Update – Transportation Pool Fund TPF 5(294)

Develop Mix Design and Analysis Procedures for Asphalt Mixtures Containing High-RAP Contents

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FHWA Asphalt Mixture Expert Task Group Meeting

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Outline

- ❑ *Status Update*
- ❑ Objectives/Scope
- ❑ Materials
- ❑ Test Methods
- ❑ Results and Discussions
- ❑ Summary

Objective

- Evaluate fatigue/fracture tests that can be conducted on plant mixtures (lab or field compacted)
  - Ranking quality of RAP and/or RAS mixtures as compared to virgin mixtures.
  - Develop score card
- Effect of RAP on mixtures’ cracking performance

Project Scope

- Two field projects
  - Each field project
    - Two mixtures: Conventional, RAP and/or RAS
      - Conventional may include 15% RAP
  - Four mixtures
- Mixture experiment
  - Direct Tension Cyclic Fatigue (SVECD),
  - SCB Jc,
  - Texas Overlay,
  - Beam fatigue
  - FL IDT

Status Update

U.S. Department of Transportation
Federal Highway Administration

- FHWA ALF
  - *Advance Use of Recycled Asphalt in Flexible Pavement Infrastructure: Develop and Deploy Framework for Proper Use and Evaluation of Recycled Asphalt in Asphalt Mixtures*
  - Mixture experiment – All Completed
    - Direct Tension Cyclic Fatigue
      - SVECD
    - SCB (Semi-Circular Bend)
    - Texas Overlay
    - Florida IDT
    - Beam Fatigue

Status Update

- Project 1: Florida & Colorado
  - Mixture experiment
    - Direct Tension Cyclic Fatigue: Completed
      - ✓ SVECD
    - SCB (Semi-Circular Bend): Completed
    - Texas Overlay: Completed
    - Florida IDT: Completed
    - Beam Fatigue: On-going

Status Update

- ❑ Project 1: Louisiana
  - ❖ Mixture experiment – On-going
    - ➢ Direct Tension Cyclic Fatigue
      - ✓SVECD
    - ➢ SCB (Semi-Circular Bend)
    - ➢ Texas Overlay
    - ➢ Florida IDT
    - ➢ Beam Fatigue

Materials

❑ Mixture Composition

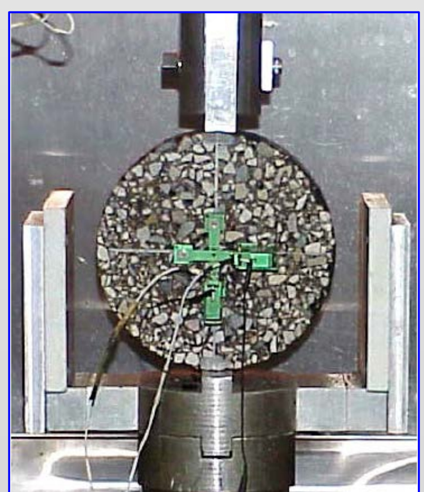
Mixture Designation	Mixture Source	RAP RBR (%)	Base Binder PG
CO-V	Colorado DOT	0	64-22
CO-18RAP		18	58-28
FL-17RAP	Florida DOT	17	58-22
FL-36RAP		36	52-28
ALF-L1-V	FHWA ALF	0	64-22
ALF-L6-20RAP		20	64-22
ALF-L5-40RAP		40	64-22

Note: RBR = recycled binder ratio, percentage of recycle binder in the total binder.

Test Methods

- SCB Jc, ASTM D 8044
- SVECD,
  - AASHTO TP 107, AASHTO TP 79 (T 378)
- IDT, FDOT
  - UF
- Texas Overlay, Tex-248-F



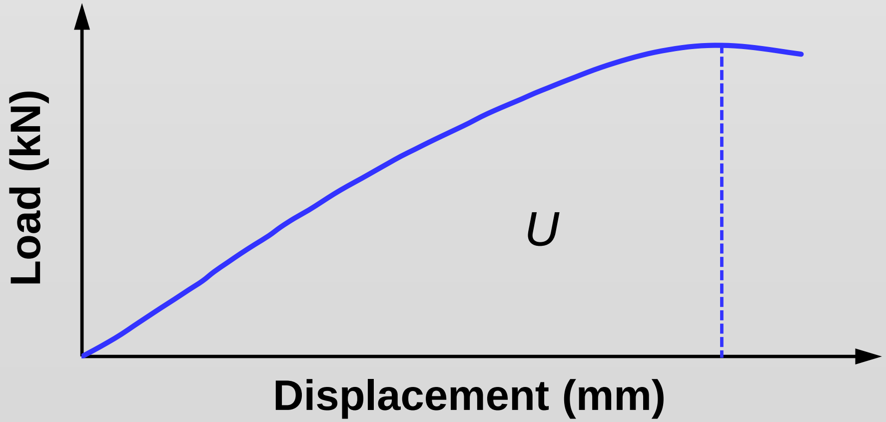


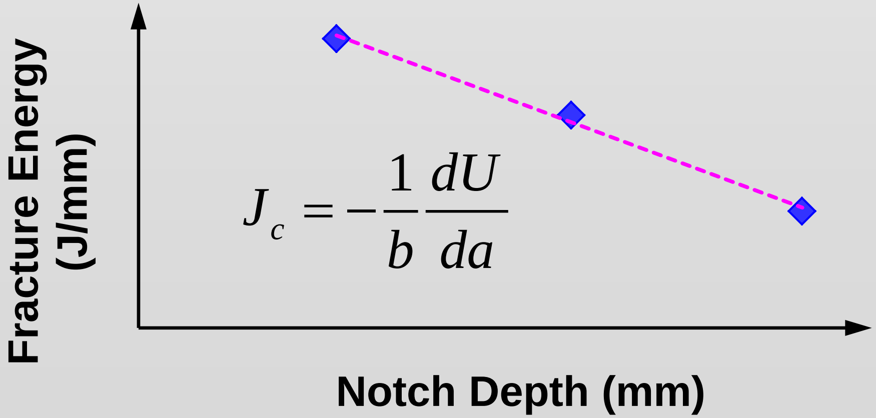

Summary of Test Methods

Test	Temp.	Protocol	Test Mode	Specimen Geometry	Cracking Phases	Engineering Properties
SCB Jc	25°C	ASTM D8044	Monotonic, 0.5 mm/min.	Semi-circular, ϕ150 mm × 57 mm	Crack propagation	• Critical strain energy release rate
SVECD	18°C	• AASHTO TP79 (T 378) • AASHTO TP107	Cyclic, 10 Hz	• ϕ100 mm × 150 mm for modulus • ϕ100 mm × 130 mm for fatigue	Crack initiation	• Dynamic modulus • Damage characteristic curve • Material Fatigue Sensitivity
IDT	10°C	UF draft procedure	• Cyclic for modulus, 10 Hz • Monotonic for strength test, 50 mm/min.	ϕ150 mm × 38 mm	Crack initiation	• Dynamic modulus • Creep compliance • Indirect tensile strength • Dissipated creep strain energy
Texas overlay	25°C	Tex-248-F	Cyclic, 0.1 Hz	Oval brick, ϕ150 mm × 76 mm × 38 mm	Crack initiation & propagation	• Number of cycles to failure • Critical fracture energy • Crack progression rate

SCB Jc

- ❑ Test Method
  - ❖ ASTM D8044
  - ❖ Temperature: 25°C
  - ❖ Loading rate: 0.5 mm/min
- ❑ Specimen Preparation
  - ❖ SGC: Φ150×57mm
  - ❖ Air void: 7.0 ± 0.5%
  - ❖ Long-term oven aging at 85°C for 120 hours
  - ❖ Notch depths: 1″, 1.25″, 1.5″.





S-VECD

- Dynamic Modulus Test
  - AASHTO TP 79 (T 378)
    - Temperature: 4.4°C, 25°C, 37.8°C
    - Frequency: 25, 10, 5, 1, 0.5, 0.1 Hz
- Direct Tension Cyclic Fatigue Tests
  - AASHTO TP 107
    - Temperature: 18°C
    - Frequency: 10 Hz
  - Specimen
    - Air void: 7.0 ± 0.5%
    - Long-term aging: 85°C for 120 hours

S-VECD Test - Analysis

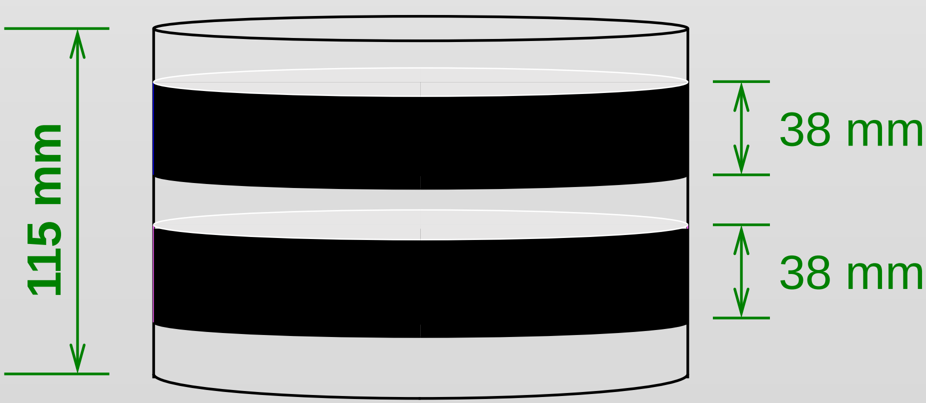
- Damage Characteristic Curve C(S)
  - Follow AASHTO TP 107:

$$C = e^{aS^b}$$

- Material Fatigue Sensitivity (MFS)
  - Measure materials' resistance to fatigue cracking
  - Higher MFS represents lower fatigue resistance
  - *Cao et al., Assessing the effects of RAP, RAS, and warm-mix technologies on fatigue performance of asphalt mixtures and pavements using viscoelastic continuum damage approach. AAPT, 2017.*

Florida IDT Test

- ❑ UF Draft Procedure
- ❑ Specimen Preparation
  - ❖ SGC: Φ150×115 mm
  - ❖ Cut to obtain two 38-mm thickness specimens
  - ❖ Air void: 7.0 ± 0.5%
  - ❖ Long-term aging: 85°C for 120 hours



Standard Method of Test for

Tensile Creep Compliance, Tensile Failure Limits and Energy Ratio of Asphalt Mixtures Using the Superpave Indirect Tension (IDT) Test

AASHTO Designation:

1 SCOPE

1.1. This standard provides distinct procedures for determining the tensile creep compliance, tensile failure limits and energy ratio of asphalt mixtures using the Superpave Indirect Tension (IDT) test.

1.2. The procedures described in this standard provide tensile properties of asphalt mixtures for evaluation of cracking performance at intermediate temperatures (i.e., 0-25 ºC). These procedures apply to dense graded, gap graded and open graded test specimens prepared from either field cores or laboratory compacted samples. Test specimens under these procedures are nominally 150 mm (6 in) in diameter.

