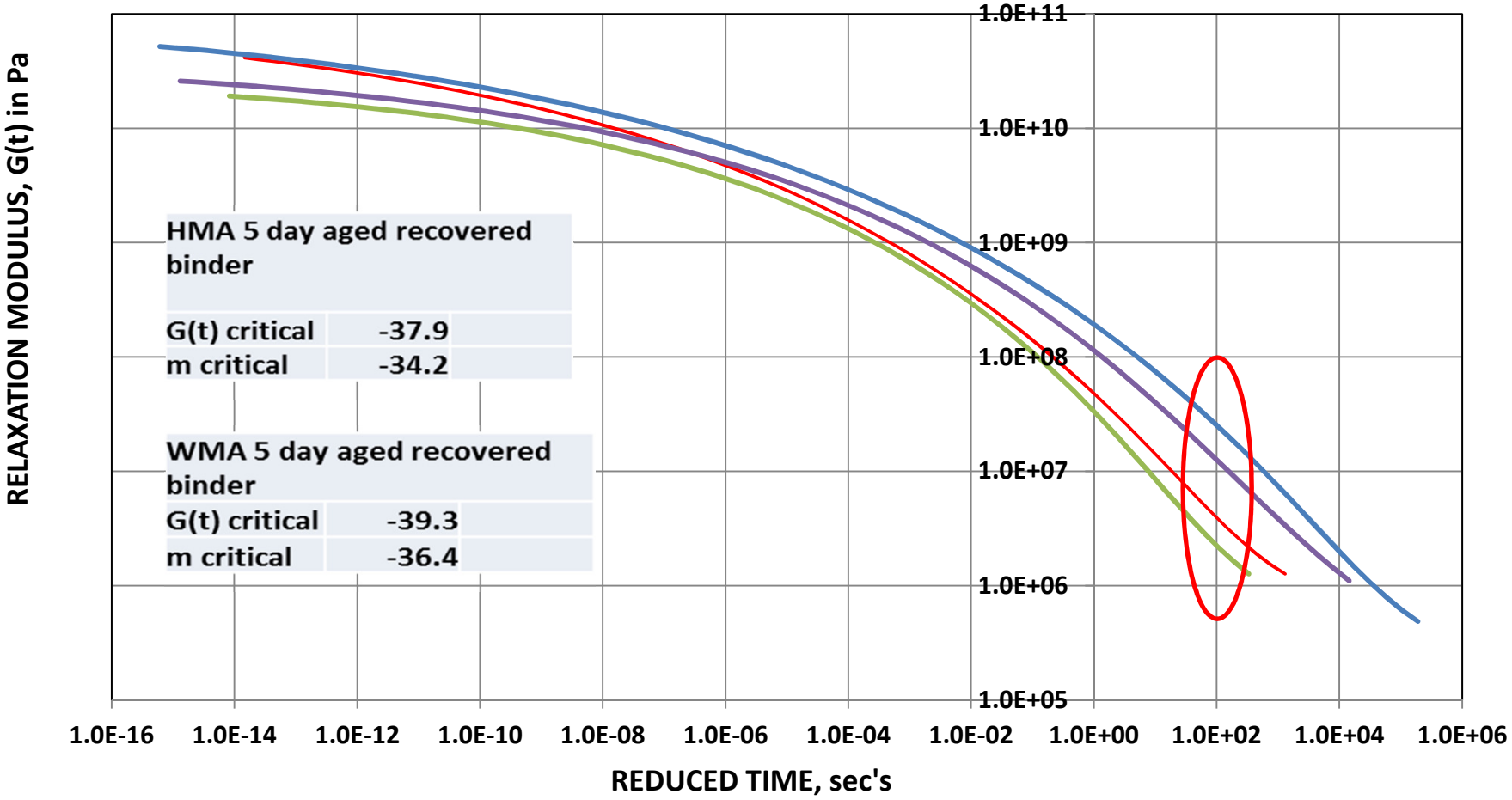
RELAXATION MODULUS FROM TORSION BAR MIX TESTS OF HMA & WMA MIXES MADE WITH SHINGLES TREATED WITH 15% OIL @ Tref=+20°C



