Influence of RAP and RAS addition on mixture and binder performance: Three years of ALF activity

Asphalt Mixture and Construction Expert Task Group

September, 2017

Pavement Materials Team, TFHRC

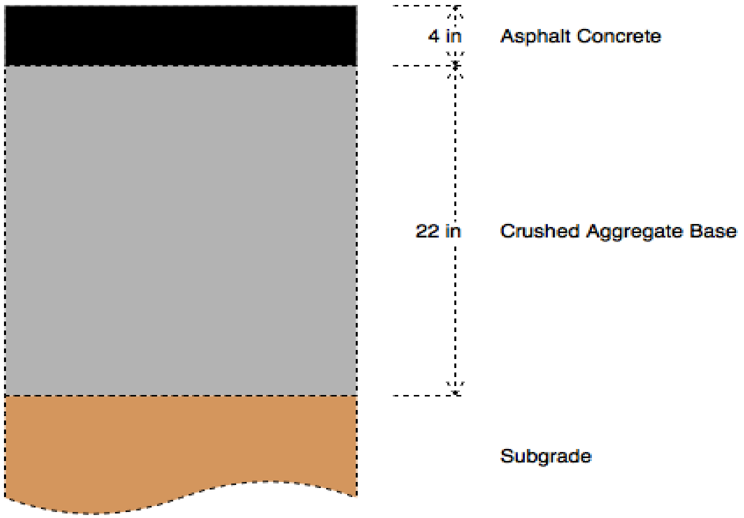
RAP/RAS and WMA

- **Purpose**
  - Advance Use of Recycled Asphalt in Flexible Pavement Infrastructure: Develop and Deploy Framework for Proper Use and Evaluation of Recycled Asphalt in Asphalt Mixtures
- **Objective**
  - Quantify cracking resistance of high RAP/RAS mixtures that considers the use of lower temperature production with warm-mix asphalt (WMA) technologies

The Experiment

Structure

- 10 Lanes (10 Mixes)
- 2 Layers (2 inches each)
- Build in 2013



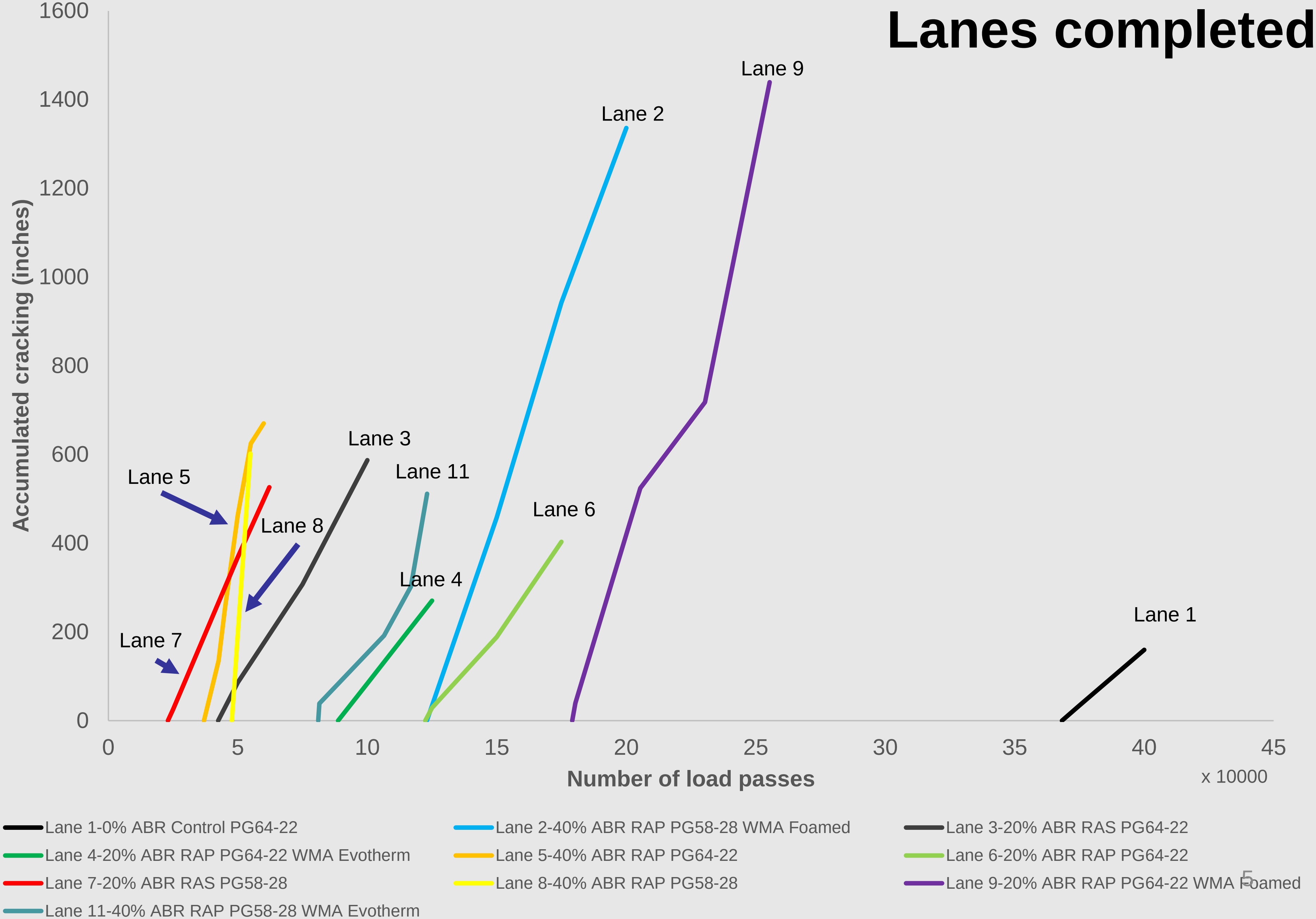
Materials

- 2 Base Binder Grades (PG 64-22 and PG 58-28)
- RAP/RAS
- 2 WMA Technologies
- 3 ABR contents

ALF experimental design
Ten lanes total

HMA / WMA Drum Discharge Temperature	300°F - 320°F		240°F - 270°F	
Warm Mix Technology	-		Foam	Chem.
Recycle Content				
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

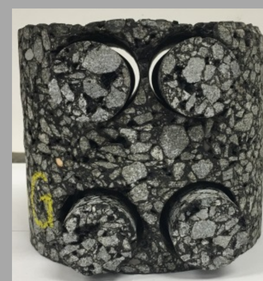
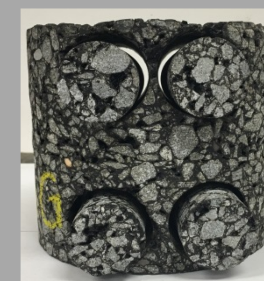
Lanes completed



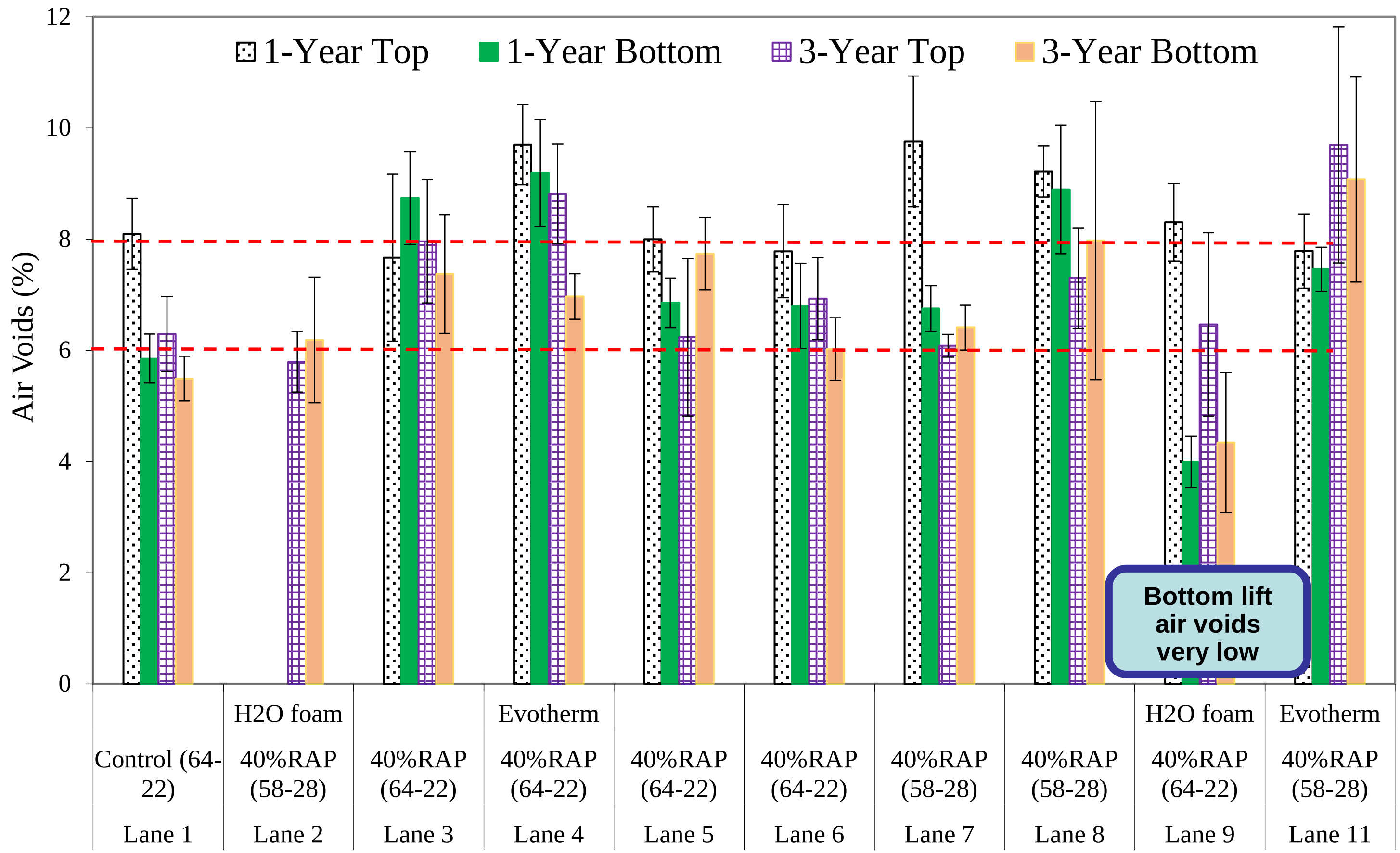
Crack Data Summary

Lane	Mix	Age when tested (months)	Duration (Days)	Cycles to First Crack (Calculated)	Total Passes	Total Cracking (in)
1	0% ABR Control PG64-22	7	286	368,254	400,000	160
2	40% ABR RAP PG58-28 WMA Foamed	38	79	123,035	200,000	1,336
3	20% ABR RAS PG64-22	14	28	42,399	100,000	587
4	20% ABR RAP PG64-22 WMA Evotherm	16	71	88,740	125,000	271
5	40% ABR RAP PG64-22	11	98	36,946	60,000	670
6	20% ABR RAP PG64-22	24	81	122,363	175,000	403
7	20% ABR RAS PG58-28	18	43	23,005	62,200	526
8	40% ABR RAP PG58-28	31	47	47,679	54,844	602
9	20% ABR RAP PG64-22 WMA Foamed	2	163	179,167	255,397	1,439
11	40% ABR RAP PG58-28 WMA Evotherm	3	147	81,044	123,052	512

Field Core Sampling and Testing

	2013	2014	2015	2016
				
	t = 0m Top Bottom	t = 12m Top Bottom	t = 24m Top Bottom	t = 36m Top Bottom
|E*|	✓	✓	✓	✓
Fatigue	✓	✓	✓	✓
Monotonic		✓		✓
Binder Extraction & Testing			✓	✓

Air Voids of the Tested Field Cores



Clear variation from construction compaction and

Need to take construction variation into account analyzing performance testing data

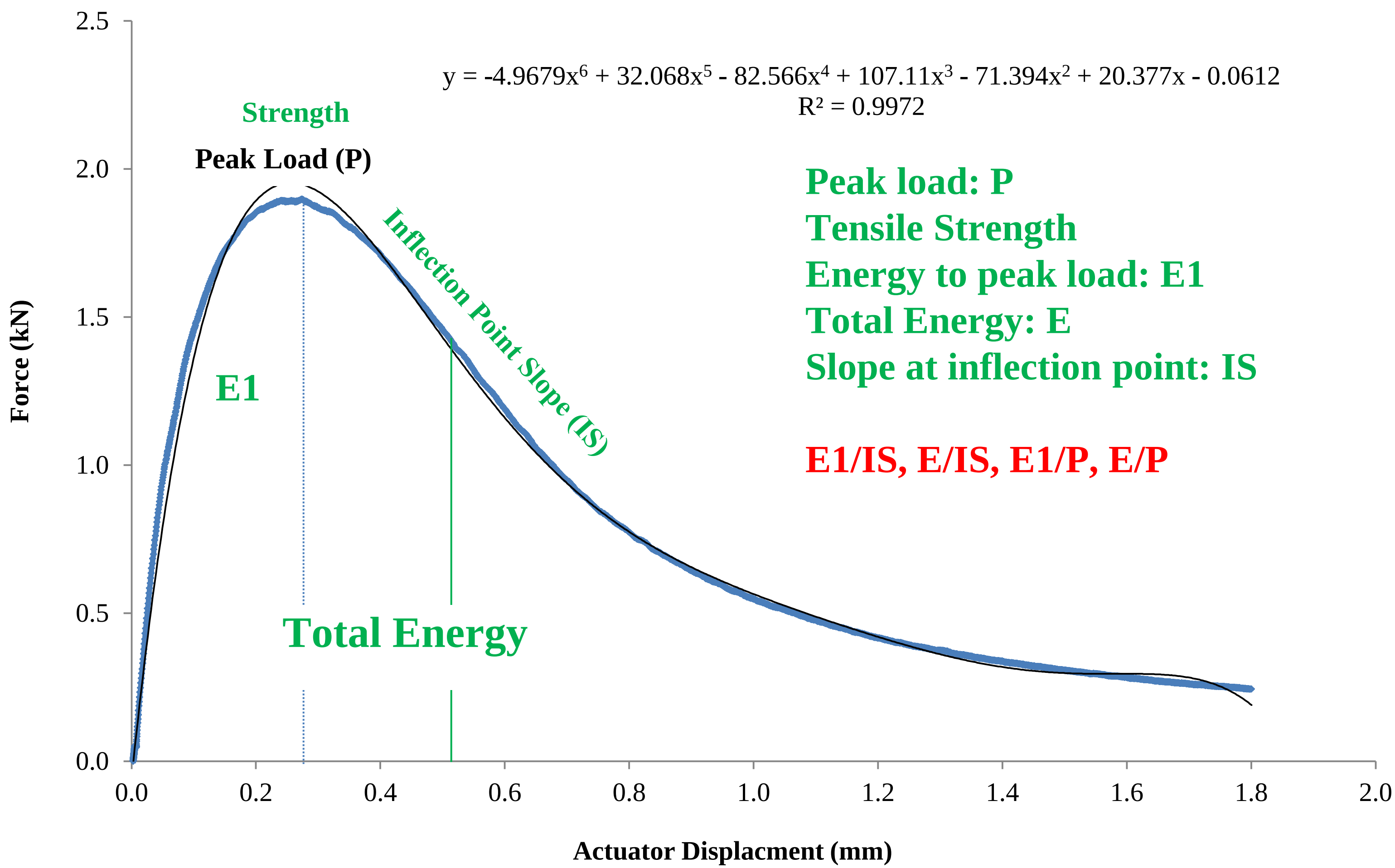
Mixture Field Sample Testing

- **Reduced Size (38mmx110mm)**
- **Dynamic Modulus**
- **Fatigue (AASHTO TP 107)**
- **Monotonic Direct Tension**
- **All testing done on AMPT**

Testing Conditions and Materials

- **Loading Rates**
  - Actuator displacement control
  - An recent research effort shows 10mm/min ideal
  - This study 10 mm/min
- **Temperature**
  - All tested at 18°C
  - Minimize visco-plasticity effects and no strain decomposition
- **Materials**
  - Loose mix (STOA+ 5-day LTOA)
  - 1-year and 3-year field cores