1.3. *These tests may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.*

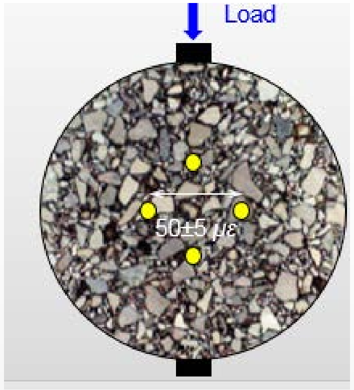
2 REFERENCE DOCUMENTS

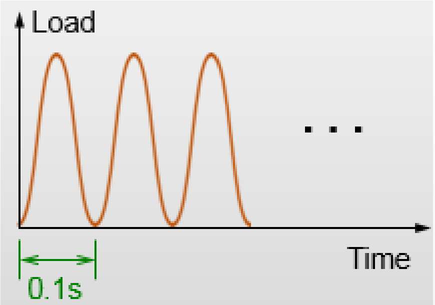
2.1. *AASHTO Standards:*

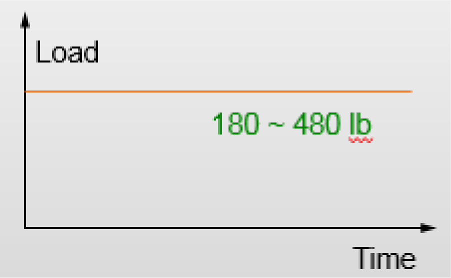
- M 323 Superpave Volumetric Mix Design.
- R 30-02 Mixture Conditioning of Hot Mix Asphalt (HMA).
- R 35 Superpave Volumetric Design for Asphalt Mixtures.
- T 166 Bulk Specific Gravity (G_{mb}) of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens.
- T 168-03 Sampling Bituminous Paving Mixtures.

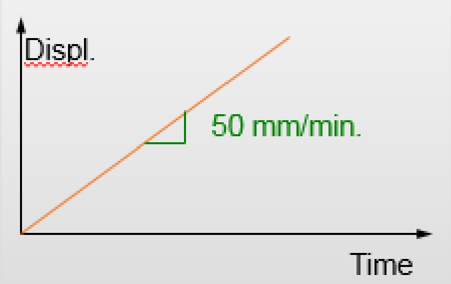
Florida IDT Test

- ❑ Dynamic Modulus Test
  - ❖Frequency: 10 Hz, 50 cycles
  - ❖horizontal strain: 50±5 $\mu\varepsilon$
- ❑ Creep Test
  - ❖ Creep time: 1000 s
  - ❖ Maximum horizontal strain @ t = 1000s:
- ❑ Strength Test
  - ❖ Displacement rare: 50 mm/min.
- ❑Test temperature
  - ❖10°C

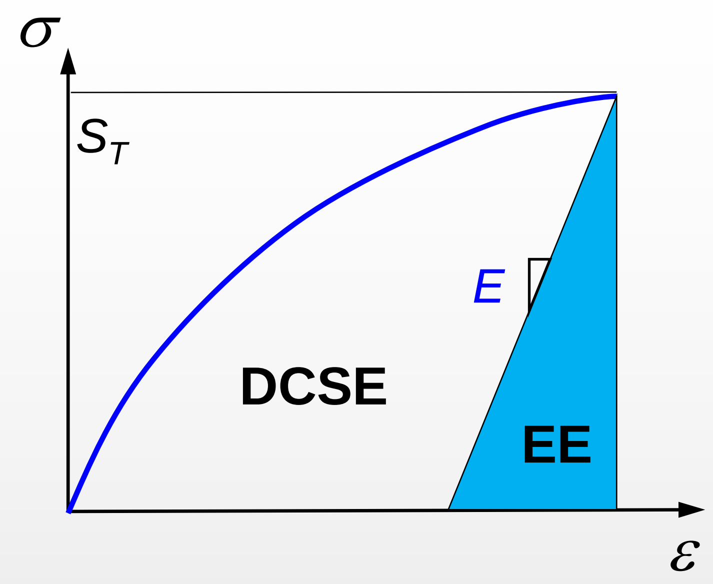








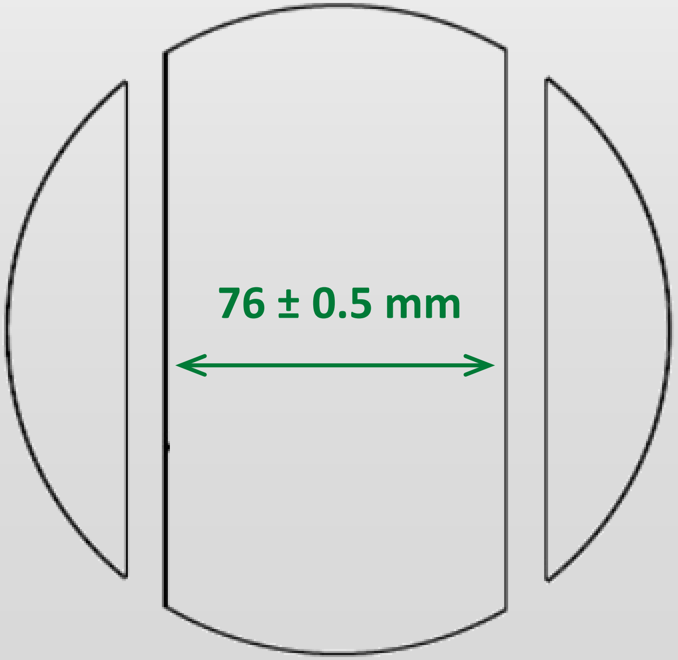
IDT Test - Analysis

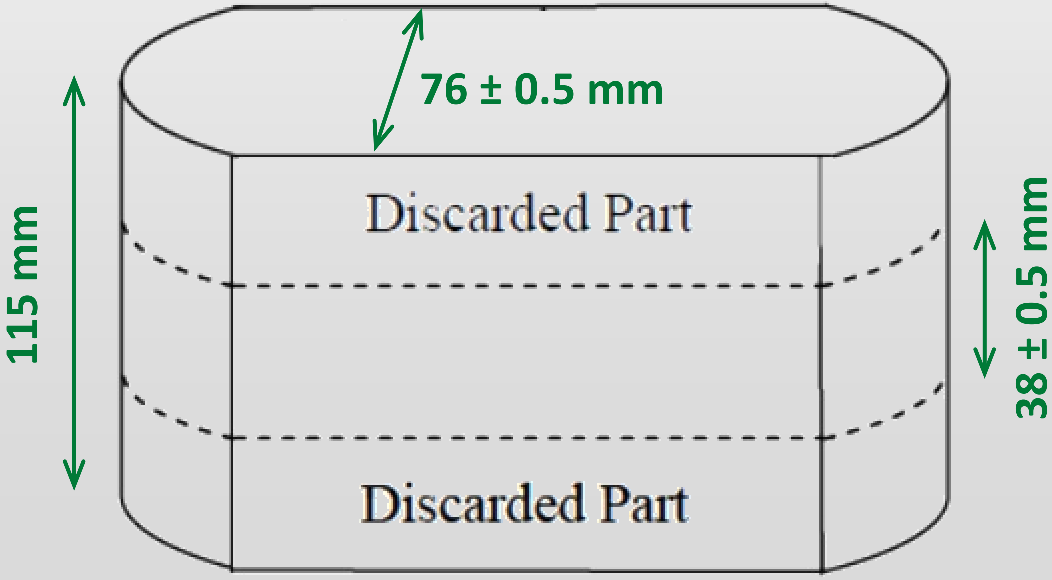


- DCSE – dissipated creep strain energy
  - FE = fracture energy
    - Area under σ-ε curve up to peak stress S_T
  - EE = elastic energy
    - EE = 1/2 × $(S_T)^2$ / E
  - DCSE = FE - EE

Texas Overlay Test

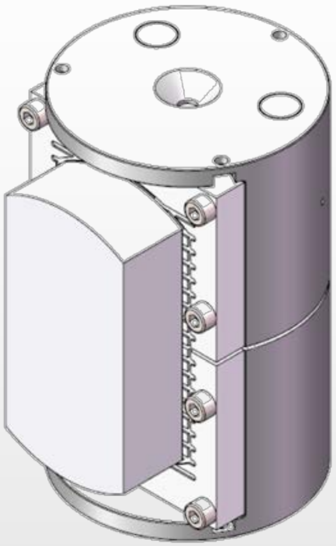
- ❑ Specimen Preparation
  - ❖ SCG: Φ150×115 mm
  - ❖ Test specimen: Φ150×76×38 mm
  - ❖ Air void: 7.0 ± 0.5%
  - ❖ Long-term aged

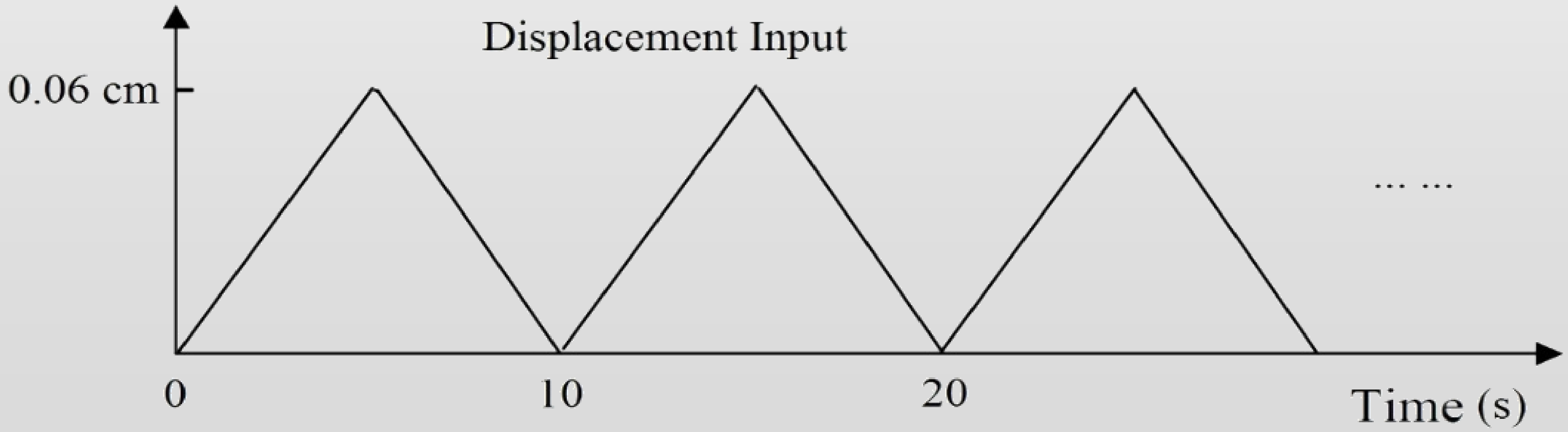




Texas Overlay Test

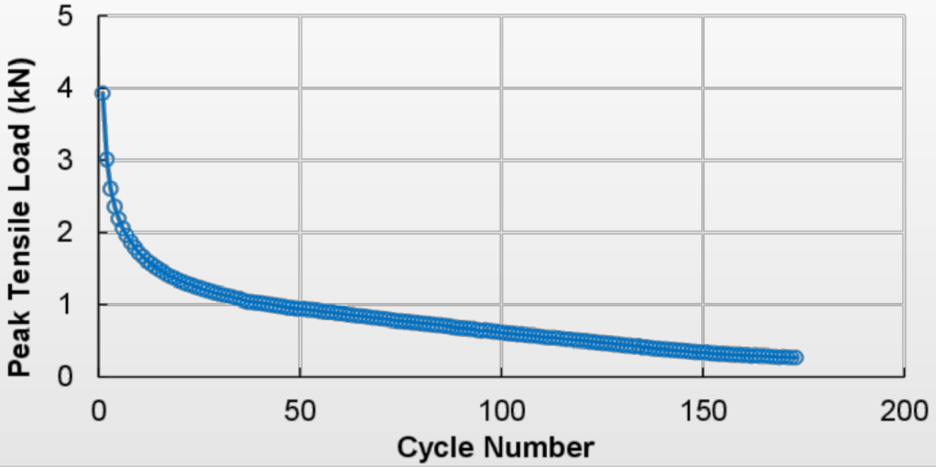
- ❑ Test Method
  - ❖ Tex-248-F
  - ❖ Temperature: 25°C
  - ❖ Triangular displacement controlled

