CRACKING RESISTANCE: Issues, Testing, Evaluation & Future

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U.S. Department of Transportation
Federal Highway Administration

Cracking Resistance

Outline

- Cracking Types
- Laboratory Test Loading Types
- Overview of 10 Tests (NCHRP 9-57)
- Recycled Materials
- Focus on AMPT Cyclic Fatigue
  - Rehabilitation Scenario
  - Performance Based Mix Design

Cracking Resistance

Cracking Types (Modes)

- Four (4) basic cracking modes
  - Low Temperature — Climate Associated
  - Reflection / Reflective — Climate & Load Associated
  - Bottom-Up — Load Associated
  - Top-Down — Load Associated

Does mode matter? Are cracks simply cracks from an evaluation and prevention point of view?

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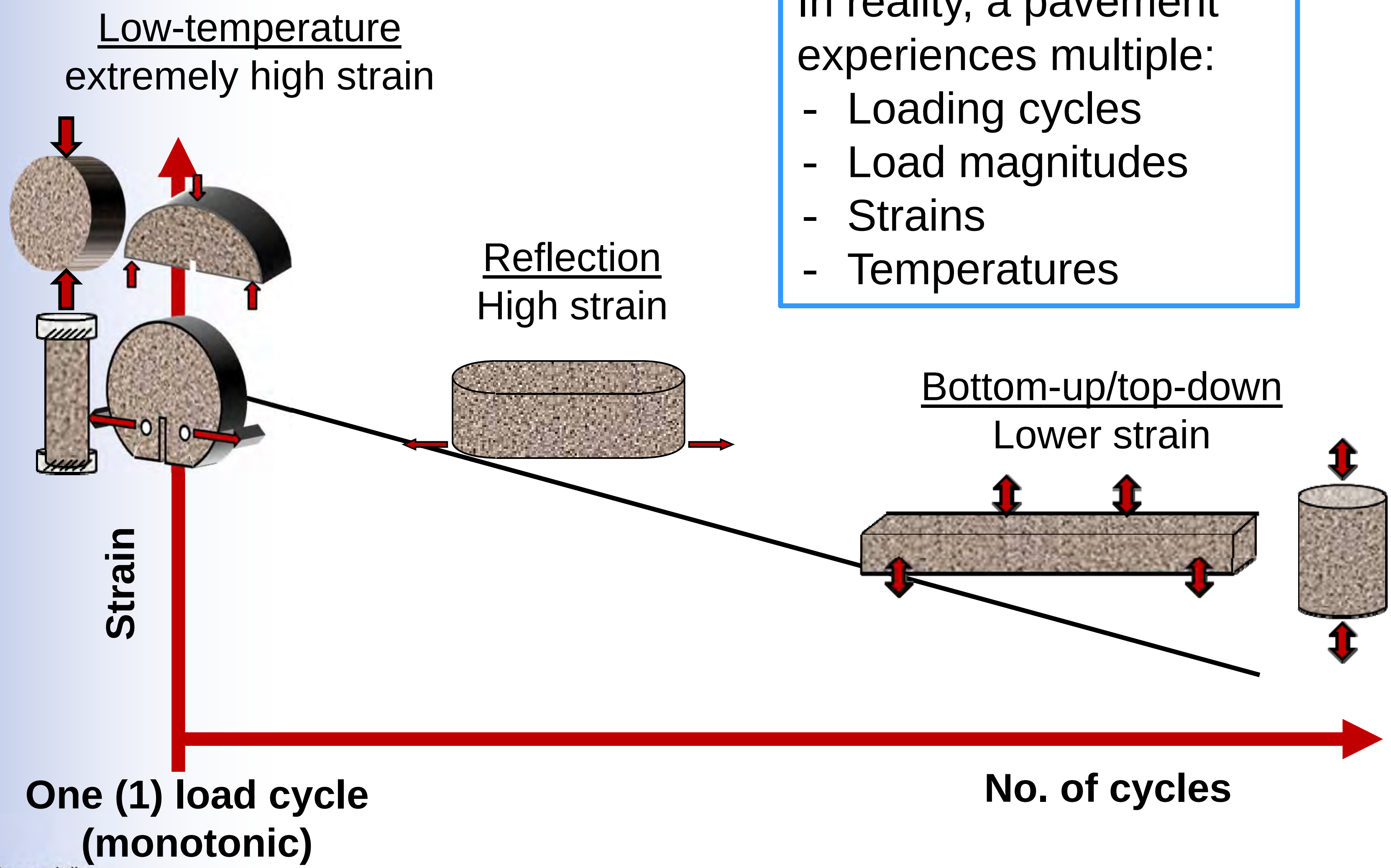
Loading Types (Modes)

Cracking Resistance

- Two (2) basic materials test loading modes
  - Monotonic load - gradually applying a load until reaching the test load magnitude (one cycle)
    - Tension
    - Compression
  - Cyclic load - multiple cycles of incremental loading and unloading
    - Oscillating
      - Tension
      - Compression
      - Combination of compression and tension

Cracking Modes versus Tests

In reality, a pavement experiences multiple:
- Loading cycles
- Load magnitudes
- Strains
- Temperatures



Cracking Laboratory Tests

Ten (10) protocols - highlighted as part of NCHRP Project 09-57

- Indirect Tensile (IDT)
  - for low temperature cracking
- Indirect Tensile (IDT)
  - for top-down cracking
- Semicircular Bend (SCB)
  - at low temperature
- Semicircular Bend (SCB)
  - at intermediate temp.
- Disk Shaped Compact Tension (DCT)
- Thermal Stress Restrained Specimen Test / Uniaxial Thermal Stress and Strain Test (TSRST/UTSST)
- Texas Overlay Test (TxOT or OT)
- Repeated Direct Tension (RDT)
- Bending Beam Fatigue
- AMPT Cyclic Fatigue (S-VECD)

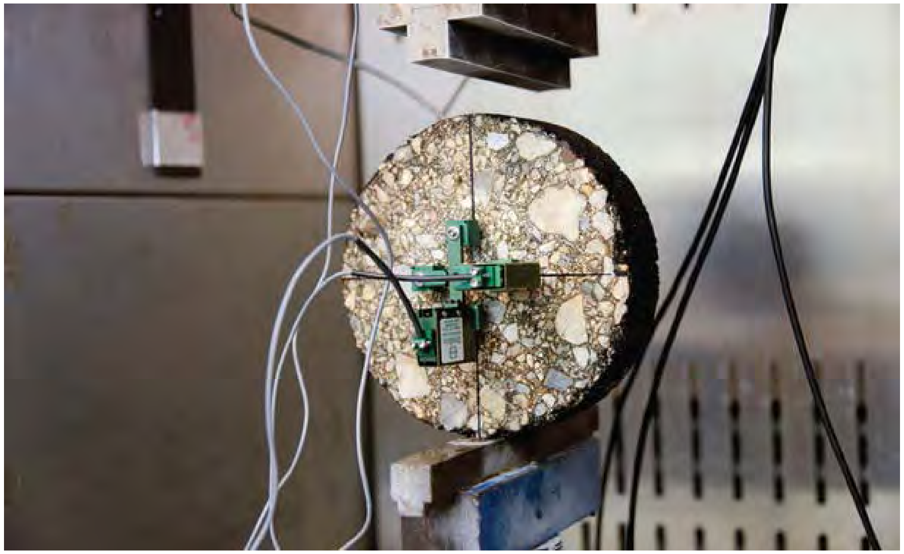
Cracking Laboratory Tests

Ten (10) protocols - cracking mode(s)

Low Temperature	Reflection	Bottom-Up	Top-Down
DCT (ASTM D7313-13)	Texas OT (TxDOT-Tex 248-F)	Beam fatigue (AASHTO T321)	IDT (Univ. of Florida)
SCB (AASHTO TP105)	DCT (ASTM D7313-13)	AMPT Cyclic Fatigue (AASHTO TP107)	AMPT Cyclic Fatigue (AASHTO TP107)
IDT (AASHTO T322)	SCB (Louisiana State Univ. - LTRC)	RDT (Texas A&M Univ.)	RDT (Texas A&M Univ.)
TSRST/UTSST (Univ. of Nevada, Reno)		SCB (LTRC and Univ. of Illinois)	SCB (LTRC and Univ. of Illinois)
		Texas OT (TxDOT-Tex 248-F)	

Indirect Tensile (IDT)

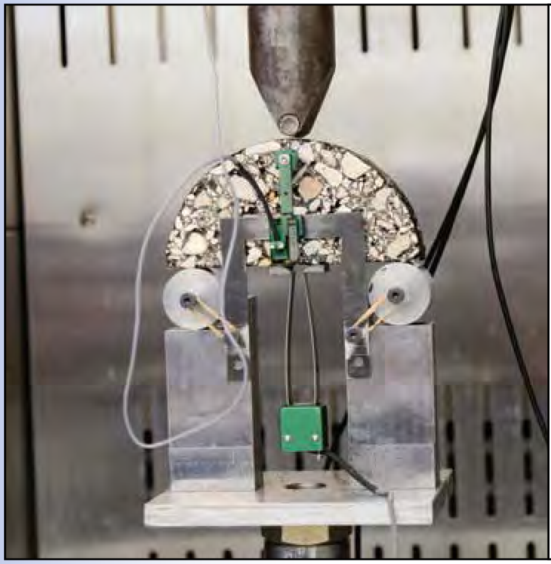
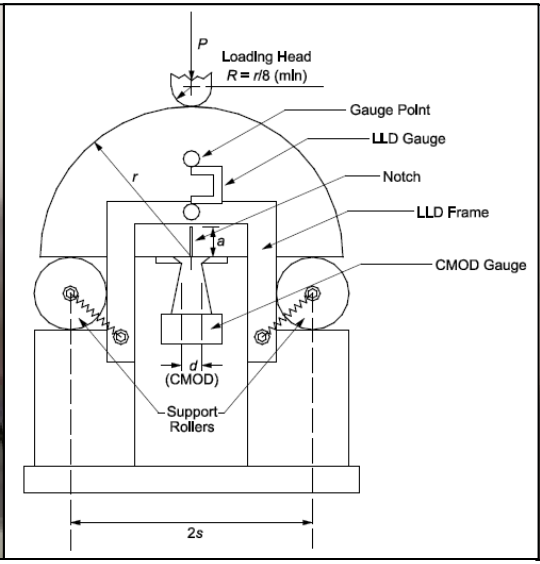
- Low Temperature – AASHTO T 322-07 (2011) Determining the Creep Compliance and Strength of Hot Mix Asphalt (HMA) Using the Indirect Tensile Test Device
- Top-down - University of Florida
  - M_r test (optional), D_t test, and tensile strength test (cyclic and monotonic tests)
  - Energy Ratio

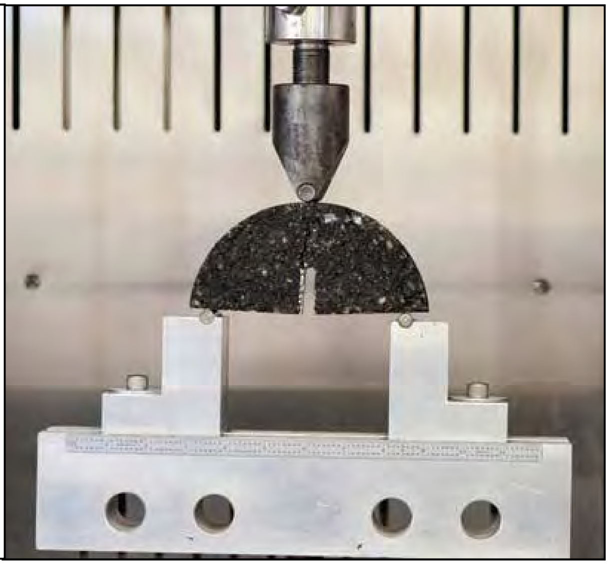


www.youtube.com/watch?v=xycvHX0XoyA

Semicircular Bend (SCB)

- Low Temperature - AASHTO TP 105-13(2015) Determining the Fracture Energy of Asphalt Mixtures Using the Semicircular Bend Geometry (SCB)
- Intermediate Temperature – LTRC and University of Illinois Testing Protocols, critical energy release rate



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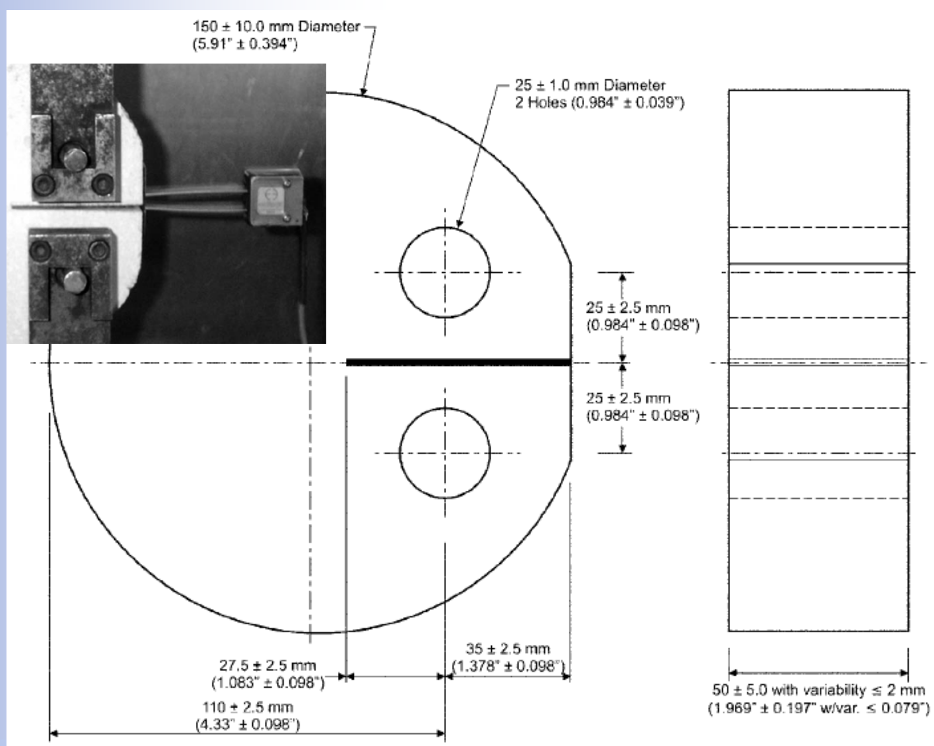
Disk Shaped Compact Tension

- ASTM D7313-13 Determining Fracture Energy of Asphalt-Aggregate Mixture Using the Disk-Shaped Compact Tension Geometry



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TSRST / UTSST

- Low Temperature - Fracture temperature (coefficient of thermal contraction from UTSST)

- AASHTO TP10-93 Thermal Stress Restrained Specimen Tensile Strength (withdrawn)
- UTSST is also known as the Modified TSRST
  - University of Nevada, Reno

www.youtube.com/watch?v=gDdHMhAhnTU

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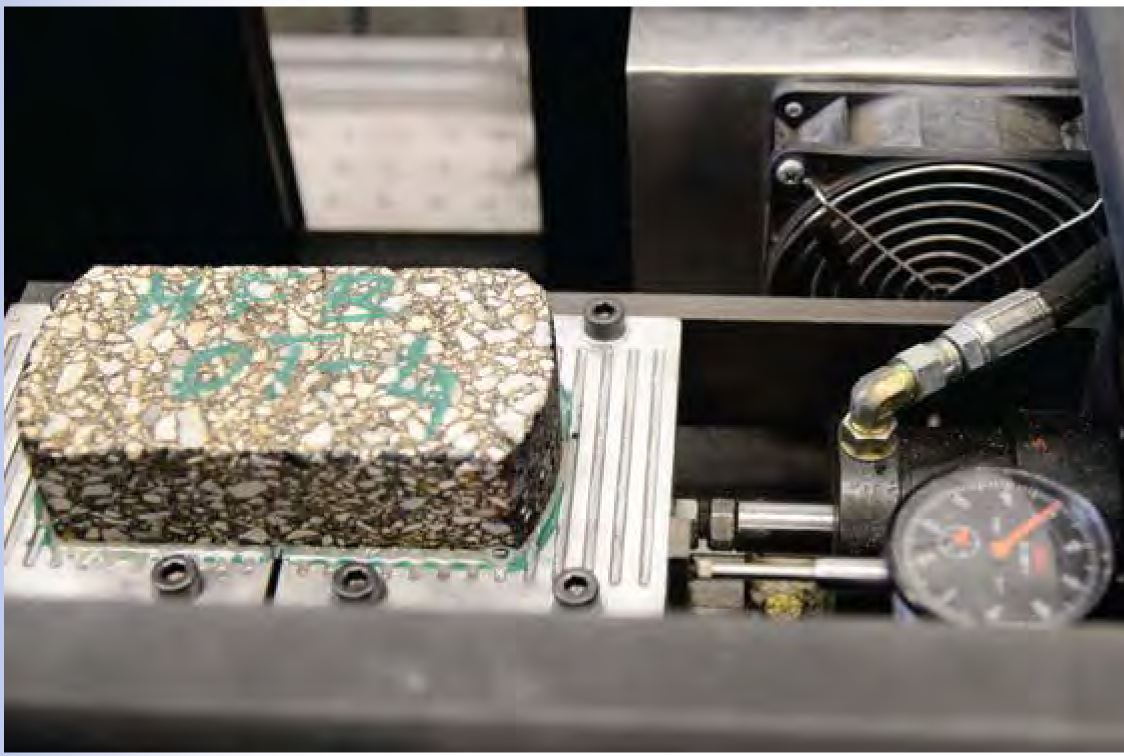
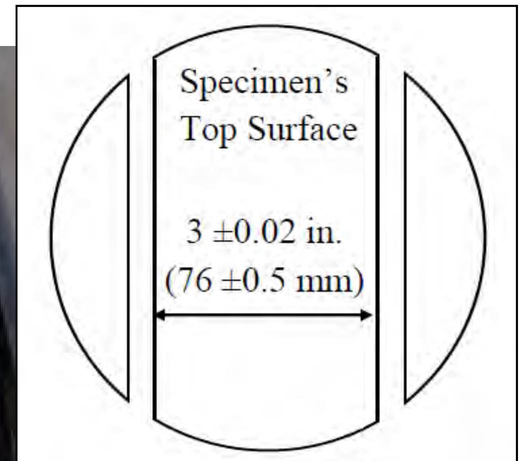
Texas Overlay Test (TxOT)

- Reflection cracking & bottom-up fatigue cracking – TxDOT Test Standard Tex-248-F (cyclic test)