Testing Results

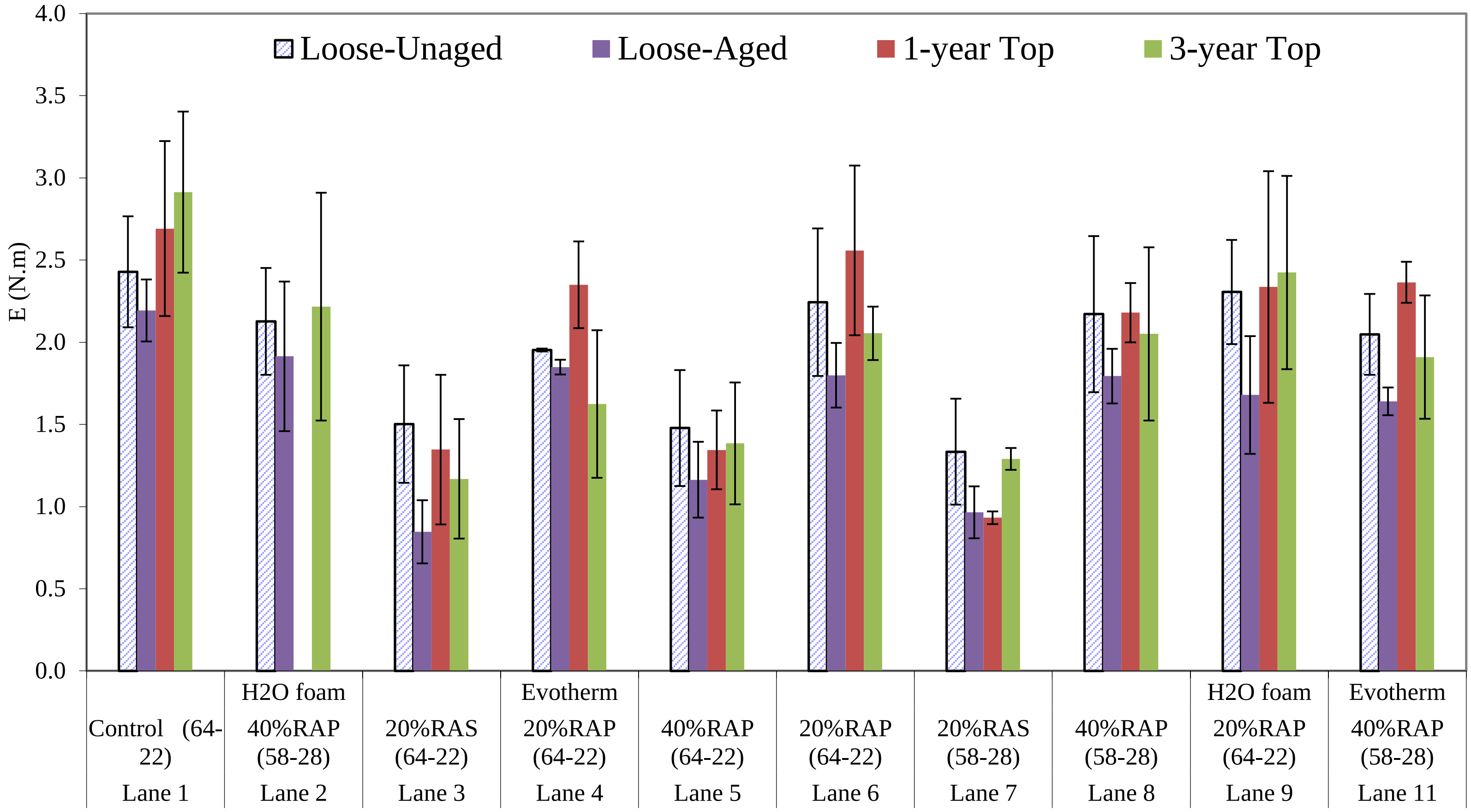


Peak load: P
Tensile Strength
Energy to peak load: E1
Total Energy: E
Slope at inflection point: IS

E1/IS, E/IS, E1/P, E/P

Energy to Peak Load, Total Energy, Slope at Inflection Point + Derived Indexes

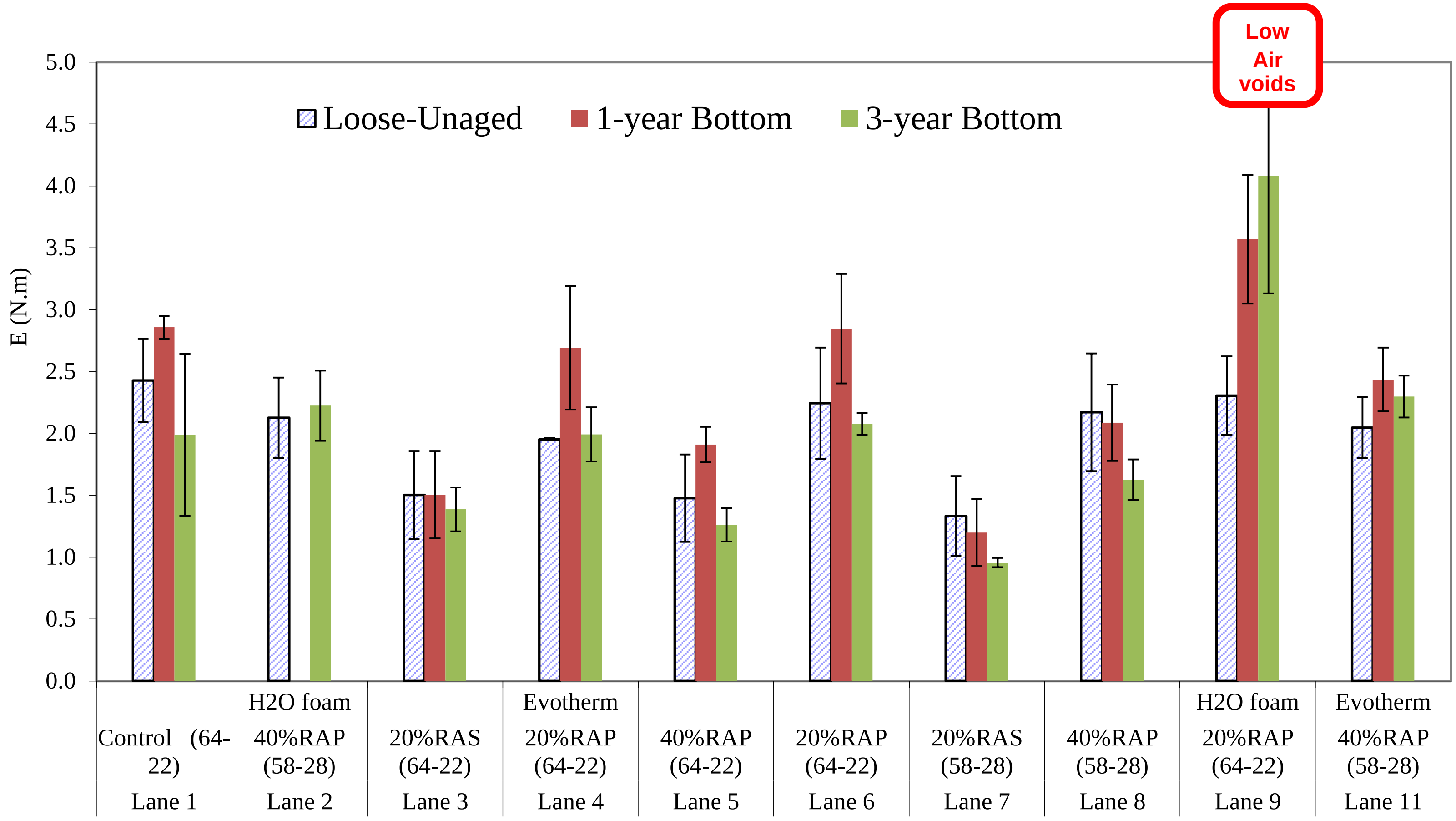
Fracture Energy (Loose + Top Lift)



STOA > LTOA **L3, L5 and L7 lowest**

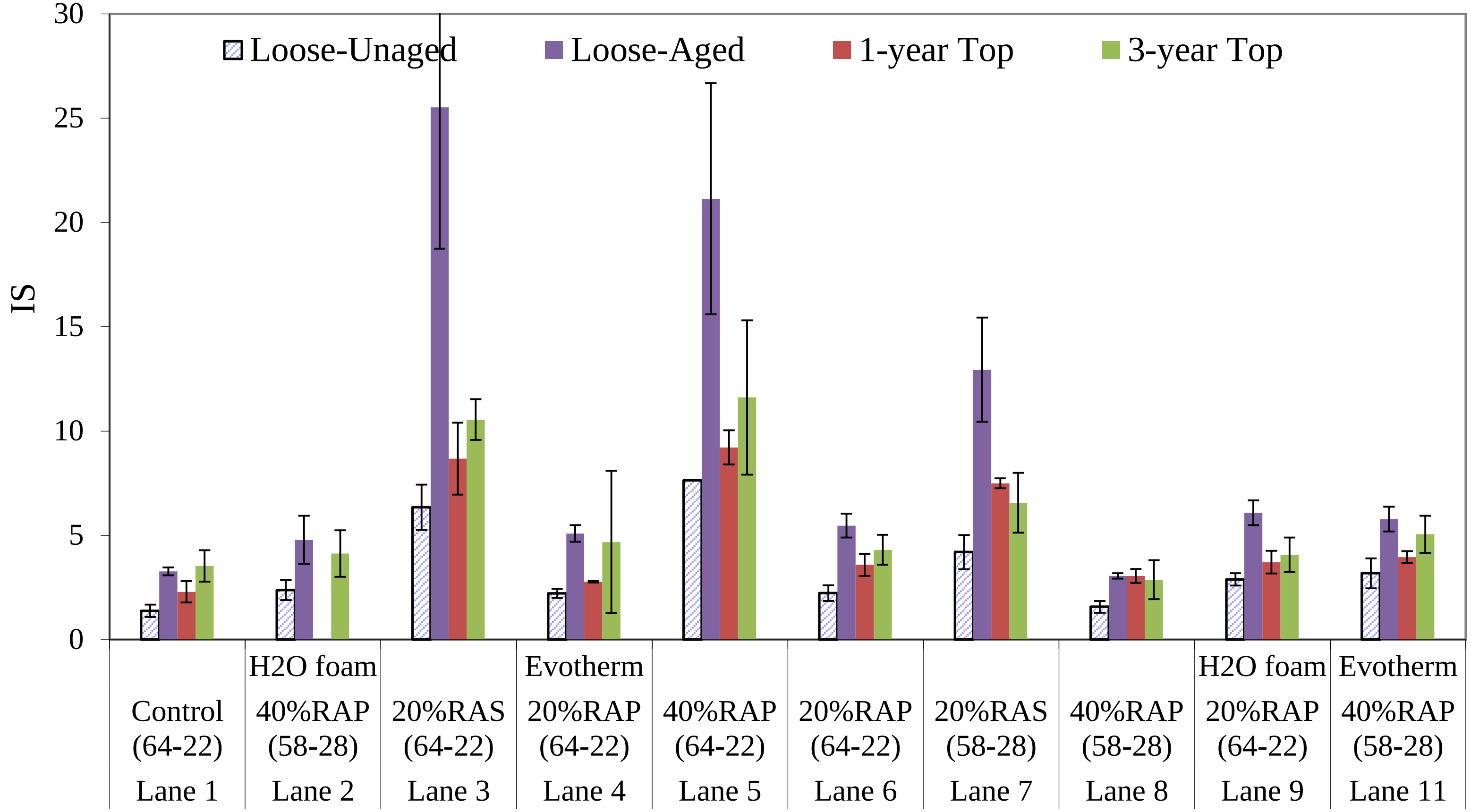
Decrease with time but complicated by construction variation

Fracture Energy (Bottom Lift)



Trend with time complicated by construction variation

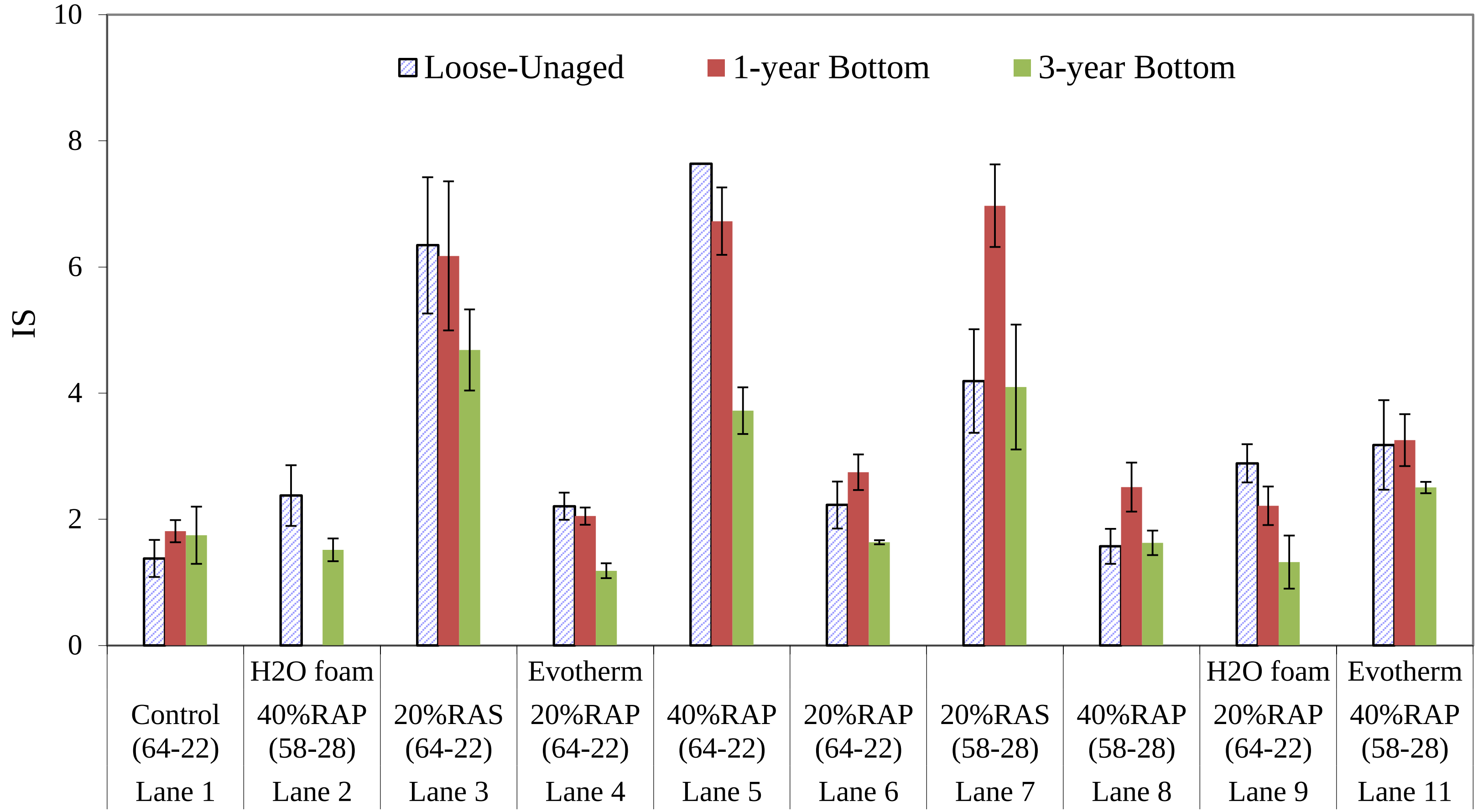
Inflection Point Slope (Top Lift)



LTOA >>> 3 year > 1 year > STOA

L3, L5 and L7 highest

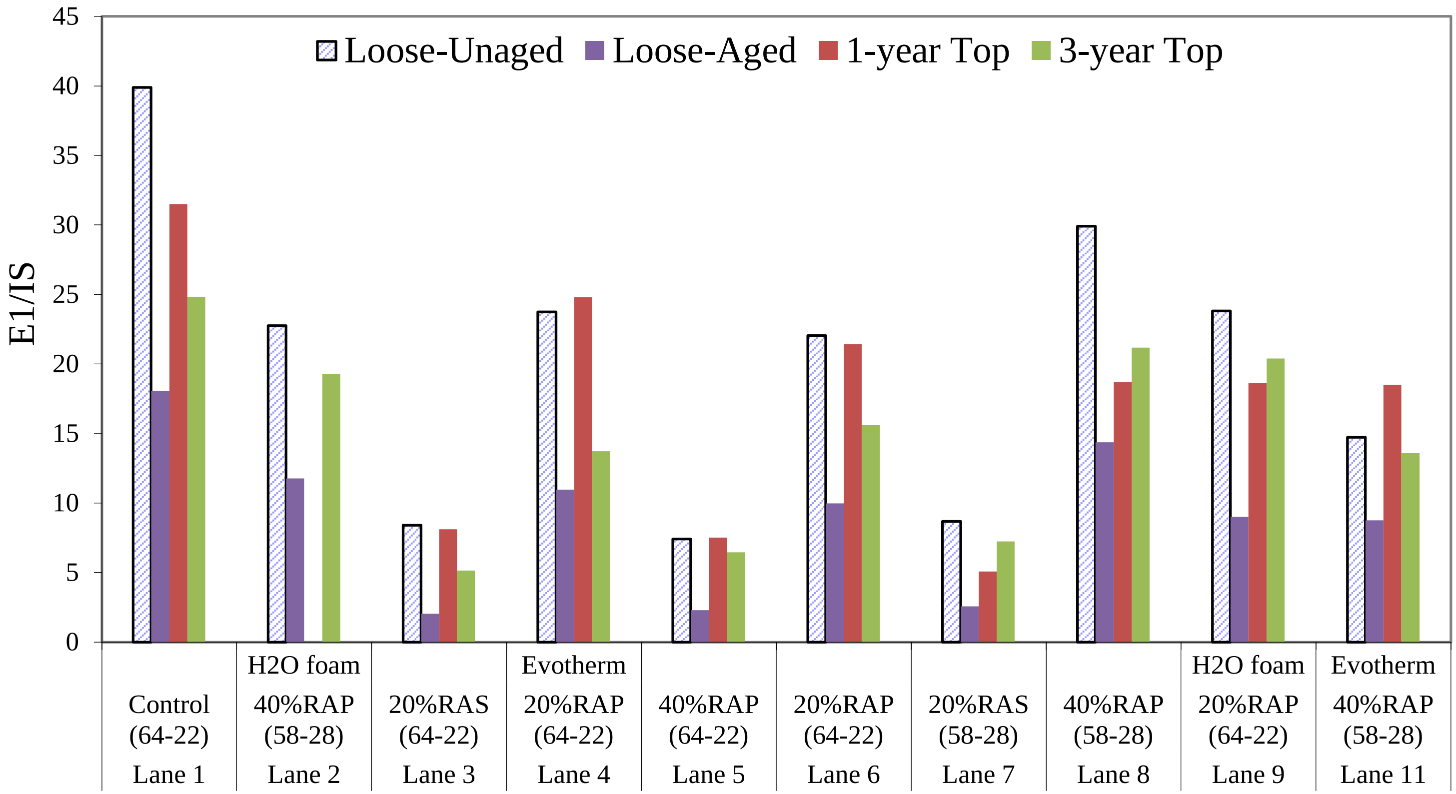
Inflection Point Slope (Bottom Lift)



