Cracking Group Experiment – Evaluation of Laboratory Cracking Tests

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NCAT
at AUBURN UNIVERSITY

FHWA Mixture ETG – May 2018

Project Team

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Cracking Group Experiment

- 7 Test Sections
- Common Structure
  - Subgrade, Aggregate Base, Base and Binder Mixture
- 7 Unique Surface Mixtures
  - Wide Range of Expected Cracking Resistance
- Top-Down, Load-Related Cracking
- Intermediate Temperatures
- Compare Field Cracking Performance to Laboratory Cracking Test Results
- Constructed in 2015

NCAT Test Sections

1 Cycle, 10 MESALs

Section	Description	Rutting (mm)	Δ IRI (in/mi.)	Δ MTD (mm)	Cracking (% of lane)
N1	20% RAP (Control)	1.7	3	0.4	21.5*
N2	Control w/ High Density	2.2	7	0.5	6.2*
N5	Low AC, Low Density	1.2	5	0.4	5.0*
N8	20% RAP, 5% RAS	1.2	13	0.7	16.9
S5	35% RAP, PG 58-28	1.5	1	0.5	0
S6	Control w HiMA	1.4	10	0.6	0
S13	AZ Rubber Mix	2.8	3	0.1	0

- * = Low Severity Hairline Cracking
- Trafficking will continue in 2018 Research Cycle

Testing Plan

- Mix Types
  - Production Plant Mix (PMLC)
  - Lab-Mixed, Lab-Compacted from Production Raw Materials (LMLC)
  - Density – All specimens to 7% Air Void Except N2 (4%) and N5 (10%)
- Aging Protocols
  - Reheated Plant Mix (RH)
  - Short-term oven aged (STOA)
  - Long-term oven aged (LTOA)
    - a.k.a. 'Critical Aging' (CA)

Testing Plan

- Cracking Tests
  - 2 aging conditions (STOA/RH and Critically Aged)
  - X 2 production methods (LMLC and PMLC)
  - X 6 cracking tests (I-FIT,SCB-Jc,ER,OT-TX,OT-NCAT, IDEAL-CT)
  - X 7 unique surface mixes
  - = 168 sets of specimens
- Outlier Analysis performed using ASTM E178-16a

Testing Plan

	Energy Ratio	I-FIT	OT - TX	OT - NCAT	SCB-Jc	IDEAL-CT
RH PMLC	X	X	X	X	X	X
STOA LMLC	X	X	X	X	O	X
CA PMLC	X	X	X	X	X	X
CA LMLC	X	X	X	X	O	X

- X = Testing Complete
- O = Analysis in Progress

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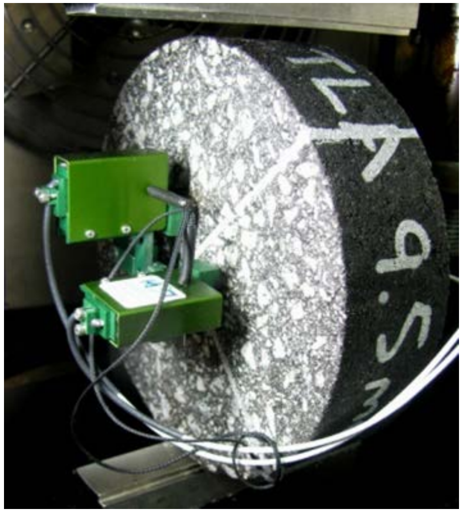
Energy Ratio



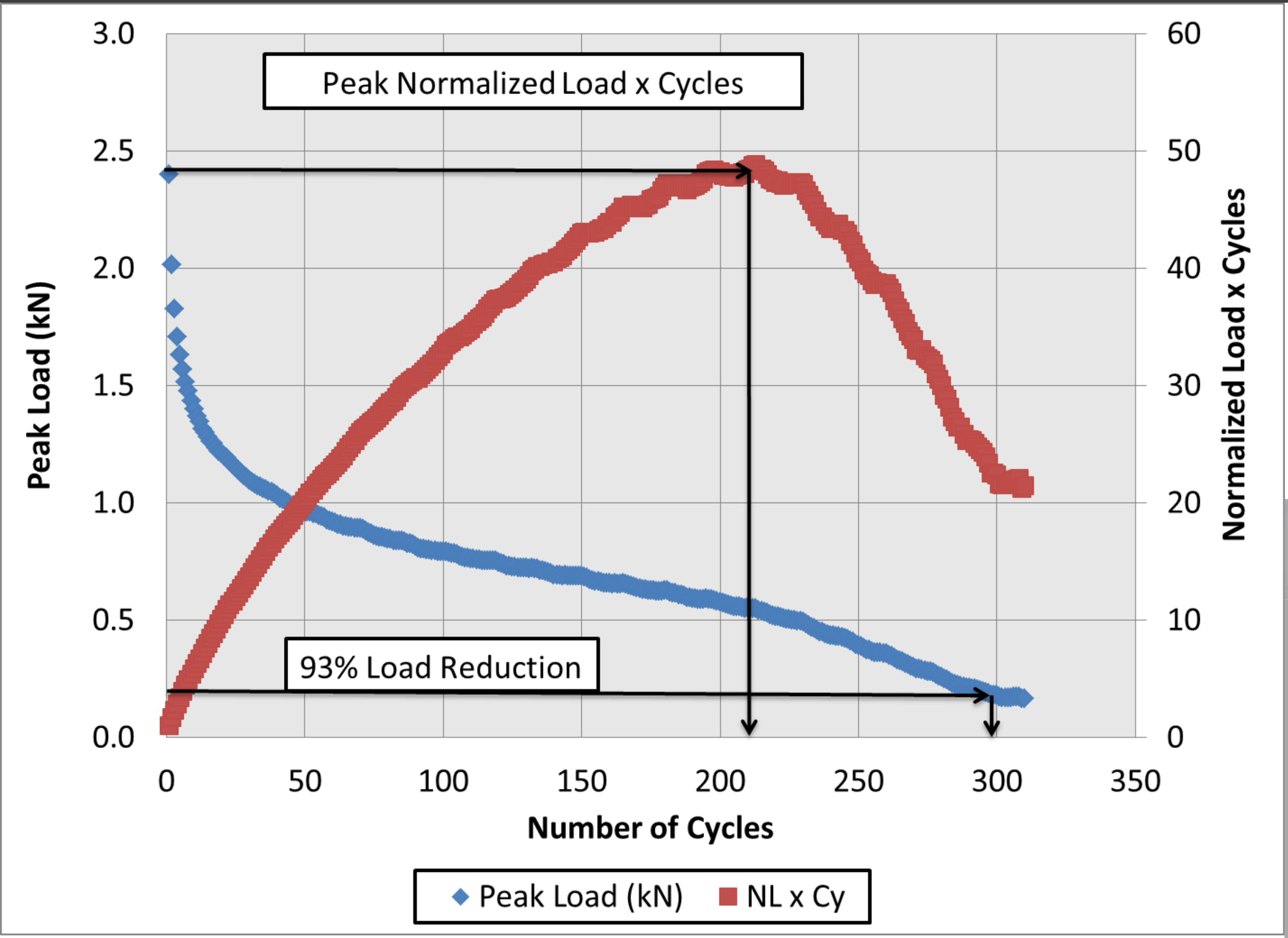
- Test Temperature = 10°C
- Combination of 3 Tests
  - Resilient Modulus
    - How stiff is my material?
  - Creep Compliance
    - How does it deform under a constant load?
  - Fracture Energy
    - How much energy can my material absorb before it breaks?
  - Results combined to calculate Energy Ratio

Overlay Tester – TX vs. NCAT

- OT-TX
  - 25°C
  - Tex-248-F Parameters
  - 0.1 Hz
  - 0.025” Maximum Opening Displacement
  - Cycles to Failure
    - 93% Reduction in Peak Load
  - AMPT OT Jig

- OT-NCAT
  - 25°C
  - Modified Parameters
  - 1 Hz
  - 0.015” Maximum Opening Displacement
  - Cycles to Failure
    - Peak of Load x Cycles Graph
  - AMPT OT Jig