MODEL: G(t) @+20C Proj 1309 07-26-12-K HMA 0 aged 15% 161 oil pre added to shinglesTEMP FREQ TEST HR3-2 (1)

MODEL: G(t) @+20C Proj 1309 07-26-12-L HMA 5 aged 15% 161 oil pre added to shinglesTEMP FREQ TEST HR3-2

MODEL: G(t) @ +20C Proj 1309 07-26-12-R WMA 0 aged 15% 161 oil pre added to shinglesTEMP FREQ TEST HR3-2 (2)

MODEL: G(t) @+20C Proj 1309 07-26-12-S WMA 5 aged 15% 161 oil pre added to shinglesTEMP FREQ TEST HR3-2

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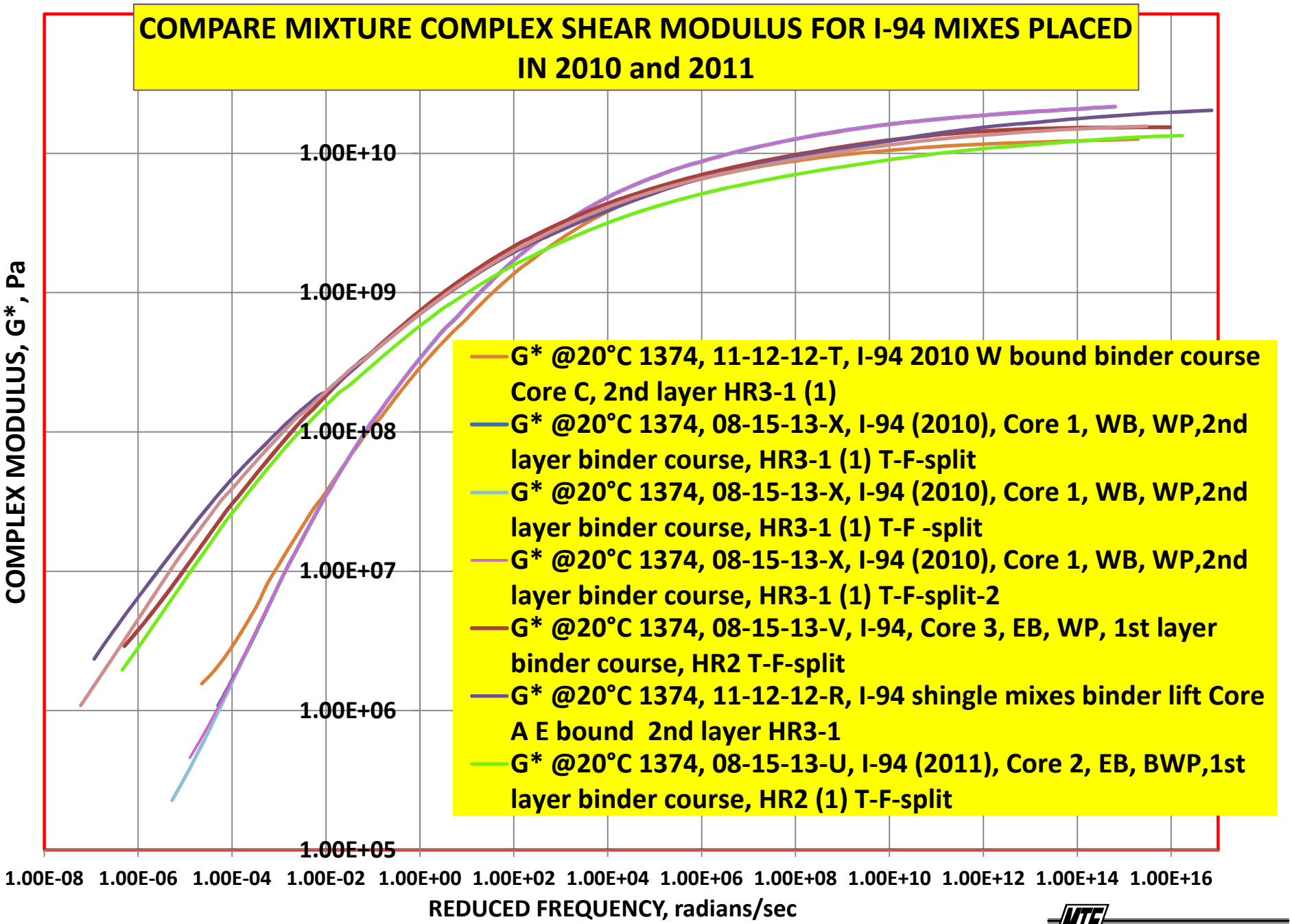
Low Temp Grade Coating Binder Blends from 4 mm DSR Data