L3, L5 and L7 highest

Trend not as clear as top lift

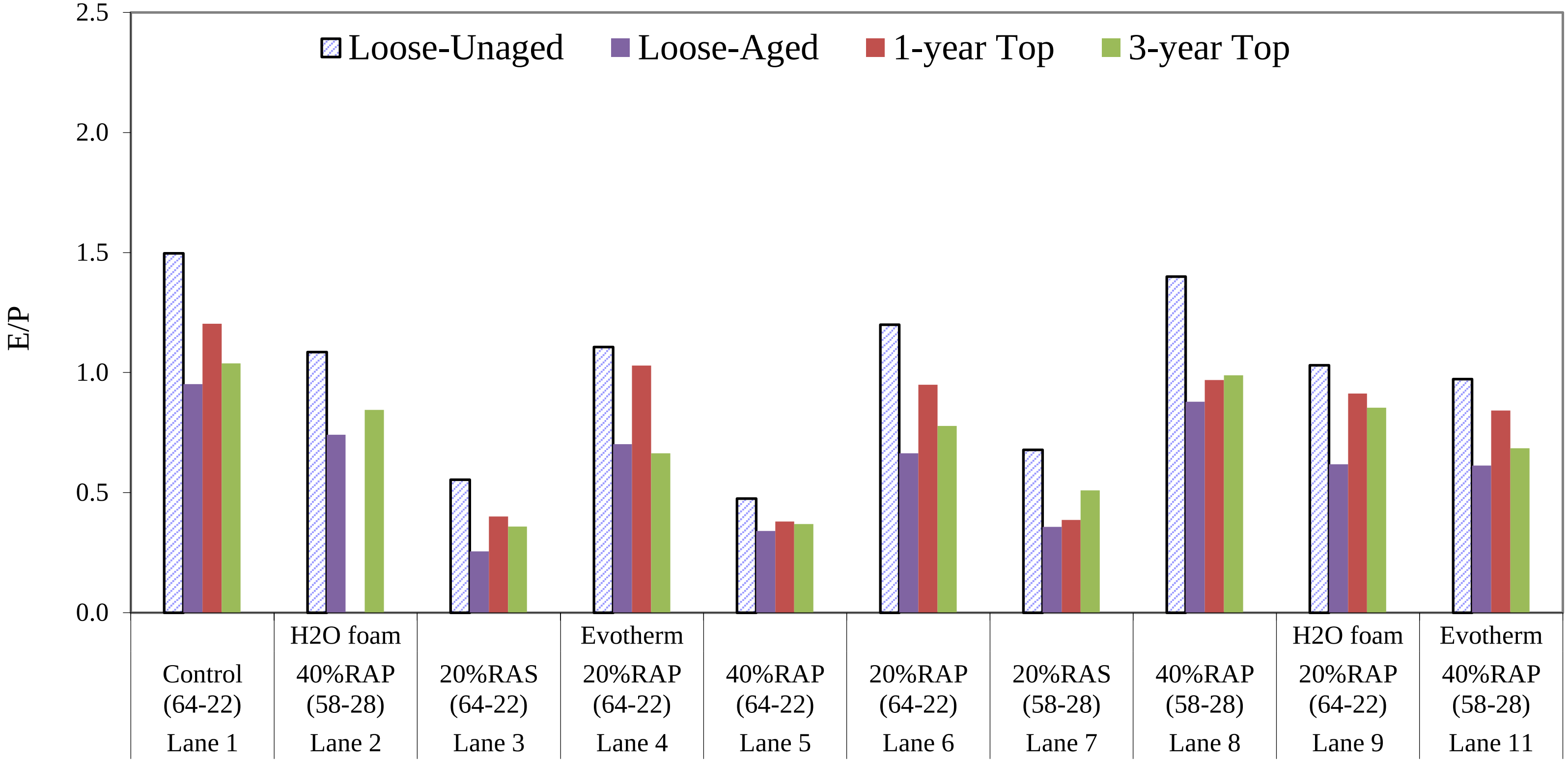
Fracture Energy 1 / IP Slope (Top)



STOA > 1 year > 3 year > LTOA

L3, L5 and L7 lowest

Fracture Energy / Peak Load (Top)

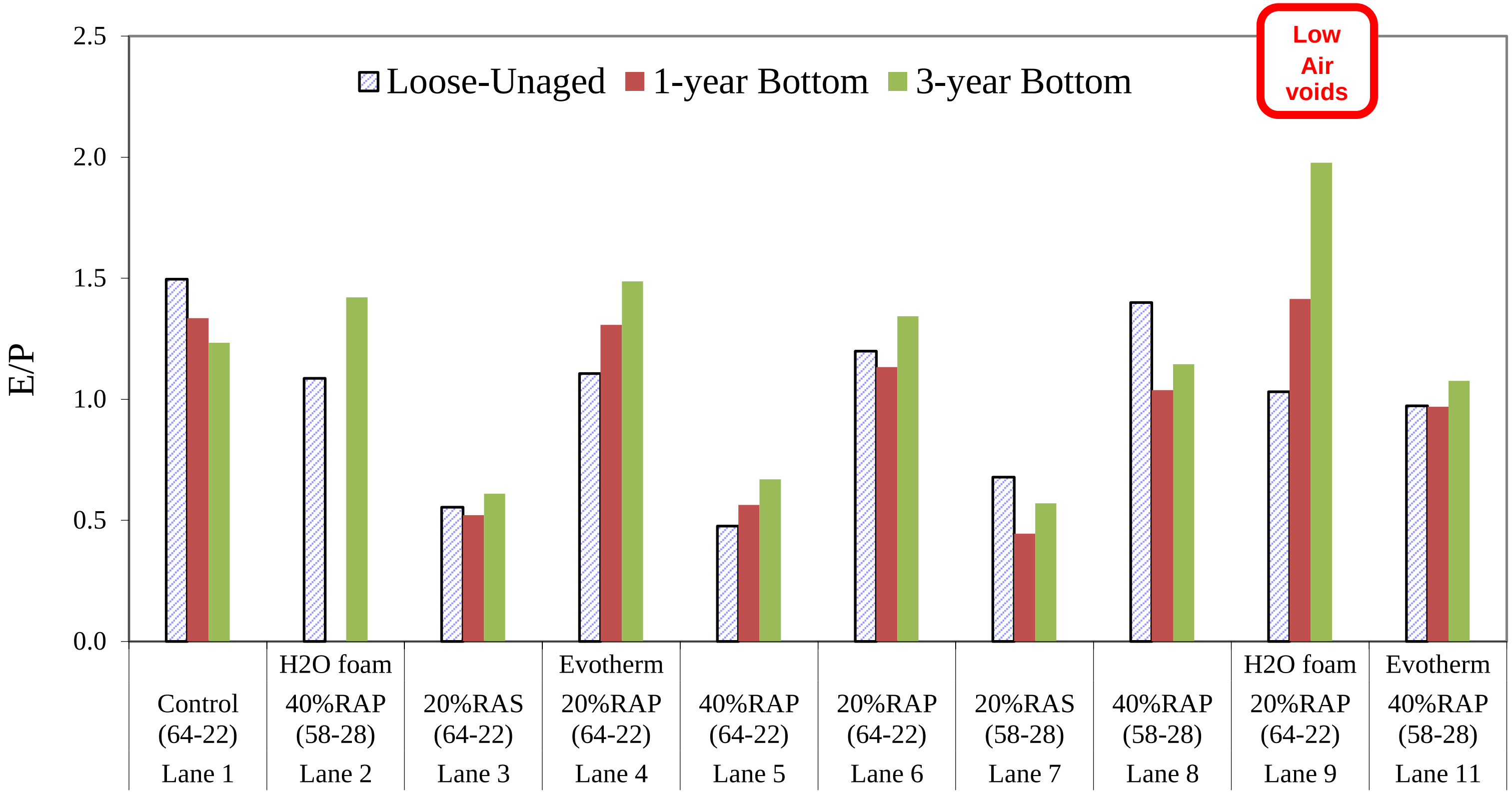


LTOA < 3 year < 1 year < STOA

L3, L5 and L7 lowest

An indicator of the averaged deformability

Fracture Energy / Peak Load (Bottom)

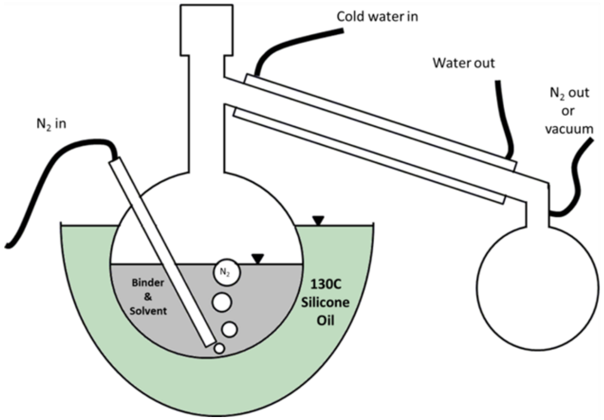


Trend not as clear as top lift **L3, L5 and L7 lowest**

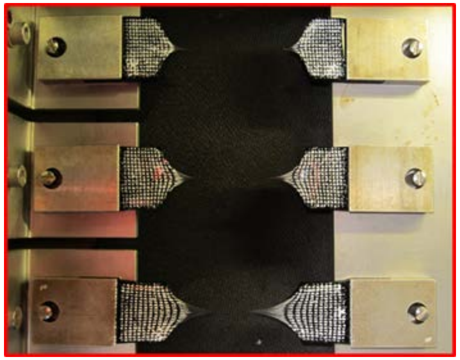
An indicator of the averaged deformability