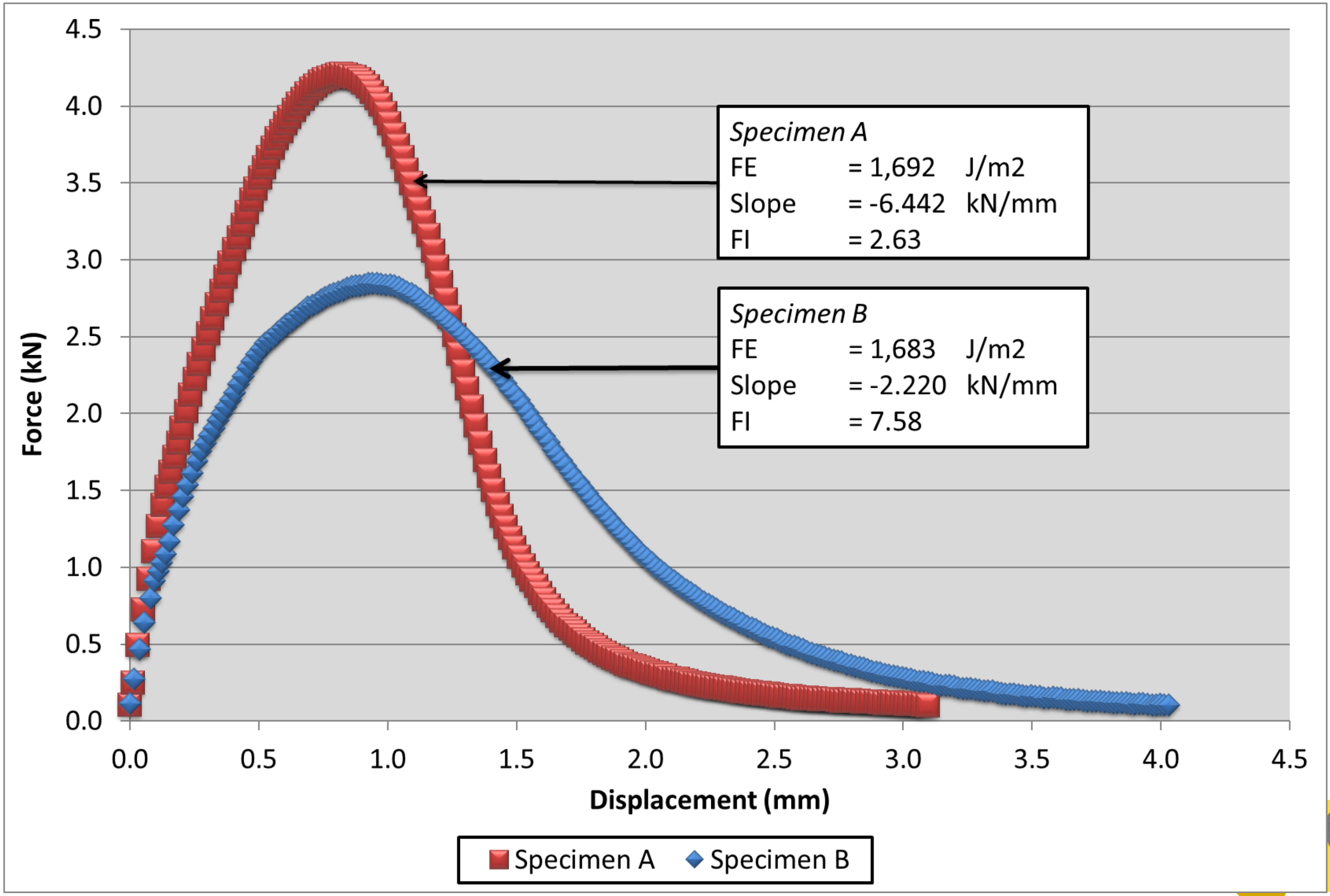
Overlay Test – Failure Analysis



Illinois Flexibility Index Test (I-FIT)

- 25°C
- 50 mm/min load rate
- Minimum 4 replicates
- 50 mm wide specimens
- Notch Depth = 15 mm
- Notch Width = 1.5 mm
- Load vs. Axial Deformation
- Test until load drops below 0.1 kN
  - Complete Fracture

I-FIT Flexibility Index



Semi-Circular Bend – J_c Method

- 25°C
- 0.5 mm/min load rate
- 57 mm wide specimens
- 12 replicates
- 3 notch depths
  - 25.4 mm
  - 31.8 mm
  - 38.1 mm
- 3.0 ± 0.5 mm notch width

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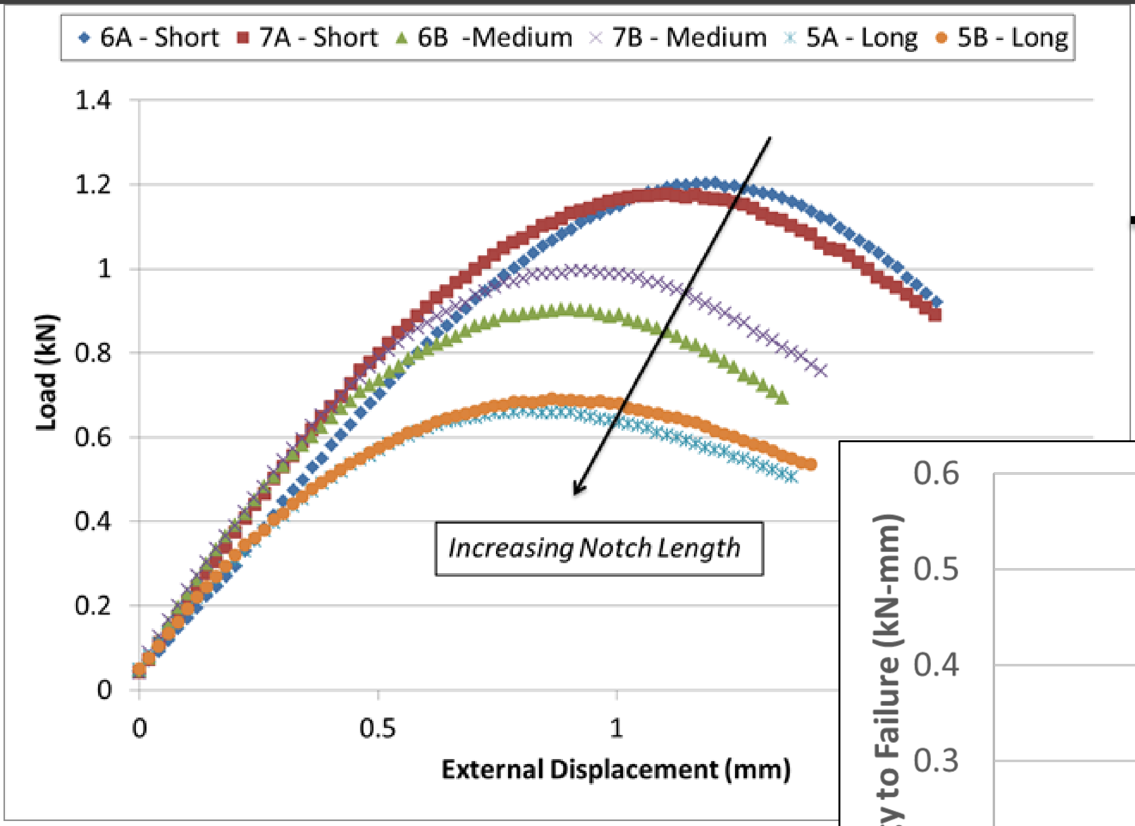
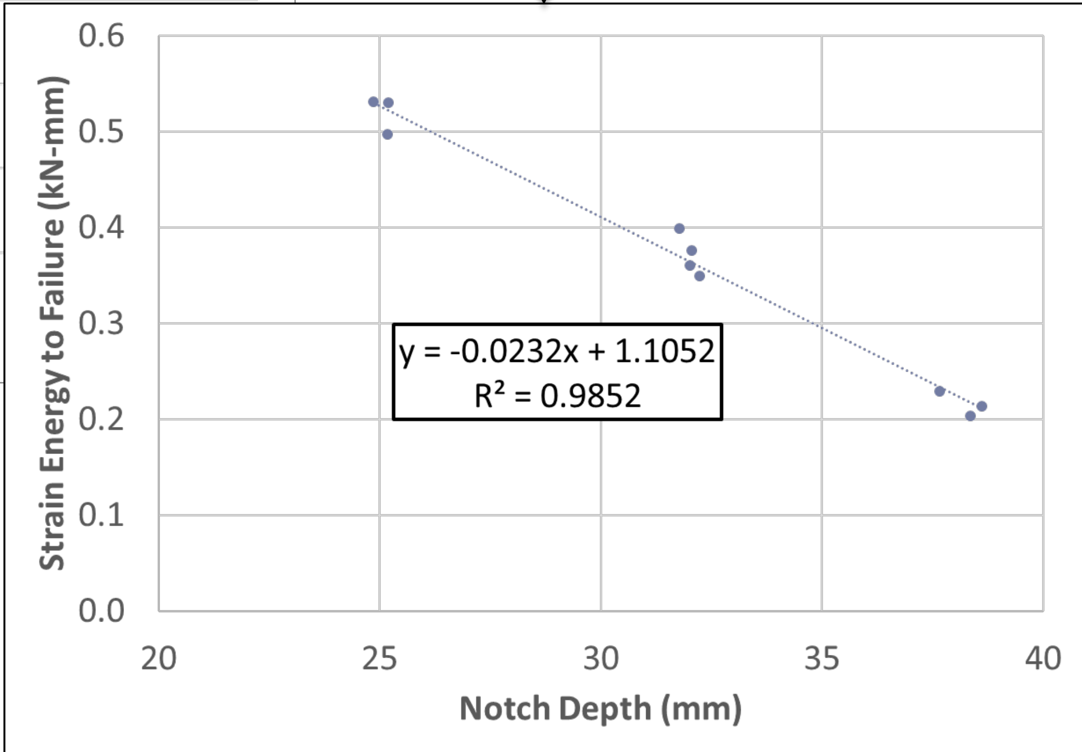
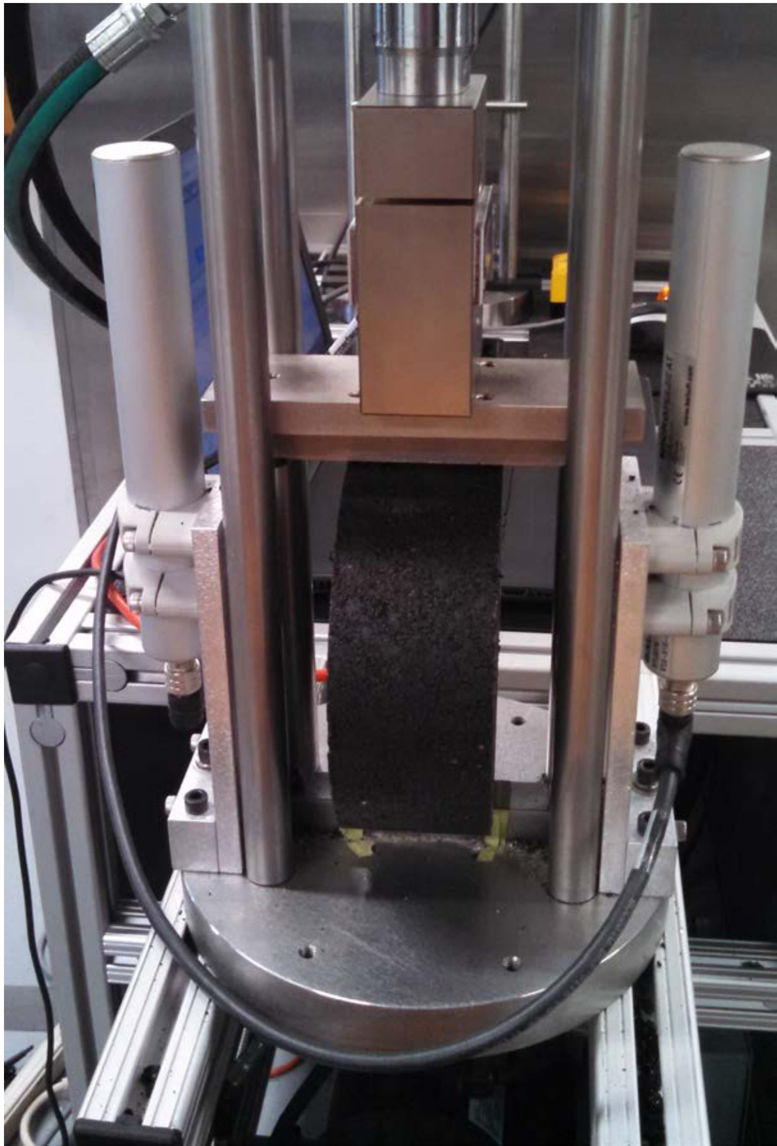
Semi-Circular Bend – J_c Method