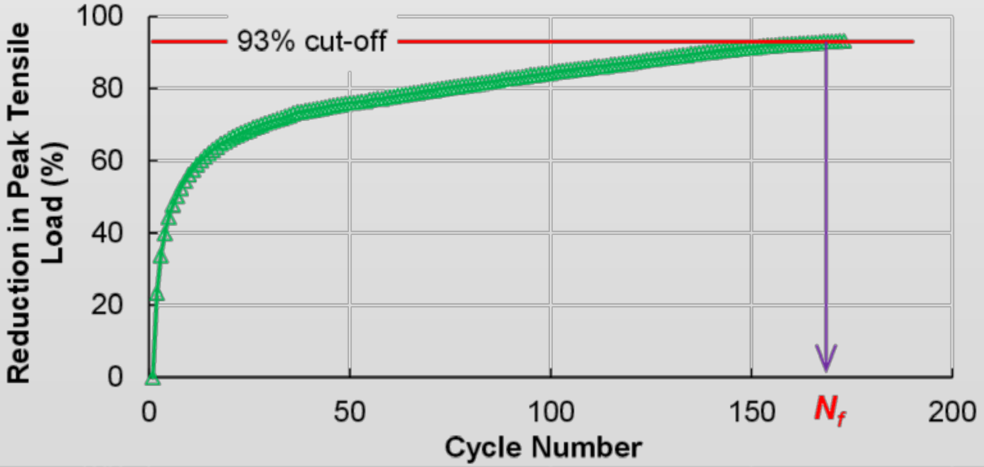




Texas Overlay Test - Analysis

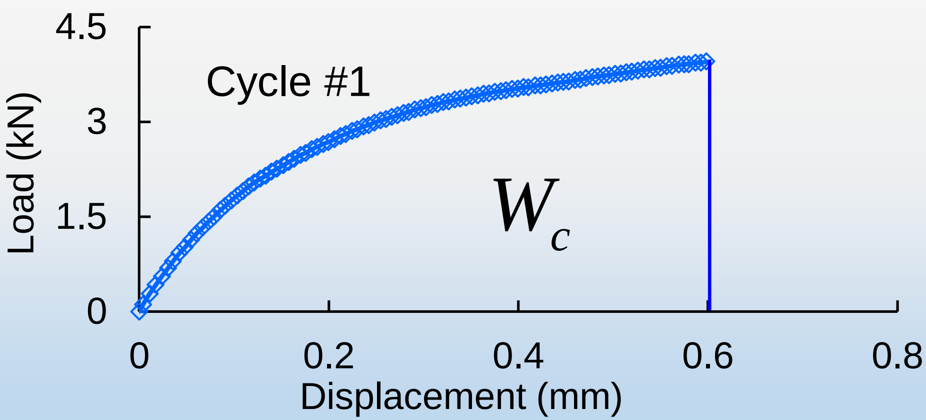
- Fatigue Life *Nf*
  - Extract peak tensile load in each cycle
  - Plot peak tensile load versus cycle number
  - N_f is defined as the cycle number at 93% drop





Texas Overlay Test - Analysis

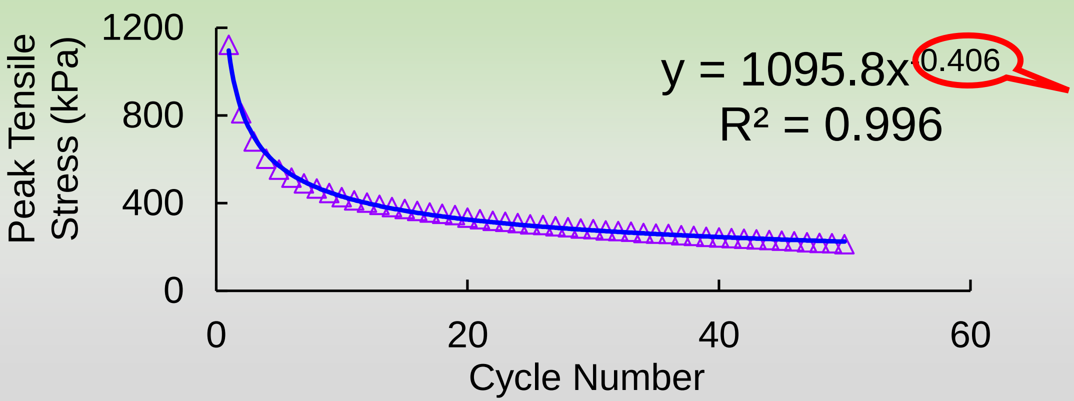
- Critical fracture energy & crack progression rate
  - *Garcia et al., Improved Overlay Tester for fatigue cracking resistance of asphalt mixtures. Report No. TxDOT 0-6815-1. The University of Texas at El Paso, 2017.*



Critical fracture energy (kJ/m^2)

$= W_c / B$

where *B* is cross-sectional area of test specimen.