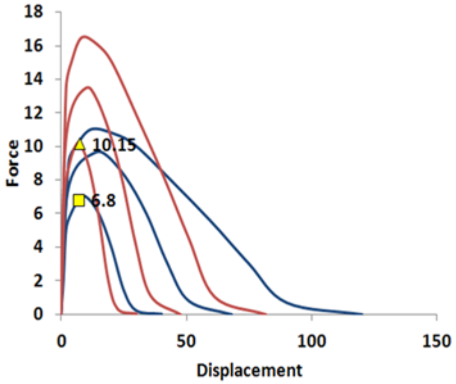
Binder Extraction and Testing

- Rheology (PG)
- Double Notched Tension: Ductile Strain Tolerance

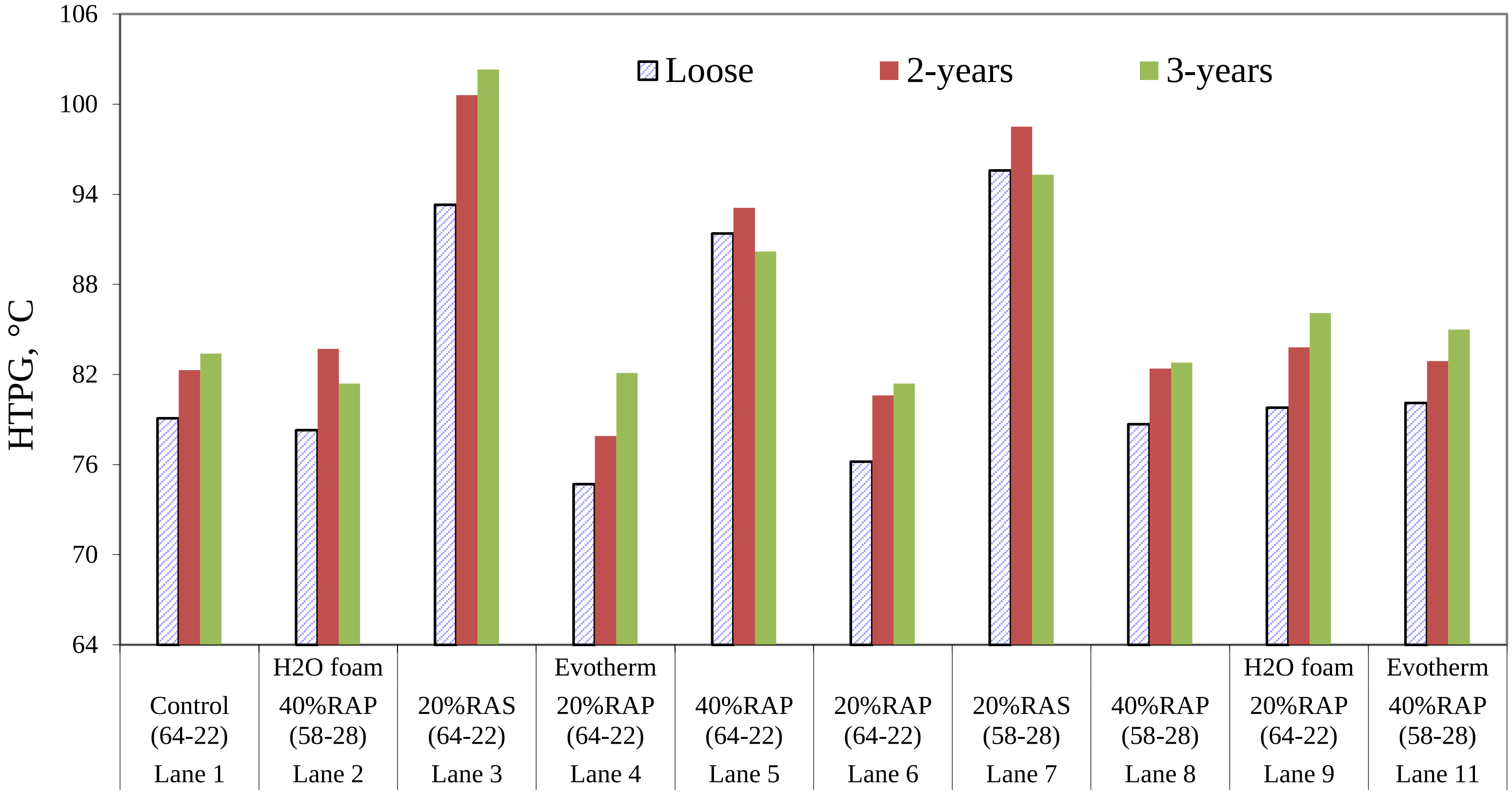


- Loose mix
- 2-years field core
- 3-years field core





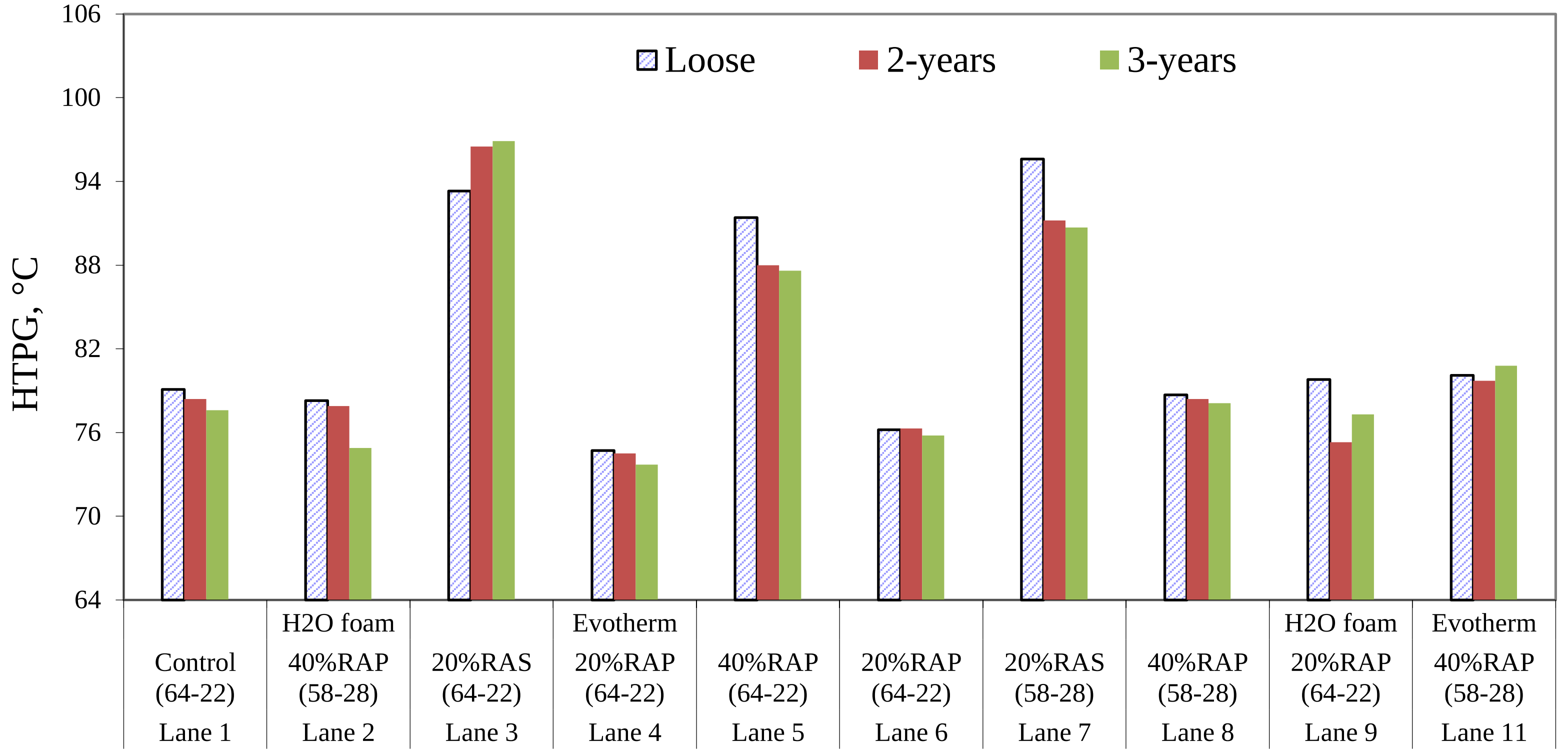
HTPG Variation



Top Lift

3 Years > 2 Years > Loose Mix

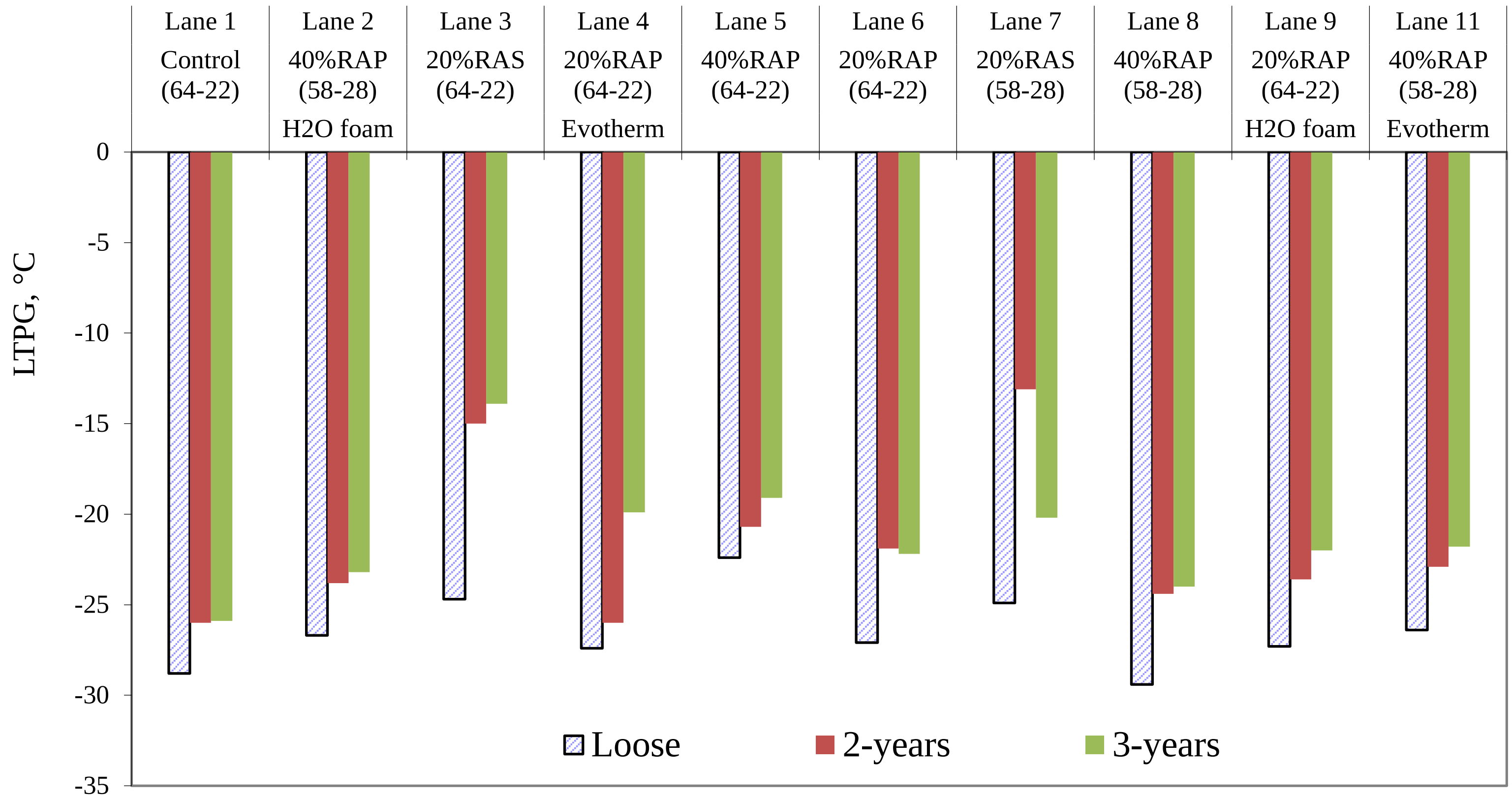
HTPG Variation



Bottom Lift

Relative Minor Changes

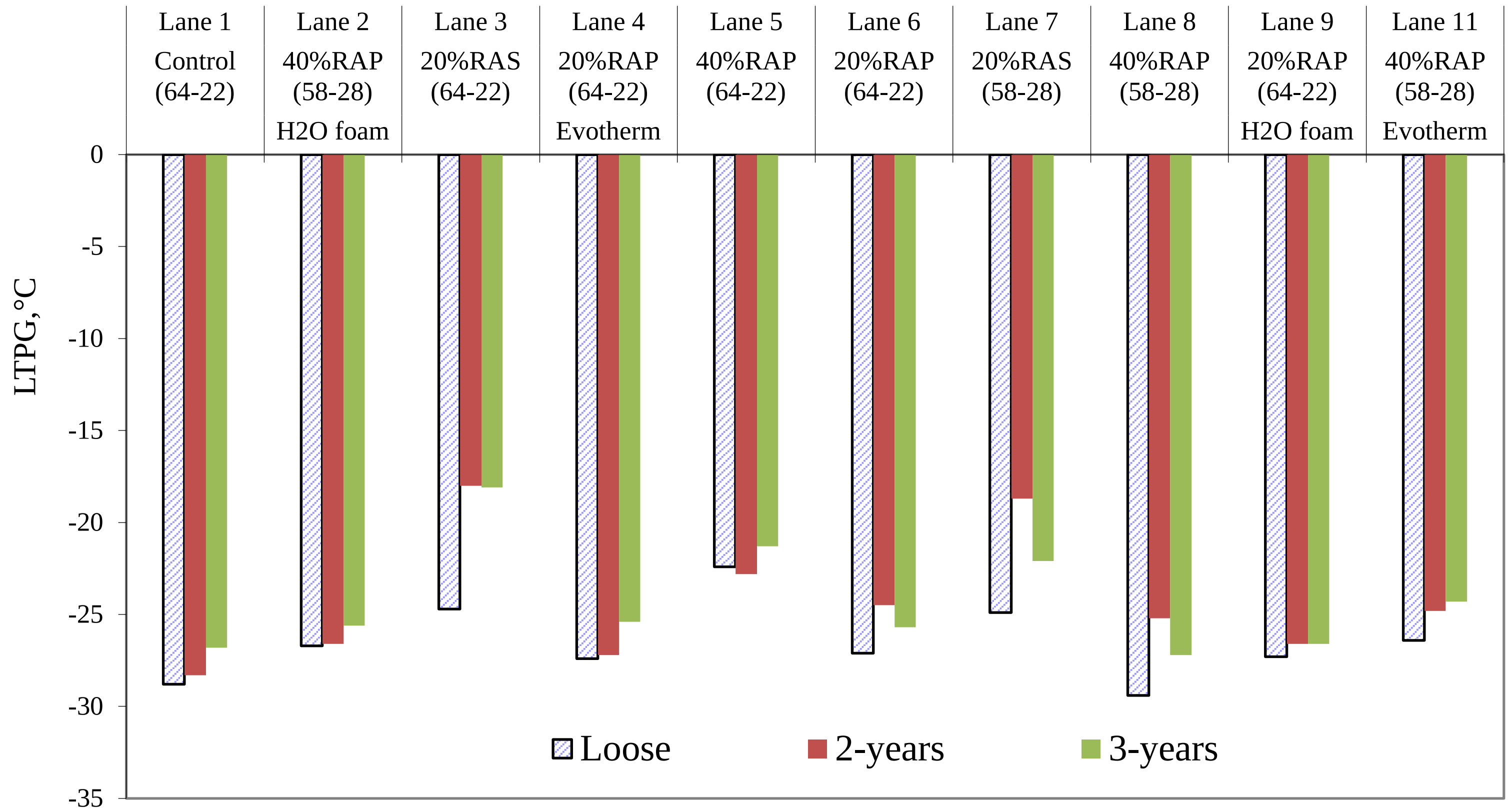
LTPG Loss with Aging



Top Lift

3 Years < 2 Years < Loose Mix

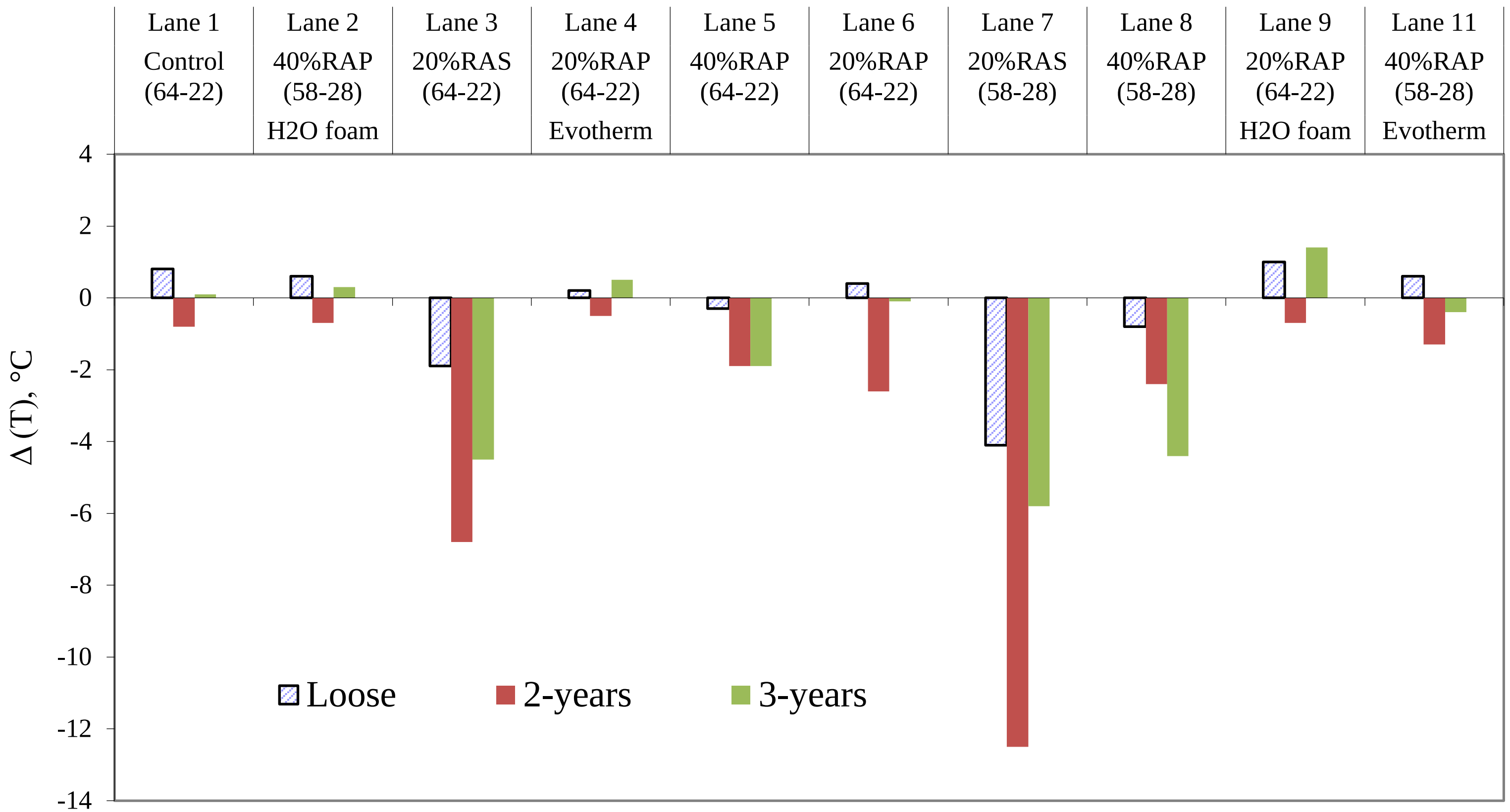
LTPG Loss with Aging



Bottom Lift

Relative Minor Changes

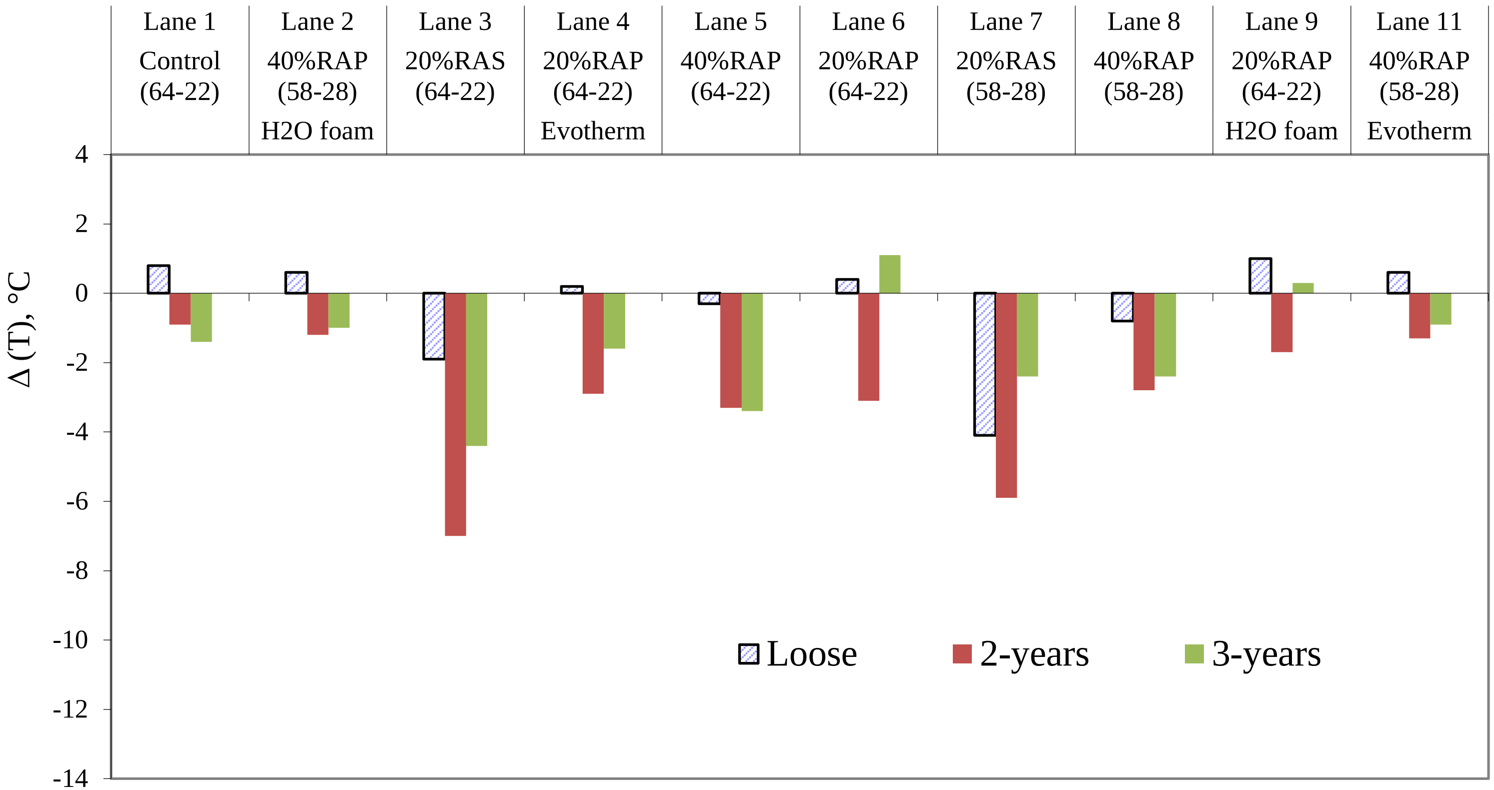
Delta (T) Variation with Aging



Top Lift

Delta (T) Higher for 20% RAS Addition and Aging

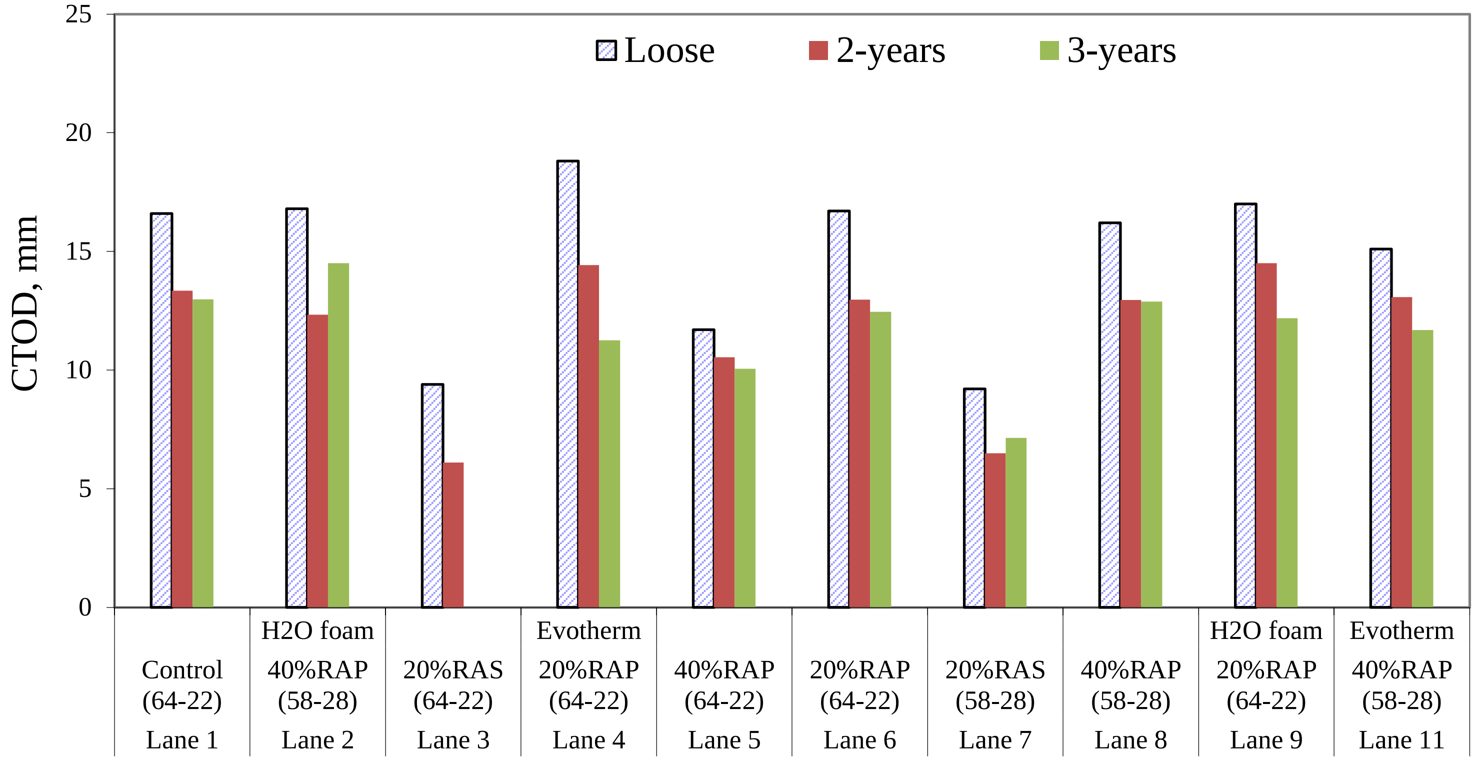
Delta (Tc) Variation with Aging



Bottom Lift

Delta (T) Higher for 20% RAS Addition and Aging

Change in Ductile Strain Tolerance with Aging

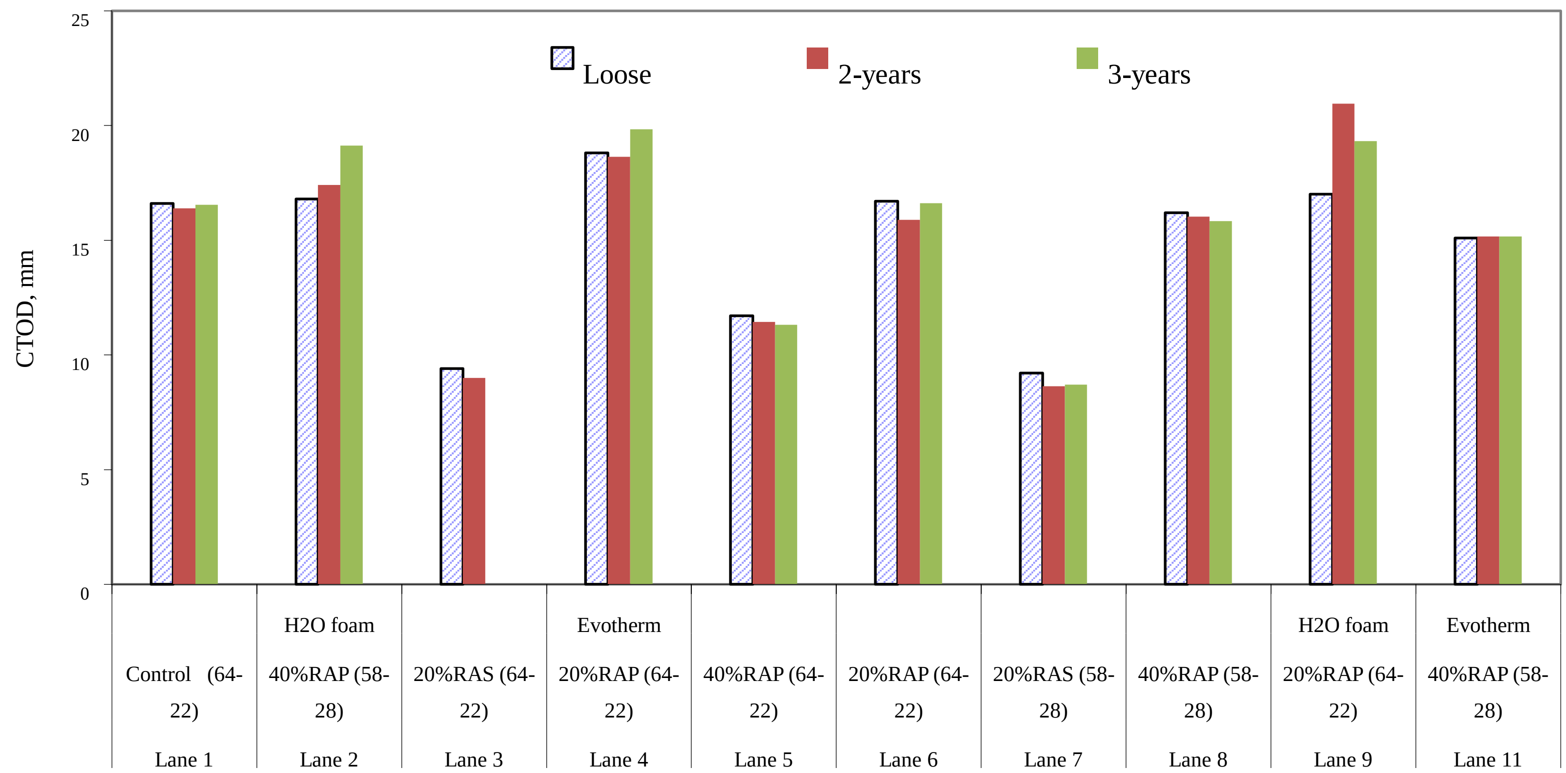


Top Lift

3 Years < 2 Years < Loose Mix

L3, L5 and L7 smallest

Ductile Strain Tolerance Loss with Aging

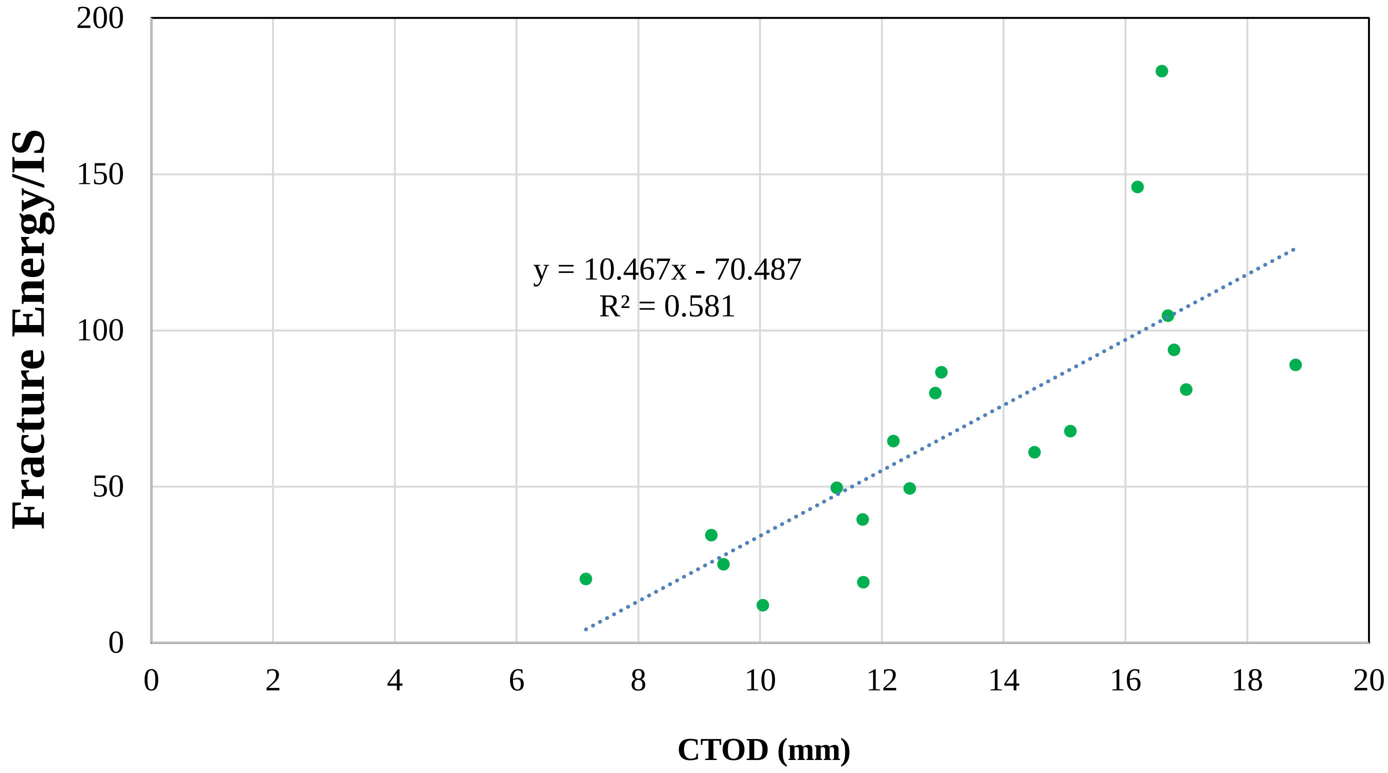


Bottom Lift

Relative Minor Changes

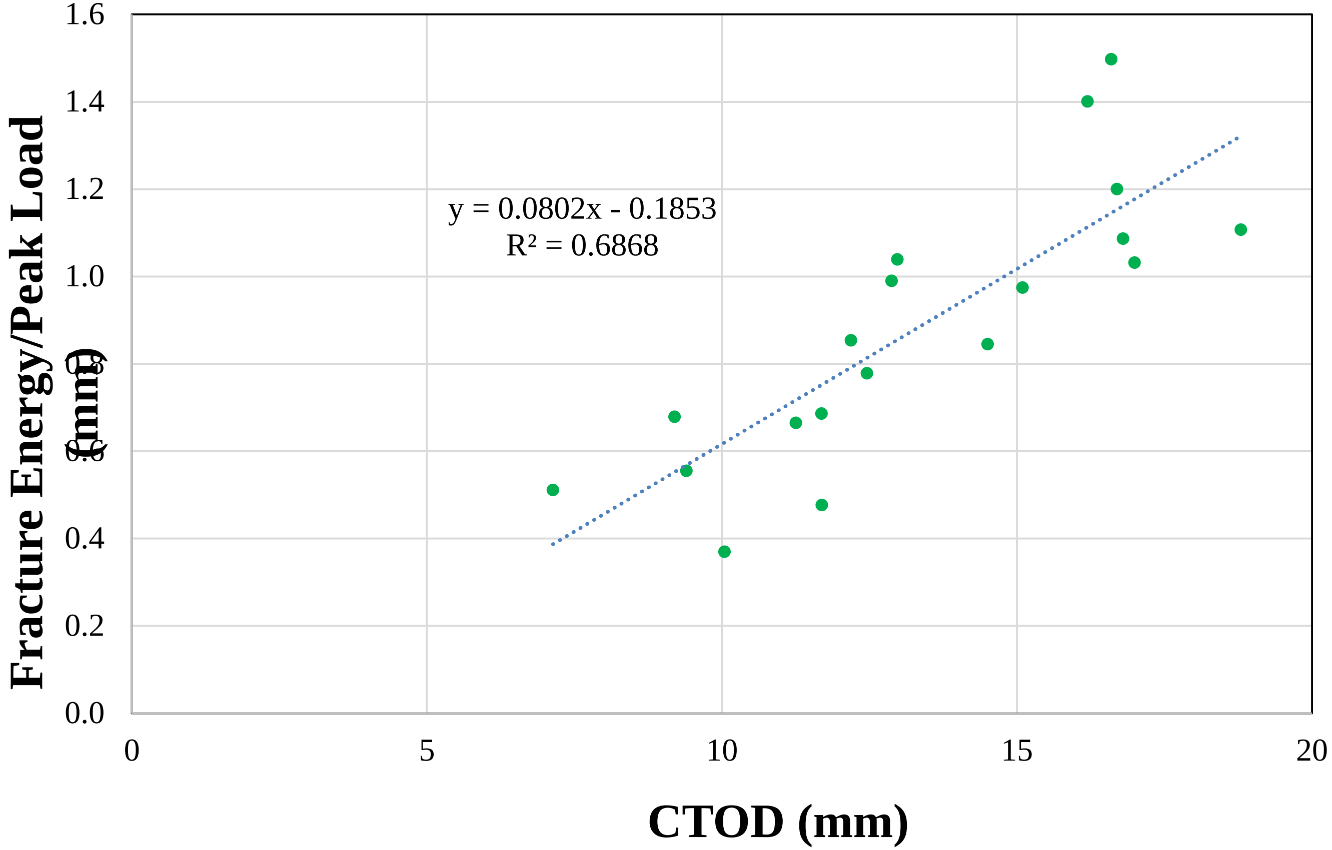
L3, L5 and L7 smallest

Correlation Between Binder & Mix



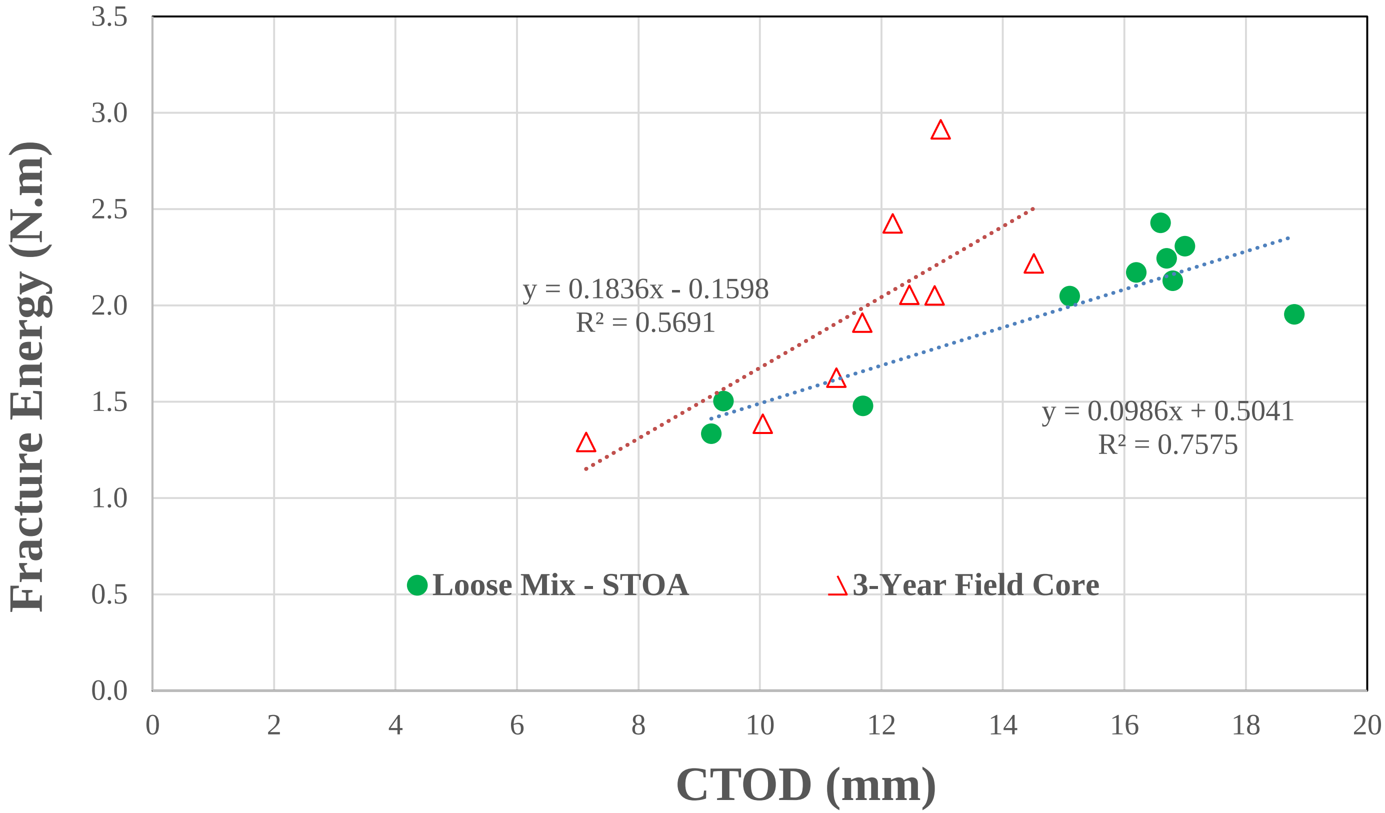
CTOD vs. (Fracture Energy/IS)

Correlation Between Binder & Mix



CTOD vs. (Fracture Energy/Peak Load)

Correlation Between Binder & Mix



CTOD vs. (Fracture Energy)

Laboratory Test + Field Performance

- Statistical Method (Kendall's Tau)

Material	Fracture Energy (E)	E1/IS	E/IP	E1/P	E/P
Loose Unaged	**0.94**	**0.72**	**0.78**	**0.83**	**0.67**
Loose Aged	**0.61**	**0.56**	**0.50**	**0.67**	**0.56**
1-Year Top	0.71	0.79	0.86	0.71	0.71