IDEAL-CT

- 25°C
- Indirect Tensile Strength
  - No specimen cutting or notching
- 50 mm/min load rate
- Measure Load-Line Displacement
- Similar Post-Peak Analysis to I-FIT
- CT_{Index}



Long-Term Aging Procedure

- Past Research at NCAT and elsewhere
- 70,000 CDD
  - Between 3-5 years of field aging in Alabama
- Dubbed ‘Critical Aging’ (CA)
- Rheological Property Study conducted by Fan Yin and Chen Chen
- <u>8 hours at 135°C</u> for Test Track Materials

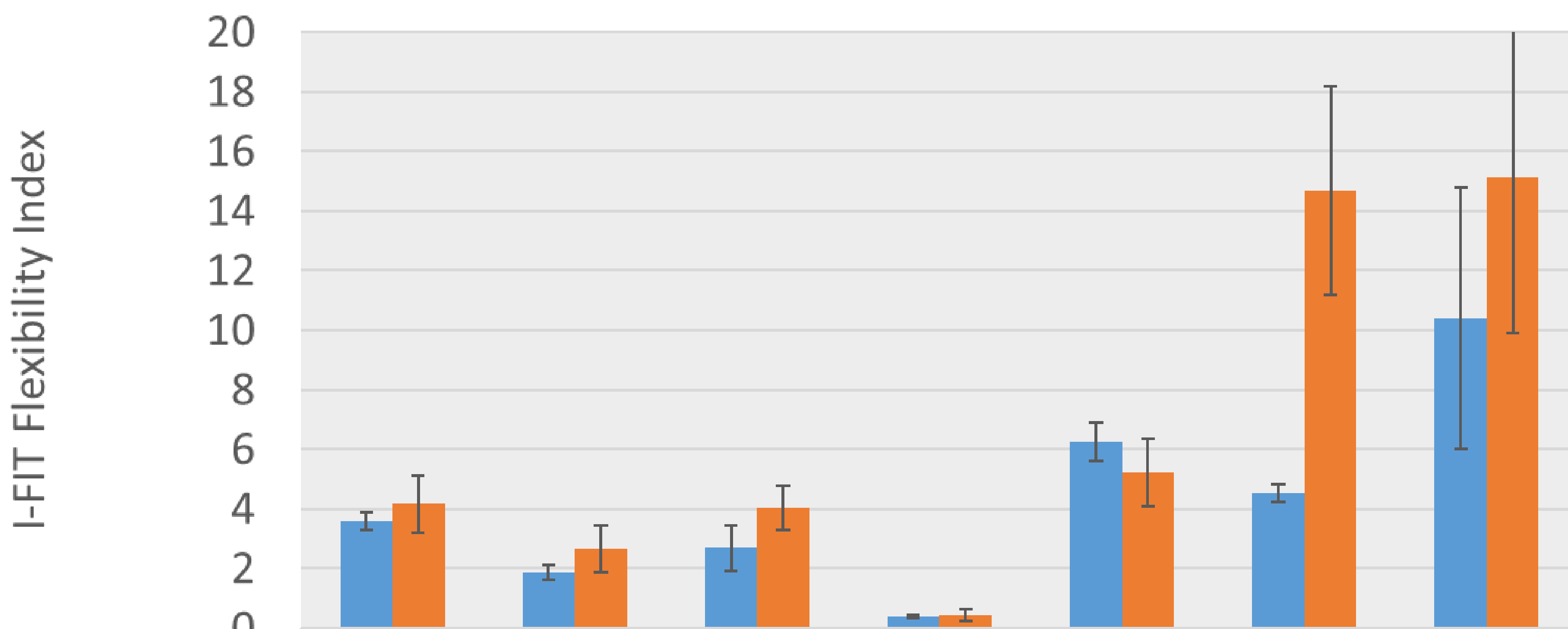
Questions to Answer

- Which laboratory cracking test best relates to field performance?
  - A: Ongoing. Additional cycle of trafficking required to get full field cracking behavior.
  - At this point, test should identify N8 (Ctrl + 5% RAS) as most cracking susceptible
  - S5, S6, and S13 (no cracking) should be among top performers

Questions to Answer

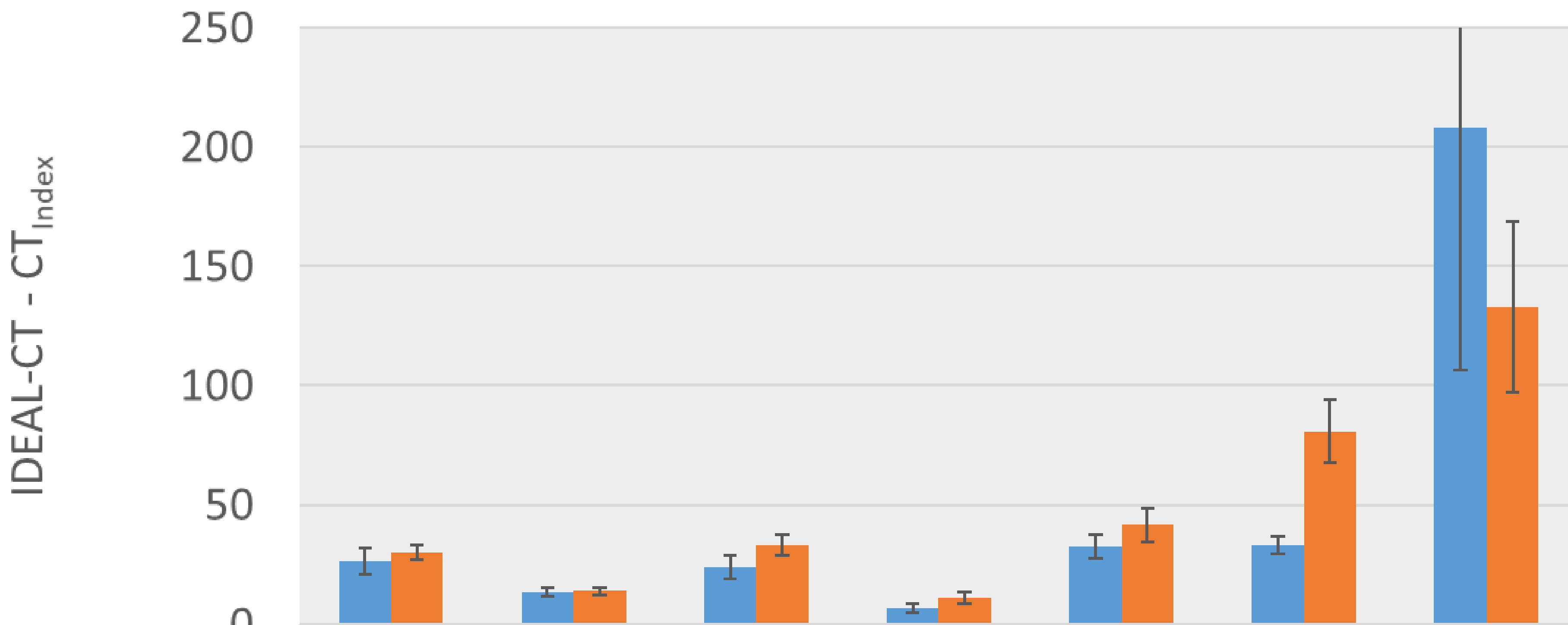
- What are the general trends these tests are showing between the seven unique CG surface mixtures?