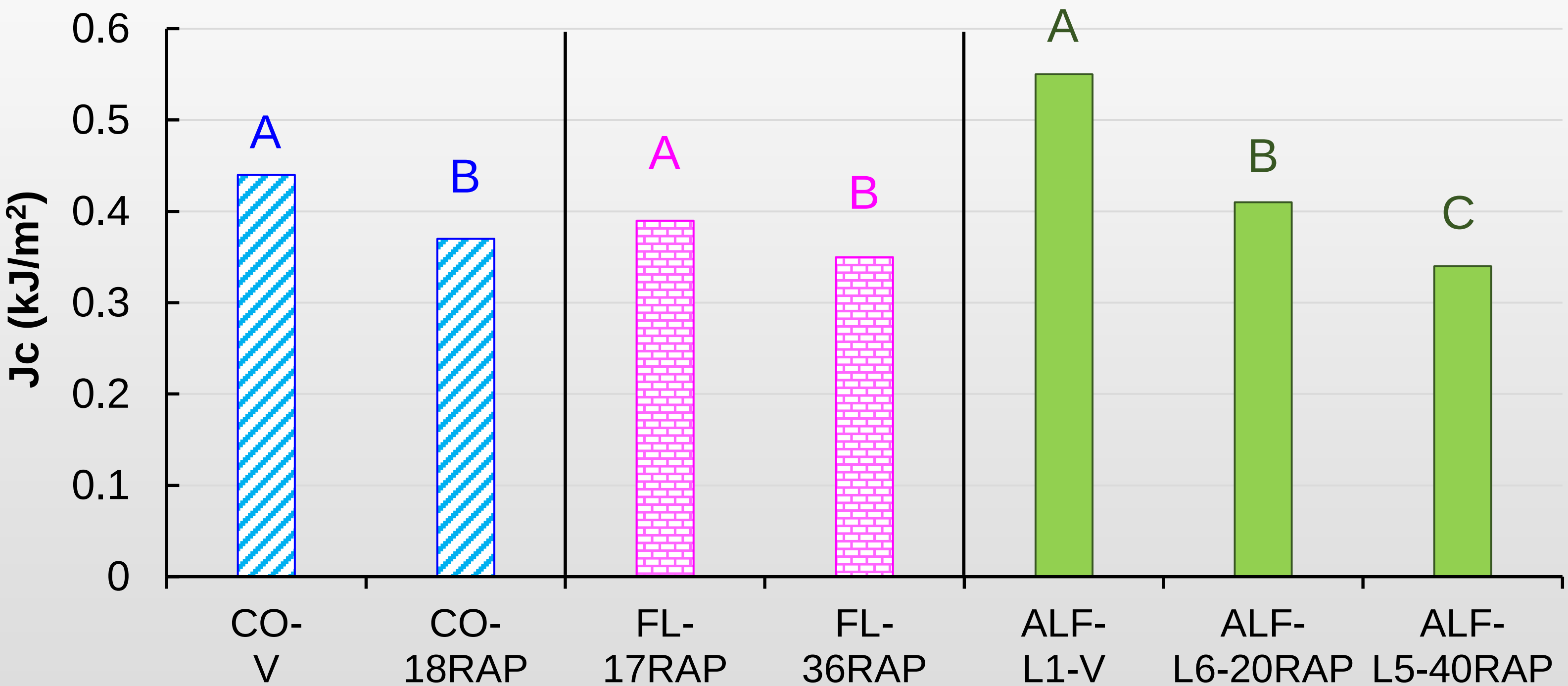


Crack progression rate

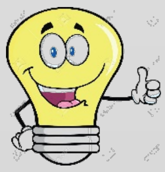
Results

SCB Jc Results

- Critical Strain Energy Release Rates



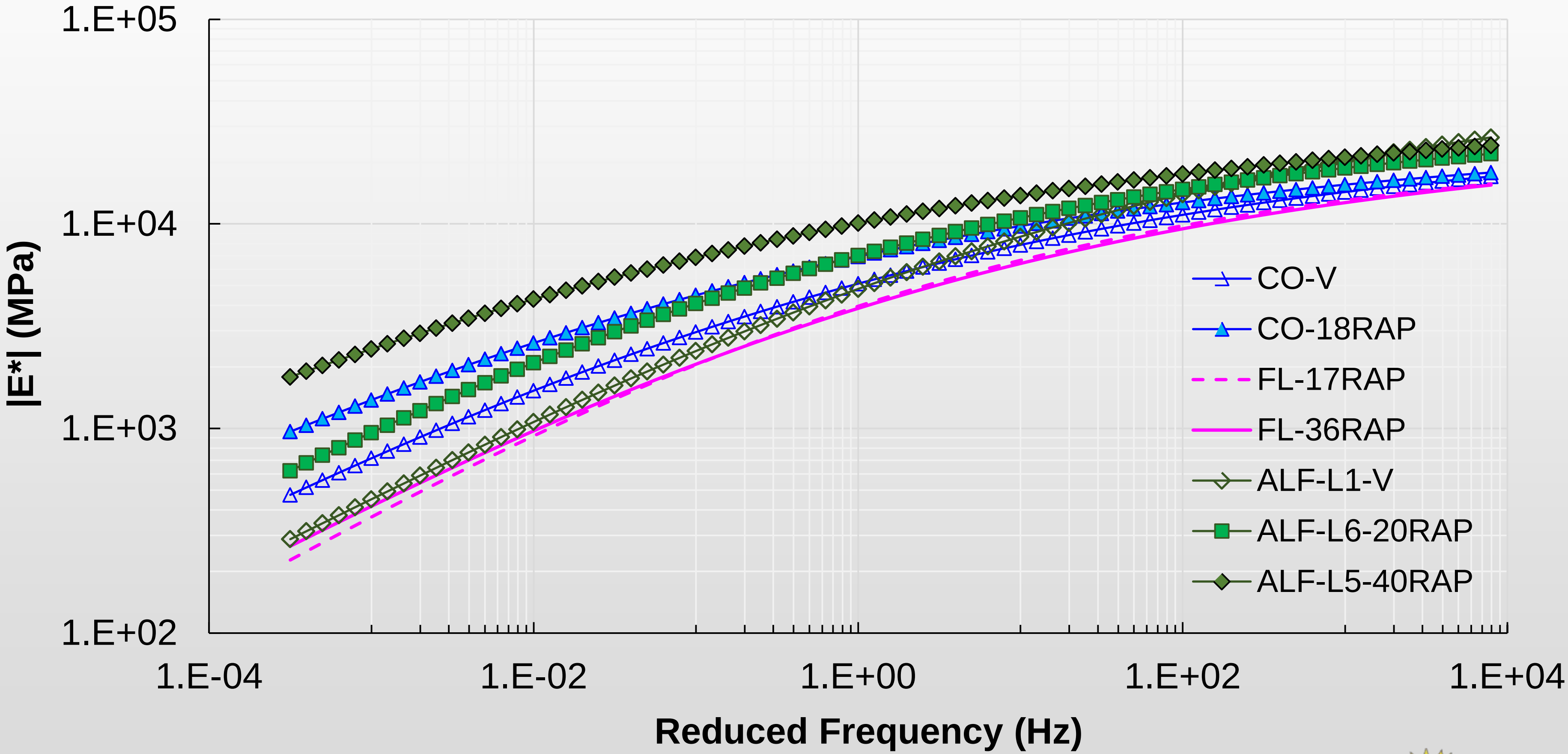
CoV: 10% 12% 14% 12% 10% 12% 10%



<u>Increase in RAP content yielded significantly reduced crack resistance!</u>

S-VECD Test Results

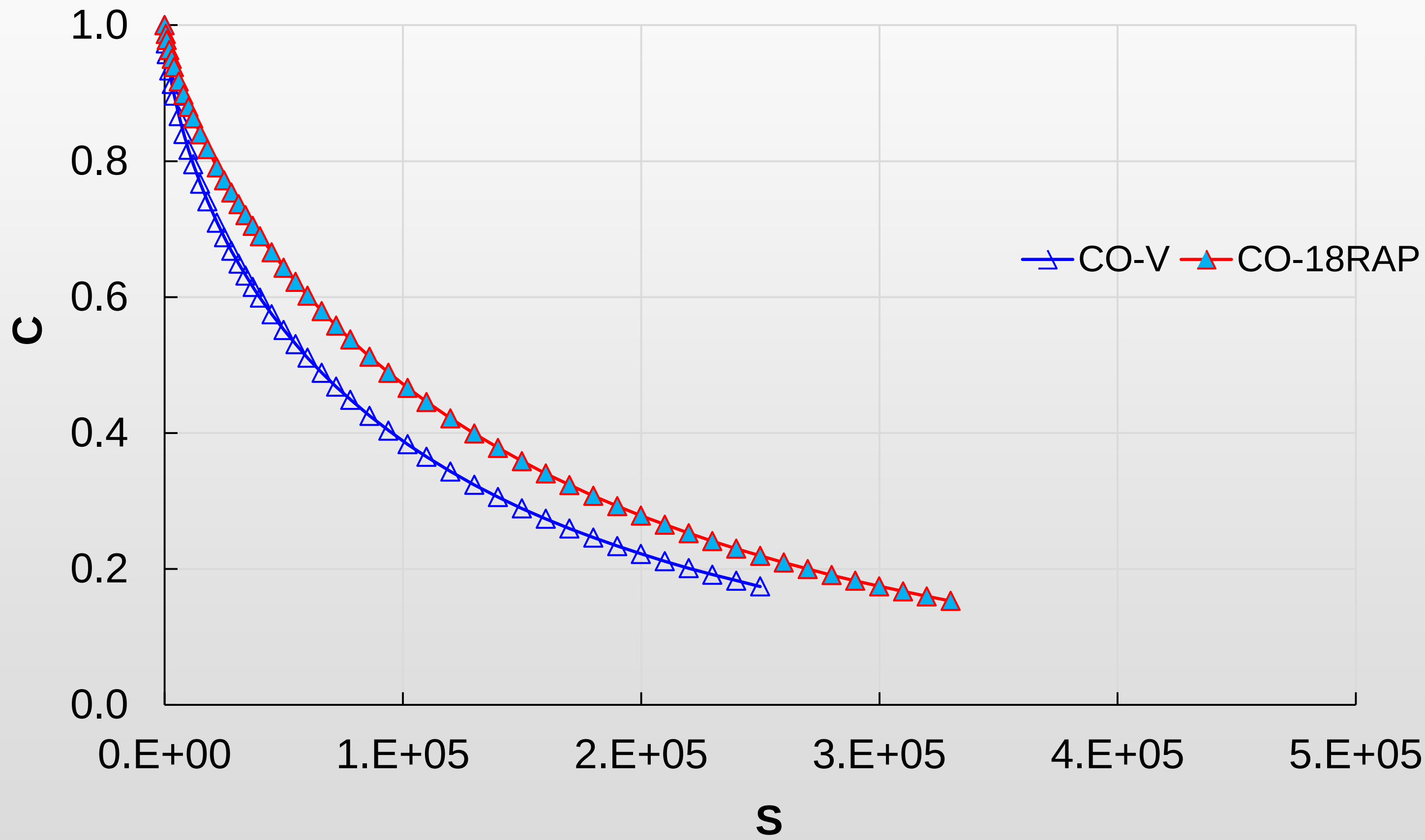
- Dynamic Modulus Master Curves



<u>Increase in RAP content yielded increased stiffness!</u>

S-VECD Test Results

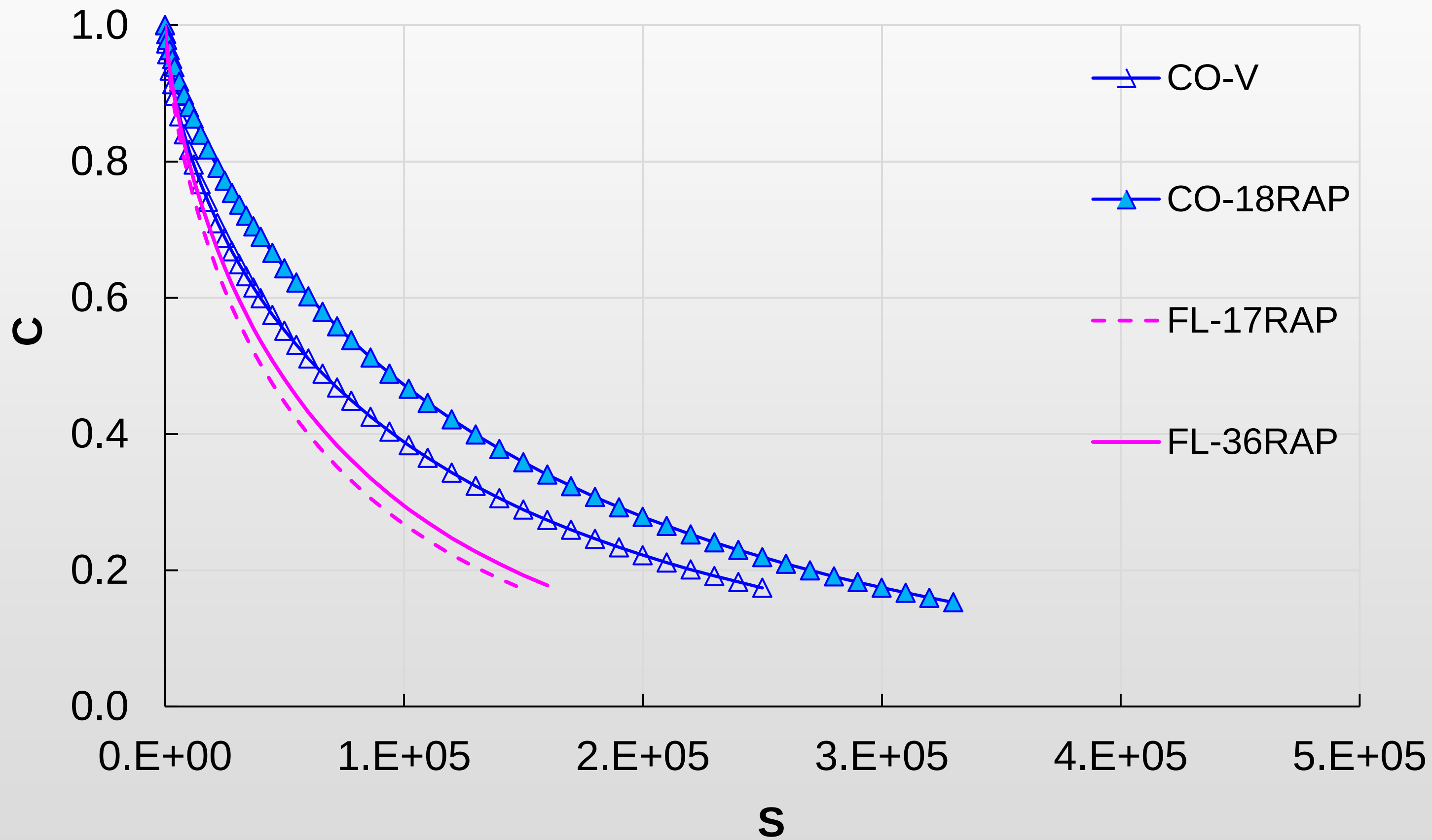
- ❑ Damage Characteristic Curves



<u>Stiffer mixtures (higher RAP) produced higher C(S) curves!</u>

S-VECD Test Results