3-Year Top	0.78	0.78	0.72	0.72	0.72

Summary and Findings

- Top lift mix was significantly more aged than the bottom lift.
- Top lift ages with time whereas the effect of aging on the bottom lift is not as evident and is partly compromised by construction variability.
- The 5-day 85°C oven aging found to age the mix significantly more severely than the 3-year field climatic aging process.
- The binder PG changes also reflect those of the mix.
- The top lift experienced significant CTOD losses with aging, while no major changes were found in the bottom lift.
- Monotonic mix results correlate reasonably well with binder CTOD results.

Summary and Findings

- Close correlation found between the mix index E/P and the binder CTOD, as indicating the strain tolerance or deformability of the material.
- The three stiff mixtures, L7, L3 and L5, either with high RAP content up to 40% RBR or with 20% RBR RAS, were the earliest to crack, indicating the worst performance in terms of cracking resistance.
- A softer PG grade was effective at improving the performance for 40% RAP BR mixes but ineffective at improving the performance of tear off RAS shingles providing 20% RBR.
- No difference in performance was observed between the HMA and WMA mixtures if other variables are the same.
- Statistical analysis illustrates strong correlation between the direct tension monotonic mix test and ALF field testing in terms of evaluating the cracking resistance of the asphalt mixtures combined with RAP/RAS and WMA.

Juicing RAP Mixes

Asphalt Mixture and Construction Expert Task Group

September, 2017

Pavement Materials Team, TFHRC

RBR + More Binder

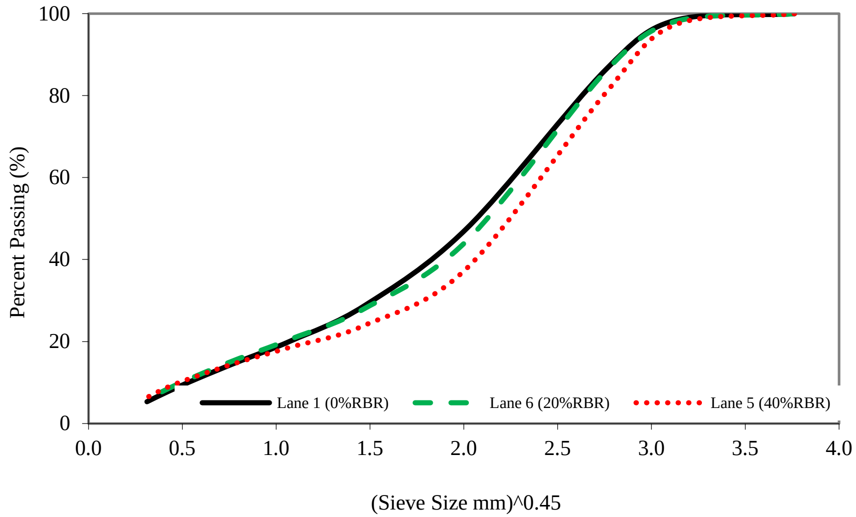
- Conducting performance tests on 20% & 40% RAP-RBR +0.25%, +0.5%, +0.75% binder.