I-FIT Flexibility Index



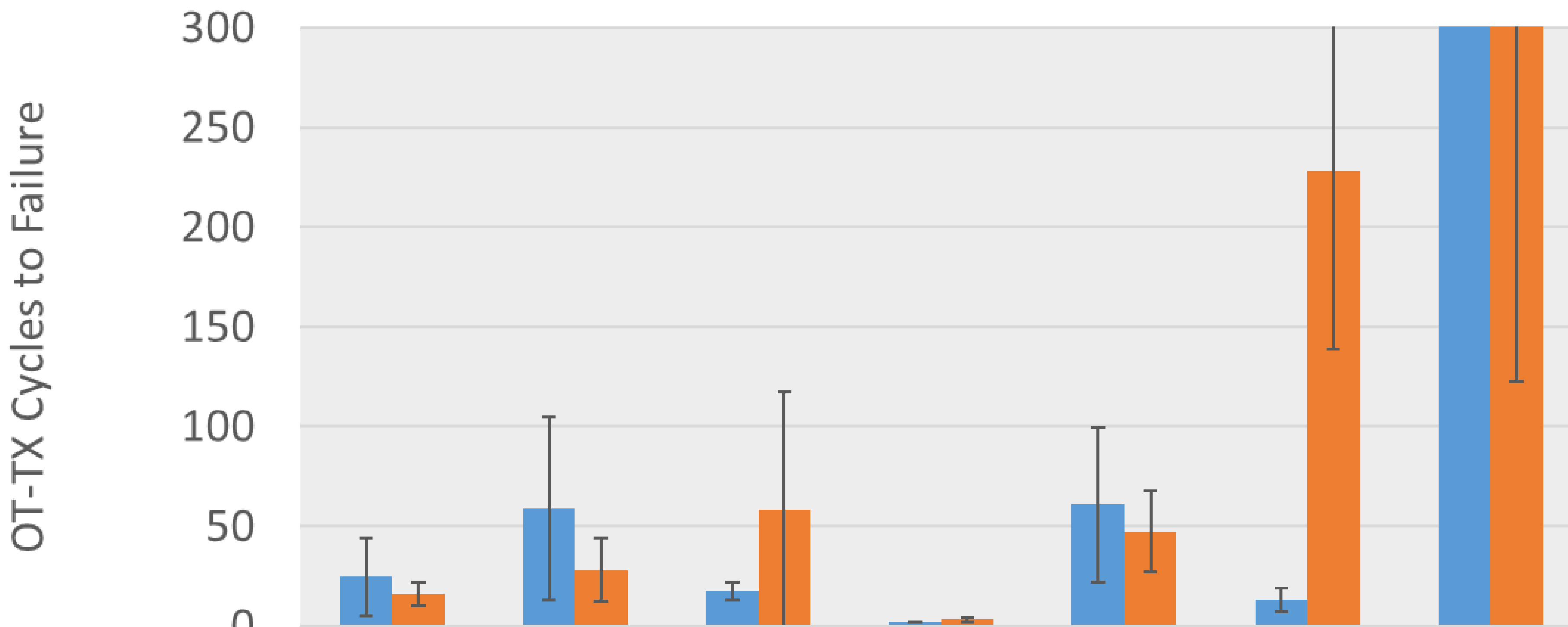
	20% RAP Ctrl.	High Dens. Ctrl.	Low Dens./ AC Ctrl	Ctrl + 5% RAS	35% RAP PG 58-28	Ctrl + HiMA	AZ Rubber
RH PMLC	3.6	1.9	2.7	0.4	6.3	4.5	10.4
STOA LMLC	4.2	2.7	4.0	0.4	5.2	14.7	15.1

IDEAL-CT - CT_{Index}



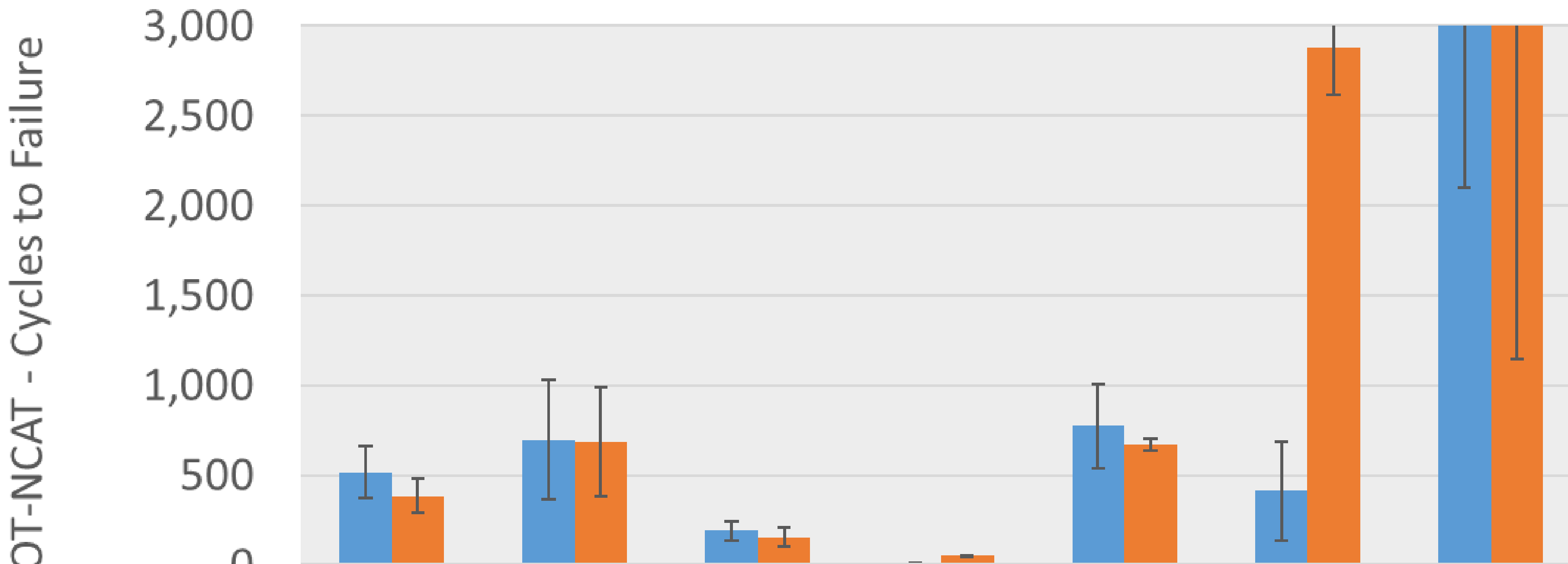
	20% RAP Ctrl.	High Dens. Ctrl.	Low Dens./ AC Ctrl	Ctrl + 5% RAS	35% RAP PG 58-28	Ctrl + HiMA	AZ Rubber
RH PMLC	26.2	13.2	23.8	6.7	32.4	32.9	208.1
STOA LMLC	30.2	13.9	33.2	10.9	41.6	80.8	133.1