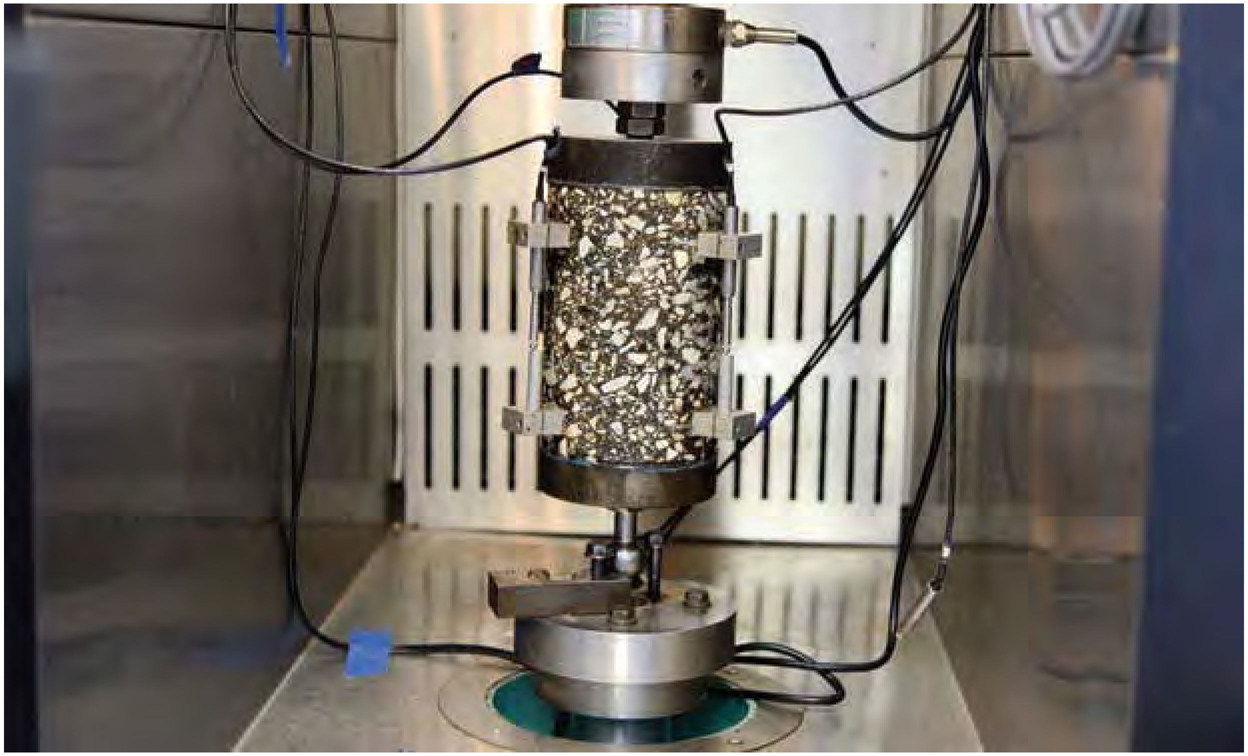


6" diam. (150mm)

www.youtube.com/watch?v=5Np6lGSPfLA

Repeated Direct Tension (RDT)

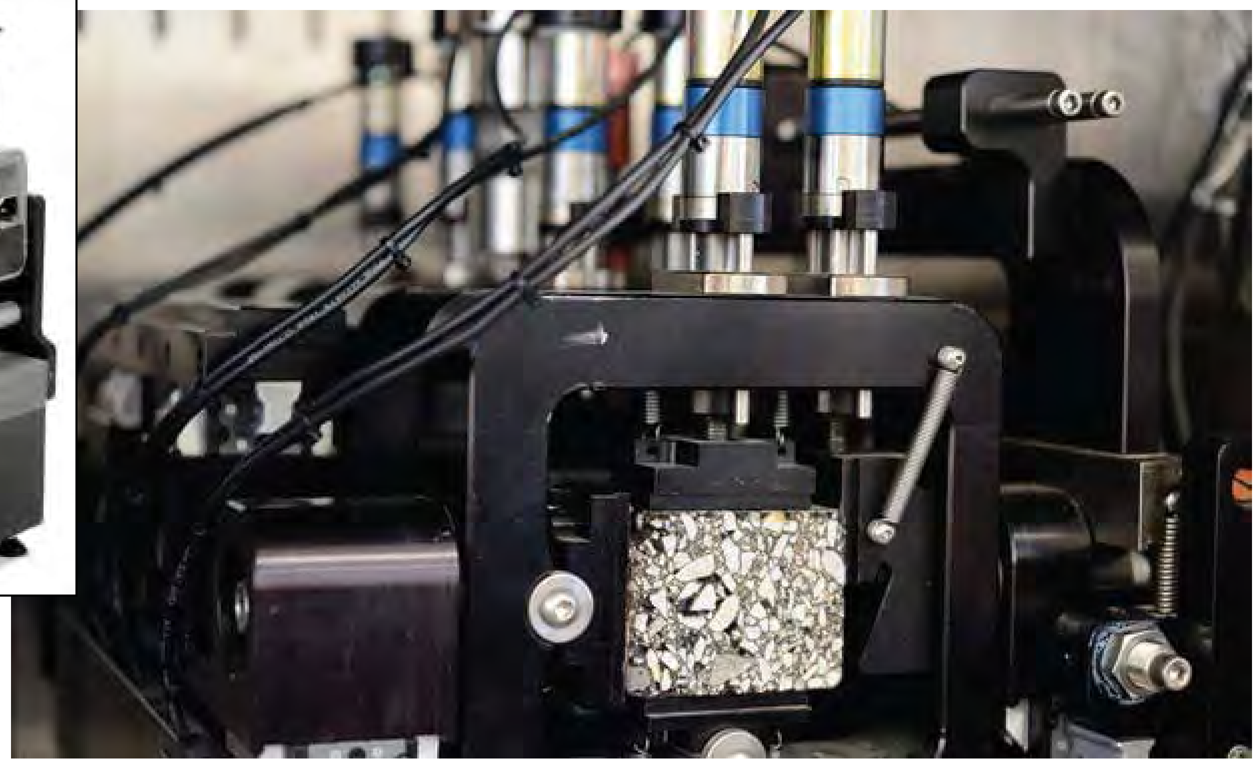
- Bottom-up and top-down - Texas A&M University
- Paris' law parameters, endurance limit, healing properties, and average crack size



www.youtube.com/watch?v=_1Avh5nMV-g

Bending Beam Fatigue

- Bottom-up cracking - AASHTO T 321-14
  Determining the Fatigue Life of Compacted Asphalt Mixtures Subjected to Repeated Flexural Bending

www.youtube.com/watch?v=3V0SW0vQ8mY

AMPT Cyclic Fatigue

Cracking Resistance

- Bottom-up and top-down cracking
- AASHTO TP 107-14 Determining the Damage Characteristic Curve of Asphalt Mixtures from Direct Tension Cyclic Fatigue Tests
- S-VECD used with more advanced models to simulate pavement performance and predict distresses
- validated with FHWA's ALF test lanes
- used in FHWA's Mobile Asphalt Testing Trailer

www.youtube.com/watch?v=9sGb2lkYb8I

Which test to use?

- Empirical vs. Mechanistic
  - simplified monotonic load single temperature
  - more robust regime of traffic loading and climate conditions

Actual pavement damage typically accumulates over multiple events

- NOT a single event
- Pavement remains intact while it looses a lot of modulus and then a crack occurs

Which test to use?

- Mixture ageing (conditioning)
  - short term vs. long term oven conditioning
  - a need for longer oven conditioning to simulate actual field conditions!

field cracking behavior worsens with time due to field ageing, therefore … laboratory oven conditioning (ageing) must be considered

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Which test to use?

- National standard test method and equipment requirements?
- Ruggedness?
- Precision and Bias?
  - requires ruggedness evaluation first!
    - otherwise not valid
  - Repeatability/Reproducibility
  - use of test for acceptance/payment

Which test to use?

- Sensitivity Analysis?
  - various materials and combinations
- Acceptance Criteria?
- Correlation from lab to actual field pavement performance?
- Integration with Structural Design?
  - Climate
  - Pavement Structure
  - Traffic

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FHWA Emphasis on AMPT Cyclic Fatigue

- Wanted a performance test that could be **defensible, not empirical correlations**
  - Circa 1999 - vetting and peer review; “winning” candidate in NCHRP 9-19 Tasks F&G
  - Heritage and “pedigree” of the theory – based in aerospace industry application for solid rocket propellant
  - **Performance Prediction** not single value index
    - ~~AASHTO 1993 Layer Coefficient~~
    - ~~Marshal Stability and Flow~~
- Extended Time-Temp Superposition = **Less Testing**
- FHWA promoting the **investment in AMPTs** for the PavementME design (formerly MEPDG) & the AMPT can do much more than just dynamic modulus |E*| testing
  - Unified/common AMPT equipment specification criteria
  - Unified/common compaction control with SGC

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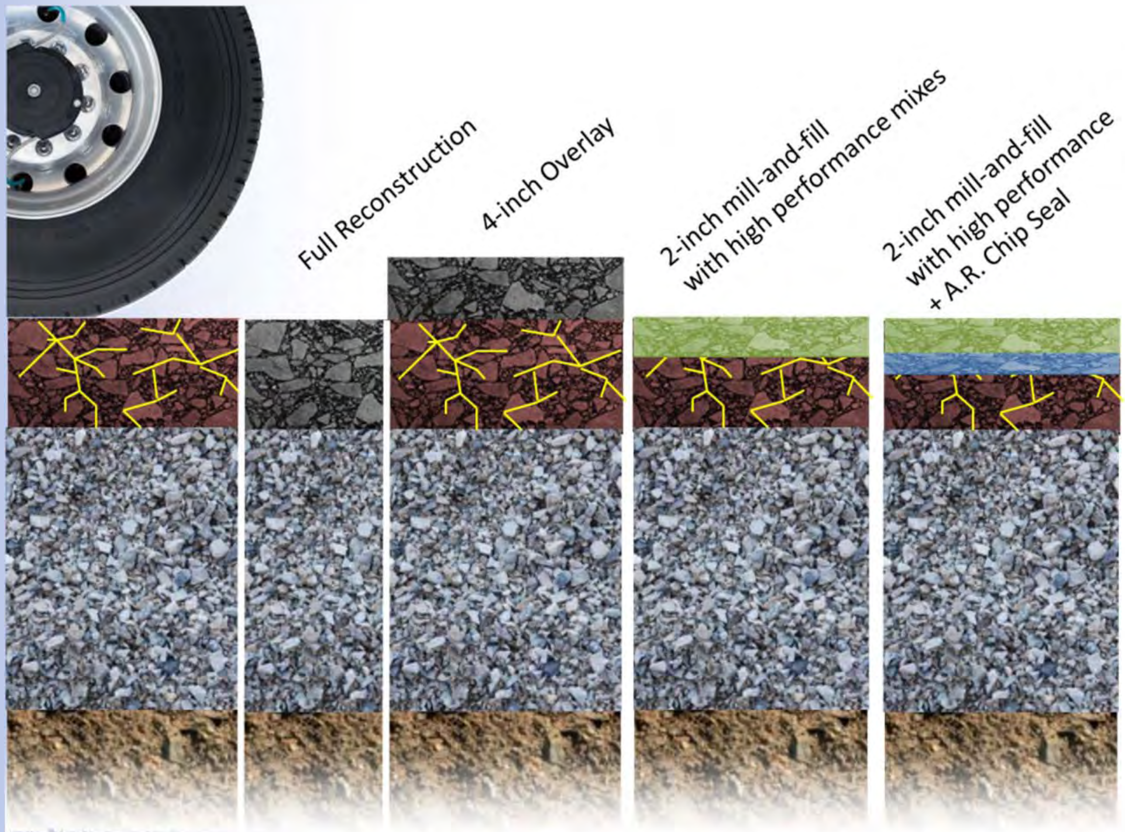
TP 107 & LVECD Handles Structure

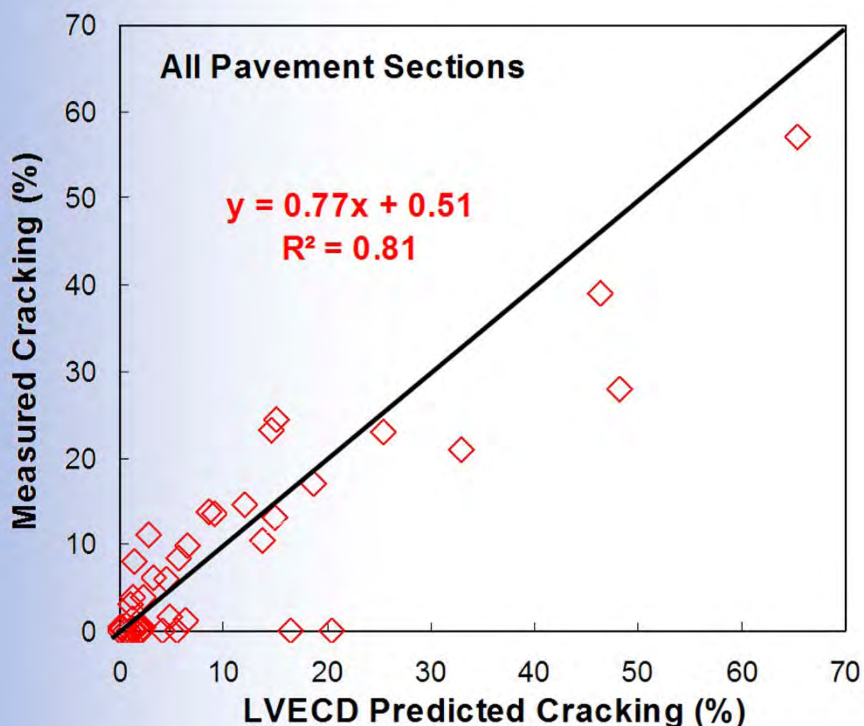
Rehab "What-if?" Scenarios
George Washington Memorial Parkway
77,000 AADT



- Control
  - PG70-22
  - PG64-22
- A.R. chip seal SAMI
- SBS PG76-22
- Ultrathin Bonded Wearing Course
- Gap-Graded Wet Process Crumb Rubber
- Kraton HiMA®
  - PG76-28 E
- Fiber reinforced

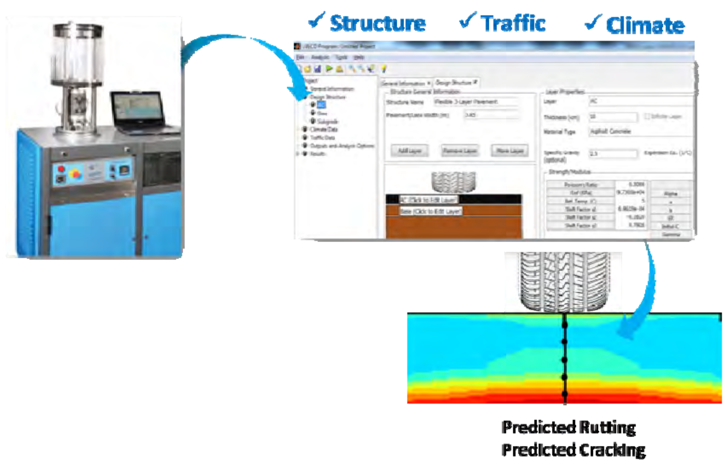
Cracking Resistance

Calibrated, Predicted Cracking



Field Sites Include:

NCAT, ALF_{2002}, Manitoba WMA, Manitoba RAP, Brazil, Korea, China, New York, Louisiana, & counting…



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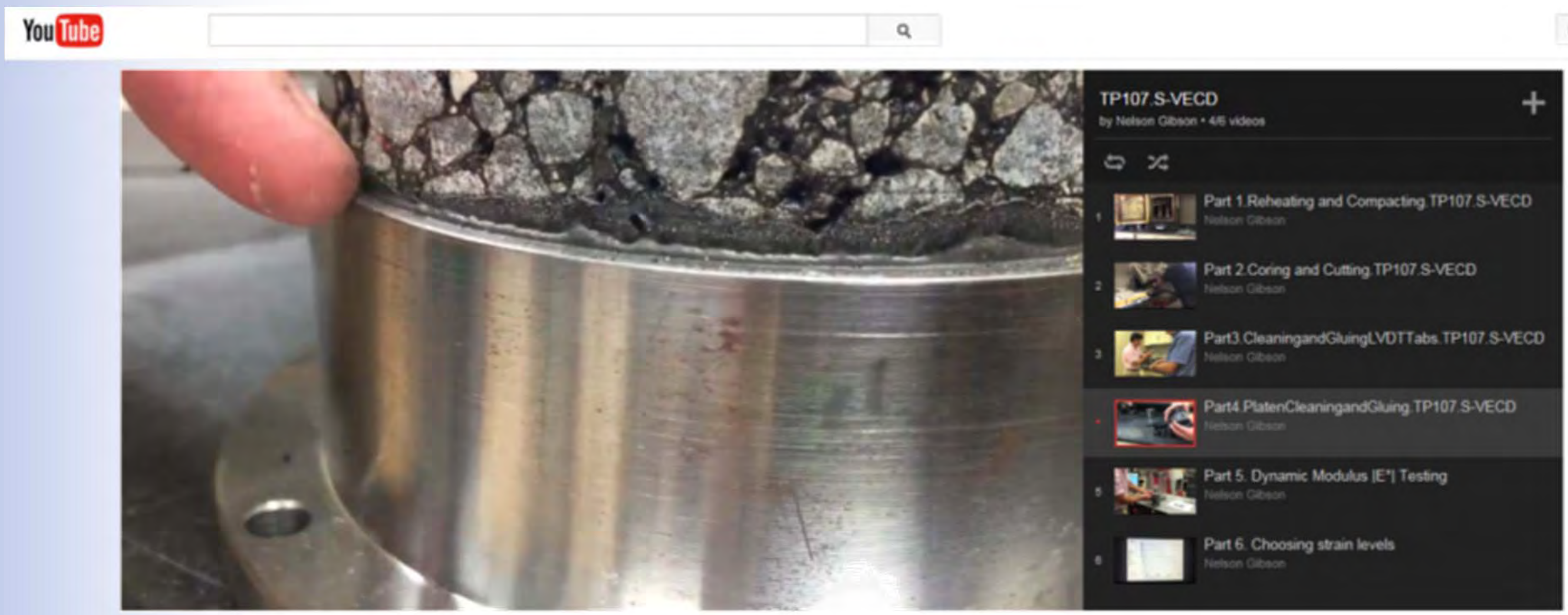
AMPT Cyclic Fatigue Test (AASHTO TP-107) Instructional Videos

Contact Nelson Gibson or Matthew Corrigan if you would like to know more …

https://www.youtube.com/playlist?list=PLyLypK-v8li-KjQq-Z6lmad4v2o_LcR3b



Provides guidance for increased lab efficiency, reduced testing/replicates, and consistent test data

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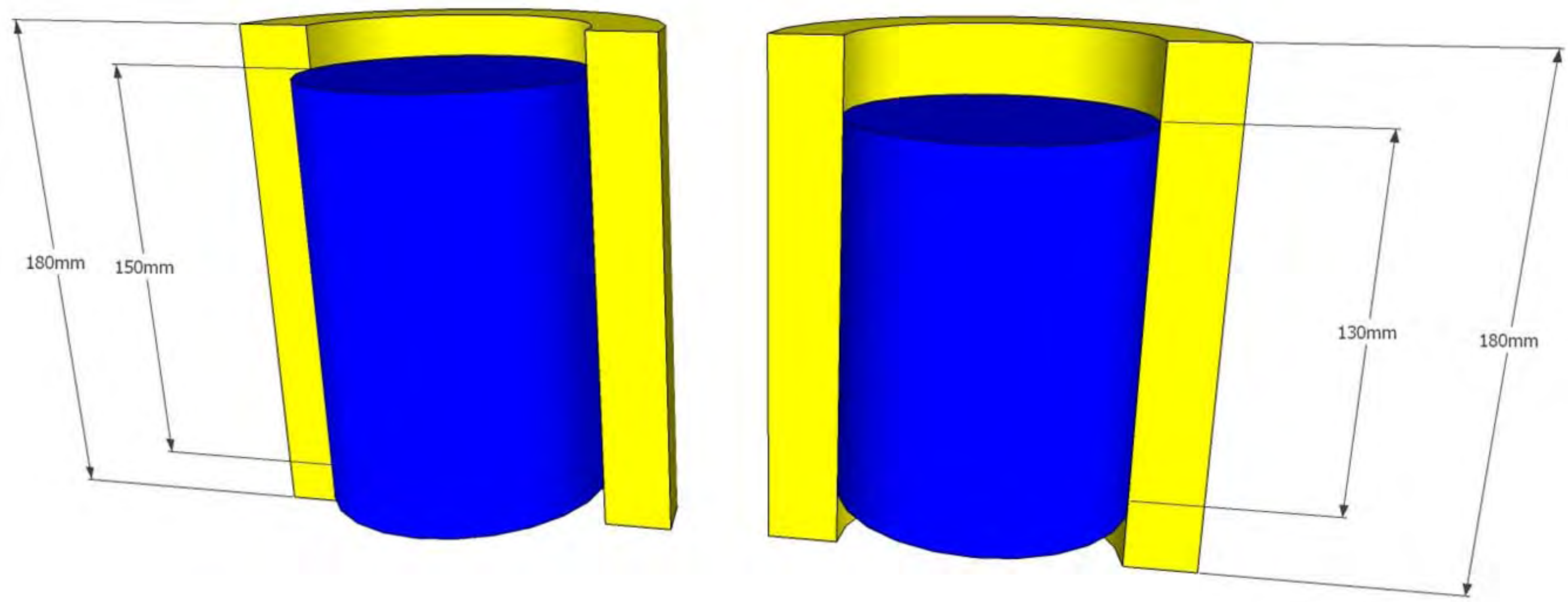
AMPT Cyclic Fatigue Test (AASHTO TP-107) Instructional Videos