- Will determine how much binder needs to be added for 20% & 40% RAP-RBR mixes to exhibit equivalent performance.
- 20% RAP-RBR mix will be the reference mix that should be the equivalent performance target.

Materials and Testing

- **Materials**
  - L1 (0% RBR, control mix)
  - L6 (20% RBR)
  - L5 (40% RBR)
- **Additional Binder**
  - +0.5%, +0.75%, (+0.25%)
- **Testing**
  - Dynamic modulus
  - Direct tension fatigue (AASHTO TP 107)
  - Stress sweep rutting (SSR)

Volumetrics

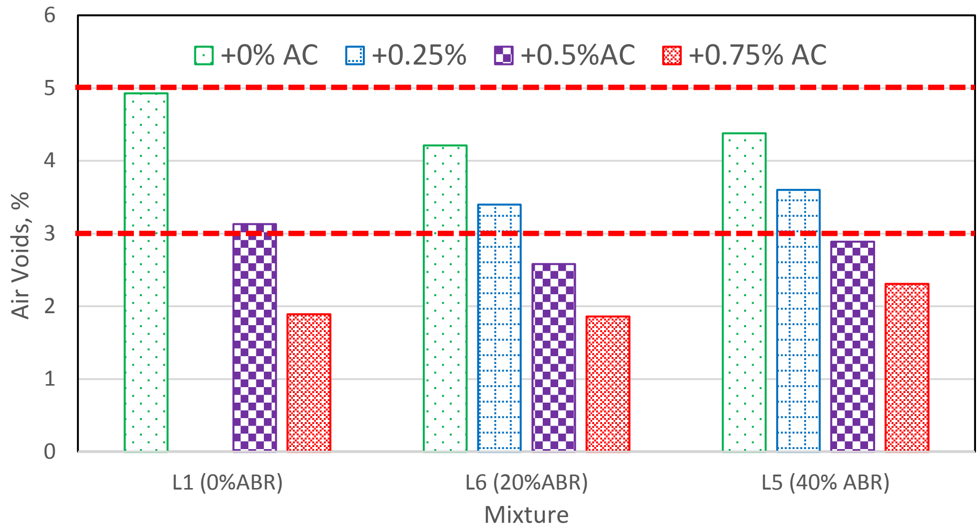
Dimension (mm)	Sieve Size	Lane 1 (0%RBR)	Lane 6 (20%RBR)	Lane 5 (40%RBR)
19	3/4 inch	100	100	100
12.5	1/2 inch	98.3	98.0	97.1
9.5	3/8 inch	86.2	85.8	80.6
4.75	# 4	47.6	44.6	37.9
2.36	# 8	28.8	28.1	24.0
1.18	# 16	20.1	20.6	18.6
0.6	# 30	15.0	15.7	14.9
0.3	# 50	11.0	11.7	11.6
0.15	# 100	7.8	8.5	8.9
0.075	#200	5.3	5.8	6.3

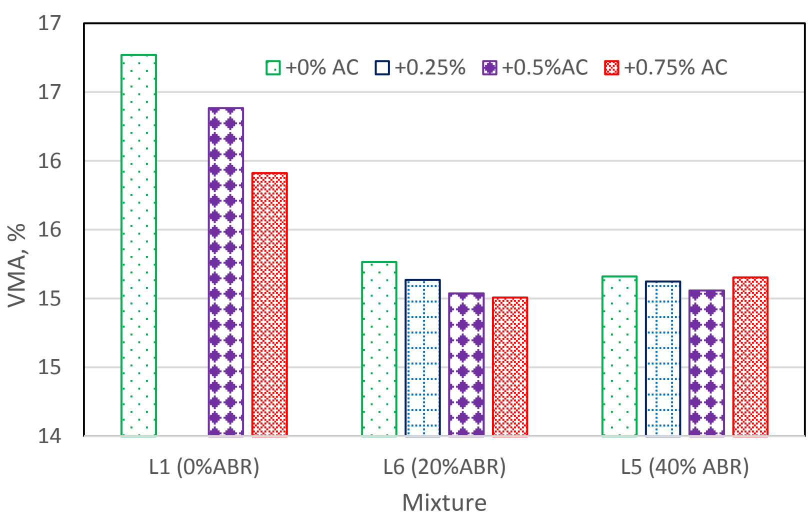


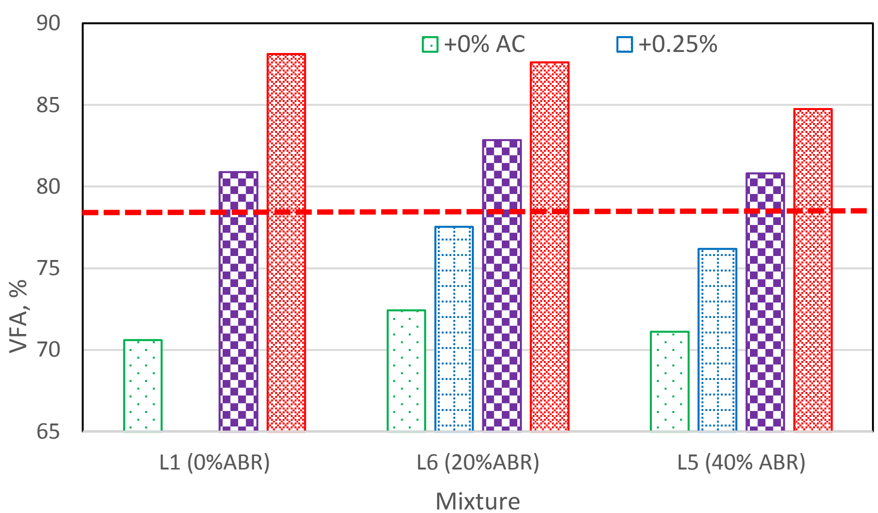
	L1 (0%RBR)				L6 (20%RBR)				L5 (40%RBR)			
+ AC	+0	+0.25%	+0.5%	+0.75%	+0	+0.25%	+0.5%	+0.75%	+0	+0.25%	+0.5%	+0.75%
G_{mm}	2.747	2.735	2.723	2.711	2.744	2.732	2.72	2.708	2.744	2.732	2.72	2.708
Air Voids	4.93	---	3.13	1.89	4.21	3.4	2.58	1.86	4.38	3.6	2.89	2.31
G_{mb}	2.612	---	2.638	2.66	2.629	2.64	2.65	2.658	2.624	2.632	2.641	2.645
P_b	5.14	5.39	5.64	5.89	4.92	5.17	5.42	5.67	4.62	4.87	5.12	5.37
P_{be}	4.63	4.89	5.14	5.39	4.30	4.55	4.80	5.05	4.20	4.45	4.70	4.95
VMA	16.8	---	16.4	15.9	15.3	15.1	15.0	15.0	15.2	15.1	15.1	15.2
VFA	70.6	---	80.9	88.1	72.4	77.5	82.8	87.6	71.1	76.2	80.8	84.8
% dust	5.3	5.3	5.3	5.3	5.8	5.8	5.8	5.8	6.3	6.3	6.3	6.3
DB Ratio	1.14	1.08	1.03	0.98	1.35	1.28	1.21	1.15	1.50	1.42	1.34	1.27

Volumetrics

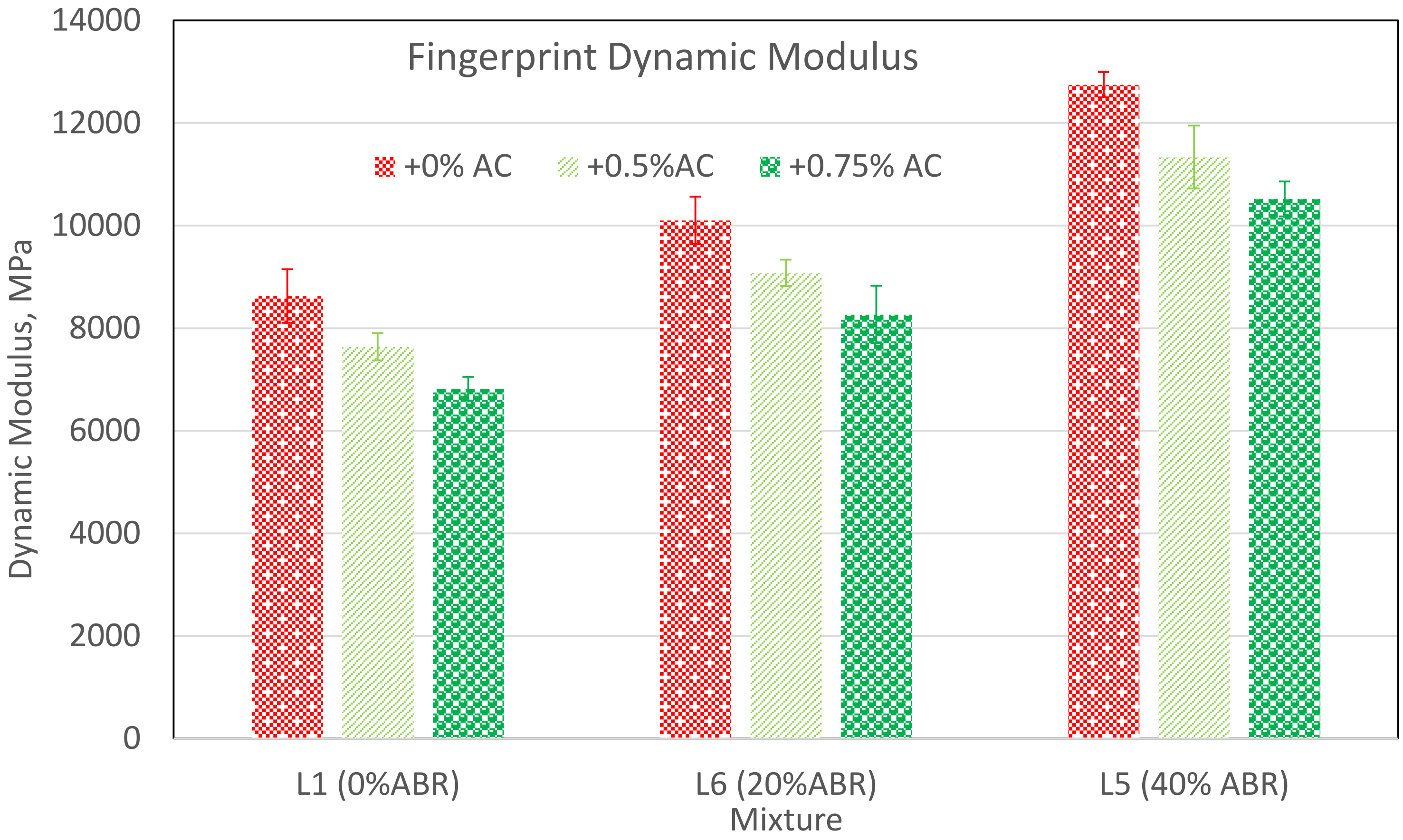
Requirements	
Air Voids	3%-5%
VMA	> 14%
VFA	65%-78%