Texas Overlay Tester



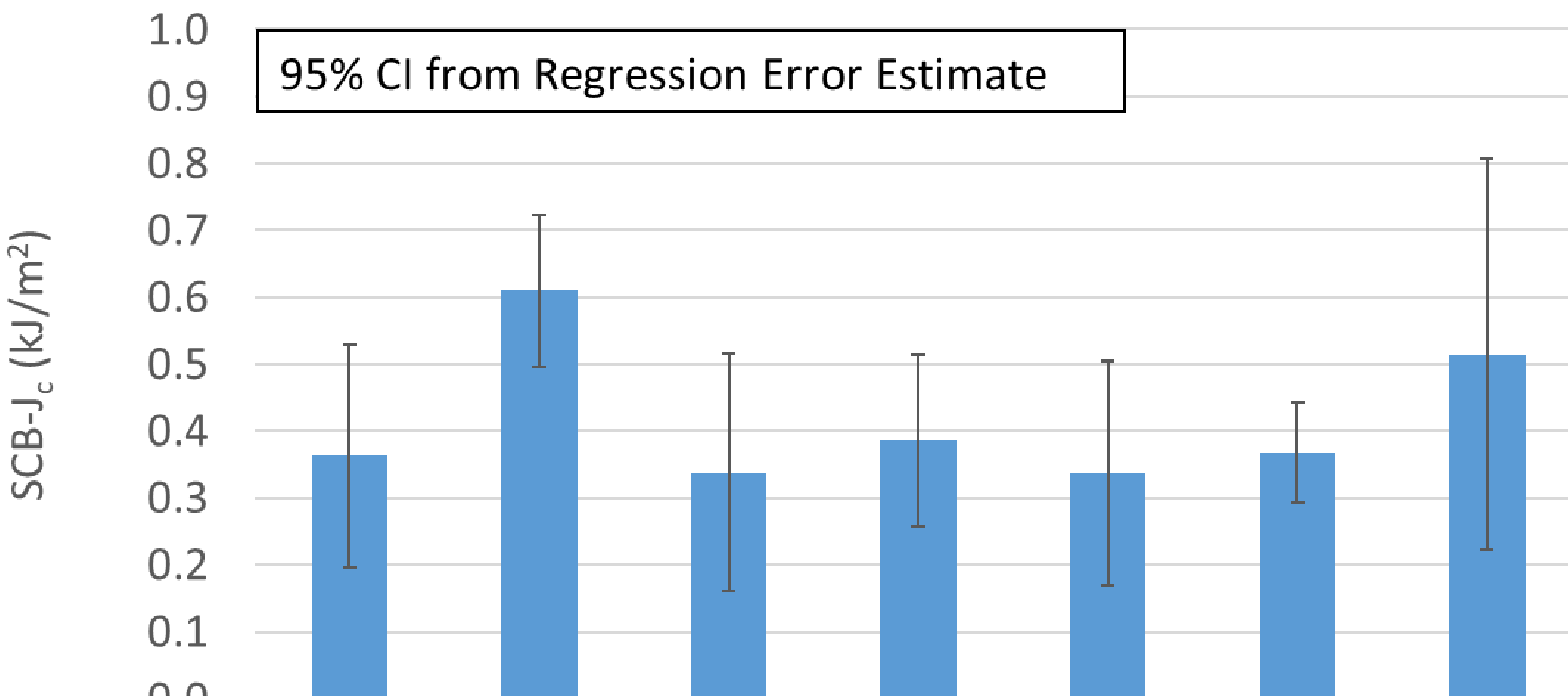
	20% RAP Ctrl.	High Dens. Ctrl.	Low Dens./ AC Ctrl	Ctrl + 5% RAS	35% RAP PG 58-28	Ctrl + HiMA	AZ Rubber
RH PMLC	25	59	17	2	61	13	1725
STOA LMLC	16	28	59	3	47	229	539

NCAT Modified Overlay Tester



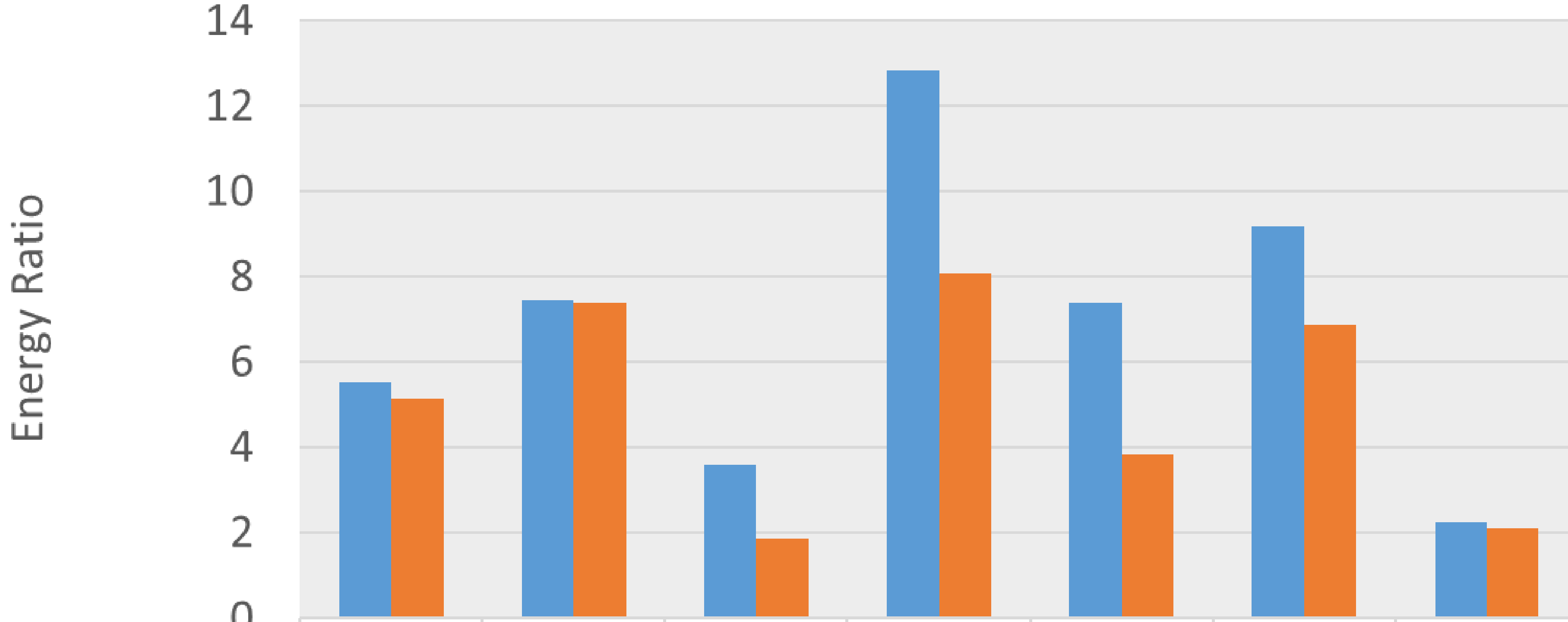
	20% RAP Ctrl.	High Dens. Ctrl.	Low Dens./ AC Ctrl	Ctrl + 5% RAS	35% RAP PG 58-28	Ctrl + HiMA	AZ Rubber
RH PMLC	516	697	189	12	773	411	3,054
STOA LMLC	382	688	155	49	672	2,881	4,382

SCB Critical J-Integral (J_c)



	20% RAP Ctrl.	High Dens. Ctrl.	Low Dens. /AC Ctrl	Ctrl + 5% RAS	35% RAP PG 58-28	Ctrl + HiMA	AZ Rubber
RH PMLC	0.36	0.61	0.34	0.39	0.34	0.37	0.51

Energy Ratio

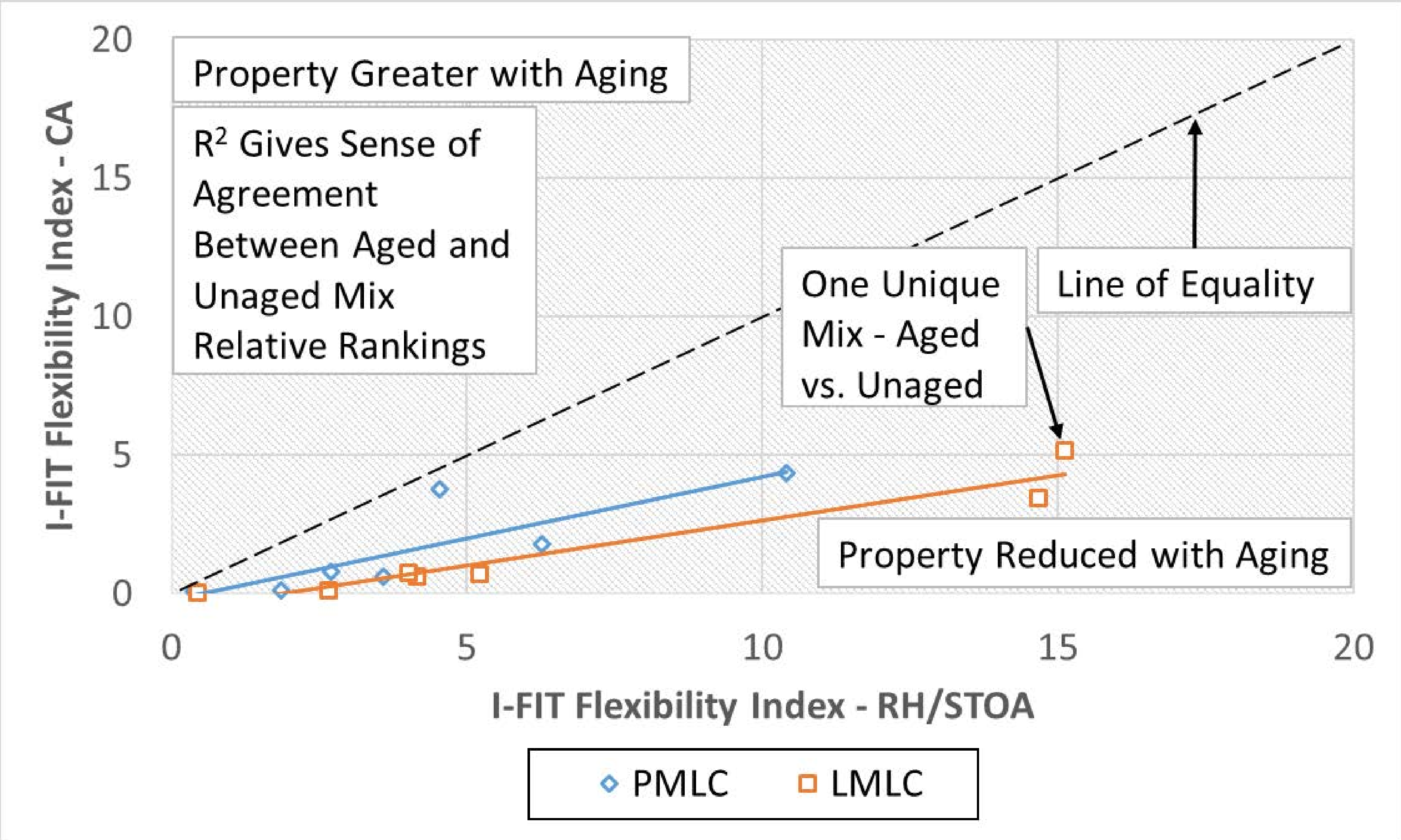


	20% RAP Ctrl.	High Dens. Ctrl.	Low Dens./ AC Ctrl	Ctrl + 5% RAS	35% RAP PG 58-28	Ctrl + HiMA	AZ Rubber
RH PMLC	5.5	7.4	3.6	12.8	7.4	9.2	2.2
STOA LMLC	5.1	7.4	1.9	8.1	3.8	6.9	2.1