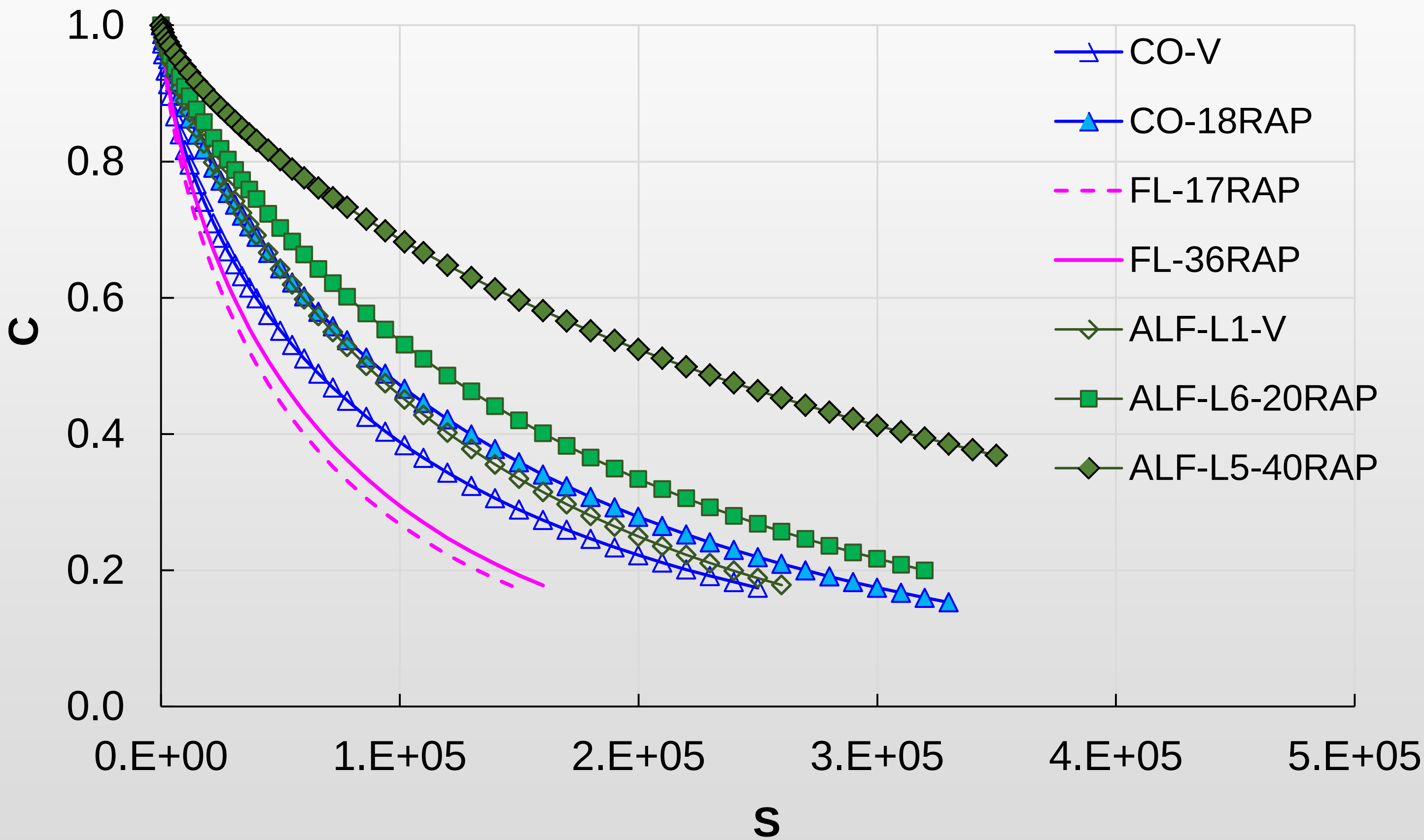
- ❑ Damage Characteristic Curves



<u>Stiffer mixtures (higher RAP) produced higher C(S) curves!</u>

S-VECD Test Results

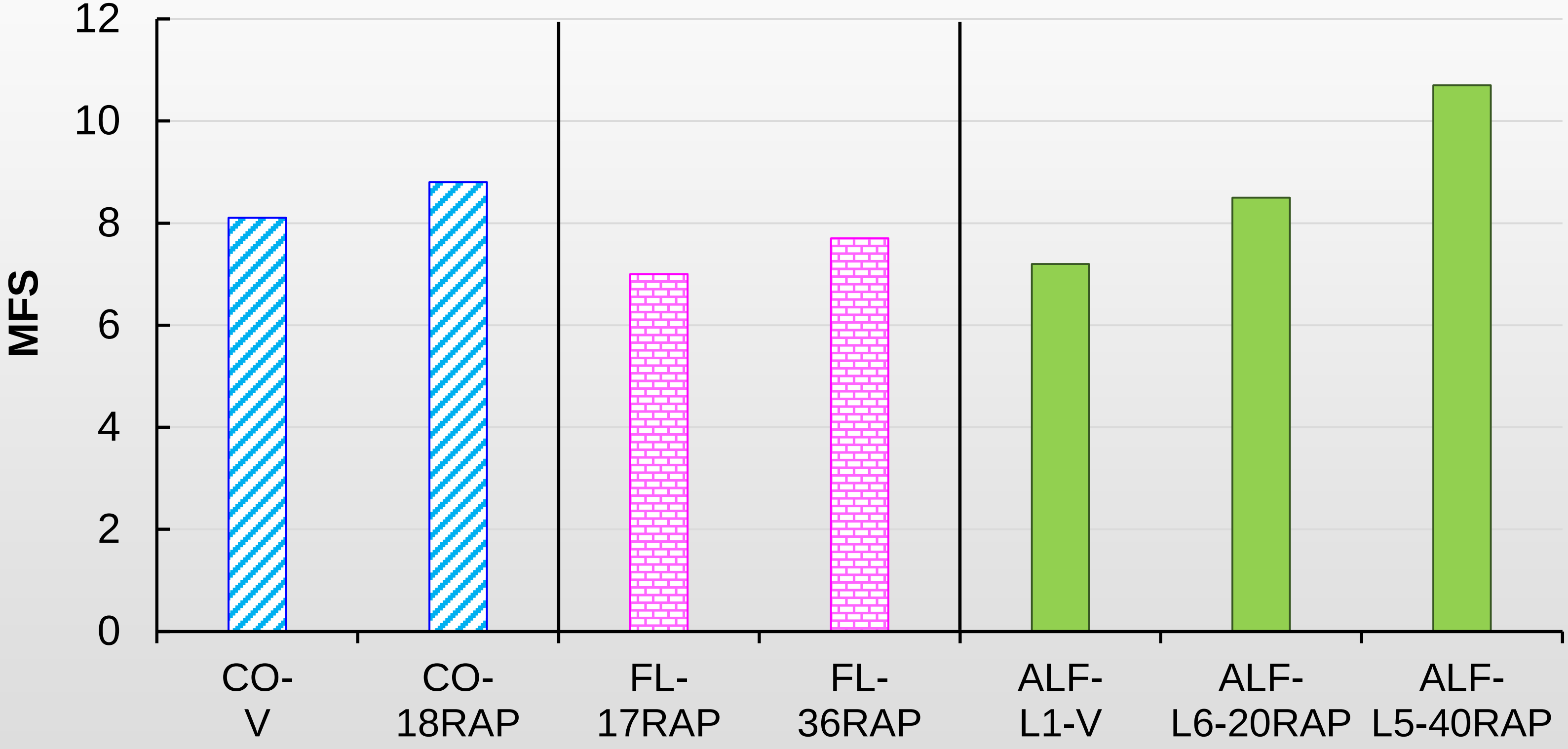
- Damage Characteristic Curves



Stiffer mixtures (higher RAP) produced higher C(S) curves!

S-VECD Test Results

- Material Fatigue Sensitivity

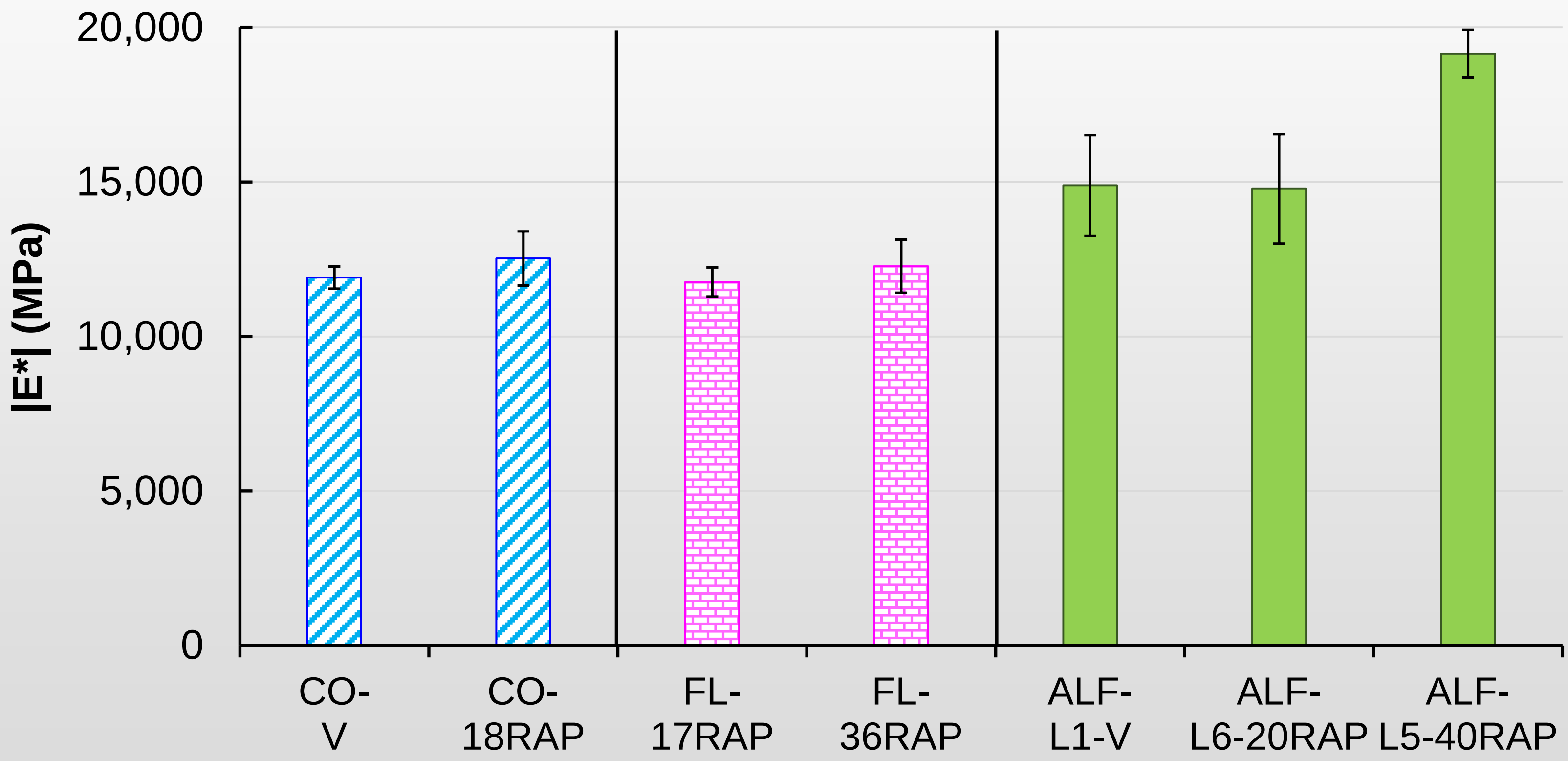


NOTE: Since MFS was obtained from fatigue simulation, no statistical grouping was available.

<ins>Increase in RAP content yielded lower fatigue resistance!</ins>

Florida IDT Test Results

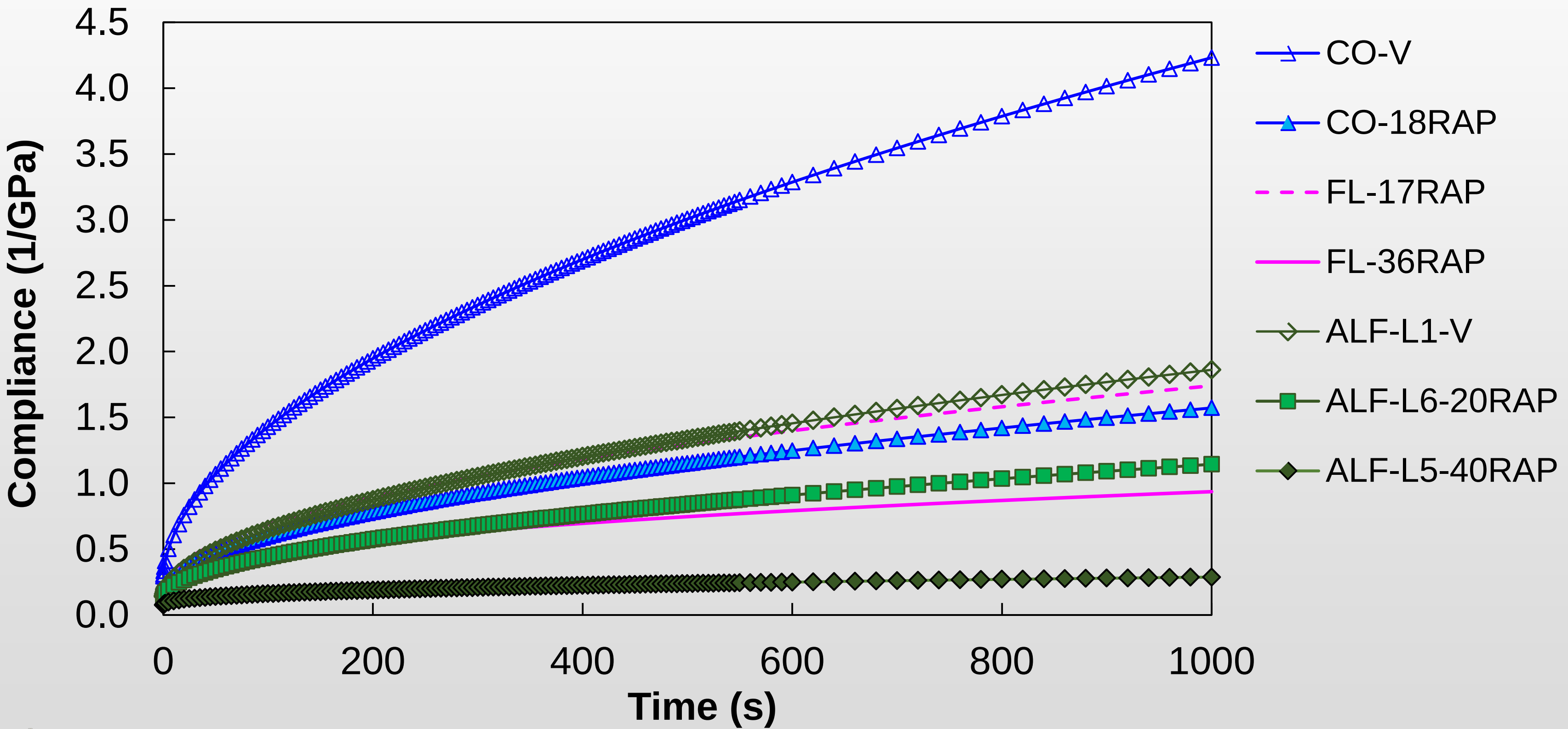
- Dynamic Modulus (10°C, 10Hz)



Increase in RAP content yielded higher stiffness!