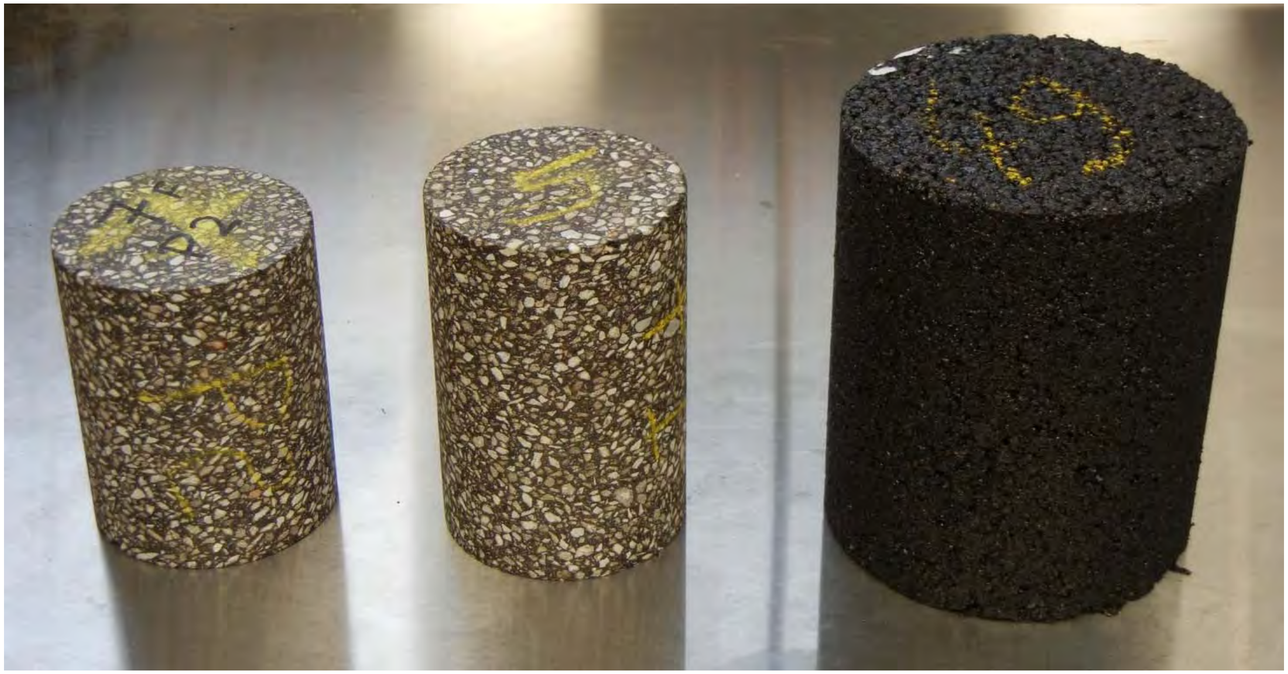
Cracking Resistance

- Part 1.Reheating and Compacting
- Part 2.Coring and Cutting
- Part 3.Cleaning and Gluing LVDT Tabs
- Part 4.Platen Cleaning and Gluing
- Part 5. Running |E*| - See also NHI Training Course
- Part 6.Choosing the Strain Level
- Part 7.Attaching Specimen and Running Test
- Part 8.Post Processing (alpha-Fatigue)
- Part 9.Post Processing LVECD Structural Analysis

Specimen Prep – Compaction Height

- Best Results for middle failure, experience-based
- Both E* and Cyclic Fatigue minimum 180mm SGC
- Cut more material away for Cyclic Fatigue
- Do not make a shorter SGC for Cyclic Fatigue





AMPT Cyclic Fatigue Test (AASHTO TP-107)

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AMPT Cyclic Fatigue Test (AASHTO TP-107)

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Guidance on Choosing Test Strain Levels*

- we went through the trial and error so you don't need to (do as much)
- based on testing of 64 different mixes
  - additional mixes and materials being added
- identified a failure pattern

*courtesy of Dr. Nelson Gibson, FHWA

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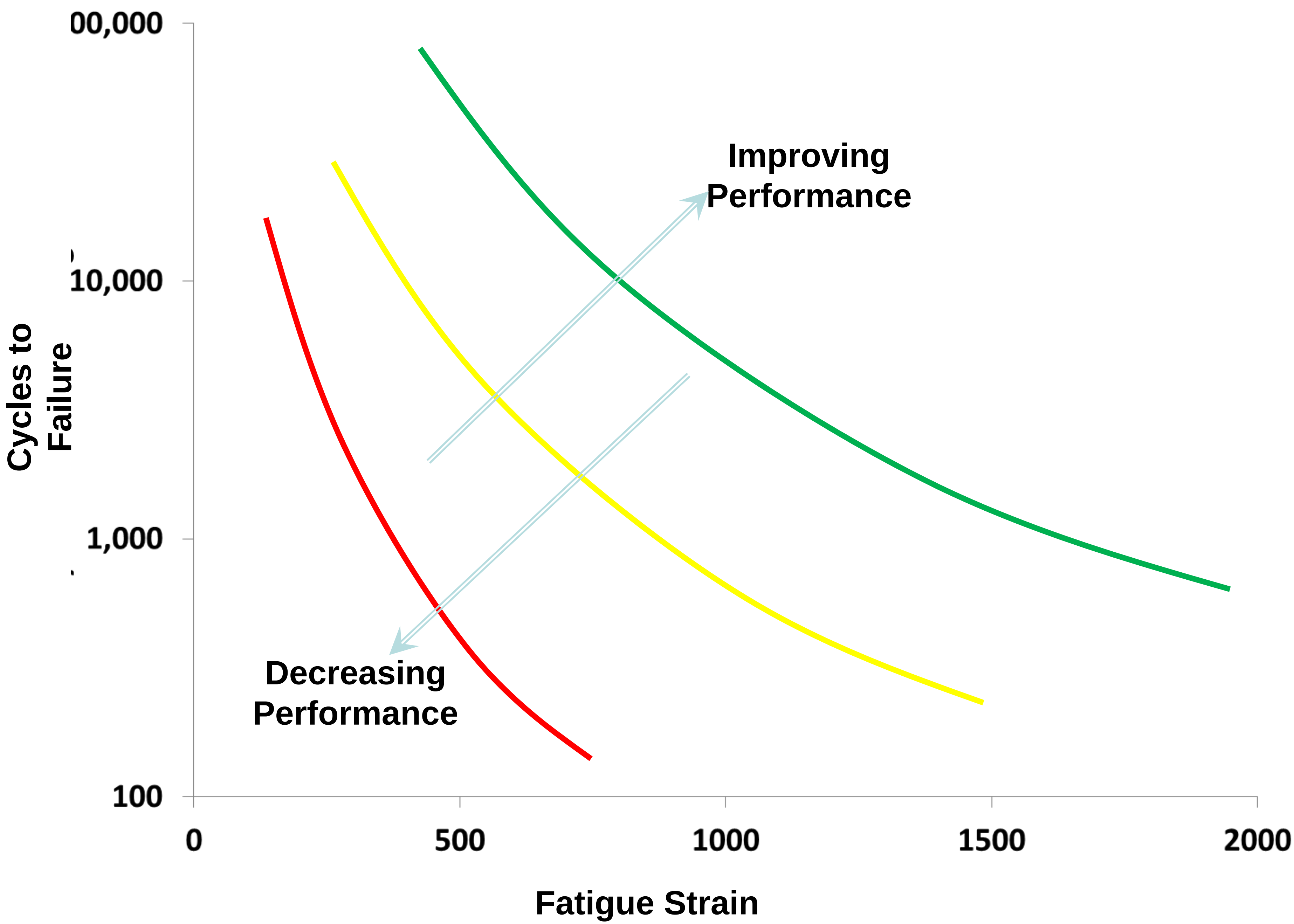
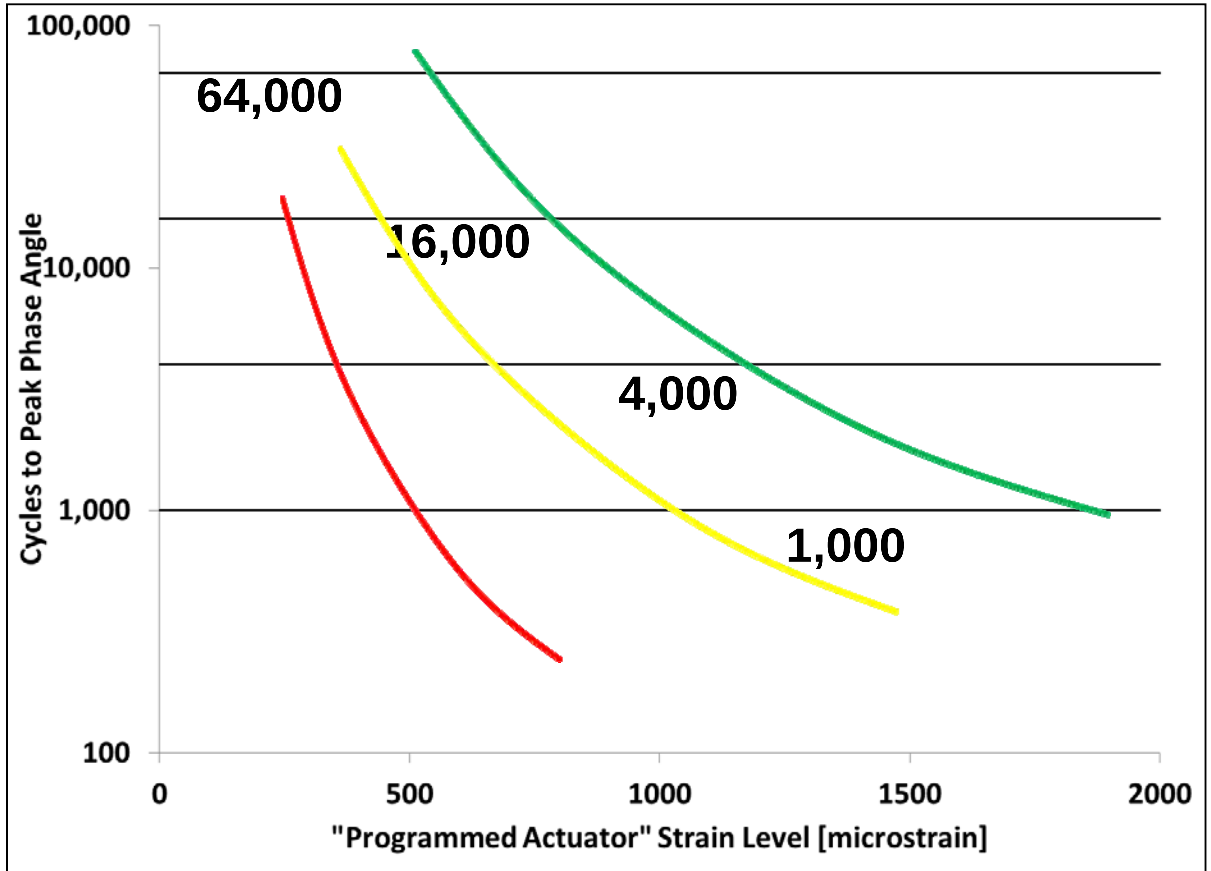
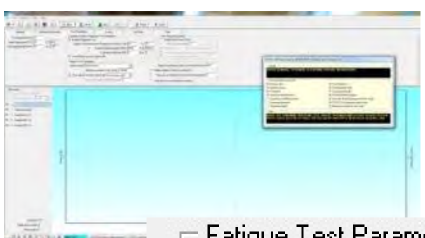
	If the |E*| is greater than 11,000 MPa, select 300 microstrain as the first specimen's strain				If 11,000 > |E*| > 5,500 Mpa, select 500 microstrain as the first specimen's strain					If the |E*| is less than 5,500 Mpa, select 800 microstrain as the first specimen's strain			
200	62,514	129,033	258,702	503,812	-	-	-	-	-	-	-	-	-
250	4,220	10,969	27,219	64,485	145,856	314,972	-	-	-	-	-	-	-
300	**467**	**1,464**	**4,324**	**12,022**	31,468	77,539	179,856	-	-	-	-	-	-
350	72	267	913	2,905	8,605	23,704	60,744	144,799	-	-	-	-	-
400	-	-	237	849	2,798	8,491	23,721	61,010	144,466	-	-	-	-
450	-	-	-	287	1,039	3,433	10,350	28,465	71,421	163,488	-	-	-
500	**-**	**-**	**-**	**-**	**428**	**1,527**	**4,929**	**14,392**	**38,032**	90,944	-	-	-
550	-	-	-	-	-	734	2,519	7,766	21,507	53,501	119,549	-	-
600	-	-	-	-	-	-	1,365	4,422	12,781	32,962	75,847	155,720	-
650	-	-	-	-	-	-	777	2,634	7,919	21,111	49,906	104,615	-
700	-	-	-	-	-	-	-	1,630	5,084	13,975	33,872	72,385	136,383
750	-	-	-	-	-	-	-	1,043	3,365	9,518	23,613	51,374	98,022
800	**-**	**-**	**-**	**-**	**-**	**-**	**-**	687	2,287	**6,646**	**16,849**	**37,278**	**71,969**
850	-	-	-	-	-	-	-	-	1,592	4,742	12,271	27,581	53,840
900	-	-	-	-	-	-	-	-	1,131	3,450	9,101	20,761	40,952
950	-	-	-	-	-	-	-	-	818	2,553	6,859	15,869	31,613
1,000	-	-	-	-	-	-	-	-	-	1,919	5,246	12,298	24,730
1,050	-	-	-	-	-	-	-	-	-	1,463	4,064	9,650	19,579
1,100	-	-	-	-	-	-	-	-	-	1,129	3,187	7,658	15,670
1,150	-	-	-	-	-	-	-	-	-	881	2,526	6,140	12,667
1,200	-	-	-	-	-	-	-	-	-	-	2,022	4,970	10,332
1,250	-	-	-	-	-	-	-	-	-	-	1,633	4,057	8,498
1,300	-	-	-	-	-	-	-	-	-	-	1,330	3,339	7,043
1,350	-	-	-	-	-	-	-	-	-	-	1,092	2,768	5,879
1,400	-	-	-	-	-	-	-	-	-	-	903	2,310	4,940
1,450	-	-	-	-	-	-	-	-	-	-	752	1,940	4,176
1,500	-	-	-	-	-	-	-	-	-	-	-	1,640	3,550
1,550	-	-	-	-	-	-	-	-	-	-	-	1,393	3,035
1,600	-	-	-	-	-	-	-	-	-	-	-	1,190	2,607
1,650	-	-	-	-	-	-	-	-	-	-	-	1,021	2,250
1,700	-	-	-	-	-	-	-	-	-	-	-	880	1,950
1,750	-	-	-	-	-	-	-	-	-	-	-	762	1,697
1,800	-	-	-	-	-	-	-	-	-	-	-	-	1,483
1,850	-	-	-	-	-	-	-	-	-	-	-	-	1,301
1,900	-	-	-	-	-	-	-	-	-	-	-	-	1,145
1,950	-	-	-	-	-	-	-	-	-	-	-	-	1,011
2,000	-	-	-	-	-	-	-	-	-	-	-	-	896


00,000
10,000
1,000
100
Cycles to Failure
0
500
1000
1500
2000
Fatigue Strain
Improving Performance
Decreasing Performance

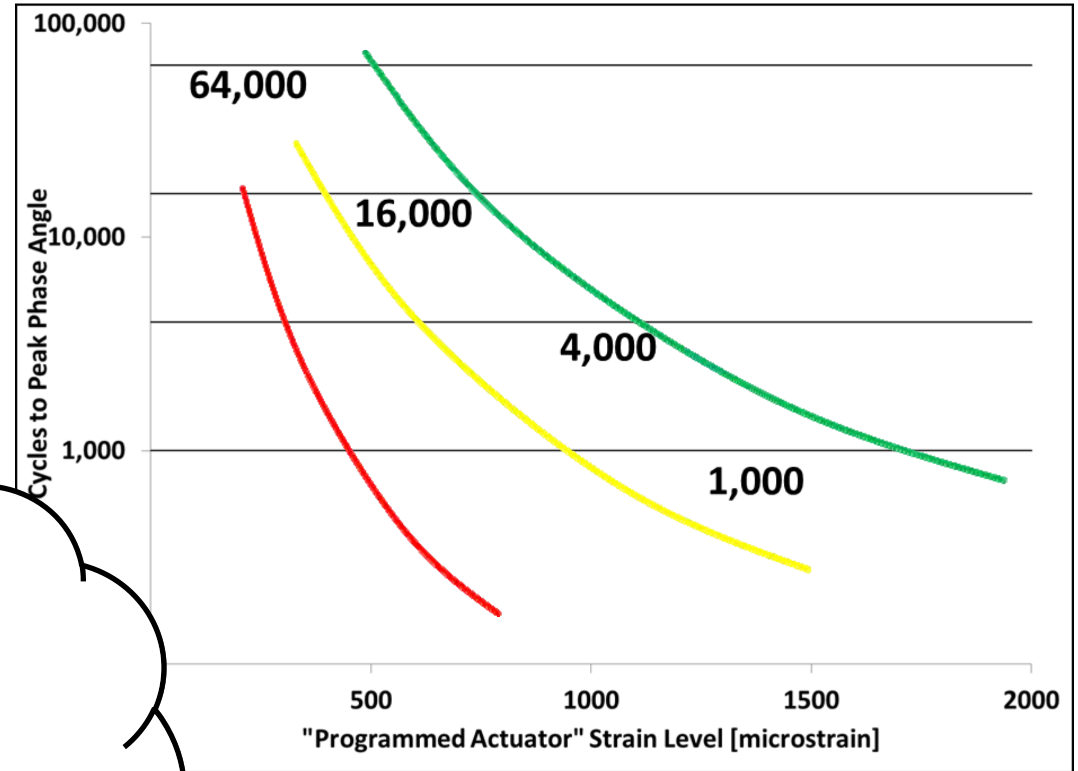
TP107-14 Section 11.2 requires three tests need to be completed at three strain levels.