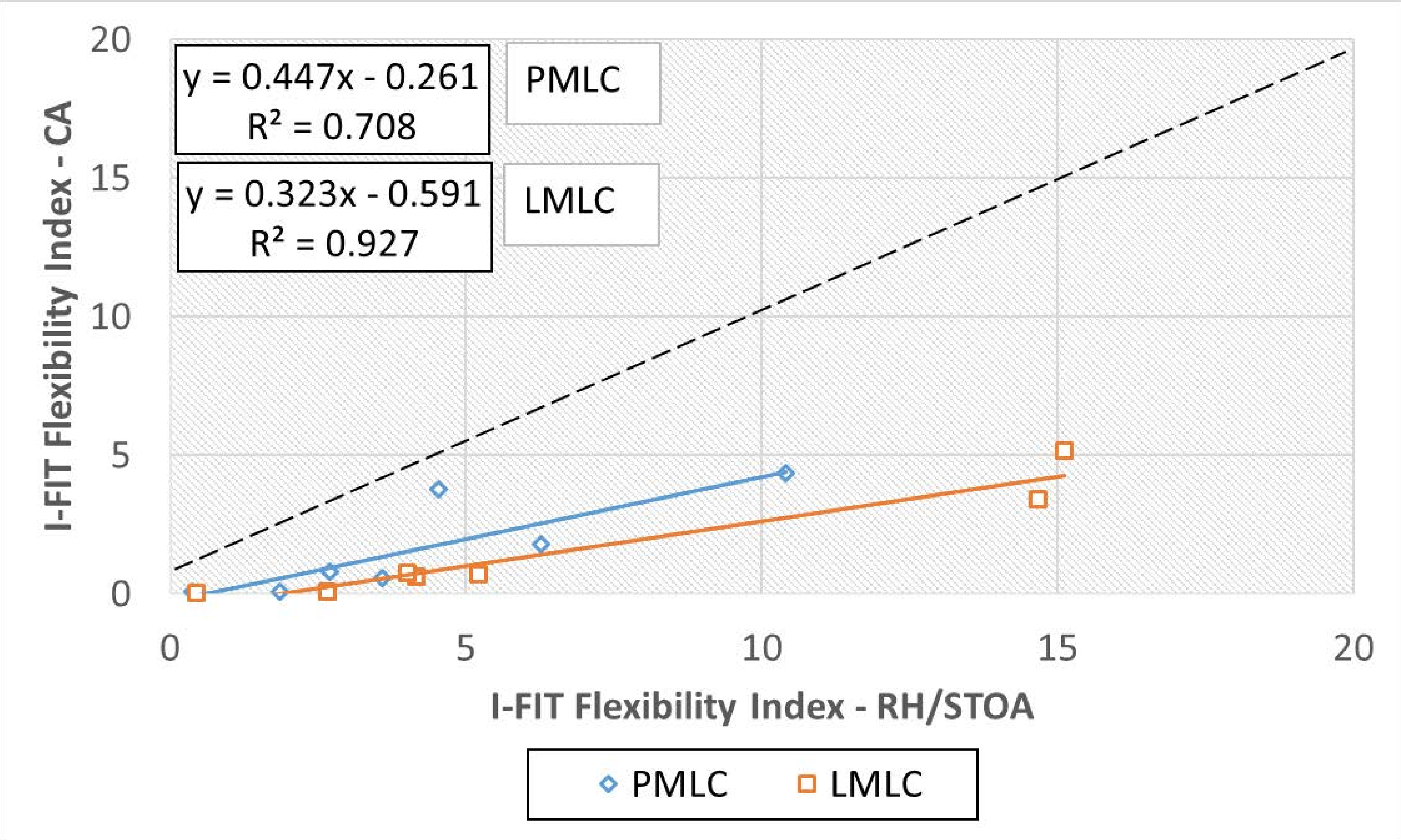
Questions to Answer

- What is the impact of additional laboratory aging on the results of these cracking tests?
- How does additional aging impact relative rankings between mixtures?

