Assessments of Cracking Tests: A Transportation Pool Fund Study

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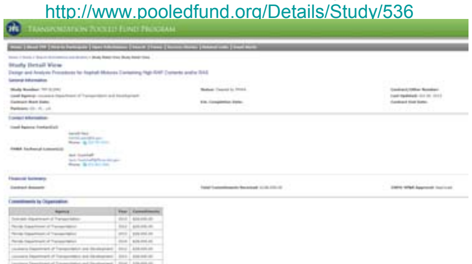
Transportation Pool Fund Program
http://www.pooledfund.org/Details/Study/536

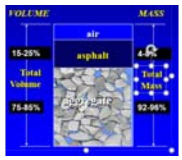


Outline

- Background
  - Mechanical test
  - Cracking
- Objectives
- Materials & Test Sections
- Methodologies
- Results & Discussion
  - Discriminating potential to mixture components
  - Ranking capability with reference to ALF fatigue performance experiment
- Summary and Conclusions

Components Materials Used In Asphalt Mixture

- Asphalt Binder
  - Petroleum-Based (refined crude oil)
  - 4-8% by weight
- Aggregates (CA, FA)
  - 92-96% by weight
- Additives



Sustainable Development

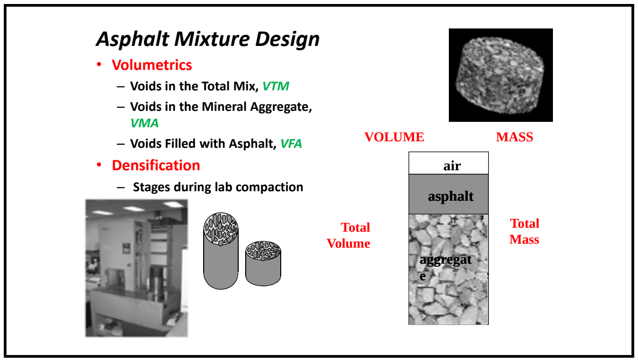
- "Meets the needs of the present without compromising the ability of future generations to meet their own needs"
  - World Commission on Environment and Development, 1987

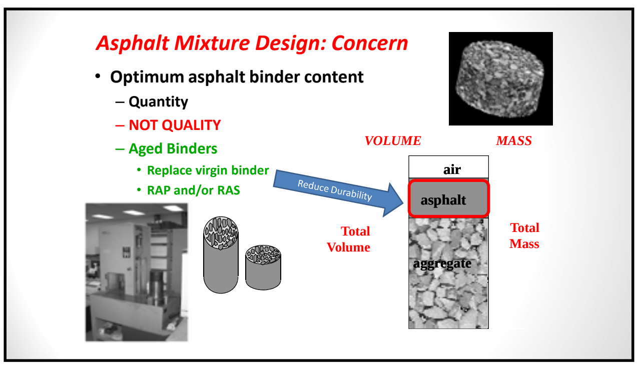
- *Economical* Sustainability
  Balanced cost-revenue relationship
- *Environmental* Sustainability
  Friendly to the ecosystems
  Minimize use of natural resources
  Reduce energy consumption
  Reduce greenhouse gas emissions
- *Social* Sustainability: Materials Performance
  Better or same performance
  Meet society's needs

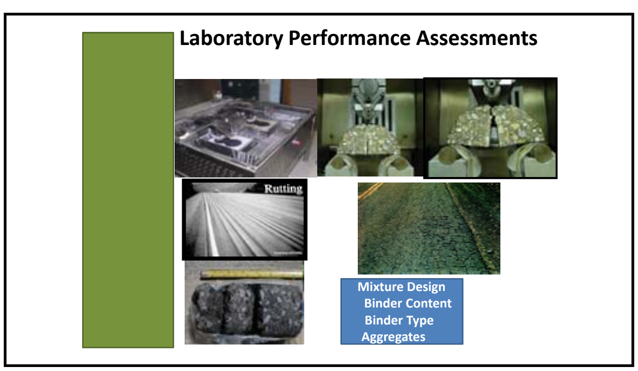
Sustainability: quality that reflects the balance of three primary components -- triple-bottom line