Florida IDT Test Results

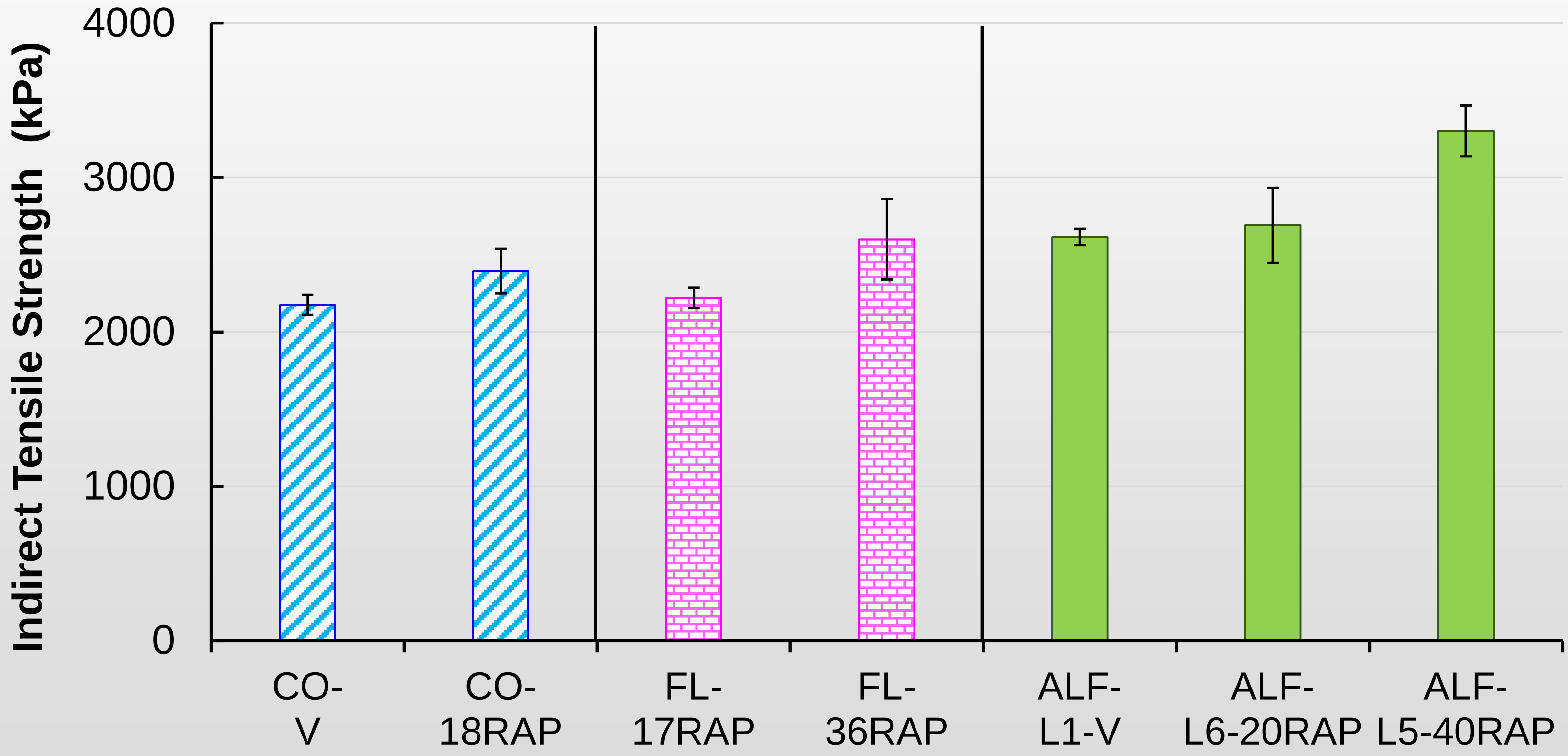
- Creep Compliance (10°C)



Increase in RAP content reduced creep compliance!

Florida IDT Test Results

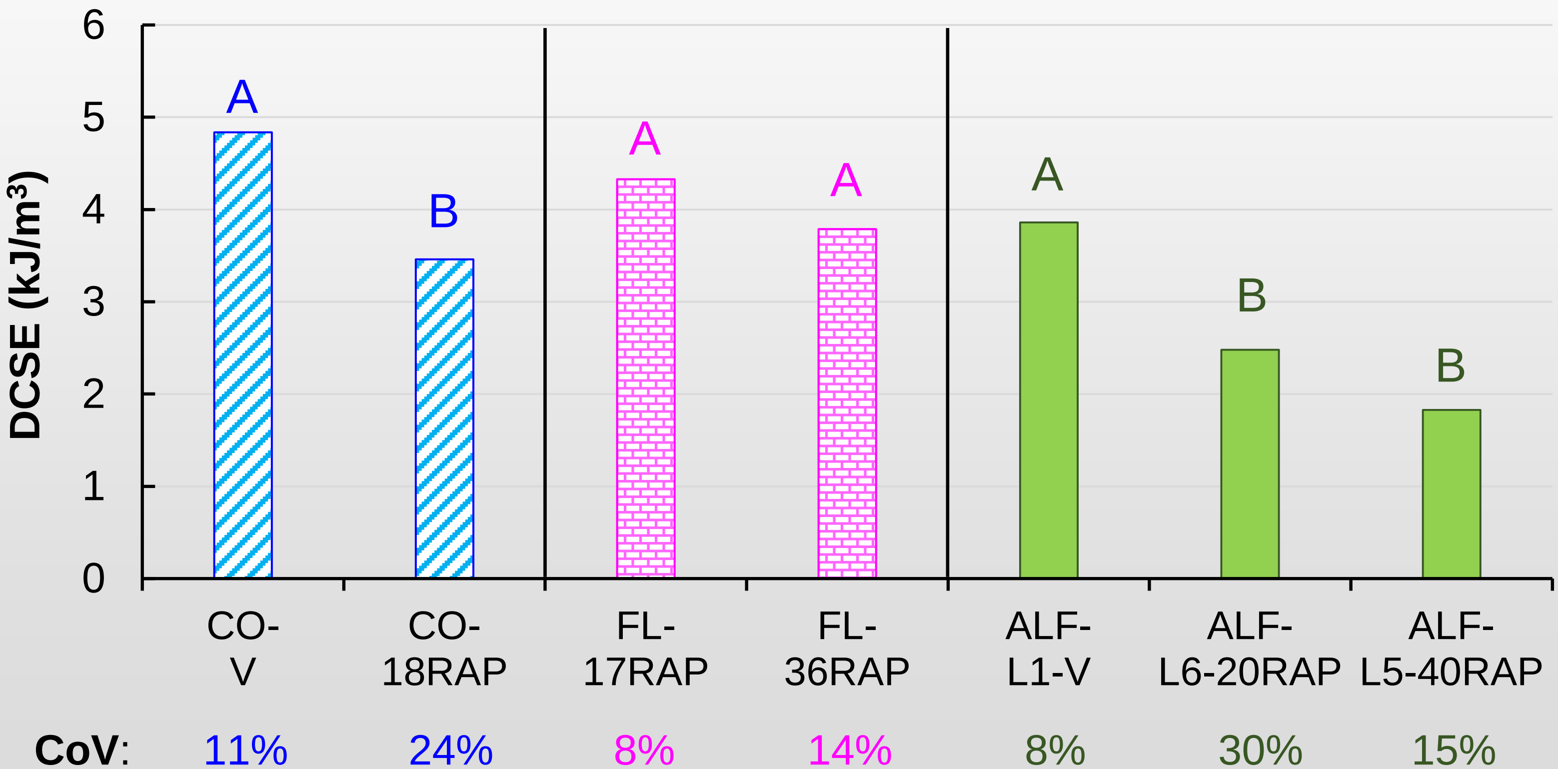
- ❑ Indirect Tensile Strength (10°C, 50 mm/min.)