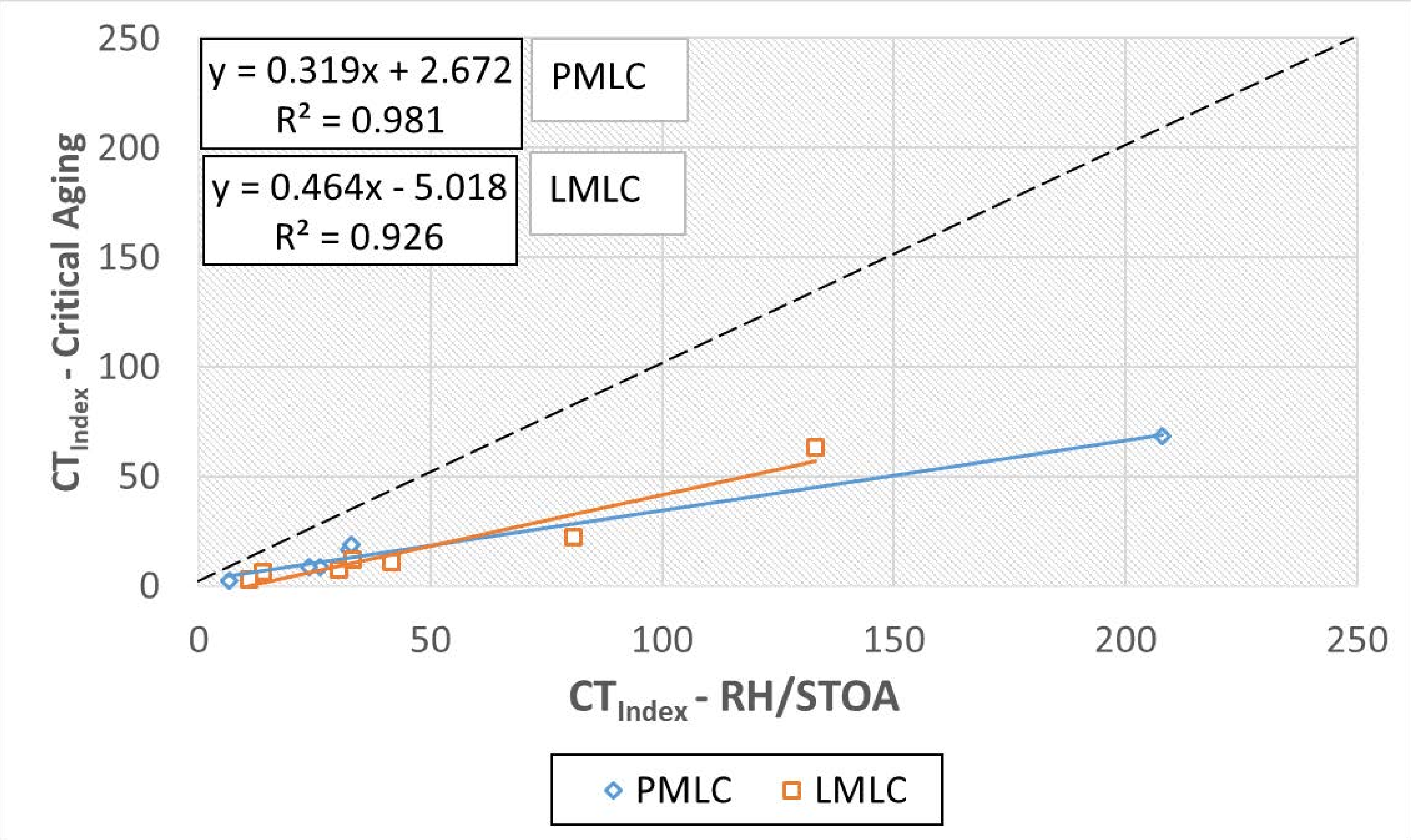
Aging Evaluation – 1:1 Plots



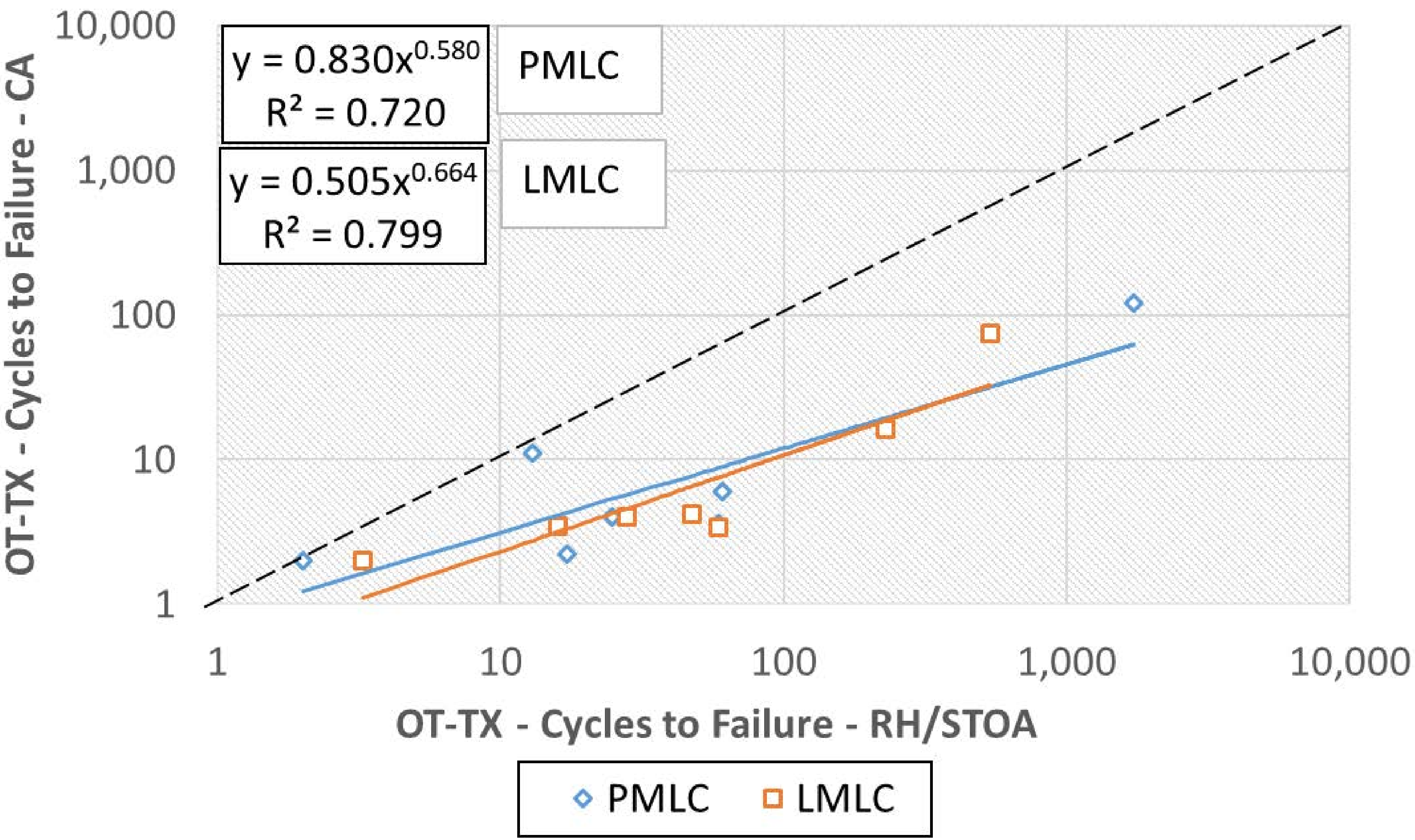
1:1 – I-FIT Flexibility Index



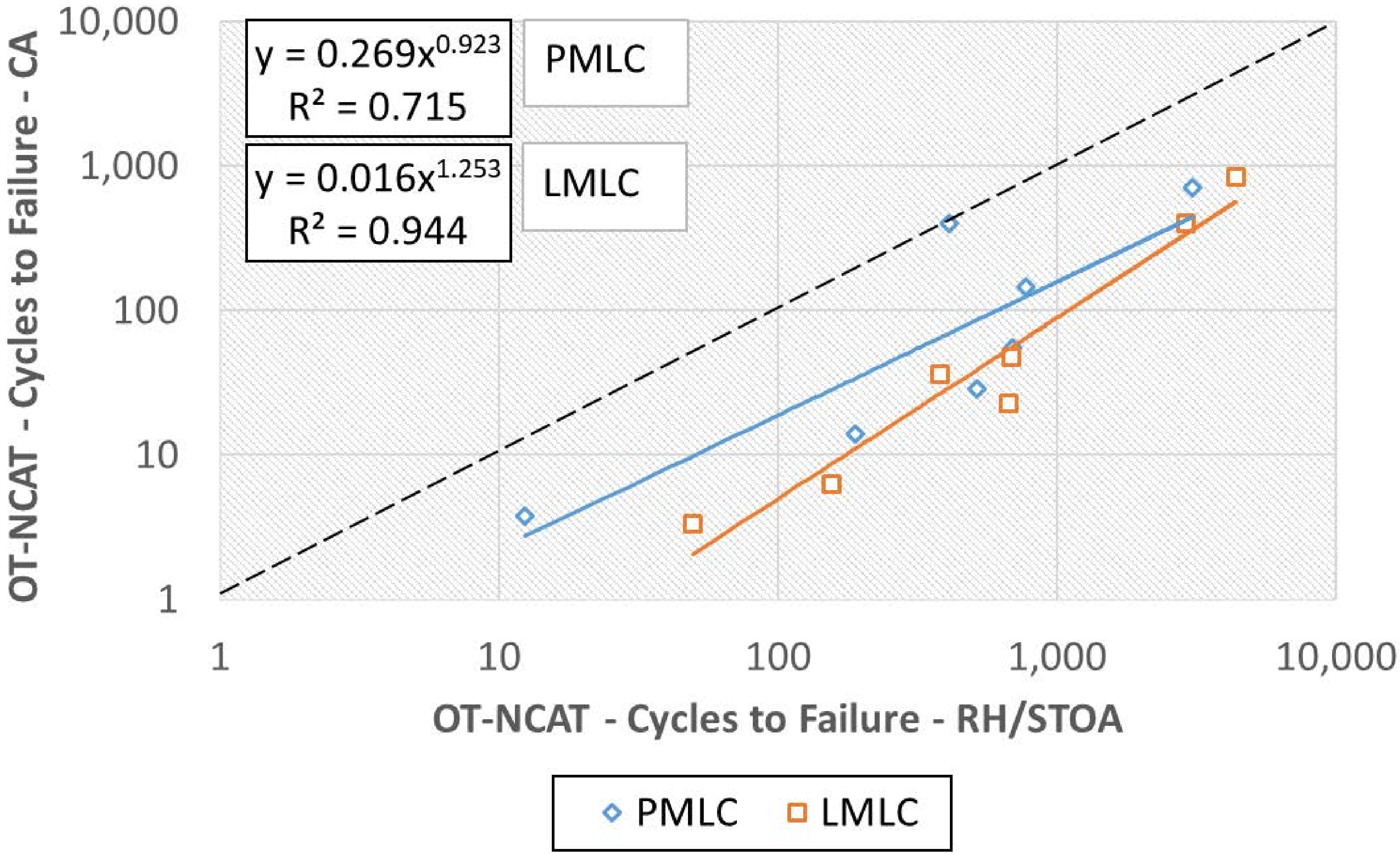
1:1 – IDEAL-CT (CT_{Index})