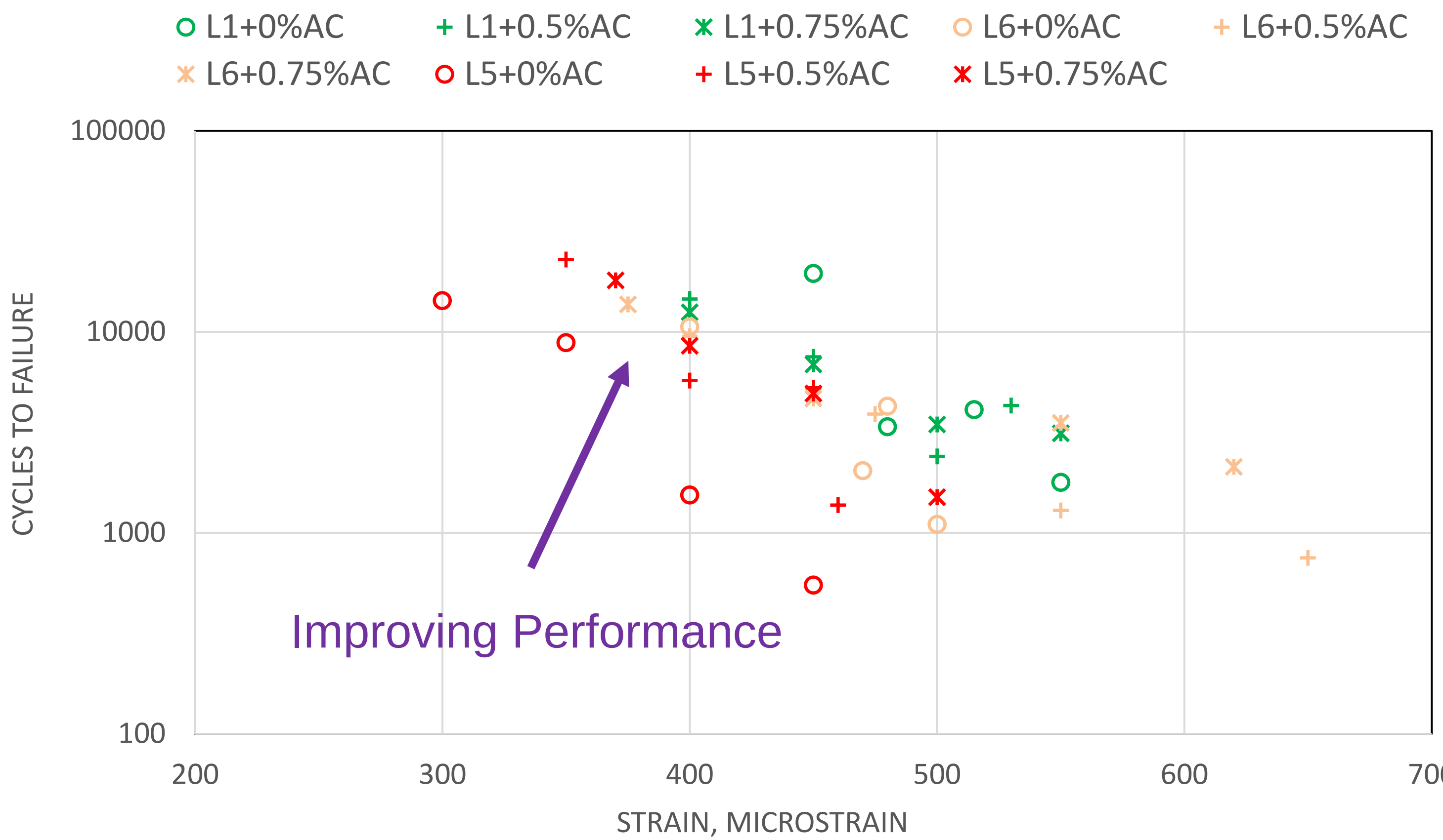


Direct Tension Fatigue Fingerprint |E*|



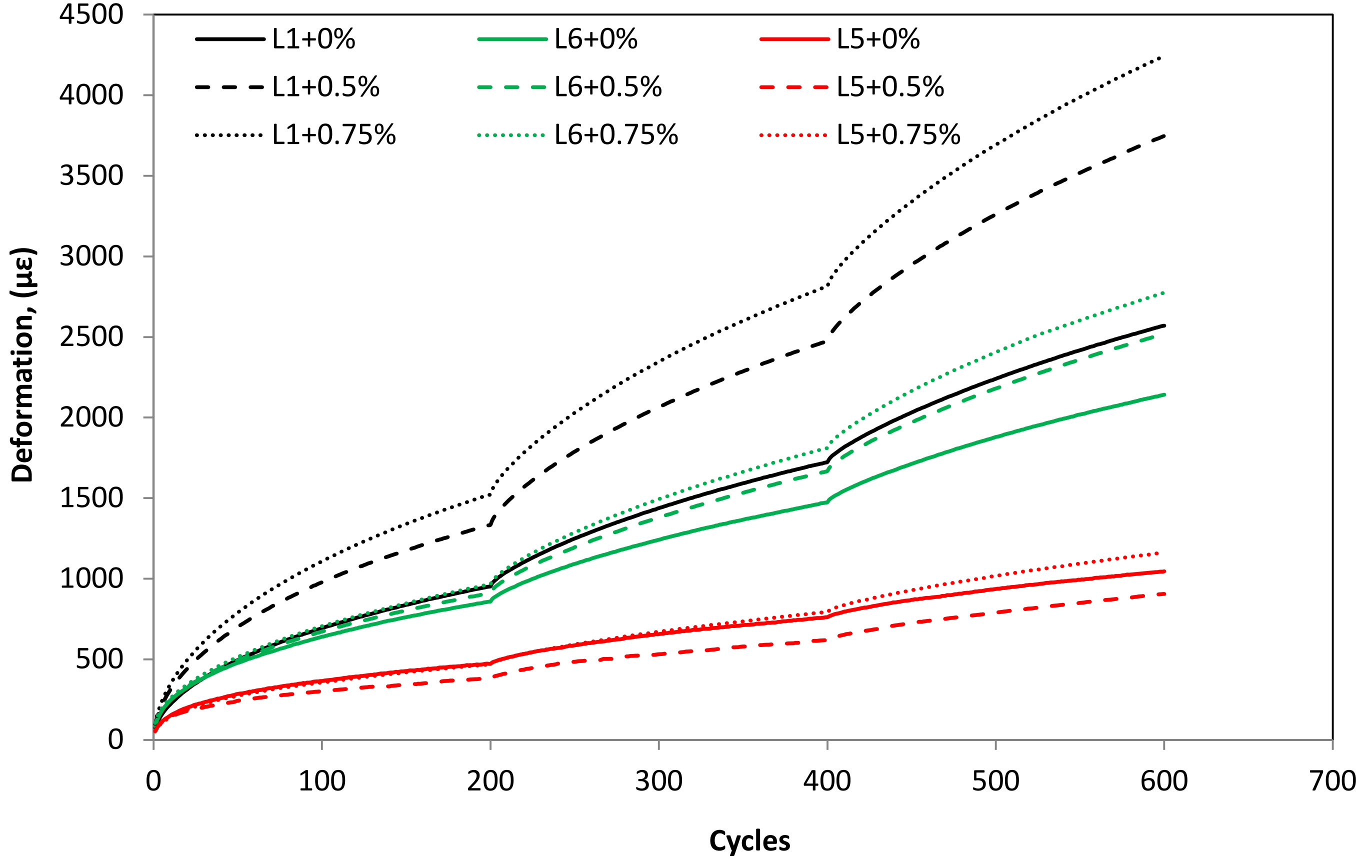
Addition of binder softening the mix; higher RBR stiffer mix

Axial Direct Tension Fatigue Testing



No clear change of fatigue performance with the addition of binder in control mix
Significant improvement of fatigue with the binder addition in L5 (40%RBR)

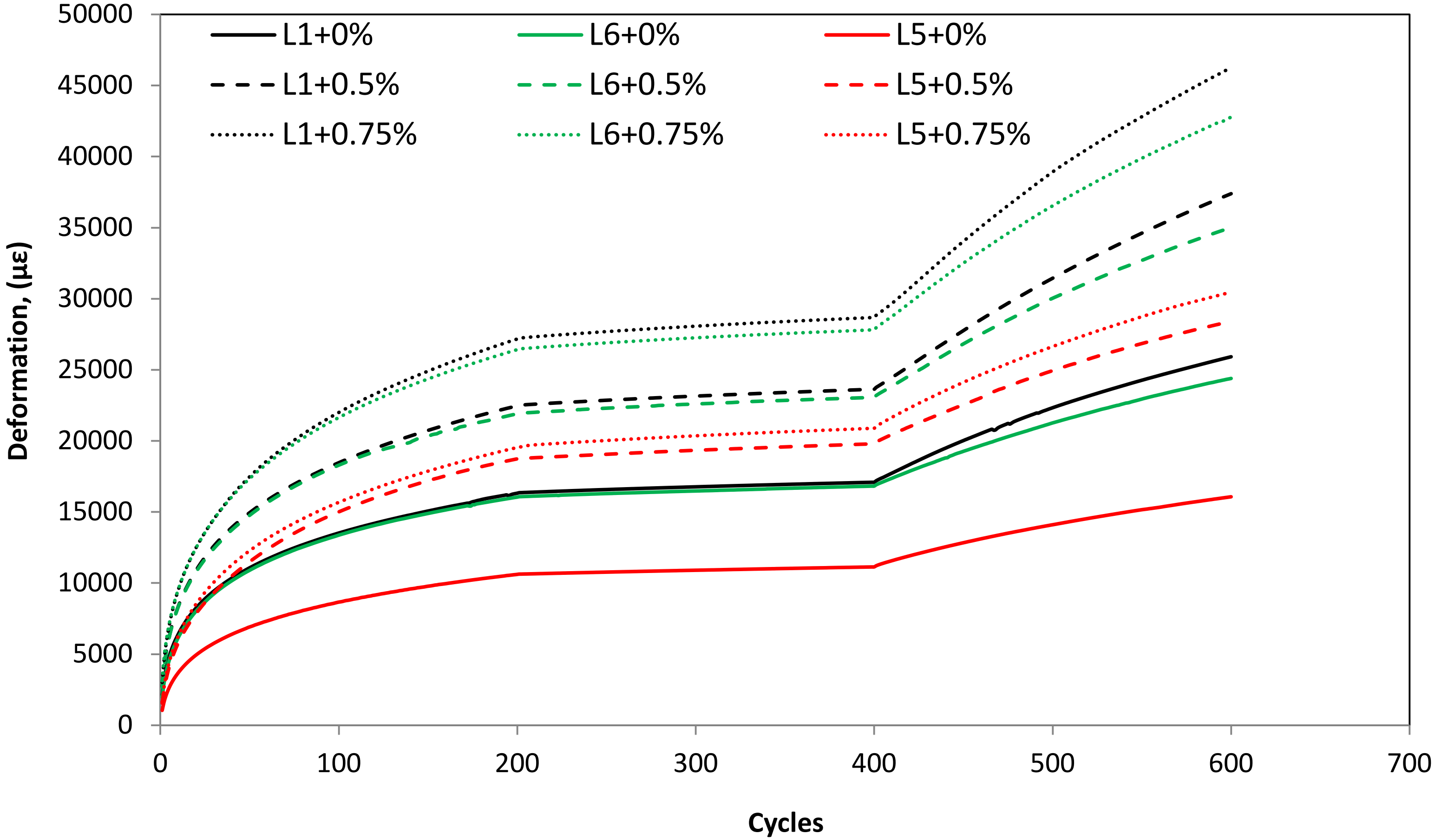
Stress Sweep Rutting (20ºC)



Higher RBR produces significant lower deformation

Addition of binder increases deformation

Stress Sweep Rutting (54ºC)



Higher RBR produces significant lower deformation

Addition of binder increases deformation

RBR + More Binder

- Conducting +0.25% binder.
- Predicted pavement performance with the fatigue and SSR data (FlexPAVE).
- Next step is to determine how much binder is needs to be added for 20% & 40% RAP-RBR mixes to achieve equivalent performance.

Thank You!

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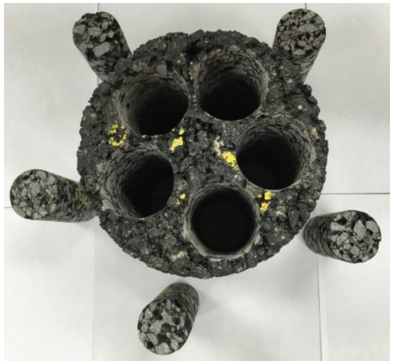
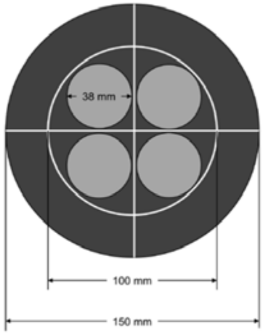
Questions?

Small Scale Specimen Fabrication

- **TFHRC Experience**
  - Started small scale specimen fabrication and testing in 2011
  - First tried to get 6 little cores from 1 gyratory specimen
  - Modified and have been getting 5 little cores
  - No dimensional tolerances; but need to meet Va criteria (target ±0.5%)
- **NCSU Proposed AASHTO Standard**
  - Get 4 cores from a gyratory specimen
  - No Va criteria, but need to meet dimensional tolerance





Small Scale Specimen Fabrication

- **TFHRC Experience with 5 Little Cores**
  - Various mixtures cored and tested (NMAS 4.75-19mm)
  - Mix with 12.5mm and below NMAS, 5-core method works satisfactorily
  - Need more data for 19.0mm and plus NMAS mix

NMAS (mm)	Total Number of Sample Produced	Target ±0.5% Va		Target±0.75% Va	
		Number of "Good" Sample	%	Number of "Good" Sample	%
4.75	5	4	80%	4	80%
9.5	20	18	90%	18	90%
12.5	740	573	77%	620	84%
19	35	12	34%	12	34%
Total	800	607	76%	654	82%

- **TFHRC Recommendations**
  - 5-core method can fabricate more specimens with quality
  - Volumetric criteria needed?

PAVEMENT TESTING FACILITY

STATUS REPORT
SEPTEMBER/2017

PTF

CURRENT PROJECT 2

Asphalt Concrete Field Density and Aggregate Base Geosynthetic Reinforcement

AC Field Density and CAB Geosynthetic Reinforcement

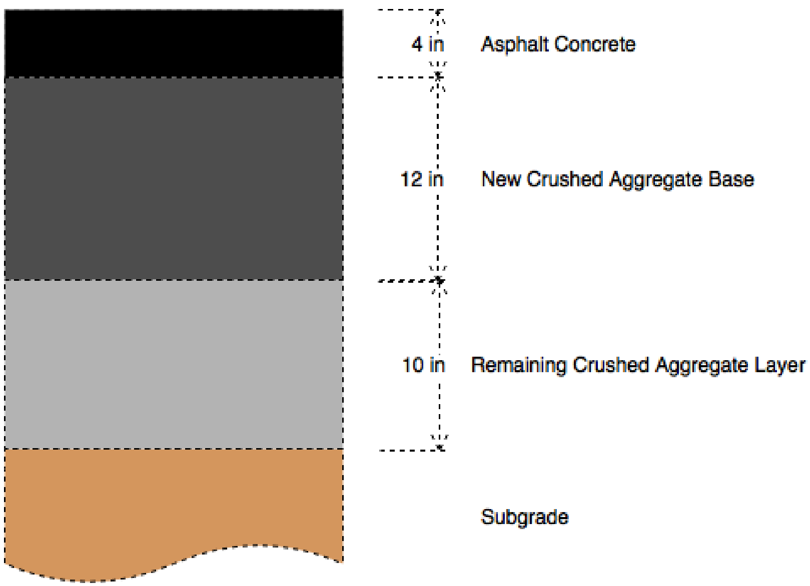
- Purpose
  - The compaction of asphalt concrete (AC) mixtures is a critical component in the process of achieving optimal pavement performance.
  - The quality and strength of the substructure (base and subgrade) have great influence of pavement performance.
- Objectives
  - Investigation of Asphalt Concrete Compaction and Its Impact on Performance of Pavements Built with and without Geosynthetic Base Reinforcement