Components Materials Used In Asphalt Mixture

- Asphalt Binder
  - Petroleum-Based (refined crude oil)
  - 4-8% by weight
- Aggregates (CA, FA)
  - 92-96% by weight
- Additives
- Sustainability
  - Replace portions of component martials
  - *RAP, RAS, …*
    - Aged asphalt binders
    - *aggregates*

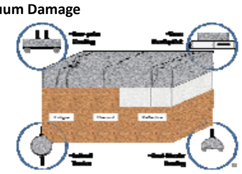

Asphalt Mixture Design
• Volumetrics
– Voids in the Total Mix, VTM
– Voids in the Mineral Aggregate, VMA
– Voids Filled with Asphalt, VFA
• Densification
– Stages during lab compaction
VOLUME
MASS
air
asphalt
aggregate
Total Volume
Total Mass


Asphalt Mixture Design: Concern
• Optimum asphalt binder content
– Quantity
– NOT QUALITY
– Aged Binders
• Replace virgin binder
• RAP and/or RAS
Reduce Durability
VOLUME
MASS
air
asphalt
aggregate
Total Volume
Total Mass


Laboratory Performance Assessments
Rutting
Mixture Design
Binder Content
Binder Type
Aggregates

Laboratory Test Methods to Characterize Fatigue/Fracture Resistance

- Four-Point Bending Fatigue Test
- Disk-shaped Compact tension Test
- Texas Overlay Tester
- Dissipated Creep Strain Energy Test
- Indirect tensile strength (IDT) test
- Simplified Viscoelastic Continuum Damage
  - Pull-Push Test
- IDT Fracture Energy
- SCB test
  - Intermediate Temperature
- ...



Objectives

- Compare laboratory performance tests with respect to
  - mixture-discriminating capability as per material composition
  - correlation with pavement performance

Materials

- Participating agencies
  - FHWA ALF (10 mixtures)
  - Colorado DOT (2 mixtures)
  - Florida DOT (2 mixtures)
  - Louisiana DOT (2 mixtures)

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Materials

- Participating agencies
  - FHWA ALF
    - 2013 construction
    - Advance Use of Recycled Asphalt in Flexible Pavement Infrastructure: Develop and Deploy Framework for Proper Use and Evaluation of Recycled Asphalt in Asphalt Mixtures
    - 10 lanes/mixtures

Materials & Test Sections

- FHWA ALF Mixtures

Mixture Designation	RAP* (%)	RAS* (%)	Base Binder PG	HMA/WMA Process
ALF-L1	--	--	64-22	HMA
ALF-L2	40	--	58-28	Water foam
ALF-L3	--	20	64-22	HMA
ALF-L4	20	--	64-22	Evotherm
ALF-L5	40	--	64-22	HMA
ALF-L6	20	--	64-22	HMA
ALF-L7	--	20	58-28	HMA
ALF-L8	40	--	58-28	HMA
ALF-L9	20	--	64-22	Water foam
ALF-L11	40	--	58-28	Evotherm

Note: * Expressed in terms of RBR (recycled binder ratio)
Design Asphalt Content, 5.0

Materials & Test Sections

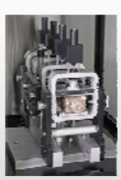
- ❑ FHWA ALF lanes design facts
  - ❖ 10 cm asphalt layer
  - ❖ 56 cm crushed aggregate base
  - ❖ Subgrade
- ❑ ALF fatigue loading facts
  - ❖ Single wide-base tire
    - ➢ 63.2 kN wheel load
    - ➢ 689 kPa contact pressure
  - ❖ Loading speed: 4.9 m/s
  - ❖ Asphalt layer temperature: 20°C
  - ❖ Surface cracking monitored