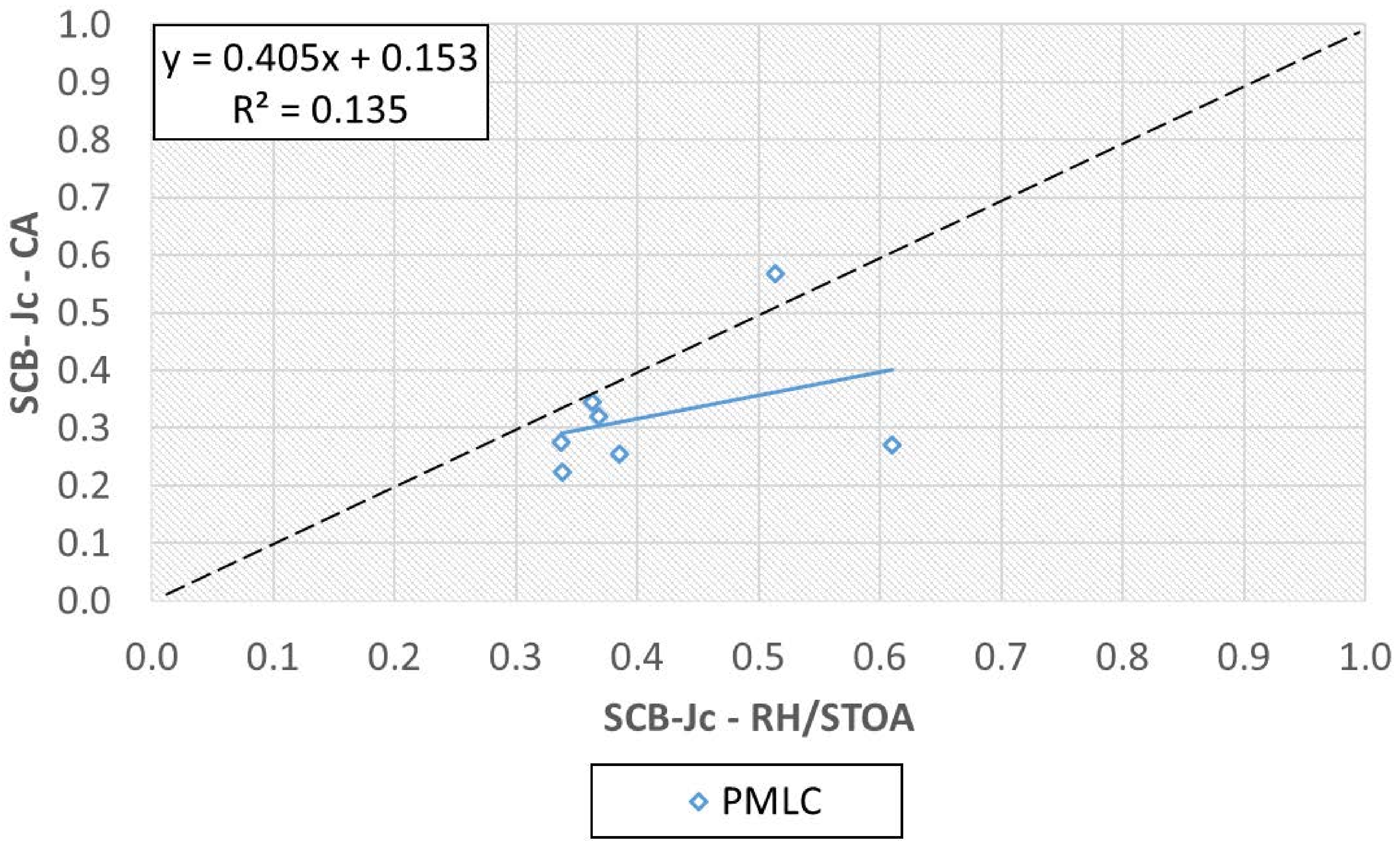
1:1 – OT-TX Cycles to Failure



1:1 - OT-NCAT Cycles to Failure

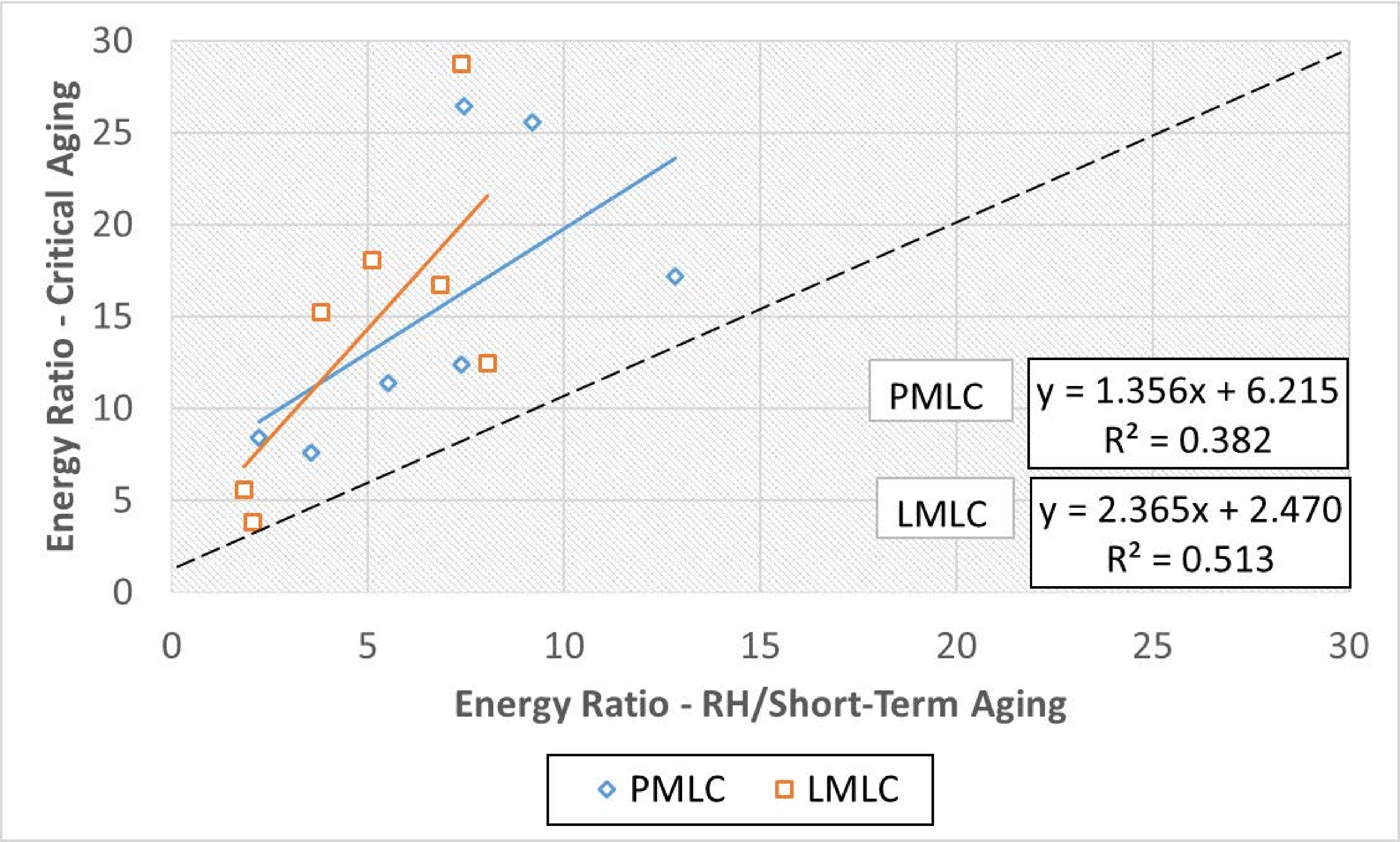


1:1 – SCB-Jc



y = 0.405x + 0.153
R² = 0.135
SCB- Jc - CA
SCB-Jc - RH/STOA
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
PMLC

1:1 – Energy Ratio



Questions to Answer

- How do these laboratory cracking test results correlate to one another?
  - A: Pearson Correlation Analysis
  - On average, do these tests correlate to one another when compared using the same aging condition?

Correlation Methodology

- According to Evans (1996)
  - Coefficient of 0.8-1.0 = Very Strong Correlation
  - Coefficient of 0.6-0.8 = Strong Correlation
- Correlation Matrix
  - 22 data sets x 7 unique mixtures
    - SCB-Jc LMLC Data still pending
  - Average Correlation Values
    - Average of 4 aging conditions
    - 4 unique Pearson Coefficients

Average Correlation Example

- Correlation Coefficients
  - RH PMLC I-FIT vs. IDEAL-CT = 0.887
  - STOA LMLC I-FIT vs. IDEAL-CT = 0.941
  - CA PMLC I-FIT vs. IDEAL-CT = 0.829
  - CA LMLC I-FIT vs. IDEAL-CT = 0.939
- ‘Average’ Coefficient
  - Average I-FIT vs. IDEAL-CT = 0.899
- Reduce 22 x 22 Matrix to ‘Average’ 6 x 6 Matrix

Average Correlation – Same Aging

	I-FIT	IDEAL-CT	OT-TX	OT-NCAT	SCB-Jc*	ER
I-FIT	1					
IDEAL-CT	0.899	1				
OT-TX	0.835	0.984	1			
OT-NCAT	0.941	0.961	0.947	1		
SCB-Jc*	0.427	0.642	0.687	0.680	1	
ER	-0.377	-0.500	-0.459	-0.357	-0.273	1

- Average of 2 data sets, not 4 (missing LMLC)

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Things We've Learned

- Strong Correlation Between 4 of the 6 Laboratory Cracking Tests
  - I-FIT, IDEAL-CT, OT-TX, OT-NCAT
  - Each test has its own idiosyncrasies
    - I-FIT/IDEAL-CT
      - Effect of density on post-peak analysis
    - OT-TX, OT-NCAT
      - Cyclic Test Variability
      - Test Speed (Gluing)

Things We've Learned

- I-FIT, IDEAL-CT, OT-TX, OT-NCAT
  - Identified N8 (Ctrl + 5% RAS) as low performer
    - First to crack and highest severity of cracking
  - Had the sections that have not cracked yet among the top performers
    - S5 (35% RAP w/ PG 58-28), S6 (Ctrl w/ HiMA), and S13 (AZ Rubber)
  - S6 (Ctrl w/ HiMA) generally showed better performance with LMLC than the PMLC for these tests

Things We've Learned

- For SCB-J_c, most PMLC mixes showed an appropriate aging trend, but lower discrimination between mixes
  - Did not distinguish N8 (Ctrl + 5% RAS) as the low performer
  - Still waiting on LMLC data for final analysis
- Energy Ratio showed reverse aging trend
  - Aging the mix improved the cracking resistance parameter
  - Logical aging trends on component tests

Things We Still Want To Learn

- Our Analysis is Ongoing and Evolving
  - Field cracking data from 2018 cycle to finalize lab to field comparisons
    - Recommend Test or Test(s) that best match field performance
  - Additional Statistical Analysis
  - Analysis of Additional Cracking Parameters
    - New Texas OT Curve Parameters
  - Density Correction Factors
    - I-FIT and IDEAL-CT


THANKS!
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