The Experiment

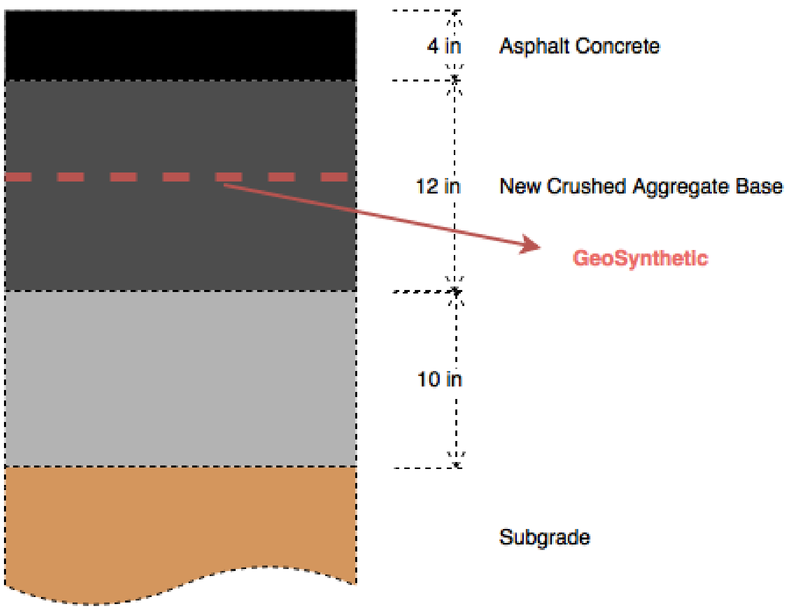
- One AC mixture
- Four Lanes (4 different AC compaction levels)
  - High (>92% compaction)
  - Medium (90-92%)
  - Low (< 90%)
- Two structures per lane
  - Unreinforced
  - Reinforced with a Standard BS-1200
- Performance measures
  - Cracking
  - Rutting

Pavement Structure

No Reinforcement



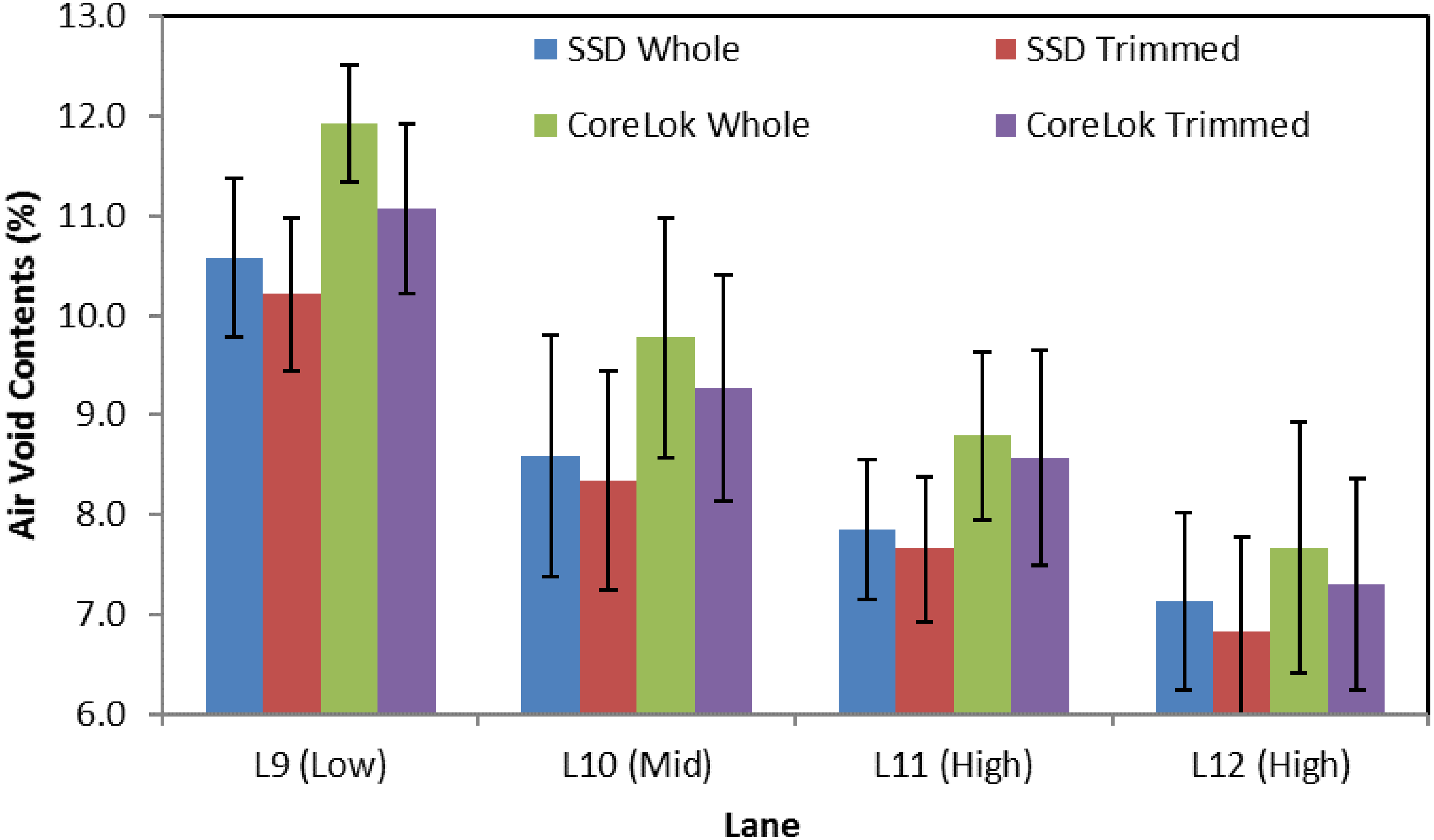
With Reinforcement



Air voids of field cores

Lane	SSD Whole		SSD Bottom Trimmed		CoreLok Whole		CoreLok Bottom Trimmed	
	Ave.	St. Dev.	Ave.	St. Dev.	Ave.	St. Dev.	Ave.	St. Dev.
L9 (Low)	10.6	0.8	10.2	0.8	11.93	0.6	11.1	0.8
L10 (Mid)	8.6	1.2	8.3	1.1	9.9	1.2	9.3	1.1
L11 (High)	7.9	0.7	7.7	0.7	8.8	0.8	8.6	1.1
L12 (High)	7.1	0.9	6.8	1.0	7.7	1.3	7.3	1.1

Air voids of field cores (cont'd)



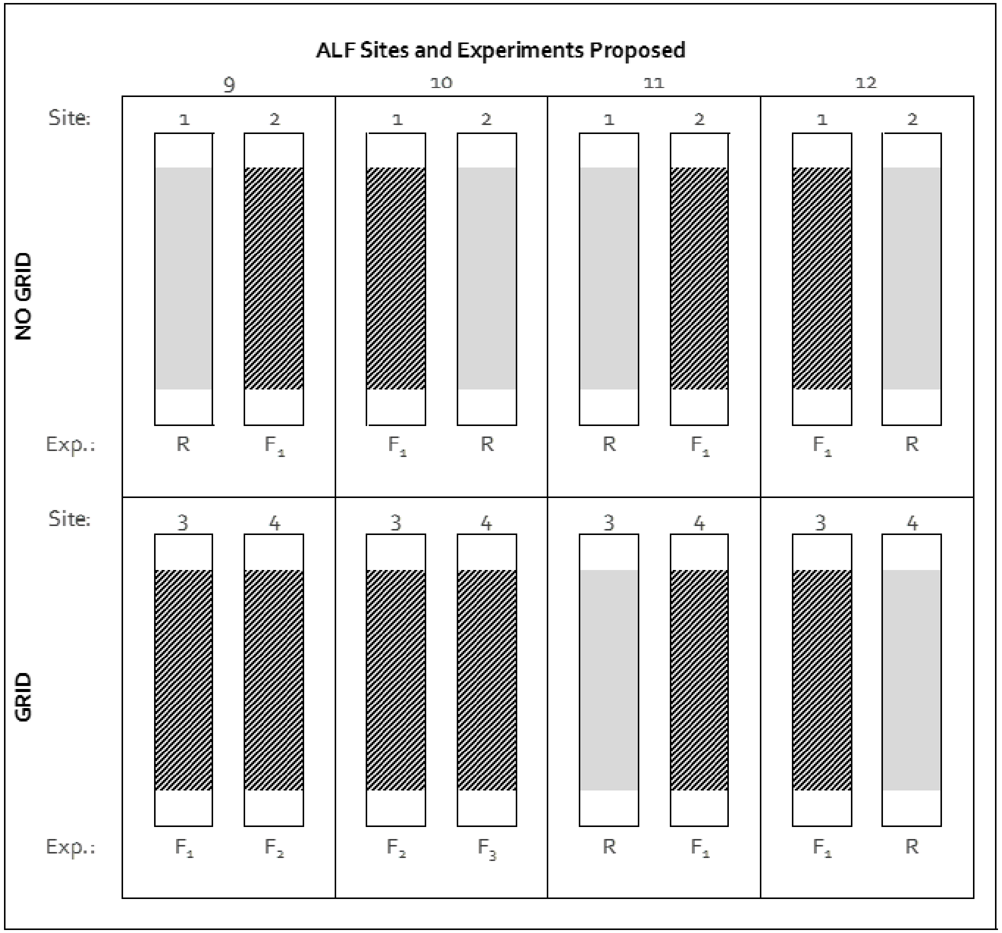
Proposed Testing

- Rutting
  - Terminal state: 1.5 to 2 inches of total permanent deformation
  - Loading temperature:
    - Variable temperature:
      - 10K passes at 40°C
      - 5K passes at 50°C (estimated)
      - Cycle until terminal state is reached
  - All lanes will have at least one rutting test at one unreinforced base site
  - Two lanes will be tested twice:
    - Impact of base reinforcement on performance

Proposed Testing (Cont'd)

- Cracking
  - Loading temperature: 20°C
  - Terminal state: total cracking length > 1,000 inches
    - Early stages of cracking in which preventive maintenance would be optimum intervention in real pavements
  - All lanes will be tested at least twice for fatigue cracking:
    - One at one unreinforced base site, and
    - One at one geosynthetic reinforced base site
  - Effects of aging
    - Two lanes will have one extra fatigue test at aged conditions

Layout and Current Status

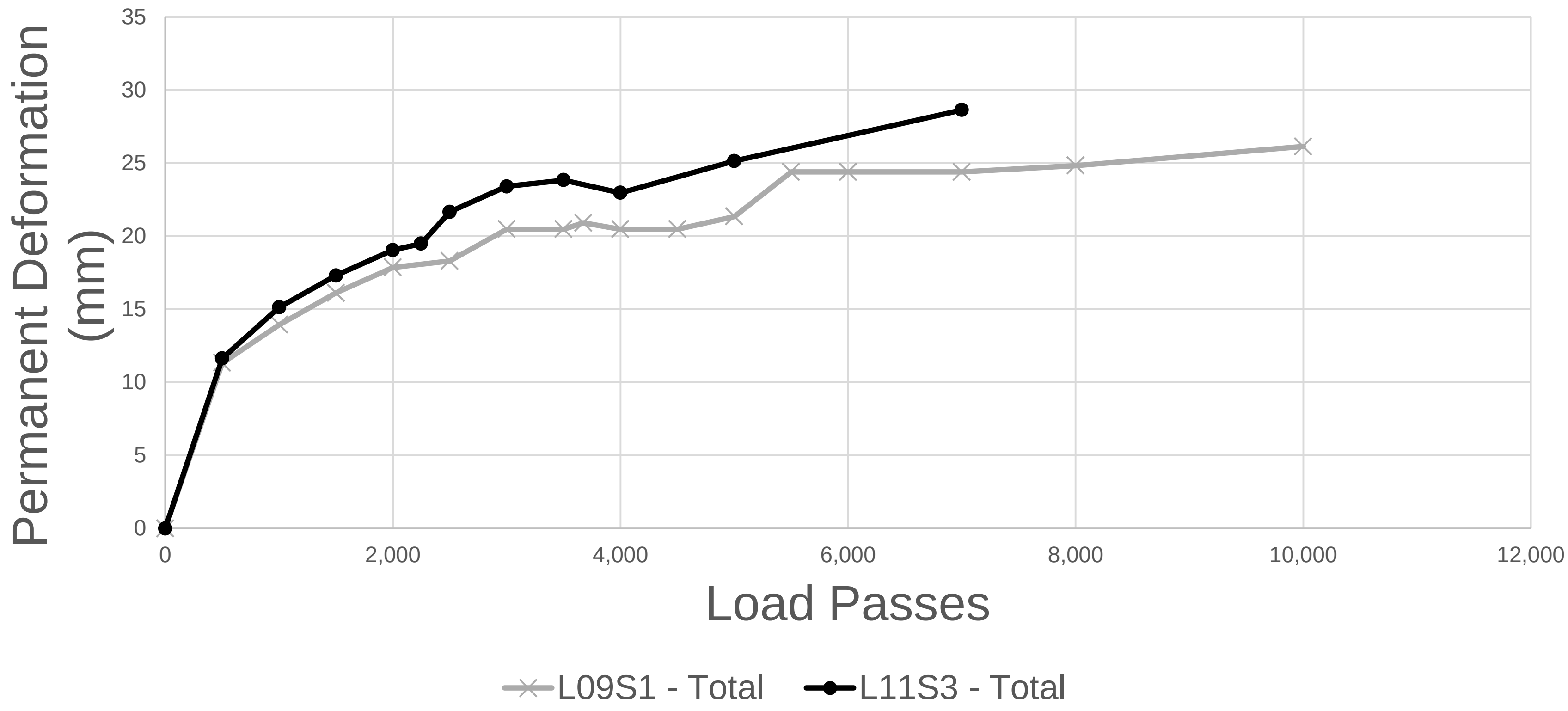


- F_i – Fatigue test at aged conditions
- R – Rutting test

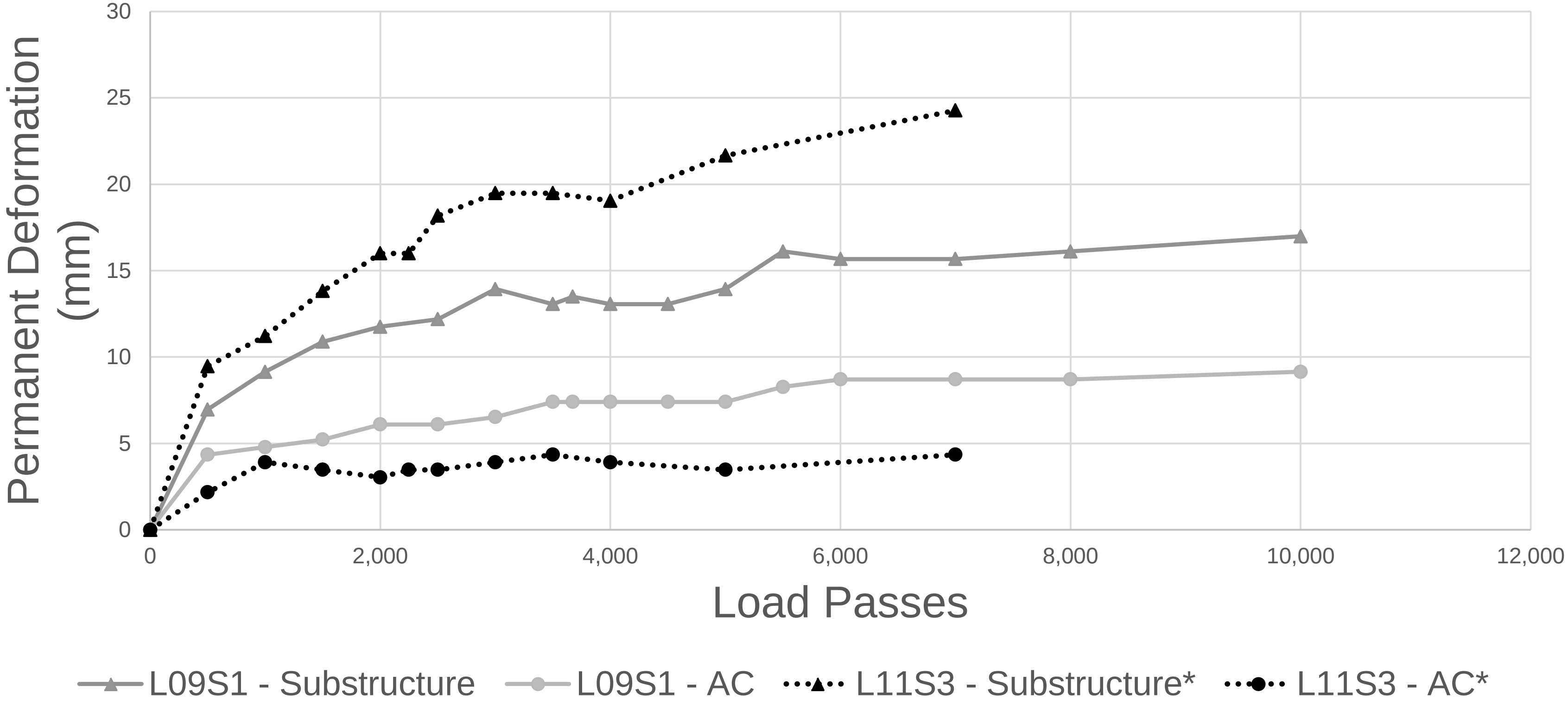
- Current Status (Rutting):
  - Lane 9 Site 1, 10,000 passes completed
  - Lane 11 Site 3, 7,000 passes completed

- Next Steps (Rutting):
  - Lane 10, Site 2
  - Lane 12, Site 4
  - Lane 11, Site 1

Preliminary Results
Total Rutting



Preliminary Results
AC & Substructure Rutting



Thank you.