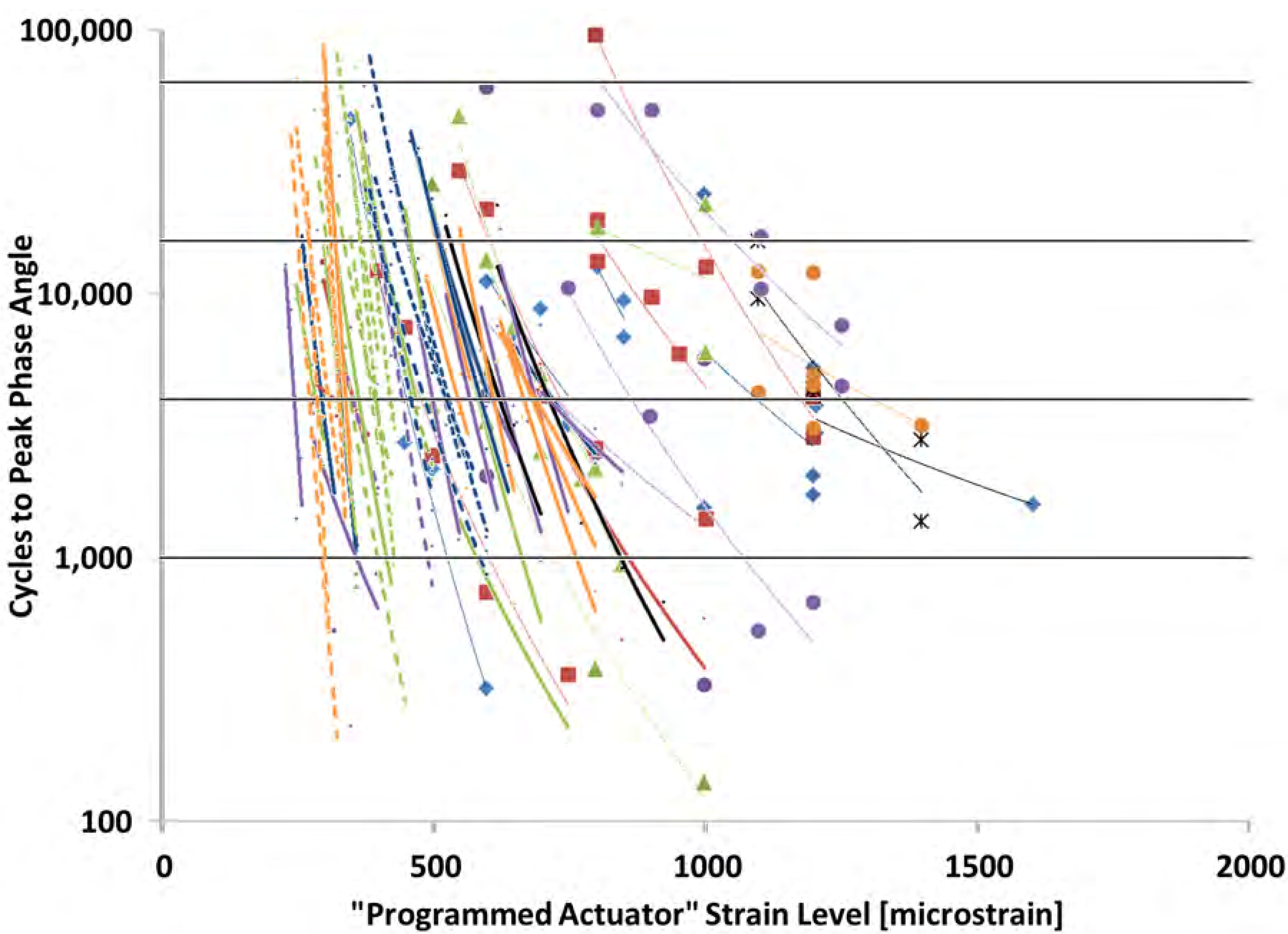
Ideally **failure cycles should be different by orders of magnitude between 1,000 - 64,000**
**ETG 2012 Meeting Minutes*



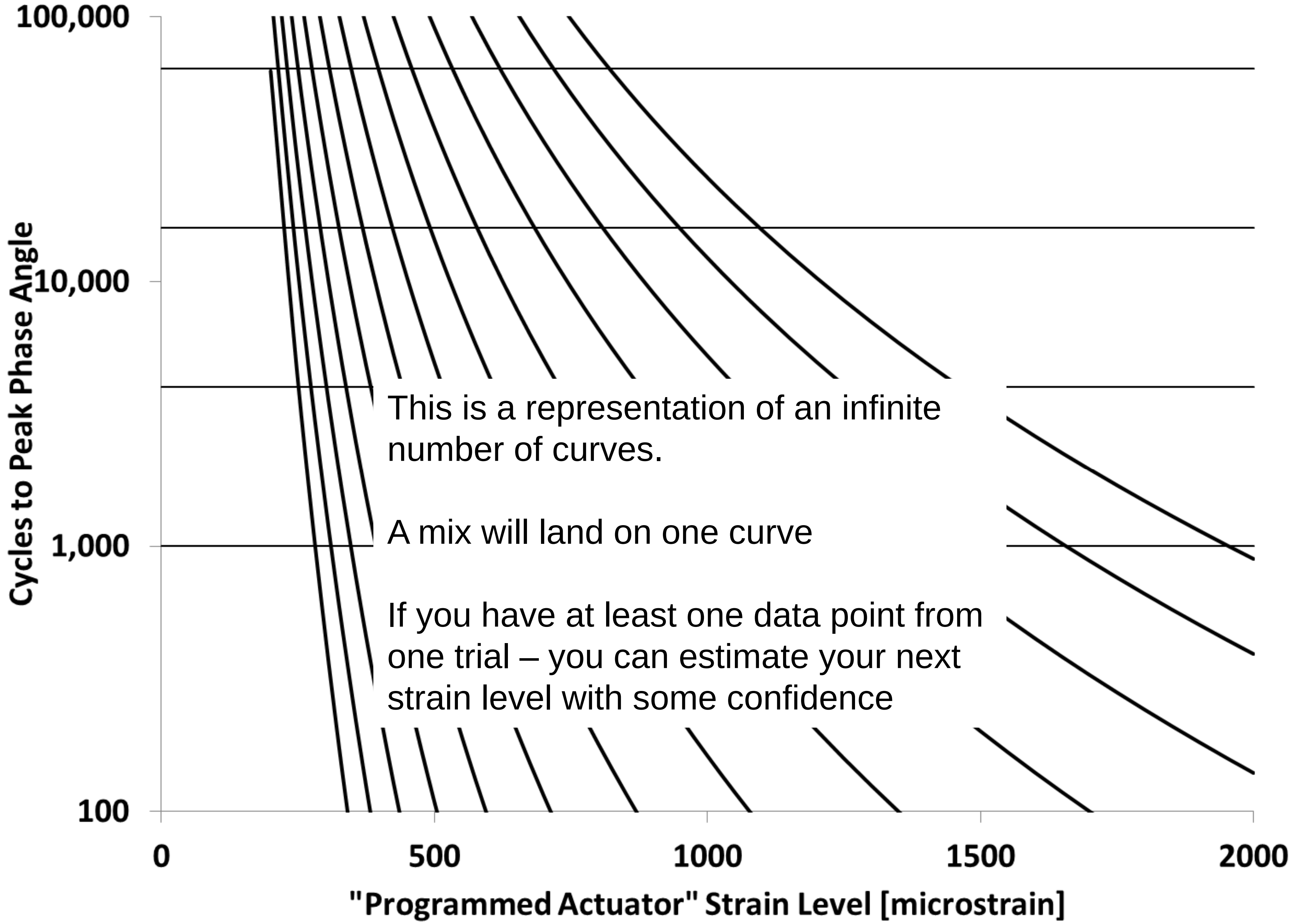


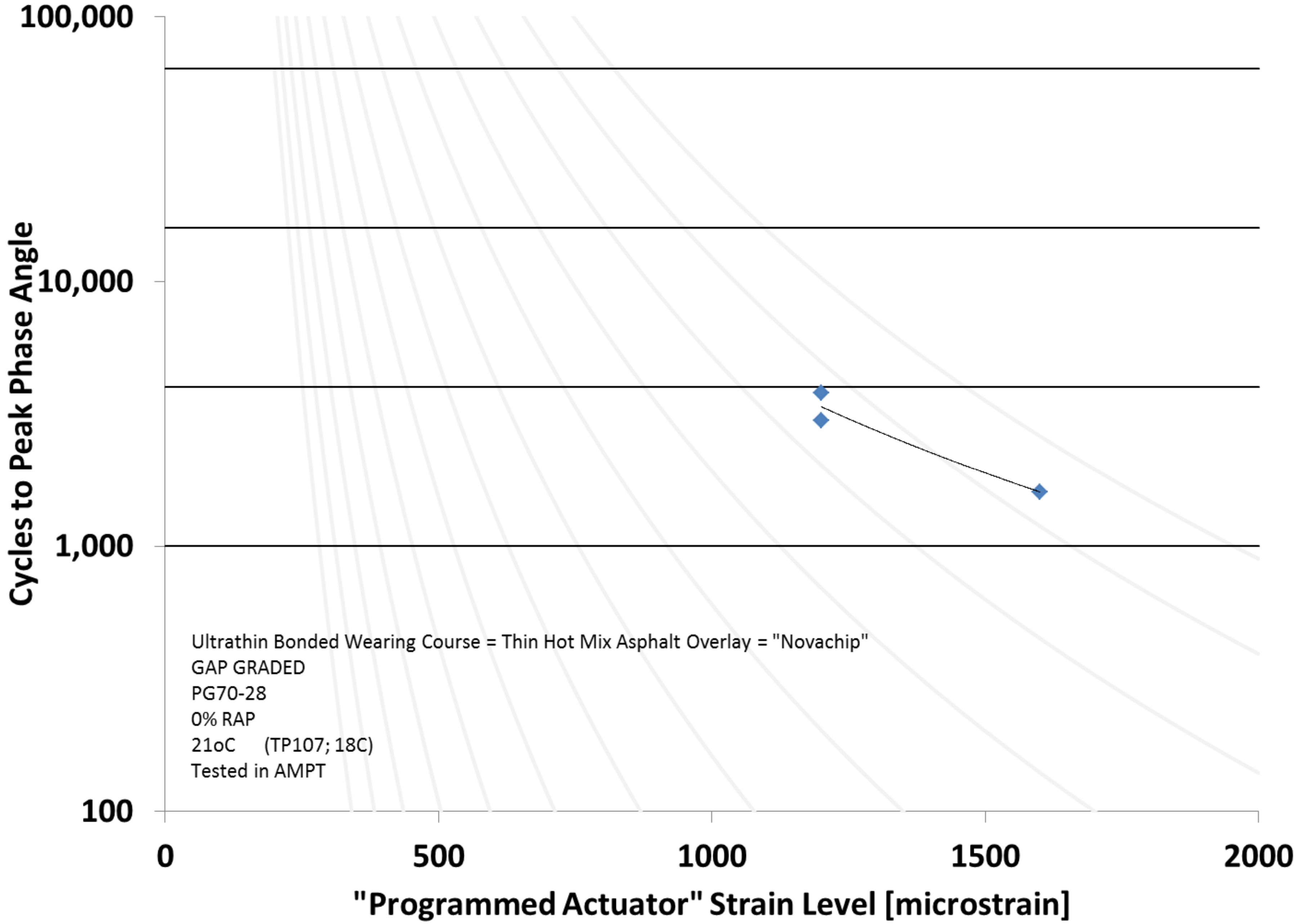
To get the right failure result ***here***, how do I figure out what to put in here???

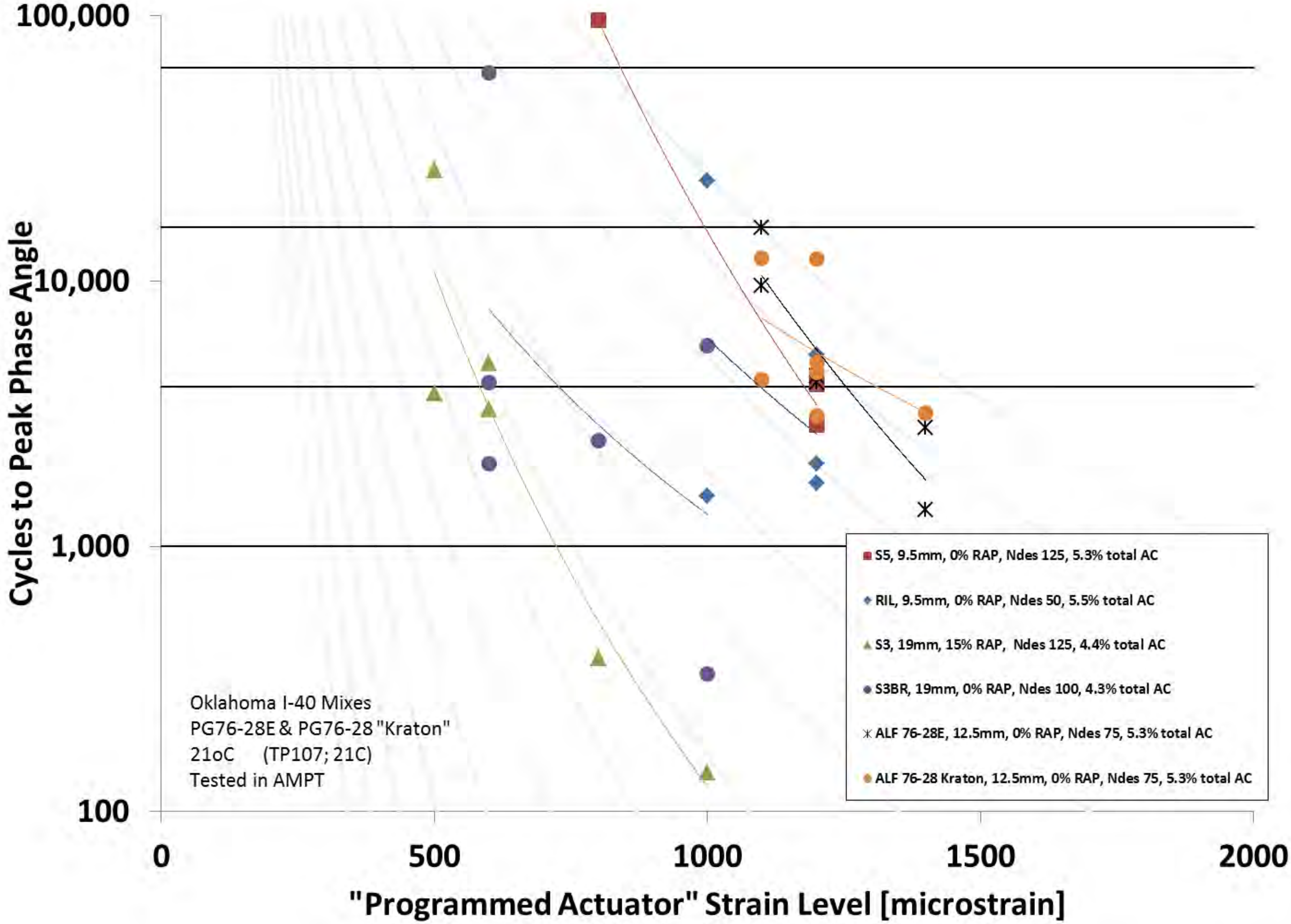




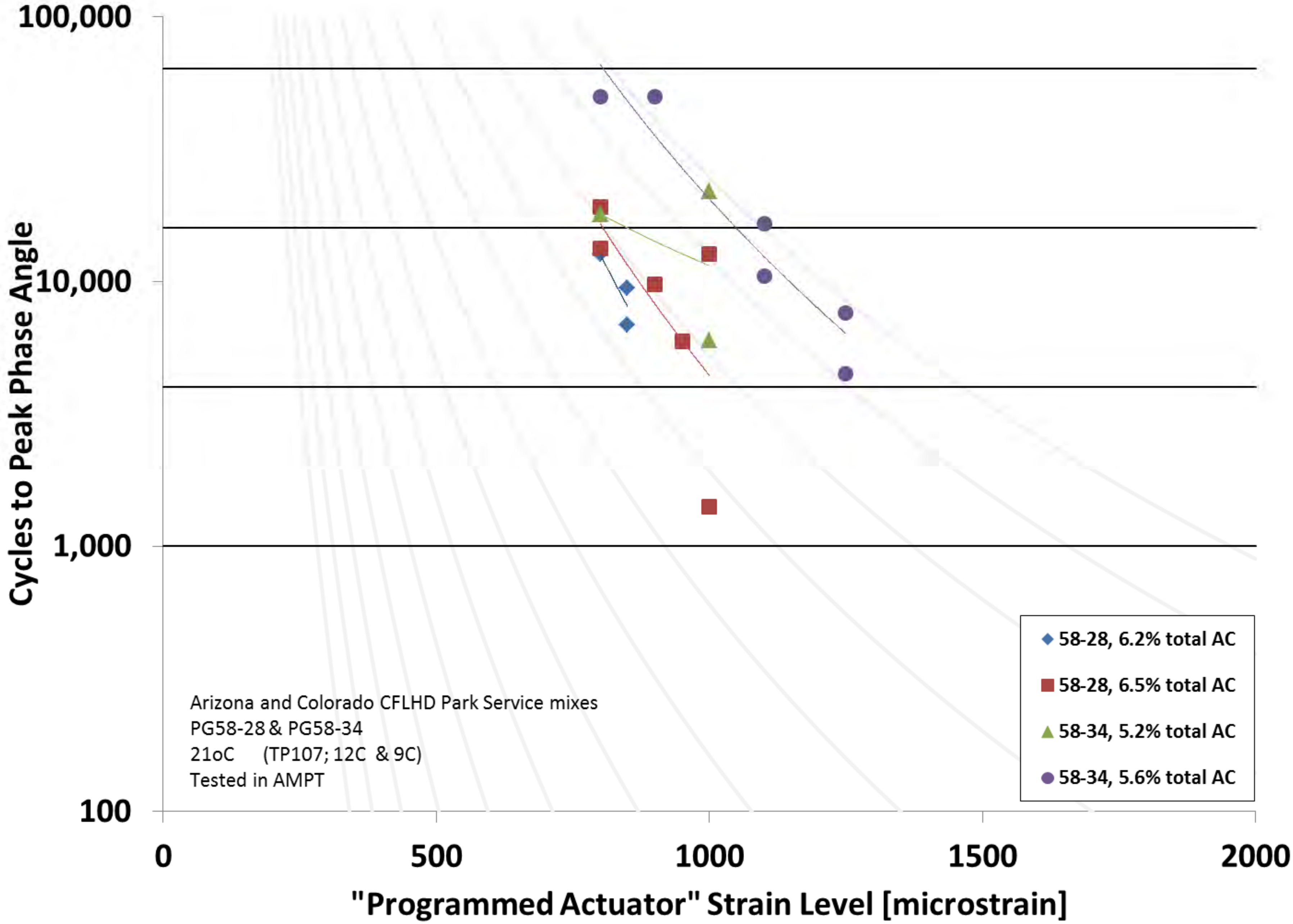
100,000
10,000
1,000
100
Cycles to Peak Phase Angle
0
500
1000
1500
2000
"Programmed Actuator" Strain Level [microstrain]

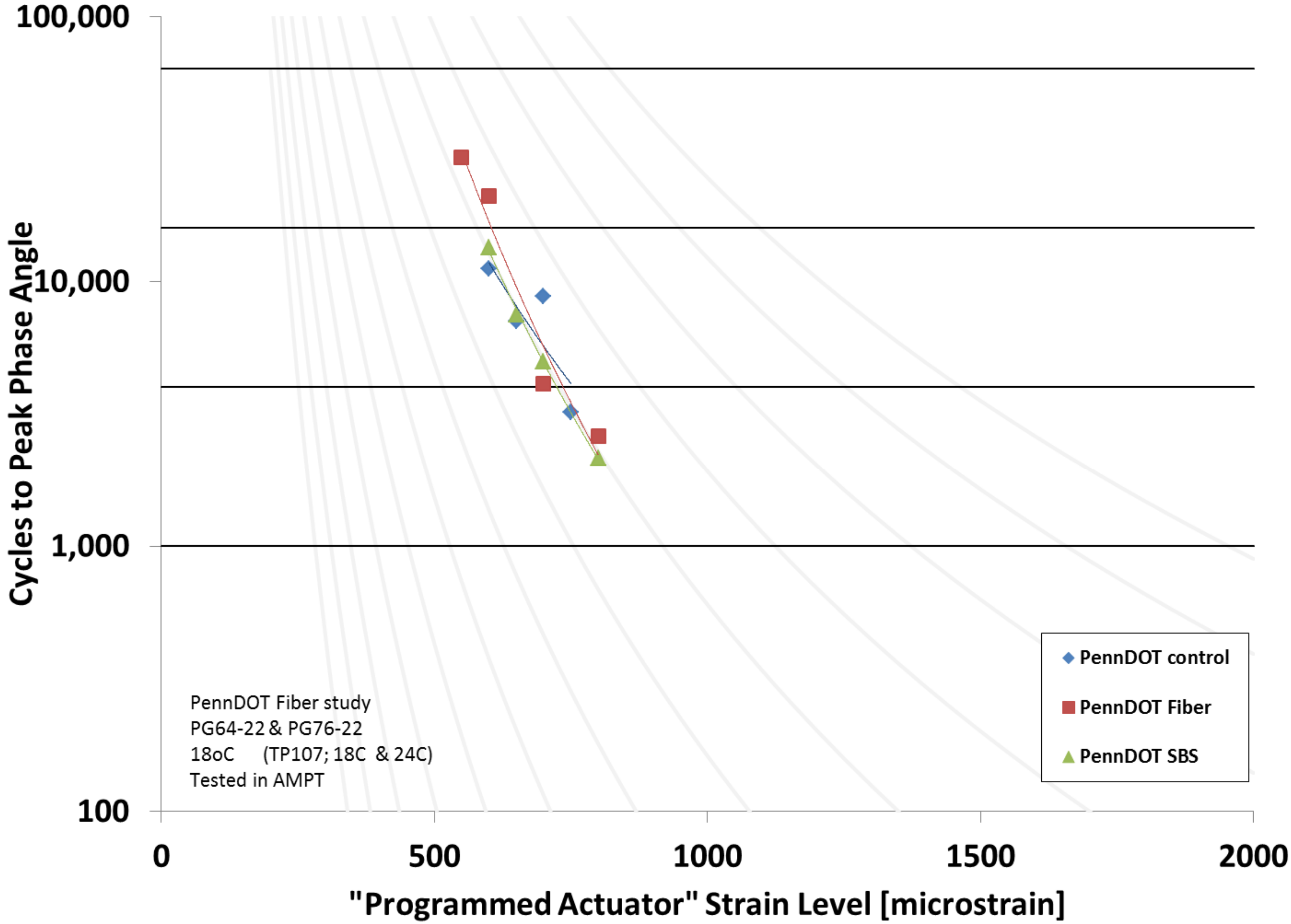

100,000
10,000
1,000
100
Cycles to Peak Phase Angle
0
500
1000
1500
2000
"Programmed Actuator" Strain Level [microstrain]
This is a representation of an infinite number of curves.
A mix will land on one curve
If you have at least one data point from one trial – you can estimate your next strain level with some confidence