Six Fracture/fatigue tests

Test	Temp.	Protocol	Test Mode	Specimen Geometry	Cracking Phases	Engineering Properties
BF	20°C	ASTM D7460	Cyclic, 10 Hz	380×63×50 mm	Crack initiation	▪ Fatigue life ▪ Relation between fatigue life and strain amplitude
OT	25°C	Tex-248-F	Cyclic, 0.1 Hz	ϕ150×76×38 mm, oval brick	Crack initiation & propagation	▪ Fatigue life ▪ Critical fracture energy ▪ Crack resistance index
S-VECD	18°C	AASHTO T378, TP107	Cyclic, 10 Hz for fatigue	▪ ϕ100×150 mm for modulus ▪ ϕ100×130 mm for fatigue	Crack initiation	▪ Dynamic modulus ▪ Damage characteristic curve ▪ Material Fatigue Sensitivity
SCB Jc	25°C	ASTM D8044	Monotonic, 0.5 mm/min	ϕ150×57 mm, semi-circular	Crack propagation	▪ Critical strain energy release rate
I-FIT	25°C	AASHTO TP124	Monotonic, 50 mm/min	ϕ150×50 mm, semi-circular	Crack propagation	▪ Flexibility index
IDT	10°C	UF draft procedure	▪ Cyclic for modulus ▪ Static for creep ▪ Monotonic for strength, 50 mm/min	ϕ150×38 mm	Crack initiation	▪ Dissipated creep strain energy ▪ Energy ratio

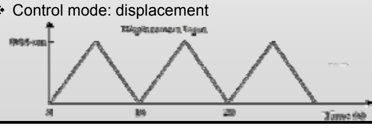
Methodologies

- ❑ Four-point bending beam fatigue
  - ❖ AASHTO T 321
  - ❖ Sample: 380×63×50 mm
  - ❖ Air void: 7 ± 1%
  - ❖ LTA AASHTO R30
  - ❖ Temperature: 20°C
  - ❖ Frequency: 10 Hz sinusoidal
  - ❖ Control mode: deflection
  - ❖ Fatigue failure: 50% drop in stiffness



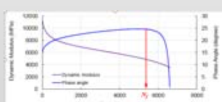
Methodologies

- Texas overlay
  - Tex-248-F (2017)
  - Sample: ∅150×76×38 mm
  - Air void: 7 ± 0.5%
  - LTA AASHTO R30
  - Temperature: 25°C
  - Frequency: 0.1 Hz triangular
  - Control mode: displacement



Methodologies

- Simplified viscoelastic continuum damage (S-VECD)
  - AASHTO T 378-17, AASHTO TP107
  - Sample: ∅100×130 mm
  - Air voids: 7 ± 0.5%
  - LTA AASHTO R30
  - Temperature: 18°C
  - Frequency: 10 Hz
  - Control mode: displacement



Fracture/fatigue testing

- Direct Tension Cyclic Fatigue – SVECD
- AASHTO TP 79-15: Standard Method of Test for Determining the Dynamic Modulus and Flow Number for Hot Mix Asphalt (HMA) Using the Asphalt Mixture Performance Tester (AMPT)
  - Stiffness
- AASHTO TP 107-14: Standard Method of Test for Determining the Damage Characteristic Curve of Asphalt Mixtures from Direct Tension Cyclic Fatigue Tests
  - Damage characteristic curve (C vs. S)

Methodologies

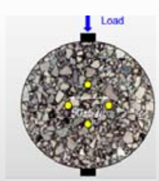
- Semi-circular bend (SCB)
  - ASTM D8044
  - Sample: ⌀150×57 mm
  - Notch depths: 1″, 1.25″, 1.5″
  - Air voids: 7 ± 0.5%
  - LTA AASHTO R30
  - Temperature: 25°C
  - Loading rate: 0.5 mm/min
  - Control mode: displacement

Methodologies

- Illinois flexibility index (I-FIT) test
  - AASHTO TP124
  - Sample: ⌀150×50 mm
  - Notch depth: 15 mm
  - Air voids: 7 ± 0.5%
  - LTA AASHTO R30
  - Temperature: 25°C
  - Loading rate: 50 mm/min
  - Control mode: displacement

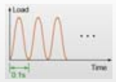
Methodologies

- Indirect tension (IDT) test
  - Univ. Florida draft procedure
  - Sample: ⌀150×38 mm
  - Air voids: 7 ± 0.5%
  - LTA AASHTO R30
  - Temperature: 10°C



Methodologies

- Indirect tension (IDT) test
  - Dynamic Modulus Test
    - Frequency: 10 Hz, 50 cycles
    - Horizontal strain: 50 ± 5 $\mu\varepsilon$



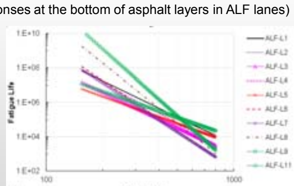
  - Creep Test
    - Creep time: 1000 s
    - Maximum horizontal strain: 150-250 $\mu\varepsilon$

  - Strength Test
    - Displacement rate: 50 mm/min.