Paragon coating	Delta between S_c & m_c	Coating + 10% 312 oil, original	Delta between S_c & m_c	Coating + 10% 312 oil, RTFO	Delta between S_c & m_c	Coating + 10% 312 oil, PAV	Delta between S_c & m_c
S_c=-32.9	24.7	S_c=-47.8	16.7	S_c=-47.0	22.1	S_c=-42.2	27.8
m_c=-8.2		m_c=-31.1		m_c=-24.9		m_c=-14.4	

These data show that adding an oil can significantly alter the binder stiffness but has only modest impact on the m-value critical temperature and further there is substantial degradation in the m-value with binder aging
The difference between S & m critical temperatures is similar for the PAV residue of the oil blended sample to the original coating asphalt and the m_c are only about 6°C better.

COMPARE MIXTURE COMPLEX SHEAR MODULUS FOR I-94 MIXES PLACED IN 2010 and 2011



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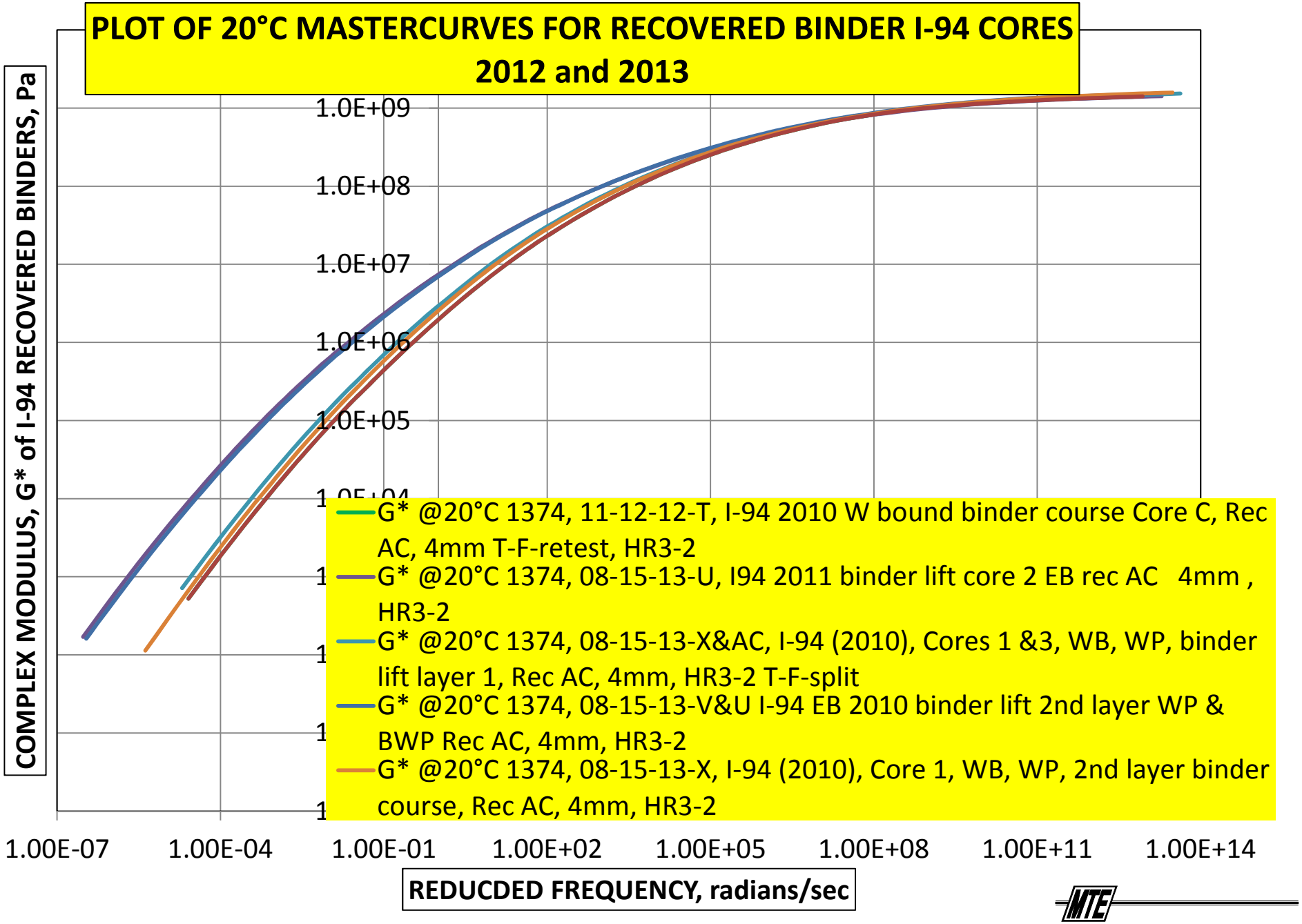
PLOT OF 20°C MASTERCURVES FOR RECOVERED BINDER I-94 CORES 2012 and 2013



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COMMENTS

1. There is **probably not** complete blending of shingle binder with virgin binder in mixes initially
   1) However it does appear as though blending (interaction?) does occur ***to some degree*** after aging of the mix
2. Low temperature grade of preblended shingle binder and virgin 58-28 appears to be acceptable, even after PAV aging
   1) I believe this give a false sense of security and likelihood for performance

COMMENTS

3. The overlay tester cracking response shows that after 5 days of conditioning all mixes containing RAS collapse to the same unacceptable level