100,000
10,000
1,000
100
Cycles to Peak Phase Angle
0
500
1000
1500
2000
"Programmed Actuator" Strain Level [microstrain]
Ultrathin Bonded Wearing Course = Thin Hot Mix Asphalt Overlay = "Novachip"
GAP GRADED
PG70-28
0% RAP
21oC (TP107; 18C)
Tested in AMPT

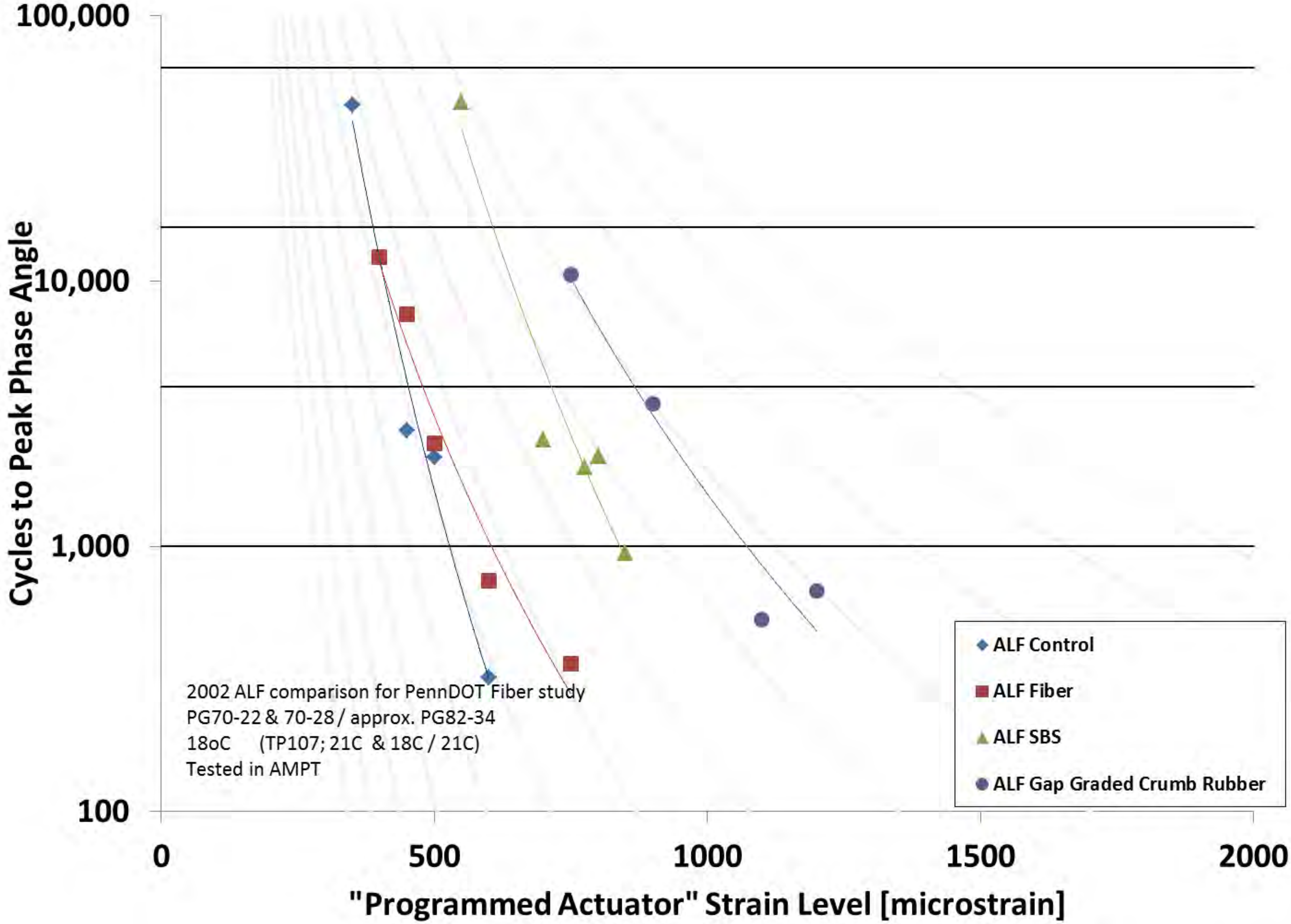


100,000
10,000
1,000
100
Cycles to Peak Phase Angle
0
500
1000
1500
2000
"Programmed Actuator" Strain Level [microstrain]
Oklahoma I-40 Mixes
PG76-28E & PG76-28 "Kraton"
21oC (TP107; 21C)
Tested in AMPT
S5, 9.5mm, 0% RAP, Ndes 125, 5.3% total AC
RIL, 9.5mm, 0% RAP, Ndes 50, 5.5% total AC
S3, 19mm, 15% RAP, Ndes 125, 4.4% total AC
S3BR, 19mm, 0% RAP, Ndes 100, 4.3% total AC
ALF 76-28E, 12.5mm, 0% RAP, Ndes 75, 5.3% total AC
ALF 76-28 Kraton, 12.5mm, 0% RAP, Ndes 75, 5.3% total AC

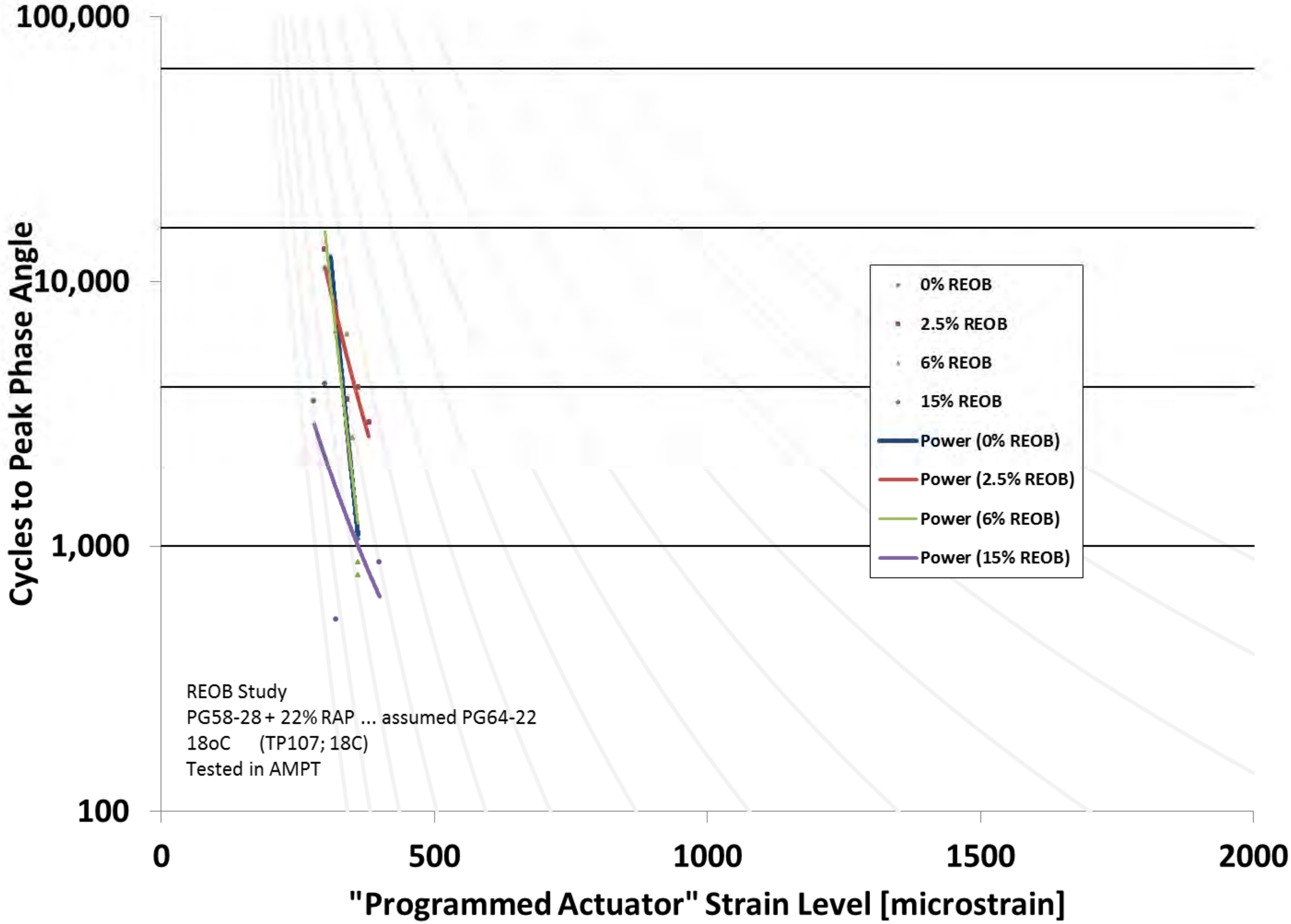

100,000
10,000
1,000
100
Cycles to Peak Phase Angle
0
500
1000
1500
2000
"Programmed Actuator" Strain Level [microstrain]
58-28, 6.2% total AC
58-28, 6.5% total AC
58-34, 5.2% total AC
58-34, 5.6% total AC
Arizona and Colorado CFLHD Park Service mixes
PG58-28 & PG58-34
21oC (TP107; 12C & 9C)
Tested in AMPT



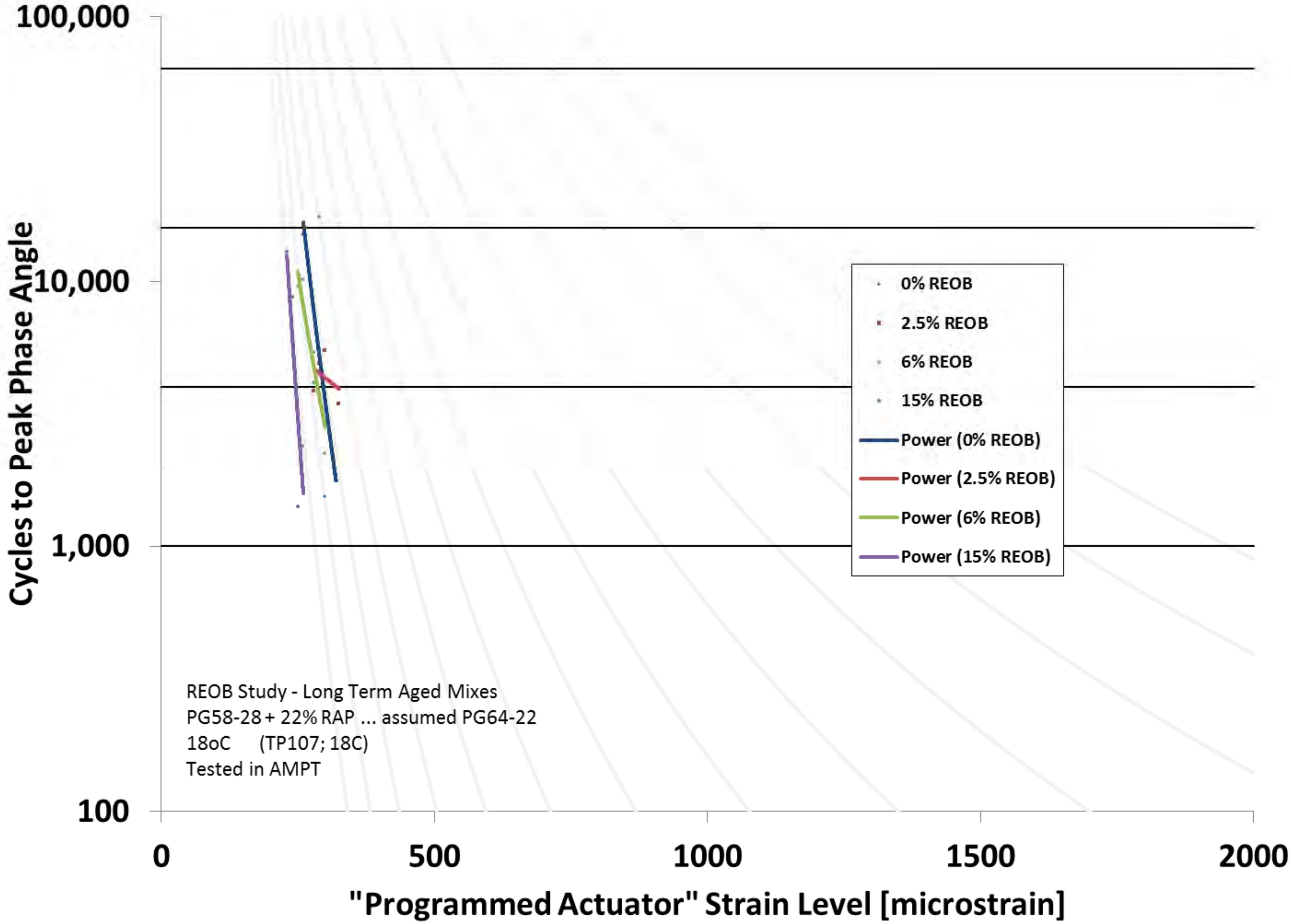
100,000
10,000
1,000
100
Cycles to Peak Phase Angle
0
500
1000
1500
2000
"Programmed Actuator" Strain Level [microstrain]
PennDOT control
PennDOT Fiber
PennDOT SBS
PennDOT Fiber study
PG64-22 & PG76-22
18oC (TP107; 18C & 24C)
Tested in AMPT

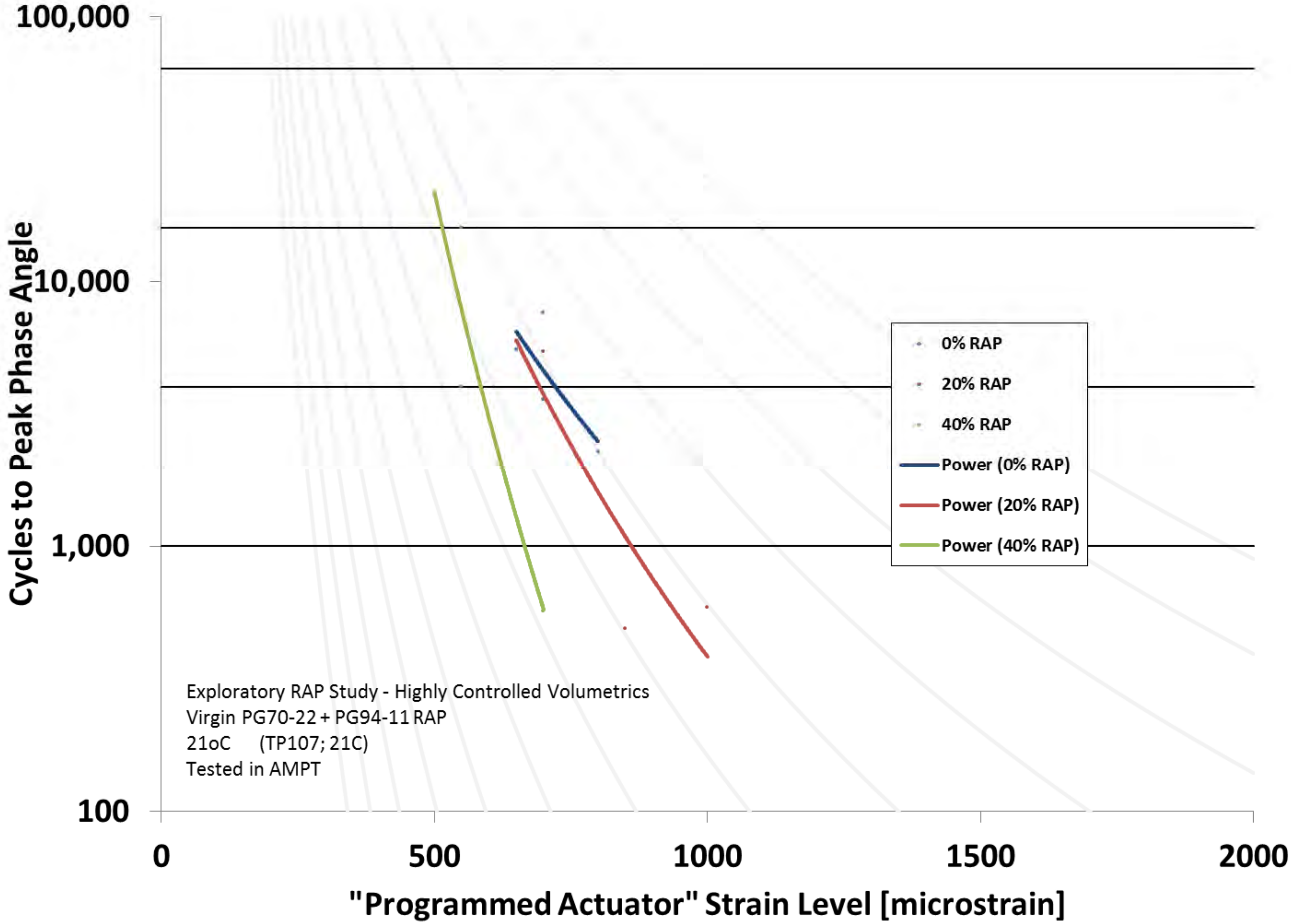


100,000
10,000
1,000
100
Cycles to Peak Phase Angle
0
500
1000
1500
2000
"Programmed Actuator" Strain Level [microstrain]
2002 ALF comparison for PennDOT Fiber study
PG70-22 & 70-28 / approx. PG82-34
18oC (TP107; 21C & 18C / 21C)
Tested in AMPT
ALF Control
ALF Fiber
ALF SBS
ALF Gap Graded Crumb Rubber