Test Results

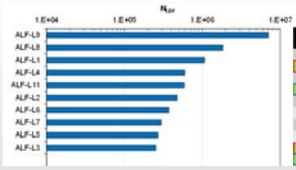
Four-point bending beam

- Performance parameter: $N_{f,BF}$
  - Interpolated at 340* microstrain (average of tensile strain responses at the bottom of asphalt layers in ALF lanes)



Note: * Cao W, Mohammad LN, Elseifi M. 2017. Assessing the effects of RAP, RAS, and warm-mix technologies on fatigue performance of asphalt mixtures and pavements using viscoelastic continuum damage approach. Road Materials and Pavement Design 18(s4): 353-371.

Four-point bending beam



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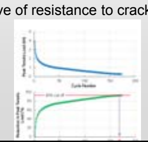
ALF-L5	40	–	64-22	HMA
ALF-L6	20	–	64-22	HMA
ALF-L7	–	20	58-28	HMA
ALF-L8	40	–	58-28	HMA
ALF-L9	20	–	64-22	Water foam
ALF-L11	40	–	58-28	Evotherm

Nf,BF parameter decreasing order
L9 exhibited highest fatigue resistance
L1 control mixture was ranked in third place following L8 .
L3, L5, and L7 yielded the lowest performance

Texas overlay test -- Analysis

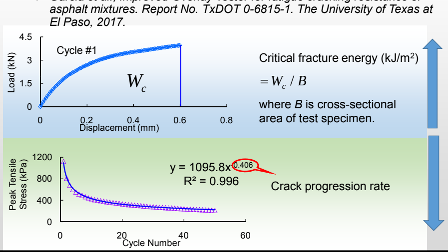
- Performance parameters
  - Fatigue life $N_{f,OT}$
    - maximum tensile load drops by 93%
  - Critical Fracture Energy (CFE)
    - indicative of resistance to crack initiation
  - Crack Propagation rate (CPR)
    - indicative of resistance to crack propagation



Texas Overlay Test - Analysis

30

- 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.*



Texas overlay test

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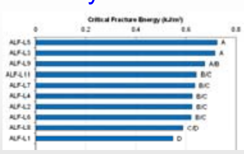
ALF-L9	20	–	64-22	Water foam
ALF-L11	40	–	58-28	Evotherm

ANOVA using Fisher's LSD method
L 9 exhibited highest fatigue life
L 3 & L7 exhibited lowest fatigue life

5

Texas overlay test



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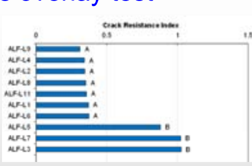
ALF-L11	40	–	58-28	Evotherm

CFE represents resistance to crack initiation. Higher values are desired
Results appear to be contrary to what was expected
Not a good indicator of cracking resistance. CFE was positively related to mixture stiffness.

Texas overlay test



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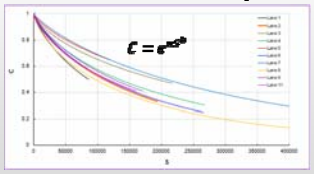
ALF-L11	40	–	58-28	Evotherm

CRI represents the crack progression rate, lower values are desired
L 5, L7, L3 exhibited highest CRI

S-VECD

- ❑ damage characteristic relationship
  - ❖ correlating material structural integrity C and an internal state variable for damage intensity S



Path along which an asphalt mixture loses its structural integrity due to accumulation of damage (microcracks)

S-VECD

- ❑ Performance parameter: MFS*
  - ❖ Material fatigue sensitivity (MFS)
  - ❖ Lower MFS, higher fatigue resistance

Note: * Cao W, Mohammad LN, Elseifi M. 2017. Assessing the effects of RAP, RAS, and warm-mix technologies on fatigue performance of asphalt mixtures and pavements using viscoelastic continuum damage approach. Road Materials and Pavement Design 18(s4): 353-371.