4. Recovered binder relaxation modulus mastercurves at +20C show that shingle blended binders relax at a an increasingly slower rate as mix ages than traditional mixes containing the same binder replacement using RAP

COMMENTS

5. Fatigue of aged mixes appears to be the major concern. Mixture testing for fatigue evaluation should be considered an essential step
   - ❑ RAS or recovered shingle binder seems to accelerate the aging of mixes and the binders therein
6. I don't believe we understand the mechanism by which aged shingle binder blends **(or doesn't)** and interacts with virgin paving binders—this needs to be studied
   - ❑ Just because both materials are "black and sticky" doesn't mean they are truly compatible

COMMENTS

7. Use of some oils appear to improve performance of shingles in mixes, however improvement does not appear to be sustainable when mixes are aged
8. So far we have not found any additive (i.e. REJUVENATOR) that provides sustainable results after aging on mix
9. If someone shows you data on an additive that shows improved performance with RAS, if he cannot show you such data on **aged mix** show him the door

COMMENTS

10. Use of RAS in lower lifts does not appear after only 2 years of tracking to be detrimental—still needs to be followed
11. NCHRP 9-58 is out for bid. Goal is to evaluate rejuvenators for RAS and RAS/RAP containing mixes
    - ❖ I think it will be a challenge, but success provides a tremendous opportunity for the industry

QUESTIONS