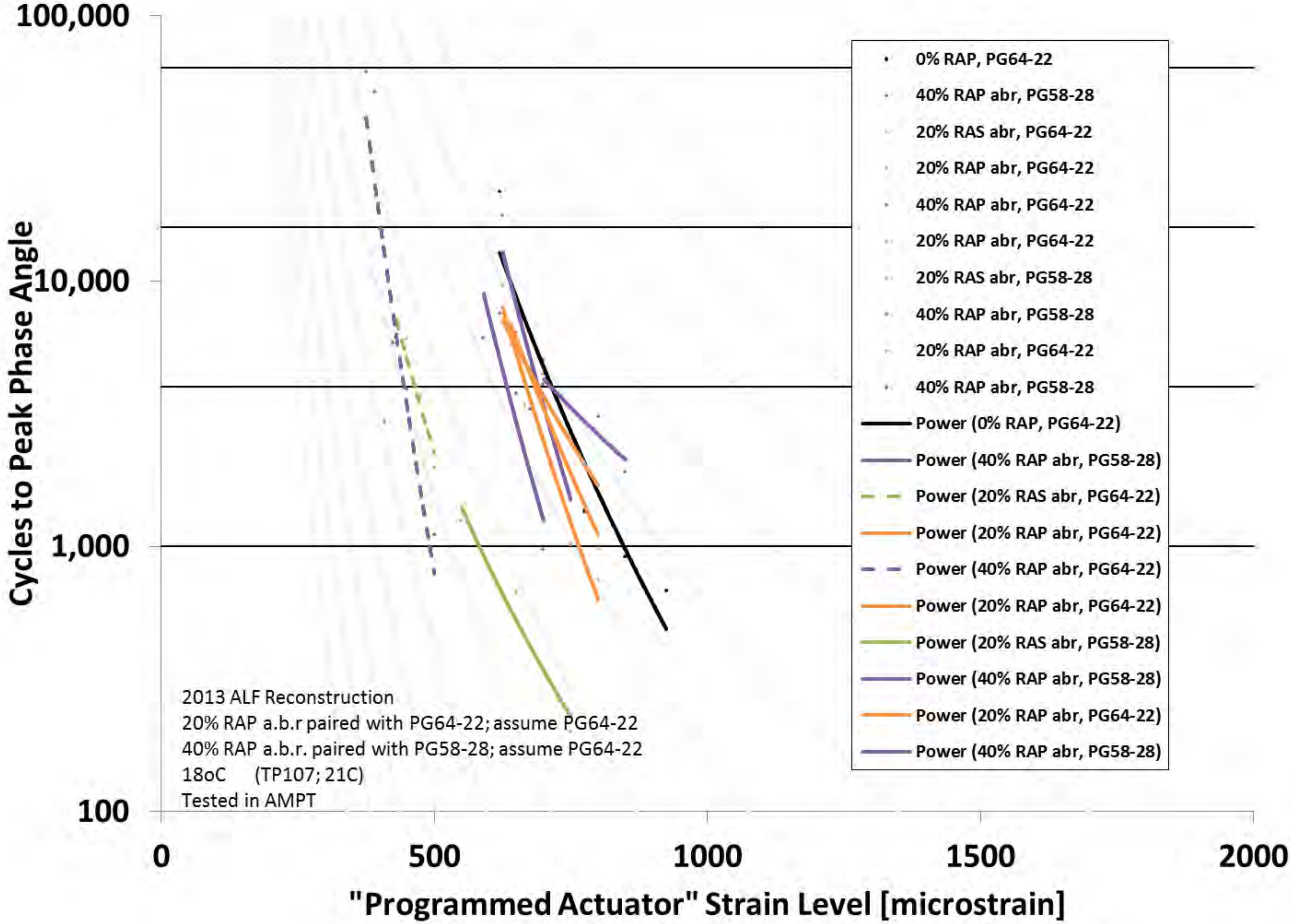


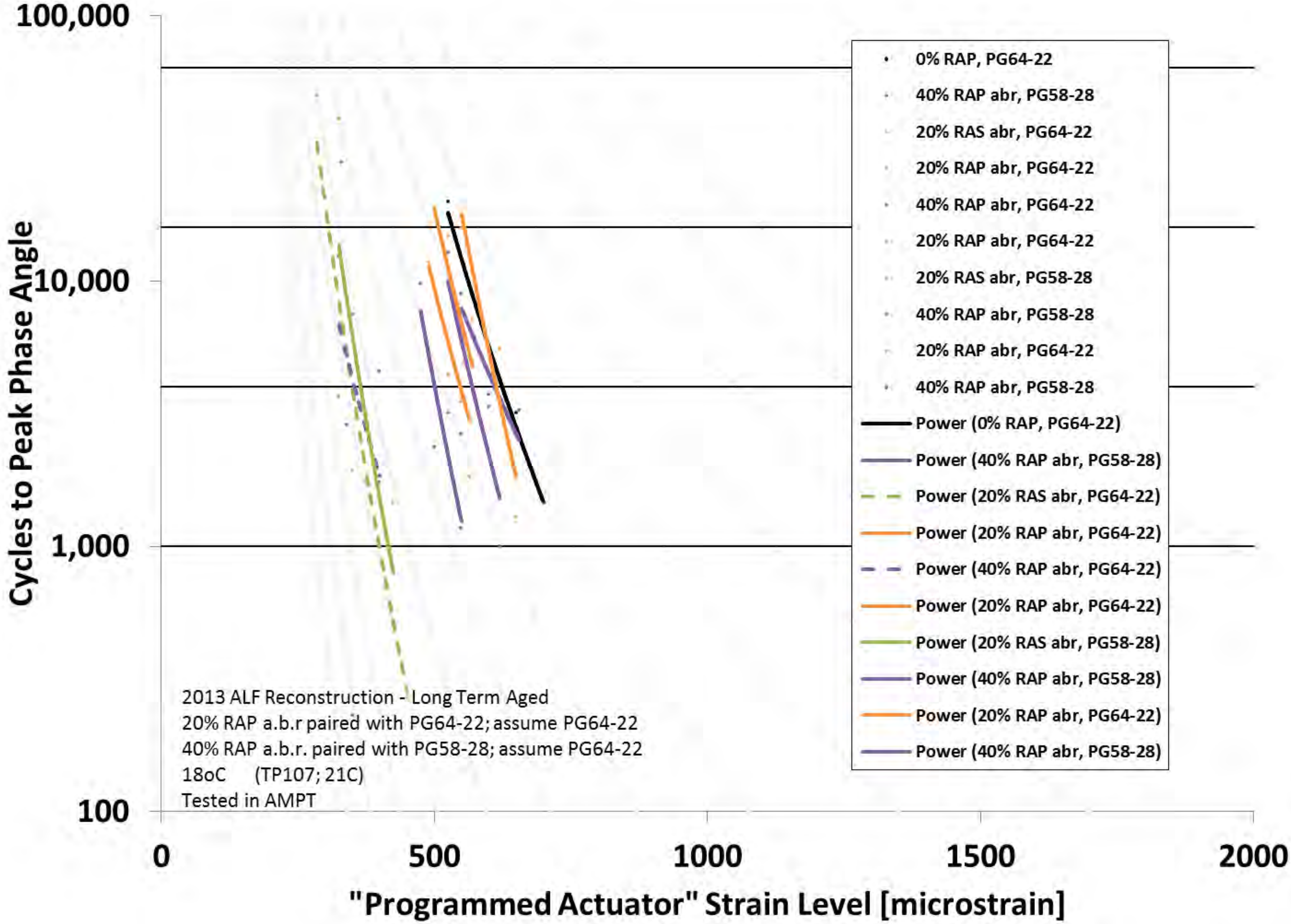
Cycles to Peak Phase Angle
100,000
10,000
1,000
100
0
500
1000
1500
2000
"Programmed Actuator" Strain Level [microstrain]
0% REOB
2.5% REOB
6% REOB
15% REOB
Power (0% REOB)
Power (2.5% REOB)
Power (6% REOB)
Power (15% REOB)
REOB Study
PG58-28 + 22% RAP ... assumed PG64-22
18oC (TP107; 18C)
Tested in AMPT


100,000
10,000
1,000
100
Cycles to Peak Phase Angle
0
500
1000
1500
2000
"Programmed Actuator" Strain Level [microstrain]
0% REOB
2.5% REOB
6% REOB
15% REOB
Power (0% REOB)
Power (2.5% REOB)
Power (6% REOB)
Power (15% REOB)
REOB Study - Long Term Aged Mixes
PG58-28 + 22% RAP ... assumed PG64-22
18oC (TP107; 18C)
Tested in AMPT

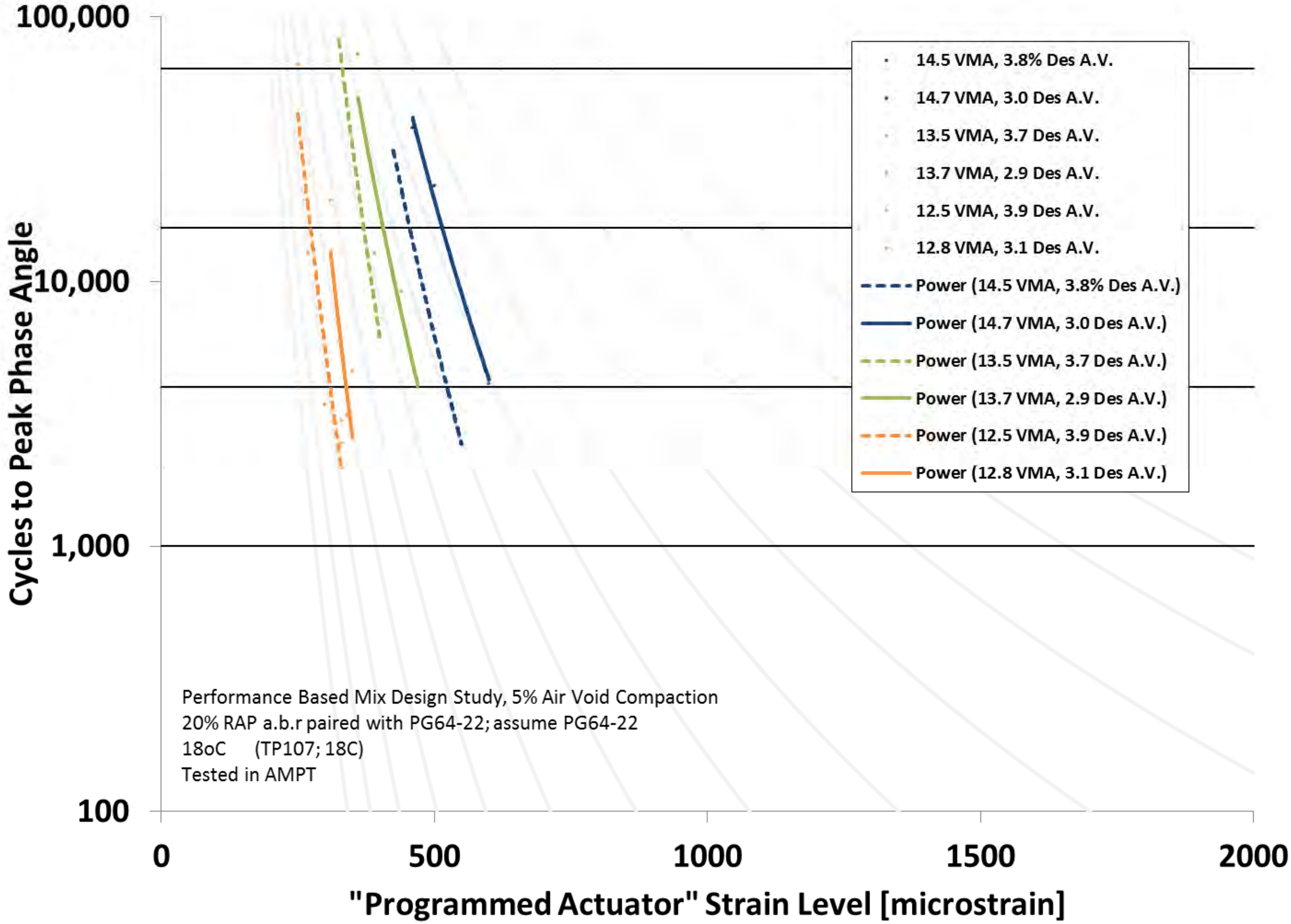


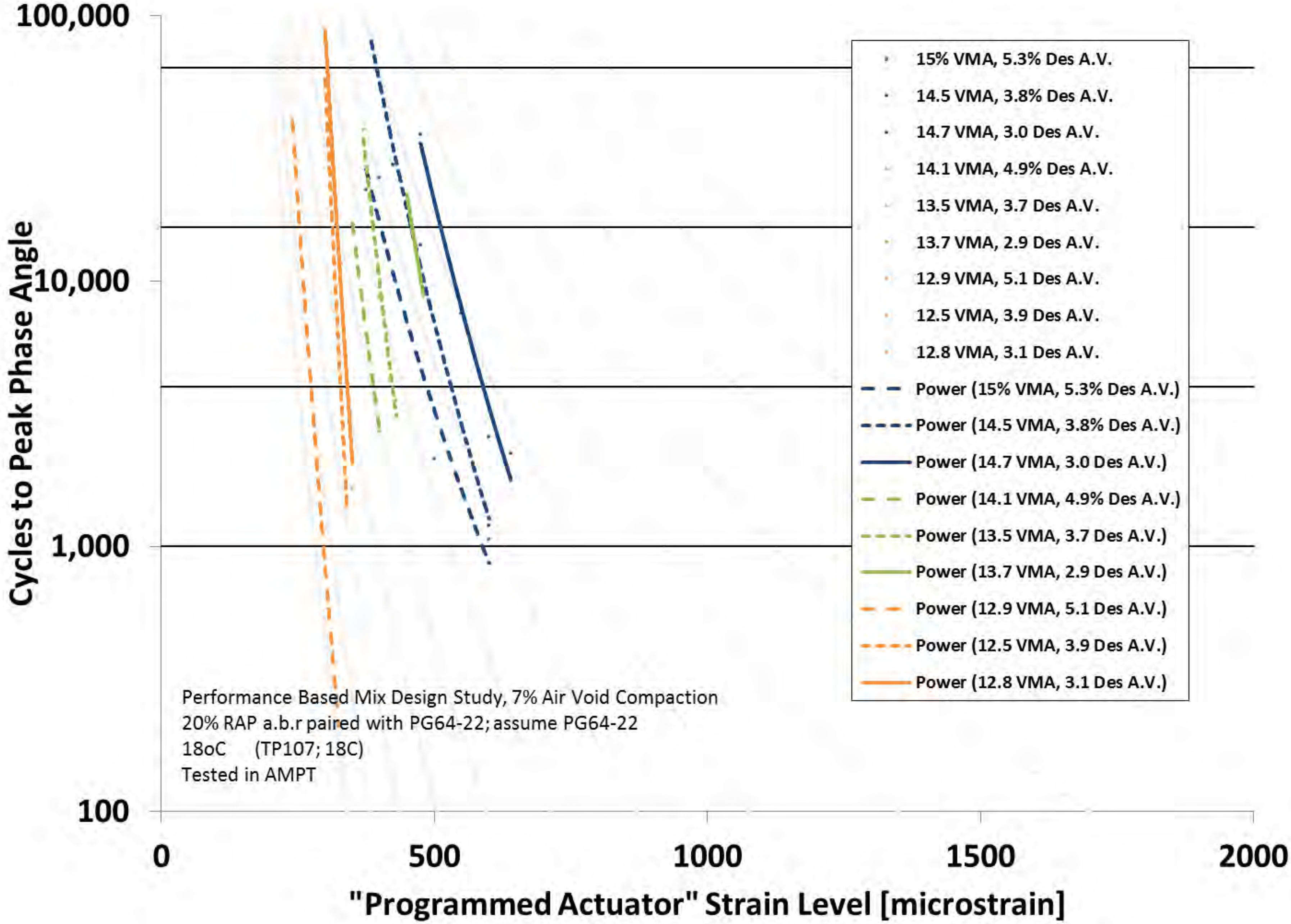
100,000
10,000
1,000
100
Cycles to Peak Phase Angle
0
500
1000
1500
2000
"Programmed Actuator" Strain Level [microstrain]
0% RAP
20% RAP
40% RAP
Power (0% RAP)
Power (20% RAP)
Power (40% RAP)
Exploratory RAP Study - Highly Controlled Volumetrics
Virgin PG70-22 + PG94-11 RAP
21oC (TP107; 21C)
Tested in AMPT


100,000
10,000
1,000
100
Cycles to Peak Phase Angle
0
500
1000
1500
2000
"Programmed Actuator" Strain Level [microstrain]
0% RAP, PG64-22
40% RAP abr, PG58-28
20% RAS abr, PG64-22
20% RAP abr, PG64-22
40% RAP abr, PG64-22
20% RAP abr, PG64-22
20% RAS abr, PG58-28
40% RAP abr, PG58-28
20% RAP abr, PG64-22
40% RAP abr, PG58-28
Power (0% RAP, PG64-22)
Power (40% RAP abr, PG58-28)
Power (20% RAS abr, PG64-22)
Power (20% RAP abr, PG64-22)
Power (40% RAP abr, PG64-22)
Power (20% RAP abr, PG64-22)
Power (20% RAS abr, PG58-28)
Power (40% RAP abr, PG58-28)
Power (20% RAP abr, PG64-22)
Power (40% RAP abr, PG58-28)
2013 ALF Reconstruction
20% RAP a.b.r paired with PG64-22; assume PG64-22
40% RAP a.b.r. paired with PG58-28; assume PG64-22
18oC (TP107; 21C)
Tested in AMPT

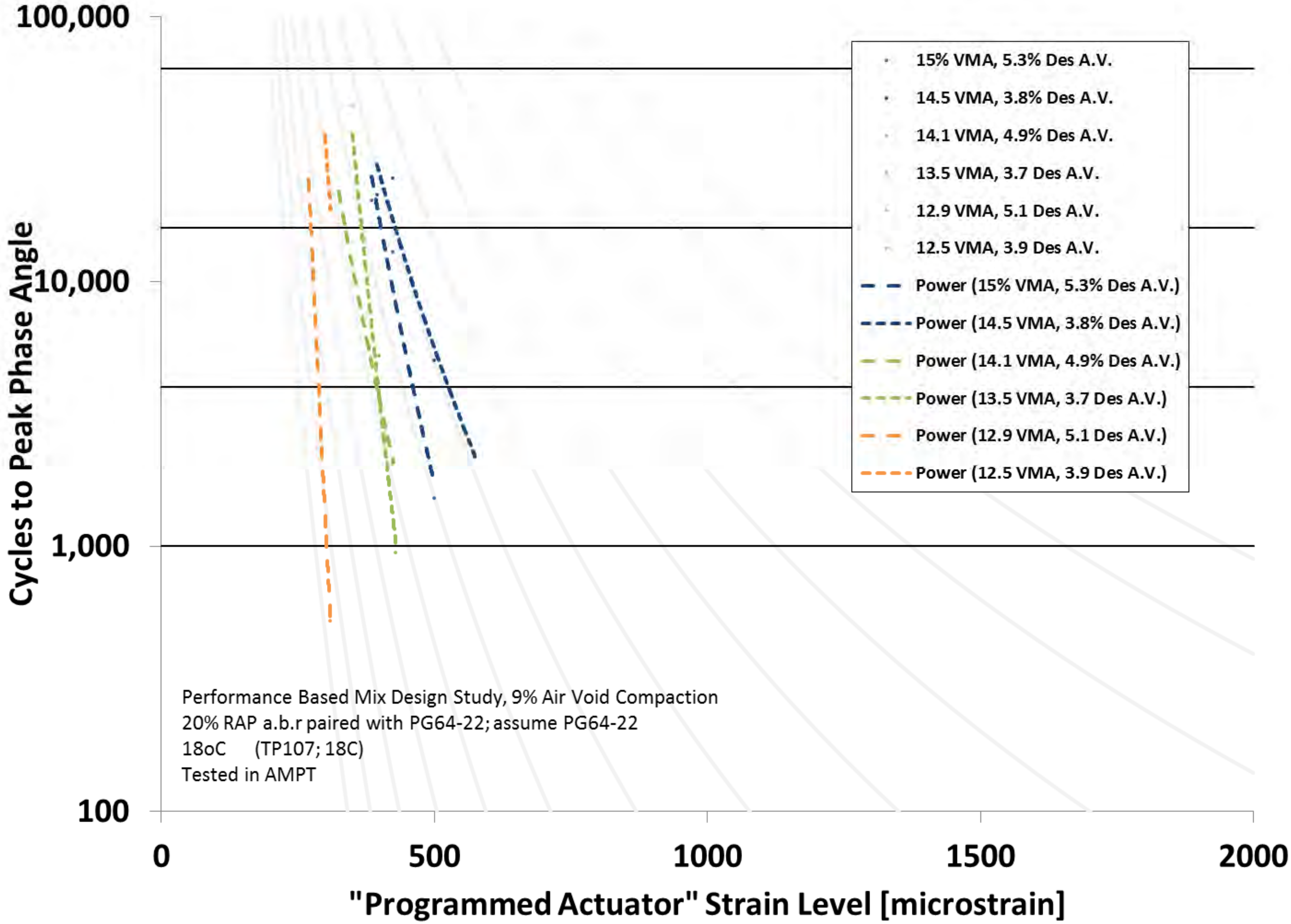


100,000
10,000
1,000
100
Cycles to Peak Phase Angle
0
500
1000
1500
2000
"Programmed Actuator" Strain Level [microstrain]
0% RAP, PG64-22
40% RAP abr, PG58-28
20% RAS abr, PG64-22
20% RAP abr, PG64-22
40% RAP abr, PG64-22
20% RAP abr, PG64-22
20% RAS abr, PG58-28
40% RAP abr, PG58-28
20% RAP abr, PG64-22
40% RAP abr, PG58-28
Power (0% RAP, PG64-22)
Power (40% RAP abr, PG58-28)
Power (20% RAS abr, PG64-22)
Power (20% RAP abr, PG64-22)
Power (40% RAP abr, PG64-22)
Power (20% RAP abr, PG64-22)
Power (20% RAS abr, PG58-28)
Power (40% RAP abr, PG58-28)
Power (20% RAP abr, PG64-22)
Power (40% RAP abr, PG58-28)
2013 ALF Reconstruction - Long Term Aged
20% RAP a.b.r paired with PG64-22; assume PG64-22
40% RAP a.b.r. paired with PG58-28; assume PG64-22
18oC (TP107; 21C)
Tested in AMPT