S-VECD

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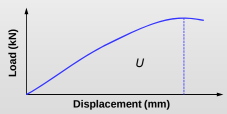
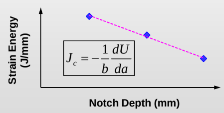
ALF-L11	40	–	58-28	Evotherm

L1 and L2 yielded highest fatigue resistance
L3, L5, and L7 lowest MFS

SCB

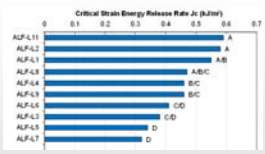
- ❑ Performance parameter: Jc
  - ❖ Critical strain energy release rate
  - ❖ Higher Jc, higher resistance to fracture





$$J_c = -\frac{1}{b}\frac{dU}{da}$$

SCB



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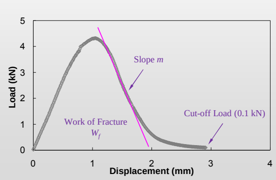
ALF-L11	40	--	58-28	Evotherm

L11 and L2 yielded highest cracking resistance, followed by L1 control.
L3, L5, and L7 the worst performers

I-FIT

- ❑ Performance parameter: FI
  - ❖ Flexibility index
  - ❖ Higher FI, higher resistance to fracture



$$FI = \frac{W_f \,/\, \text{Ligament Area}}{|m|} \times 0.01$$

I-FIT

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L11 and L1 highest cracking resistance.
L3, L5, and L7 the worst performers

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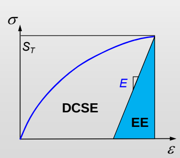
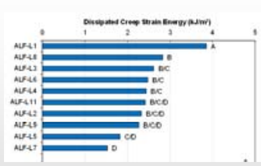
IDT

- Performance parameter: DCSE
  - Dissipated creep strain energy
  - Higher DCSE, higher resistance to crack initiation



$$DCSE = FE - \frac{1}{2}\frac{S_T^2}{E}$$

IDT



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L1 highest cracking resistance
L5, L7 lowest cracking resistance.
L3 ranked third best. Considered among the worst as per the other evaluation parameters.

Test Variability

- Test variability indicator:
  - Beam fatigue: difference in $N_{f,BF}$ < 0.787 in double-log scale for replicates
  - Others if applicable: coefficient of variation (CoV)

Test Variability

- Results
  - Beam fatigue: difference in $N_{f,BF}$ in double-log scale ranged between **0.03 and 0.72**, with an overall average of **0.24**

Test Method	Parameter	CoV Range	CoV Average
Texas overlay	$N_{f,OT}$	7 – 42%	24%
	CPR	2 – 16%	10%
S-VECD	MFS	Not Applicable	
SCB	Jc	3 – 25%	13%
I-FIT	FI	10 – 48%	25%
IDT	DCSE	4 – 34%	18%

Sensitivity to Mixture Component

- Sensitivity to composition factors
  - Effect of recycled asphalt materials
- Performance parameters were normalized with respect to values of the control mix

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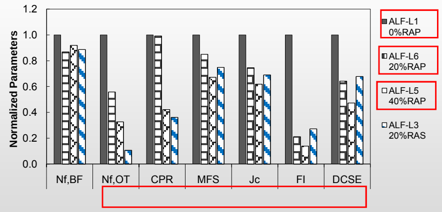
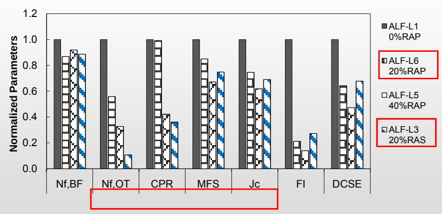
ALF-L6	20	–	64-22	HMA
ALF-L7	–	20	58-28	HMA
ALF-L8	40	–	58-28	HMA
ALF-L9	20	–	64-22	Water foam
ALF-L11	40	–	58-28	Evotherm

Effect of recycled materials



All four mixtures were HMA with PG 64-22 base binder.

Effect of recycled materials



All four mixtures were HMA with PG 64-22 base binder.