<u>Increase in RAP content yielded higher indirect tensile strength!</u>

Florida IDT Test Results

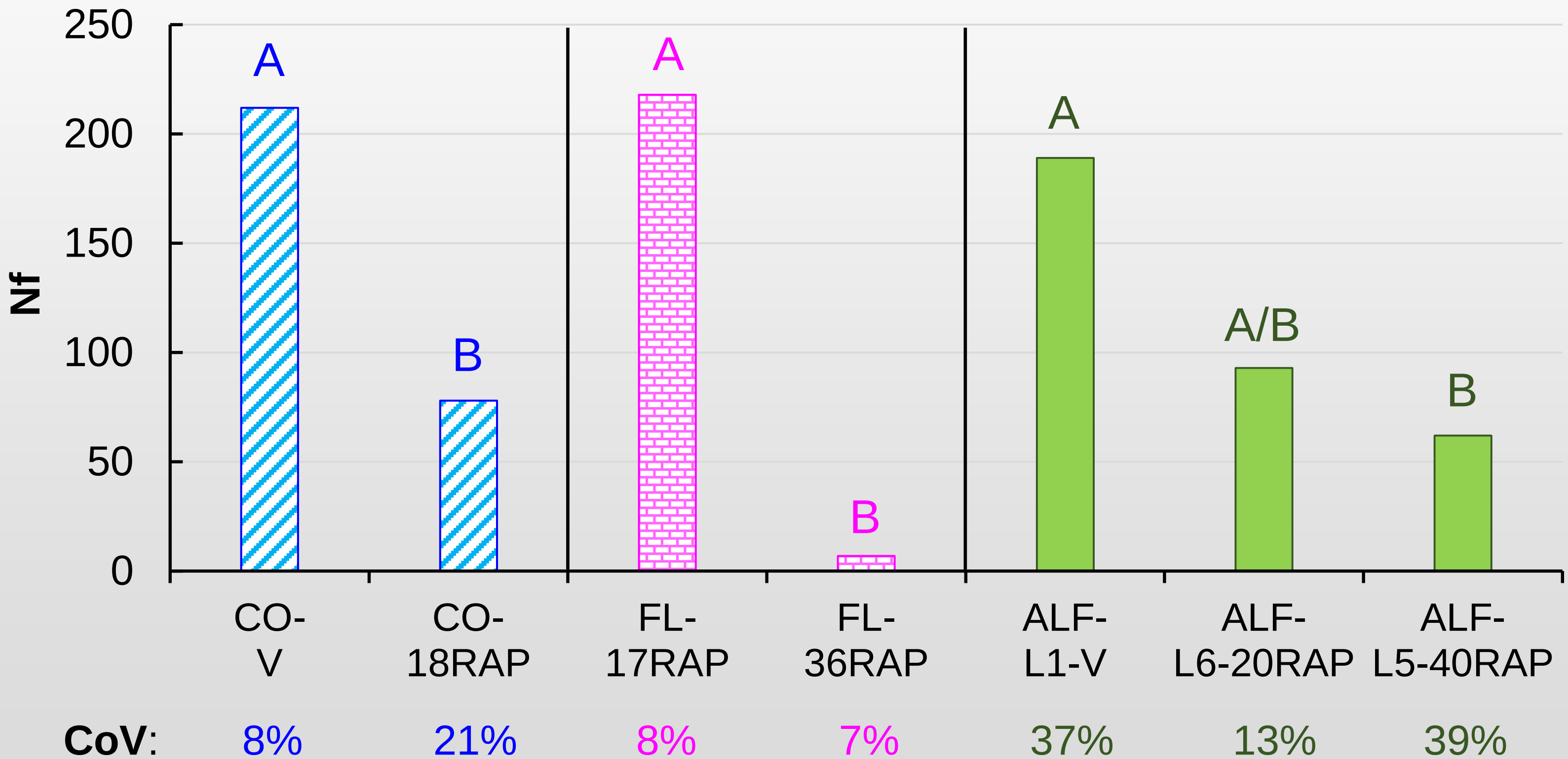
- ❑ Dissipated Creep Strain Energy (DCSE)



Increase in RAP content reduced crack resistance!

Texas Overlay Test Results

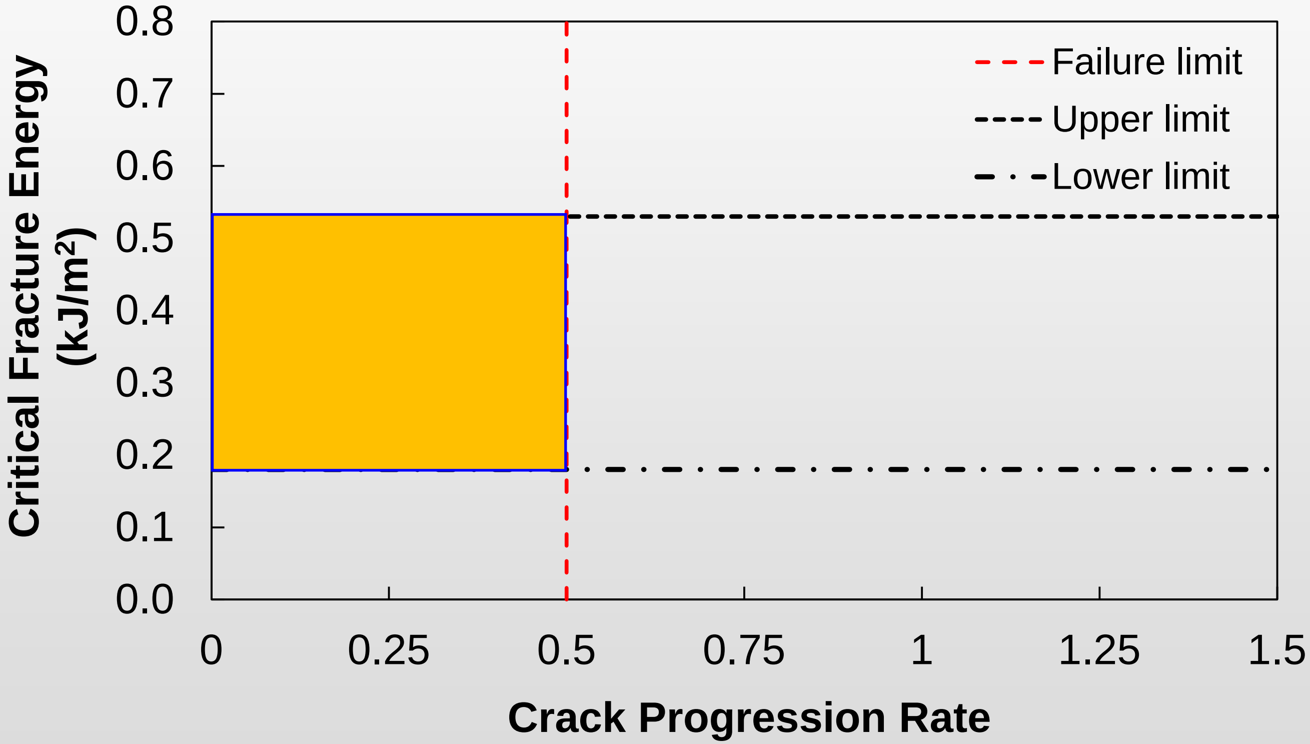
- Nf (93% drop in peak tensile load)



<u>Increase in RAP content yielded lower fatigue resistance!</u>

Texas Overlay Test Results

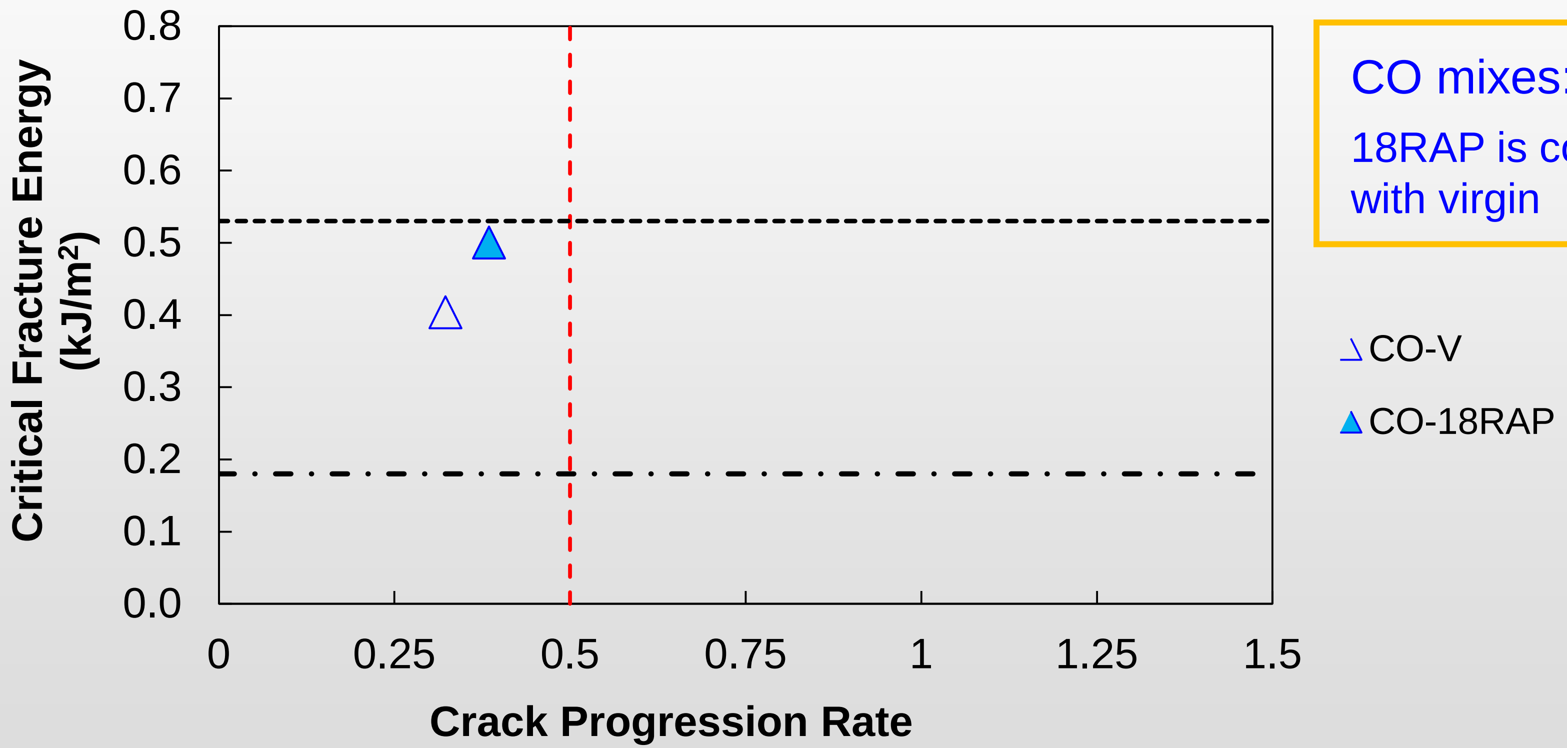
- Interaction Plot



Note: The failure, upper, and lower limits are given in the Garcia et al. (2017) report.

Texas Overlay Test Results

- ❑ Interaction Plot

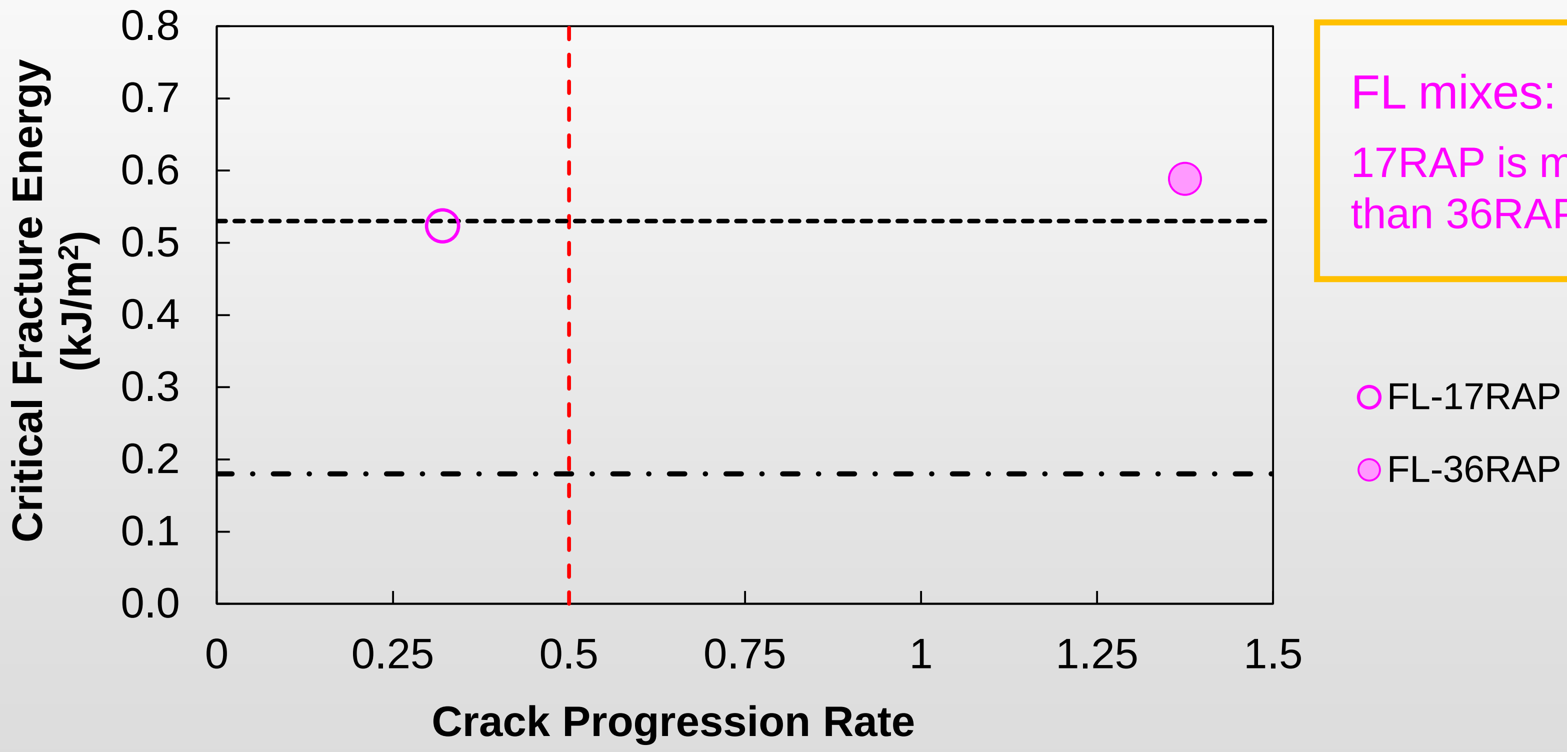


CO mixes:

18RAP is comparable with virgin

Texas Overlay Test Results

- Interaction Plot

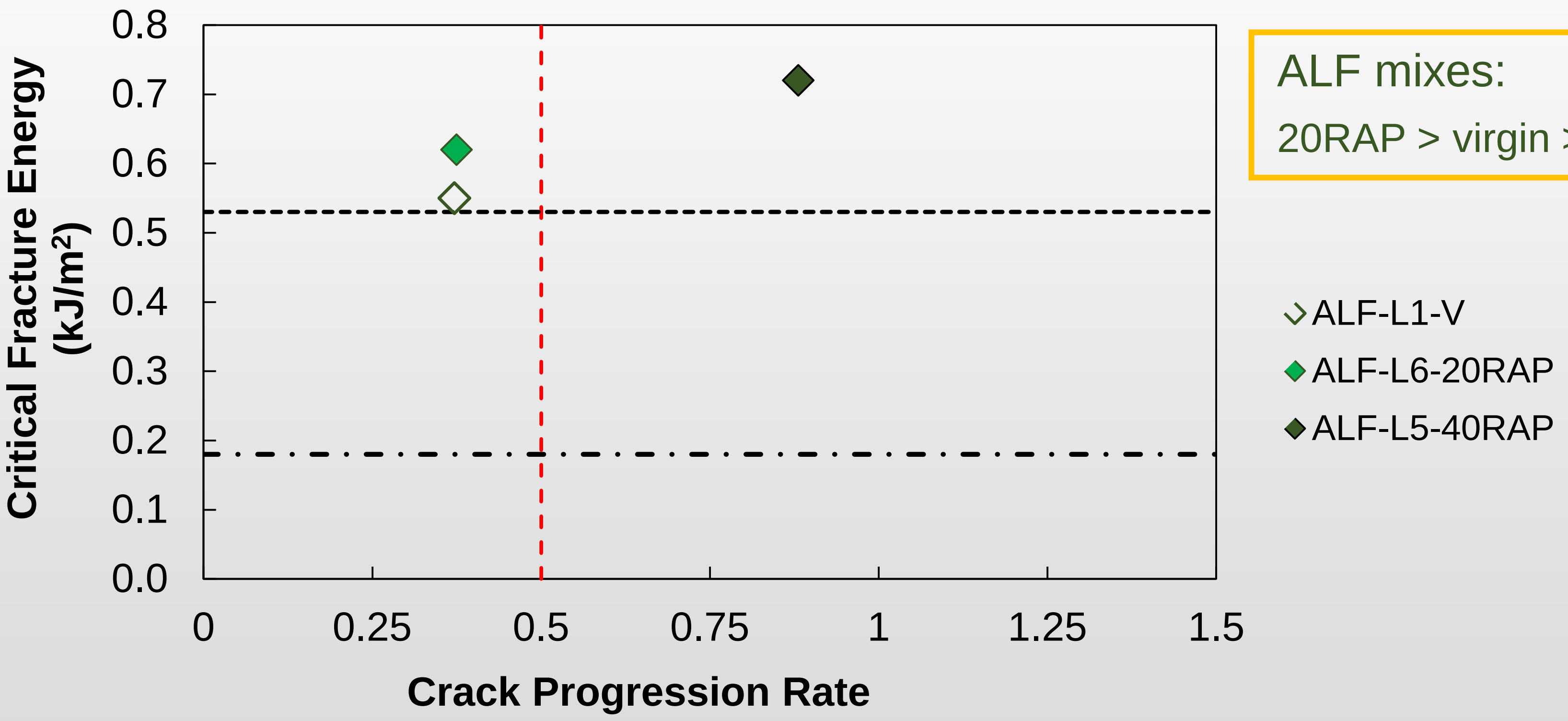


FL mixes:

17RAP is much better than 36RAP

Texas Overlay Test Results

- Interaction Plot



ALF mixes:

20RAP > virgin >> 40RAP

Summary of Test Results

- Statistical Grouping Results Summary

Test	Evaluation Parameter	CO Mixtures (% RBR)		FL Mixtures (% RBR)		ALF Mixtures (% RBR)		
		0	18	17	36	0	20	40
SCB	Jc	A	B	A	B	A	B	C
S-VECD	MFS	--	--	--	--	--	--	--
IDT	DCSE	A	B	A	A	A	B	B
Texas overlay	Nf	A	B	A	B	A	A/B	B

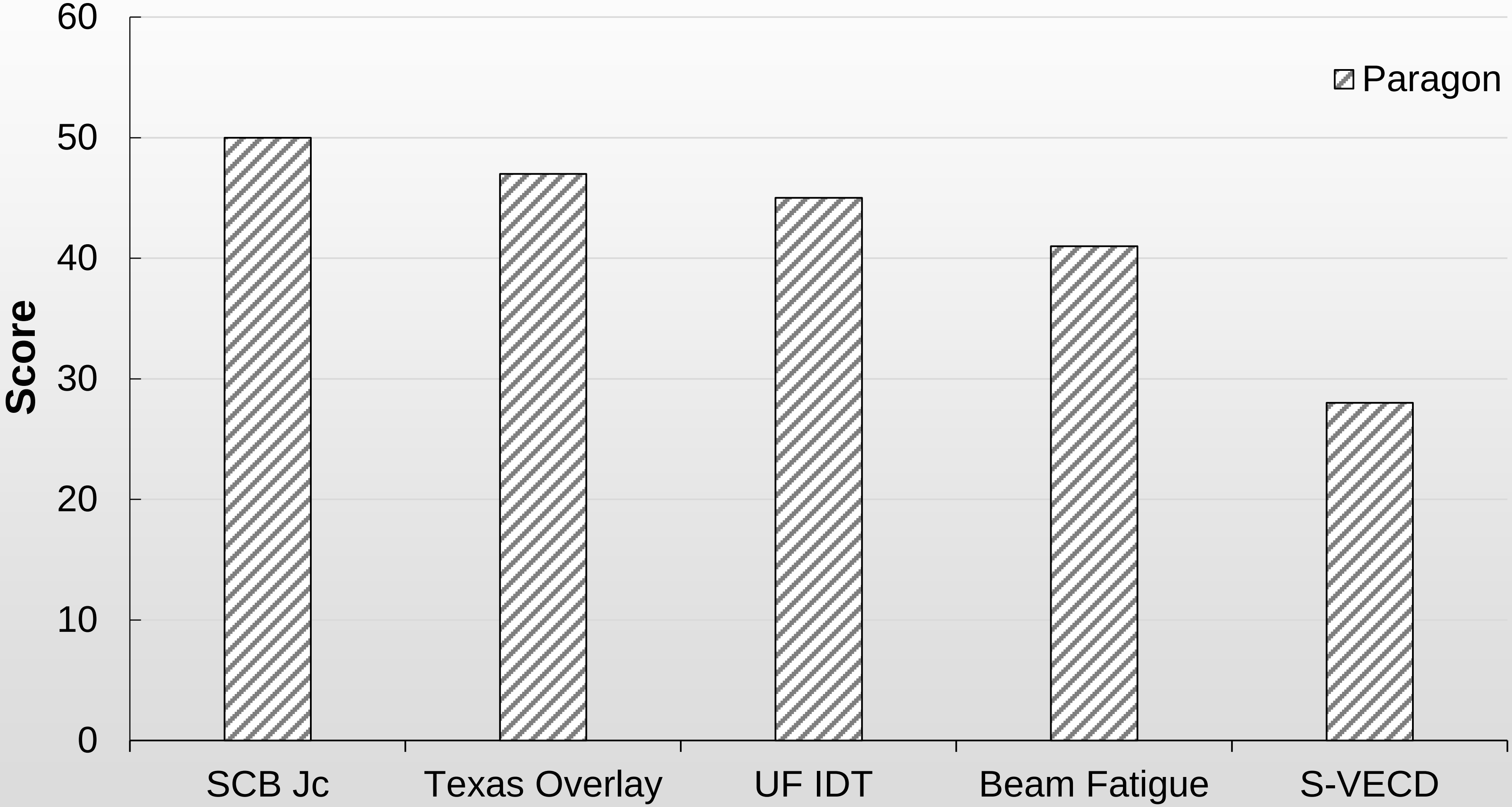
NOTE: -- = not available.

Development of Ranking Score Card

- ❑ Each test are ranked
  - ❖ Specimen preparation
  - ❖ Instrumentation
  - ❖ Standard test method
  - ❖ Testing oversight
  - ❖ Testing time
  - ❖ Training
  - ❖ Interpretation
  - ❖ Sensitivity to mix composition parameters
  - ❖ Routine Application
  - ❖ Correlation to field performance
  - ❖ Data Analysis
  - ❖ Repeatability & variability
  - ❖ Equipment cost
  - ❖ Required technical ability

1. Specimen preparation & post-test cleaning:			
1: Very long preparation time (7 days +).	2: Long preparation time (5-6 days).	3: Short preparation time (3-4 days).	4: Minimal preparation required (1-2 day).

Summary of Score Card – Max. 56



Summary

- Cracking tests presented
  - Direct Tension Cyclic Fatigue (SVECD), SCB Jc, Texas Overlay, FL IDT
- In general, higher RAP content resulted in higher crack susceptibility
  - Cracking tests considered.
- Mixtures with higher RBR exhibited higher stiffness
  - dynamic modulus test --- S-VECD characterization
- Increasing RAP content yielded lower crack resistance
  - higher stiffness, lower compliance, lower DCSE
  - FL IDT
- Mixture with increased RAP content yielded lower fatigue resistance, Nf
  - Texas overlay
  - Each mixture group.

Conclusions

- Ability to distinguish mixtures with high RAP content
  - single parameter
  - CO Mixture
    - SCB Jc, Texas Overlay, FL IDT
  - FL Mixture
    - SCB Jc, Texas Overlay,
  - FHWA ALF Mixtures
    - SCB Jc,
- Preliminary score card
  - Paragon Technical Services, Inc.

Acknowledgement

- Federal Highway Administration
- Louisiana Transportation Research Center
- Florida Department of Transportation
- Colorado Department of Transportation
- Paragon Technical Services, Inc.

Thank you!