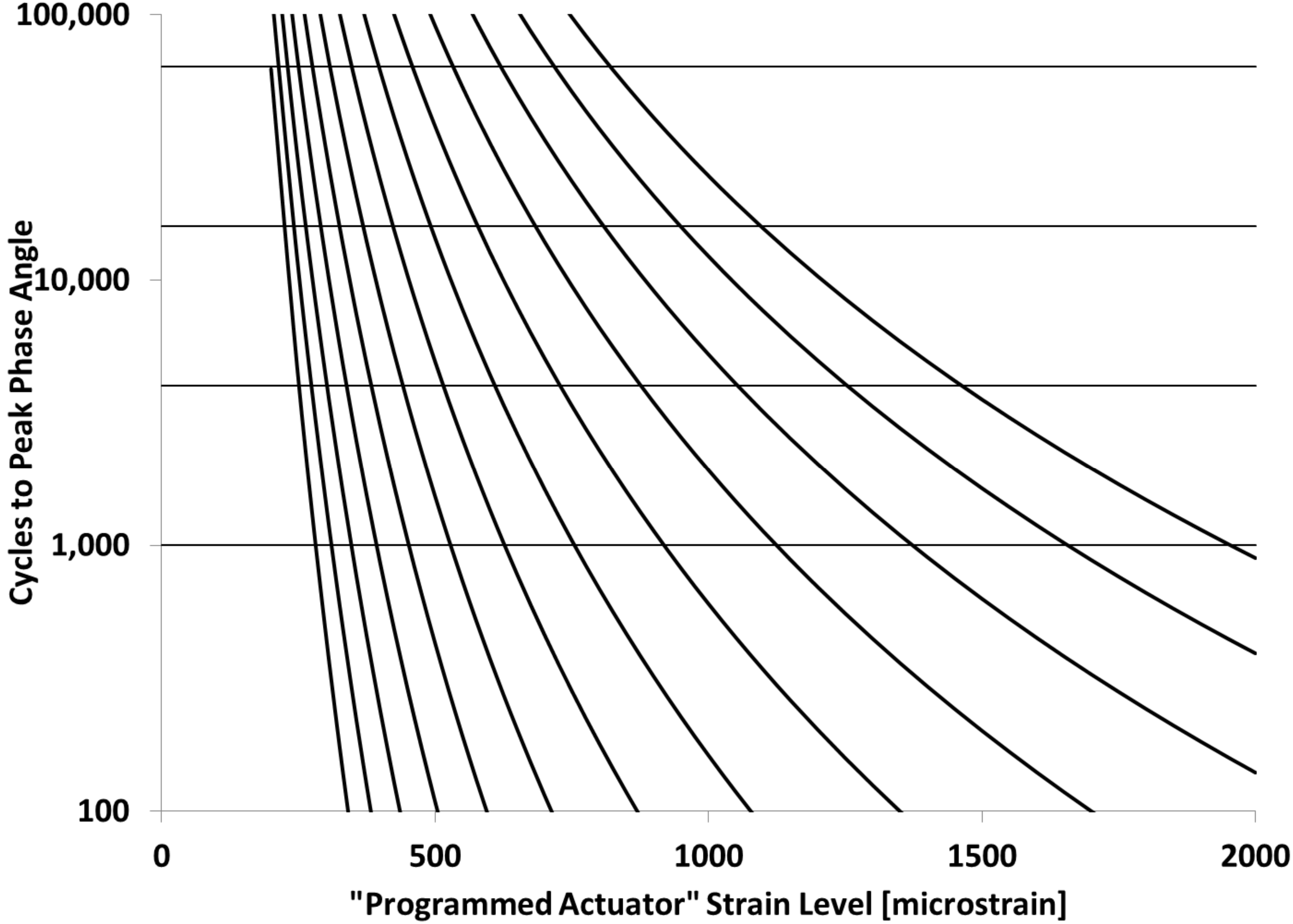

100,000
10,000
1,000
100
Cycles to Peak Phase Angle
0
500
1000
1500
2000
"Programmed Actuator" Strain Level [microstrain]
14.5 VMA, 3.8% Des A.V.
14.7 VMA, 3.0 Des A.V.
13.5 VMA, 3.7 Des A.V.
13.7 VMA, 2.9 Des A.V.
12.5 VMA, 3.9 Des A.V.
12.8 VMA, 3.1 Des A.V.
Power (14.5 VMA, 3.8% Des A.V.)
Power (14.7 VMA, 3.0 Des A.V.)
Power (13.5 VMA, 3.7 Des A.V.)
Power (13.7 VMA, 2.9 Des A.V.)
Power (12.5 VMA, 3.9 Des A.V.)
Power (12.8 VMA, 3.1 Des A.V.)
Performance Based Mix Design Study, 5% Air Void Compaction
20% RAP a.b.r paired with PG64-22; assume PG64-22
18oC (TP107; 18C)
Tested in AMPT



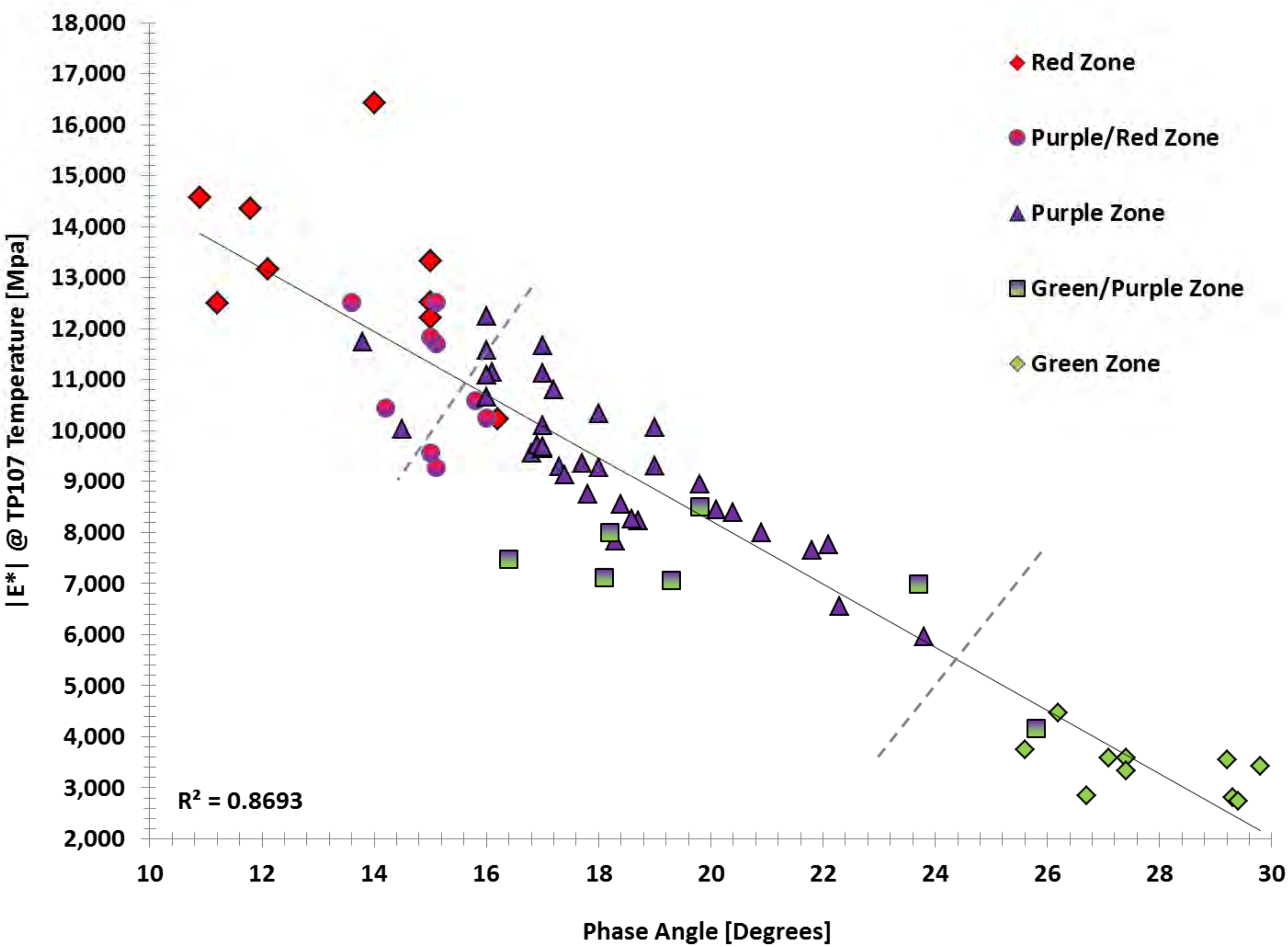
100,000
10,000
1,000
100
Cycles to Peak Phase Angle
0
500
1000
1500
2000
"Programmed Actuator" Strain Level [microstrain]
15% VMA, 5.3% Des A.V.
14.5 VMA, 3.8% Des A.V.
14.7 VMA, 3.0 Des A.V.
14.1 VMA, 4.9% Des A.V.
13.5 VMA, 3.7 Des A.V.
13.7 VMA, 2.9 Des A.V.
12.9 VMA, 5.1 Des A.V.
12.5 VMA, 3.9 Des A.V.
12.8 VMA, 3.1 Des A.V.
Power (15% VMA, 5.3% Des A.V.)
Power (14.5 VMA, 3.8% Des A.V.)
Power (14.7 VMA, 3.0 Des A.V.)
Power (14.1 VMA, 4.9% Des A.V.)
Power (13.5 VMA, 3.7 Des A.V.)
Power (13.7 VMA, 2.9 Des A.V.)
Power (12.9 VMA, 5.1 Des A.V.)
Power (12.5 VMA, 3.9 Des A.V.)
Power (12.8 VMA, 3.1 Des A.V.)
Performance Based Mix Design Study, 7% Air Void Compaction
20% RAP a.b.r paired with PG64-22; assume PG64-22
18oC (TP107; 18C)
Tested in AMPT



100,000
10,000
1,000
100
Cycles to Peak Phase Angle
0
500
1000
1500
2000
"Programmed Actuator" Strain Level [microstrain]
15% VMA, 5.3% Des A.V.
14.5 VMA, 3.8% Des A.V.
14.1 VMA, 4.9% Des A.V.
13.5 VMA, 3.7 Des A.V.
12.9 VMA, 5.1 Des A.V.
12.5 VMA, 3.9 Des A.V.
Power (15% VMA, 5.3% Des A.V.)
Power (14.5 VMA, 3.8% Des A.V.)
Power (14.1 VMA, 4.9% Des A.V.)
Power (13.5 VMA, 3.7 Des A.V.)
Power (12.9 VMA, 5.1 Des A.V.)
Power (12.5 VMA, 3.9 Des A.V.)
Performance Based Mix Design Study, 9% Air Void Compaction
20% RAP a.b.r paired with PG64-22; assume PG64-22
18oC (TP107; 18C)
Tested in AMPT



100,000
10,000
1,000
100
Cycles to Peak Phase Angle
0
500
1000
1500
2000
"Programmed Actuator" Strain Level [microstrain]



Red Zone
Purple/Red Zone
Purple Zone
Green/Purple Zone
Green Zone
|E*| @ TP107 Temperature [Mpa]
18,000
17,000
16,000
15,000
14,000
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
R² = 0.8693
10
12
14
16
18
20
22
24
26
28
30
Phase Angle [Degrees]

	If the |E*| is greater than 11,000 MPa, select 300 microstrain as the first specimen's strain				If 11,000 > |E*| > 5,500 Mpa, select 500 microstrain as the first specimen's strain					If the |E*| is less than 5,500 Mpa, select 800 microstrain as the first specimen's strain			
200	62,514	129,033	258,702	503,812	-	-	-	-	-	-	-	-	-
250	4,220	10,969	27,219	64,485	145,856	314,972	-	-	-	-	-	-	-
300	**467**	**1,464**	**4,324**	**12,022**	31,468	77,539	179,856	-	-	-	-	-	-
350	72	267	913	2,905	8,605	23,704	60,744	144,799	-	-	-	-	-
400	-	-	237	849	2,798	8,491	23,721	61,010	144,466	-	-	-	-
450	-	-	-	287	1,039	3,433	10,350	28,465	71,421	163,488	-	-	-
500	**-**	**-**	**-**	**-**	**428**	**1,527**	**4,929**	**14,392**	**38,032**	90,944	-	-	-
550	-	-	-	-	-	734	2,519	7,766	21,507	53,501	119,549	-	-
600	-	-	-	-	-	-	1,365	4,422	12,781	32,962	75,847	155,720	-
650	-	-	-	-	-	-	777	2,634	7,919	21,111	49,906	104,615	-
700	-	-	-	-	-	-	-	1,630	5,084	13,975	33,872	72,385	136,383
750	-	-	-	-	-	-	-	1,043	3,365	9,518	23,613	51,374	98,022
800	**-**	**-**	**-**	**-**	**-**	**-**	**-**	687	2,287	**6,646**	**16,849**	**37,278**	**71,969**
850	-	-	-	-	-	-	-	-	1,592	4,742	12,271	27,581	53,840
900	-	-	-	-	-	-	-	-	1,131	3,450	9,101	20,761	40,952
950	-	-	-	-	-	-	-	-	818	2,553	6,859	15,869	31,613
1,000	-	-	-	-	-	-	-	-	-	1,919	5,246	12,298	24,730
1,050	-	-	-	-	-	-	-	-	-	1,463	4,064	9,650	19,579
1,100	-	-	-	-	-	-	-	-	-	1,129	3,187	7,658	15,670
1,150	-	-	-	-	-	-	-	-	-	881	2,526	6,140	12,667
1,200	-	-	-	-	-	-	-	-	-	-	2,022	4,970	10,332
1,250	-	-	-	-	-	-	-	-	-	-	1,633	4,057	8,498
1,300	-	-	-	-	-	-	-	-	-	-	1,330	3,339	7,043
1,350	-	-	-	-	-	-	-	-	-	-	1,092	2,768	5,879
1,400	-	-	-	-	-	-	-	-	-	-	903	2,310	4,940
1,450	-	-	-	-	-	-	-	-	-	-	752	1,940	4,176
1,500	-	-	-	-	-	-	-	-	-	-	-	1,640	3,550
1,550	-	-	-	-	-	-	-	-	-	-	-	1,393	3,035
1,600	-	-	-	-	-	-	-	-	-	-	-	1,190	2,607
1,650	-	-	-	-	-	-	-	-	-	-	-	1,021	2,250
1,700	-	-	-	-	-	-	-	-	-	-	-	880	1,950
1,750	-	-	-	-	-	-	-	-	-	-	-	762	1,697
1,800	-	-	-	-	-	-	-	-	-	-	-	-	1,483
1,850	-	-	-	-	-	-	-	-	-	-	-	-	1,301
1,900	-	-	-	-	-	-	-	-	-	-	-	-	1,145
1,950	-	-	-	-	-	-	-	-	-	-	-	-	1,011
2,000	-	-	-	-	-	-	-	-	-	-	-	-	896

https://en.wikipedia.org/wiki/Disability-adjusted_life_year

Performance Based Specifications

Balanced Mix Design

Predict life.
How much life was lost? Gained ?

Hit the target.
Walk away.

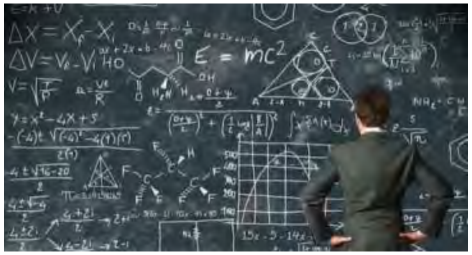
Binder Content

a number

a number

Performance Prediction

(traffic – structure – climate)



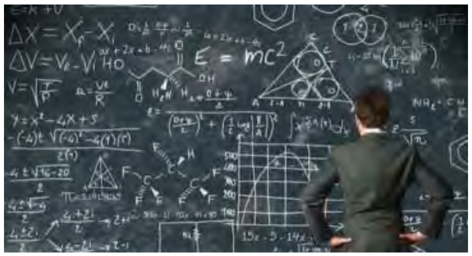
Already has capability

Involved or
Perceived as Complicated.

Make it simpler

Performance Prediction

(traffic – structure – climate)



Already has capability

Involved or
Perceived as Complicated.