Correlation with ALF fatigue performance

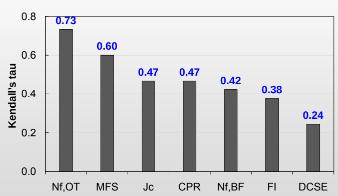
Grouping	$N_{f,ALF}$	$N_{f,BF}$	$N_{f,OT}$	CPR	MFS	J_c	FI	DCSE
Best Three	L1	L9	L9	L9	L1	L11	L11	L1
	L9	L8	L1	L4	L2	L2	L1	L8
	L2	L1	L4	L2	L11	L1	L9	L3
Moderate Four	L6	L4	L11	L8	L8	L8	L8	L6
	L4	L11	L2	L11	L4	L4	L2	L4
	L11	L2	L6	L1	L9	L9	L7	L11
	L8	L6	L8	L6	L6	L6	L4	L2
Worst Three	L3	L7	L5	L5	L3	L3	L3	L9
	L5	L5	L3	L7	L5	L5	L6	L5
	L7	L3	L7	L3	L7	L7	L5	L7

Correlation with ALF fatigue performance

- Rank correlation – Kendall's tau coefficient
  - Numerical indicator that measures degree of agreement in ranking.
  - Varies between
    - -1 fully different (reverse order)
    - 1 identical rankings
  - Ranking reference
    - ALF fatigue performance experiment

Correlation with ALF fatigue performance

- Rank correlation – Kendall's tau coefficient



Summary and Conclusions

- Cracking resistance of 10 plant-produced asphalt mixtures with different composition factors using six laboratory performance tests
- Mixture discriminating potential of these test methods
- Compare test methods ranking capability to fatigue performance form ALF experiment
- Increase in RAP content generally led to reduction in cracking resistance according to evaluation parameters.
  - Texas overlay, SCB Jc, and S-VECD tests reasonably ranked mixtures L3 and L6 with the same RBR but the former having the more oxidatively aged asphalt binder from RAS

ALF-L3	–	20	64-22	HMA
ALF-L6	20	–	64-22	HMA

Summary and Conclusions

- Effect of two warm-mix technologies was not conclusive
  - no consistent observation from laboratory tests
  - generally, water-foaming and Evotherm processes produced WMA mixtures with similar cracking resistance as compared to conventional counterparts
- Correlation between evaluation parameters and ALF fatigue performance experiment
  - beam fatigue, Texas overlay, S-VECD, and SCB Jc tests exhibited similar ranking capabilities

Acknowledgement

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  - **Colorado**
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  - **Louisiana**
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  - Wei Cao
  - Peyman Barghabany
  - Lab technicians
  - …

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95th **AAPT** Annual Meeting and Technical Sessions

The 2020 Annual Meeting will be held March 22-25, 2020
Westin San Diego Gaslamp Quarter, San Diego, California USA

Our 2020 venue
Westin San Diego Gaslamp Quarter

2020 Annual Meeting

The Annual Business Meeting and Technical Sessions of the Association of Asphalt Paving Technologists (AAPT) will be **March 22-25, 2020** in San Diego, California at Westin San Diego Gaslamp Quarter. The annual meeting includes asphalt-related technical sessions comprised of peer-reviewed papers, and invited presentations on specific topics in the AAPT-ISAP International Forum, and Symposium as well as a Student Poster Session.

Visit http://asphalttechnology.org/annual-meeting.html for more details as they become available.

Important dates

December 2019 – Annual Meeting registration opens
March 22-25, 2020 - Annual Business Meeting and Technical Sessions

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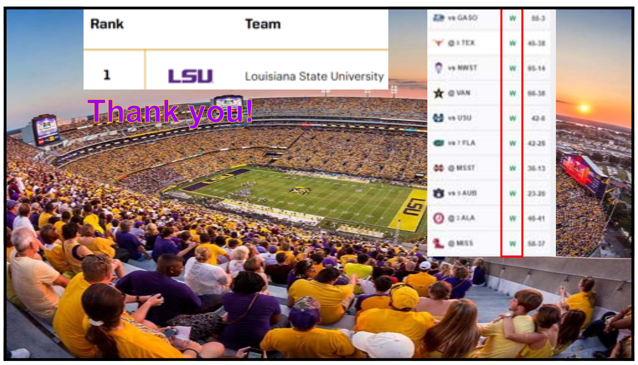

SCB at Intermediate Temperature

- **Data Analysis**