Make it simpler

Functionality has to be added

Recycled Materials

- reclaimed asphalt pavement (RAP)
- reclaimed asphalt shingles (RAS)
  - manufactured scrap
  - roofing tear-offs
- re-refined engine oil bottoms (REOB)
- ground tire rubber (GTR)
- other materials in a pre-aged condition and/or which provide accelerated ageing characteristics and behavior

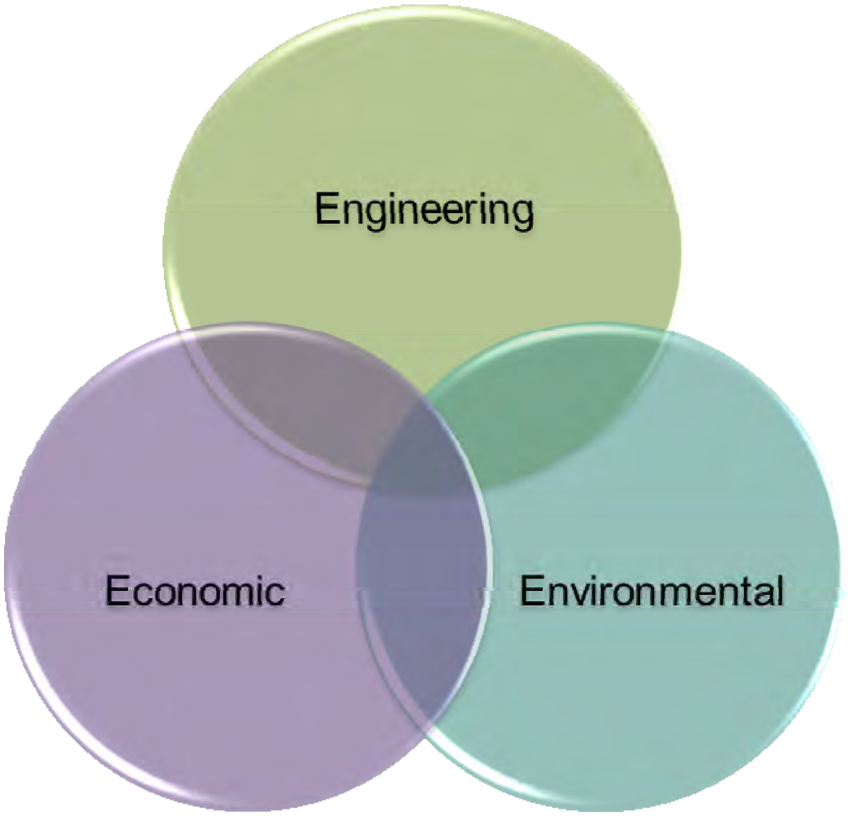
FHWA Recycled Materials Policy

FHWA longstanding position that any materials used shall not adversely affect performance, safety or the environment of the highway system

- February 7, 2002 FHWA Policy Memorandum
  - "…the policy acknowledges that recycling will not be appropriate in all cases and provides guidance for making that determination."
  - e.g. recycled/reclaimed/re-used/re-refined …

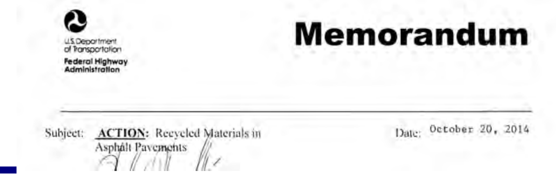
FHWA Recycled Materials Policy

1. Engineering suitability
2. Environmental suitability
3. Economic assessment



Cracking Resistance

Memorandums to FHWA Division Offices


U.S. Department of Transportation
Federal Highway Administration

Memorandum

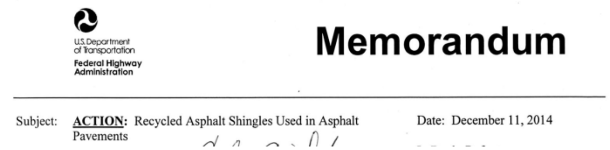
Subject: ACTION: Recycled Materials in Asphalt Pavements

Date: October 20, 2014

20 October 2014

- Walter C. Waidelich,
  Associate Administrator for Infrastructure
- Increasing number of state highway agencies reporting pre-mature cracking in relatively new asphalt pavements with high content of recycled asphalt binder
- Increased concerns with high levels of RAS use especially when RAP is already used
  - Potential increased cracking due to low temperatures, thin pavement sections, and increased asphalt ageing
- Reminder to follow sound engineering design and construction practices

Memorandum to FHWA Division & FLHD


U.S. Department of Transportation
Federal Highway Administration

Memorandum

Subject: ACTION: Recycled Asphalt Shingles Used in Asphalt Pavements

Date: December 11, 2014

11 December 2014

Cracking Resistance

- FHWA longstanding position that any materials used shall not adversely affect performance, safety or the environment of the highway system
- Nov 2014 AASHTO SOM survey shows RAS limitations in place/needed
- Need to establish appropriate level of use
- Directs the review of RAS use criteria with State
  - specification changes to mitigate risk of failures
  - ensure AASHTO standard PP 78 use for future Federal-aid projects if performance issues are identified

U.S. Department of Transportation
Federal Highway Administration

Recycled Binders - RAS & RAP

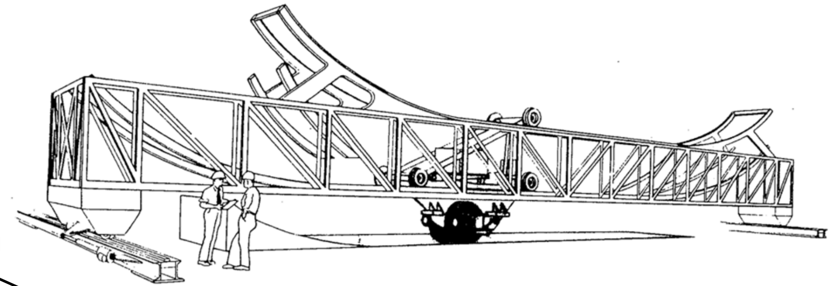
RAP/RAS Task Force within ETG

- Current main issue to be addressed:
  - How much of the RAS binder becomes effective asphalt binder? "Quantity"
  - How to address the stiffness/brittleness of the RAS binder? "Quality"
  - Binder grade adjustment guidelines

… more on this later!

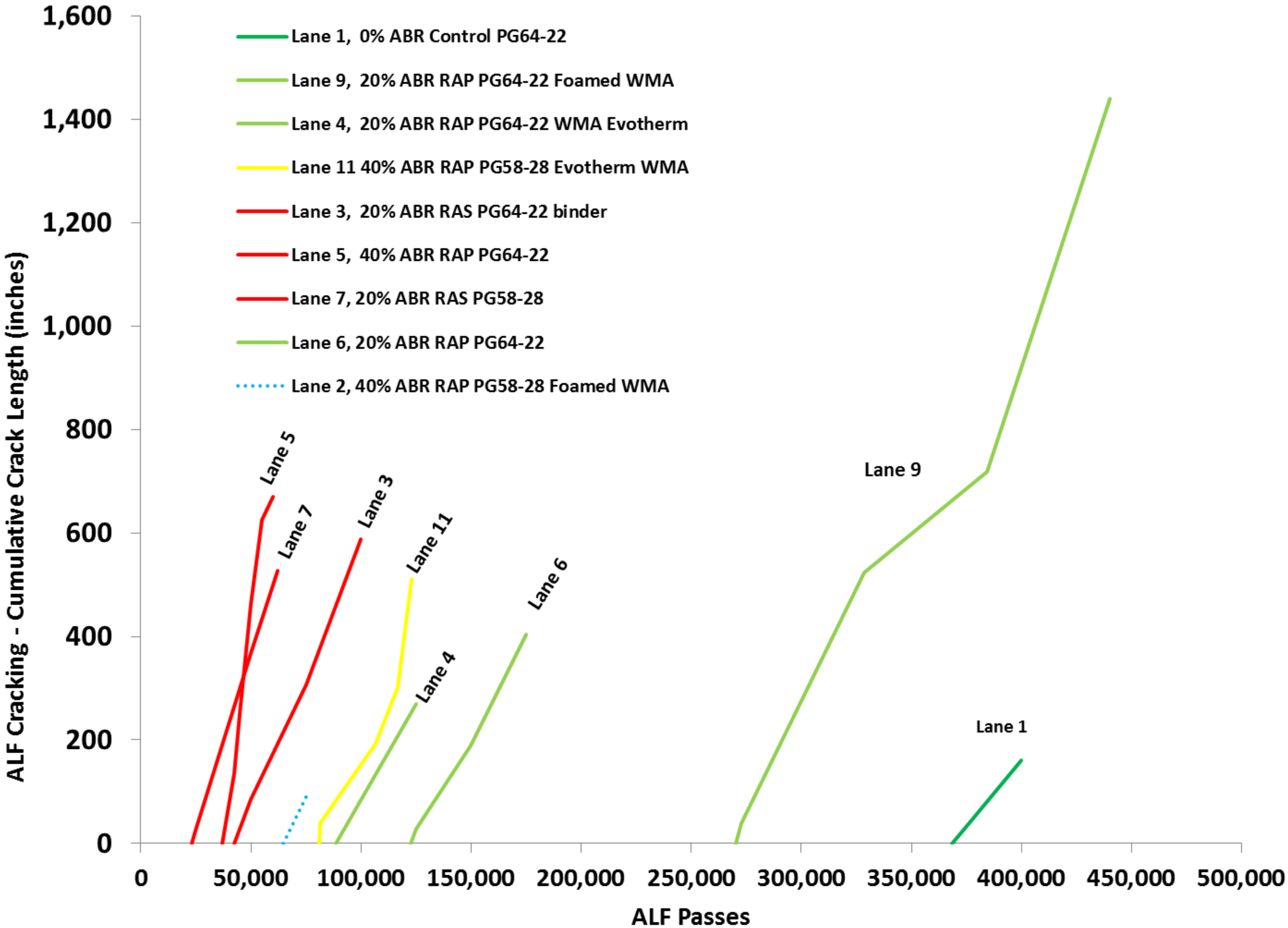
FHWA collaboration with ALF

Cracking Resistance



Recycle Content \ HMA WMA Production Temperature	300°F - 320°F		240°F - 270°F	
WMA Technology	-		Foam	Chem.
0%	✔ PG64-22		-	-
20% ABR RAP ≈ 23% by weight	✔ PG64-22		✔ PG64-22	✔ PG64-22
20% ABR RAS ≈ 6% Shingle by weight	✔ PG64-22	✔ PG58-28	-	-
40% ABR RAP ≈ 44% by weight	✔ PG64-22	✔ PG58-28	✔ PG58-28	✔ PG58-28

Cracking Resistance



U.S. Department of Transportation
Federal Highway Administration

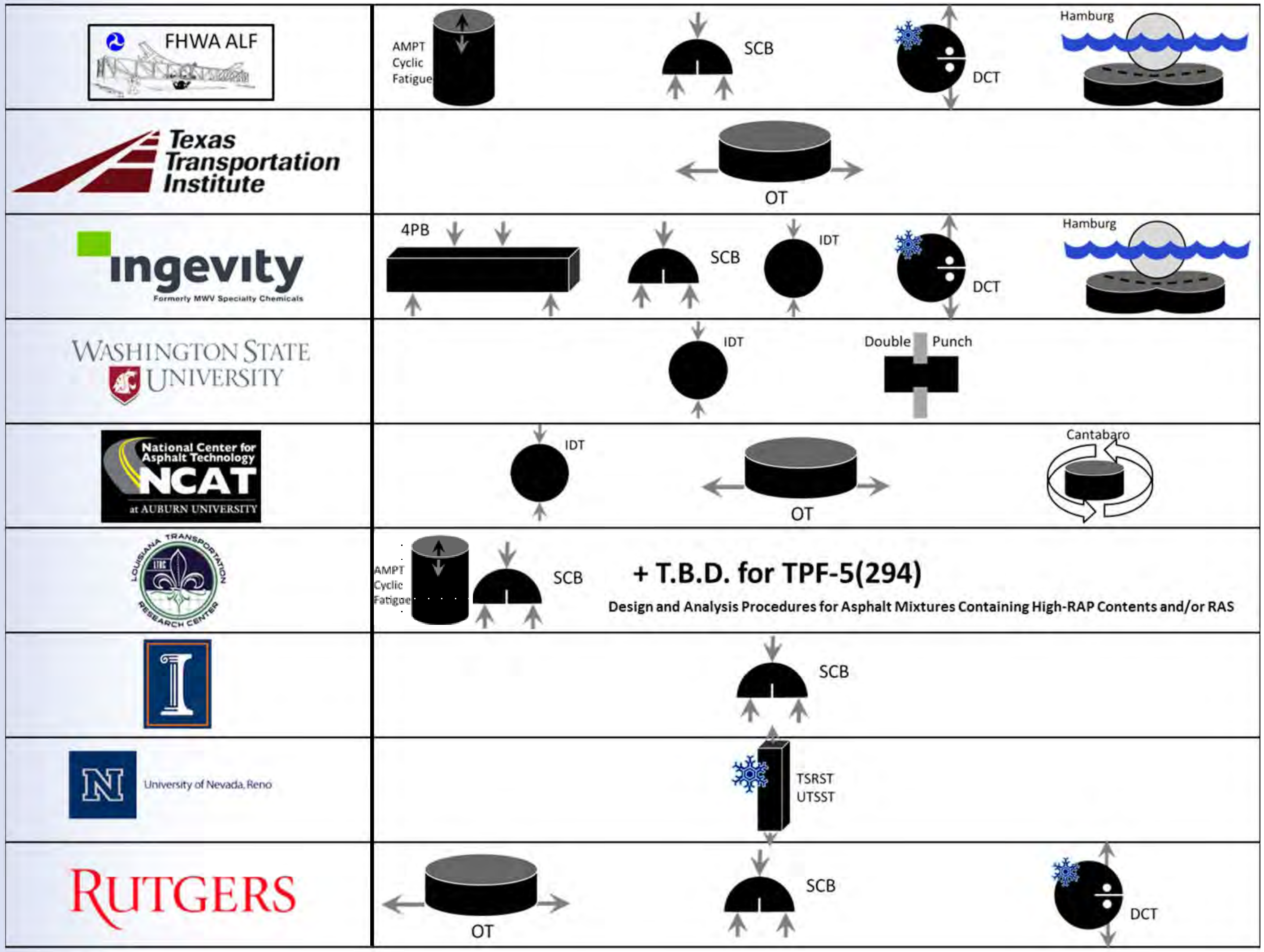
ALF Lane #	% ABR		Virgin PG Grade	Drum Discharge Temperature	WMA Process	Cycles to First ALF Crack
	RAP	RAS				
1	0	--	64-22	300-320	--	368,254
2	40	--	58-28	240-285	Water Foaming	tbd
3	--	20	64-22	300-320	--	42,399
4	20	--	64-22	240-270	Evotherm	88,740
5	40	--	64-22	300-320	--	36,946
6	20	--	64-22	300-320	--	122,363
7	--	20	58-28	300-320	--	23,005
8	40	--	58-28	300-320	--	tbd
9	20	--	64-22	240-285	Water Foaming	270,058
11	40	--	58-28	240-270	Evotherm	81,044

FHWA collaboration with ALF

Cracking Resistance

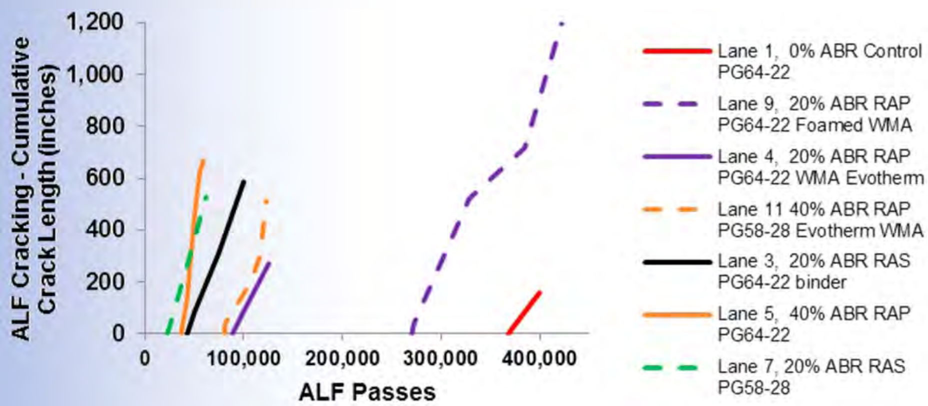
FHWA collaboration with ALF

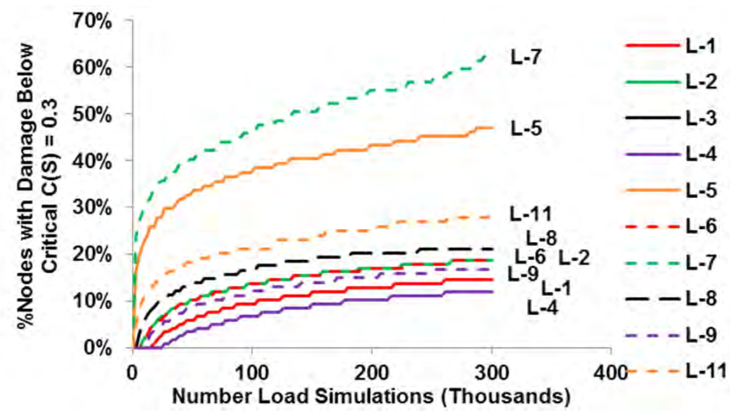
Cracking Resistance



ALF Validation Results (to date)

Cracking Resistance





LVECD Structural Prediction % Nodes Below Critical Damage										Measured ALF Performance	
Unaged					Aged						
As Built		Perfect Construction			As Built		Perfect Construction				
L2	9%	L2	11%		L1	12%	L4	12%		L1	368,254
L1	10%	L4	12%		L4	14%	L1	14%		L9	270,058
L4	13%	L6	13%		L9	16%	L9	17%		L4	88,740
L6	13%	L1	14%		L2	18%	L2	19%			
L9	15%	L9	16%		L6	19%	L6	19%		*Lanes 2, 6, and 8 remain to be tested*	
L8	18%	L8	17%		L8	22%	L8	21%			
L11	19%	L11	18%		L11	29%	L11	28%		L11	81,044
L3	31%	L3	31%		L5	42%	L5	47%		L3	42,399
L7	-	L5	35%		L7	66%	L7	62%		L5	36,946
L5	-	L7	46%		L3	-	L3	-		L7	23,005

U.S. Department of Transportation
Federal Highway Administration

Re-Refined Engine Oil Bottoms

National dialogue on understanding product, use, and limitations:

- non-bituminous additive or modifier?
- UTI improvement or dilutant?
- use in the U.S. market?
- product properties?
- final asphalt binder and mixture properties?

- effect on pavement performance?

Cracking Resistance

U.S. Department of Transportation
Federal Highway Administration

Why REOB?

- Used to soften base binder PG grade
- Increased use of RAP/RAS has led to a need for softer grades, which has led to increased demand for REOB or other "soft" fluxes
- Limited crude sources and refineries to produce "softer" grades w/o back blending
- Economic and market share pressures
- Recycling, sustainability, and "Green" initiatives

"Used since mid 1980's"… as reported by REOB re-refiners/suppliers

(re-refined) REOB…also know as:

- re-refined vacuum tower bottoms (VTB) (RVTB)
- asphalt flux, asphalt cutter
- re-refined asphalt cement
- asphalt flux, asphalt extender
- waste engine oil residue (WEO),
  WEO residue (WEOR), engine oil residue (EOR)
- re-refined asphalt cutter (RRAC)
- vacuum tower asphalt extender (VTAE),
- engine oil bottoms (EOB), recycled EOB (R-EOB)
- re-refined heavy vacuum distillation oil (RHVDB)

etc. etc. …

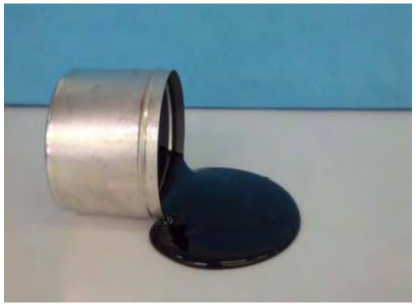
What is REOB?

- The re-refined residual distillation product from a vacuum tower in a re-refinery dedicated to processing recovered waste drain lubricating oil

Both “re-refined” and “vacuum tower” are important features for this product

Three National REOB Task Force Groups

- FHWA Binder Expert Task Group (ETG)
- Asphalt Institute
  - under direction of their Technical Advisory Committee (TAC)
  - State of the Knowledge Document
- AASHTO Subcommittee on Materials
  - respond to Standing Committee on Highways (SCOH) resolution



Cracking Resistance

U.S. Department of Transportation
Federal Highway Administration

Re-refined Engine Oil Bottoms

REOB Task Force within Binder ETG

Discussions:

- Which rheological parameter
  - critical temperature change (ΔT_c)
  - Glover-Rowe (GR)
  - rheological index (R value)
  - cross over frequency (ω_c)

All of these parameters can be interrelated from understanding the relationship between loading time (or frequency) and temperature.

Re-refined Engine Oil Bottoms

Field Studies - with distress data

- FHWA-Asphalt Research Consortium-WRI Validation Sites
  - Rochester, MN – Olmsted County 112
- MnROAD Test Track Low Volume Road Test Section Sites

- Exhibited increased cracking distress

Recycled Binders - RAS & RAP

Re-refined Engine Oil Bottoms

- ETG Task Force efforts and consensus
- Recommendations from ETG to AASHTO Subcommittee on Materials …

… more on this later in the schedule during the AASHTO and ETG presentations.

Discussion / Comments / Questions

Thank You !!

FHWA's Mobile Asphalt Testing Trailer

Office of Asset Management, Pavement, and Construction