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ARC Asphalt Research Consortium

Binder Expert Task Group Meeting
Baton Rouge, LA
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Linear Amplitude Sweep Test:

Binder Grading Specification and Field Validation

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Outline

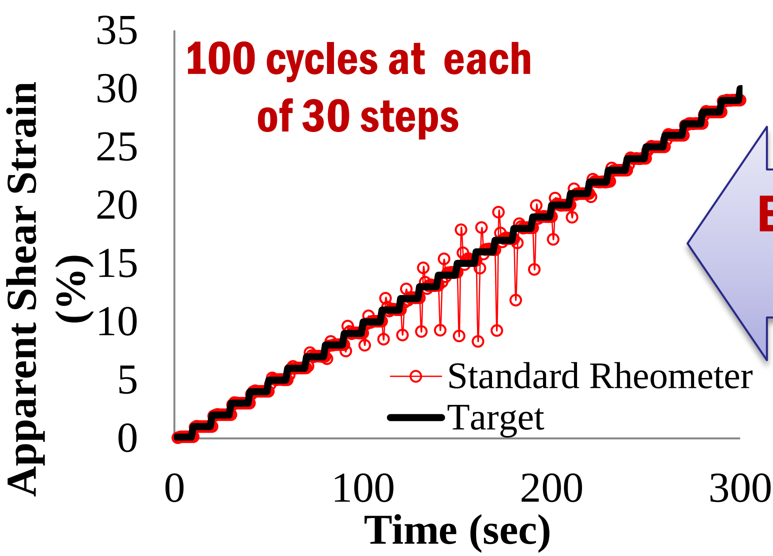
1. Review of Questions raised last ETG meeting
2. Comparison to Field Performance
3. Use of the LAS as a Performance Grading Criteria
4. Review of Ruggedness Results
5. Conclusions and Recommendations

REVIEW OF CURRENT PROCEDURE

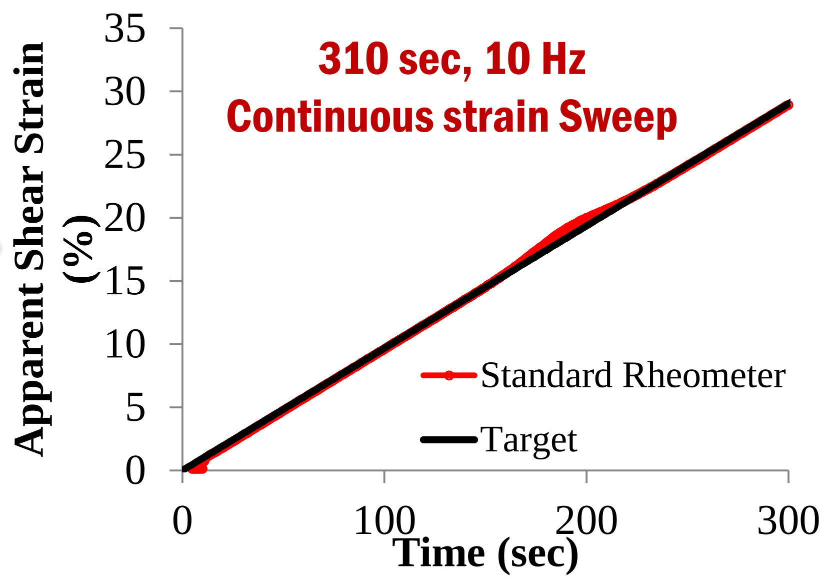
Fatigue Cracking

- PG test (DSR |G*|sinδ) is only based on small strain rheology, and does not consider damage resistance.
  - The advantages of many modifiers is manifested as "toughening" and enhancement of damage resistance.
- Currently in PG+ spec Elastic Recovery and force ductility are used at intermediate temperatures.
  - It is well recognized that ER is not considered to be a fatigue performance test. It is to indicate there is an elastomer polymer used.
- The Linear Amplitude Sweep (LAS) under AASHTO TP101 is introduced as a method of measuring "Damage Resistance". It is performance-based assessment of binder fatigue resistance.

Review: Changing from Stepped to Continuous Strain Sweep

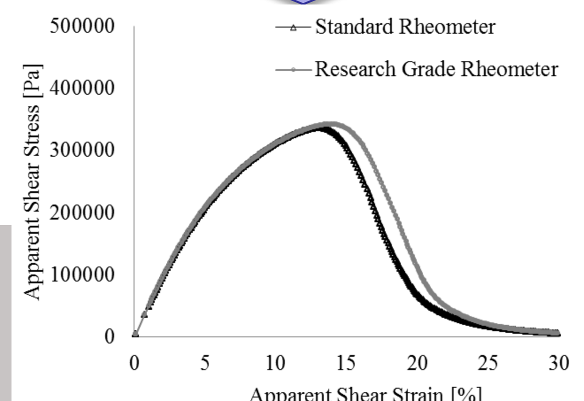


Equivalent Results



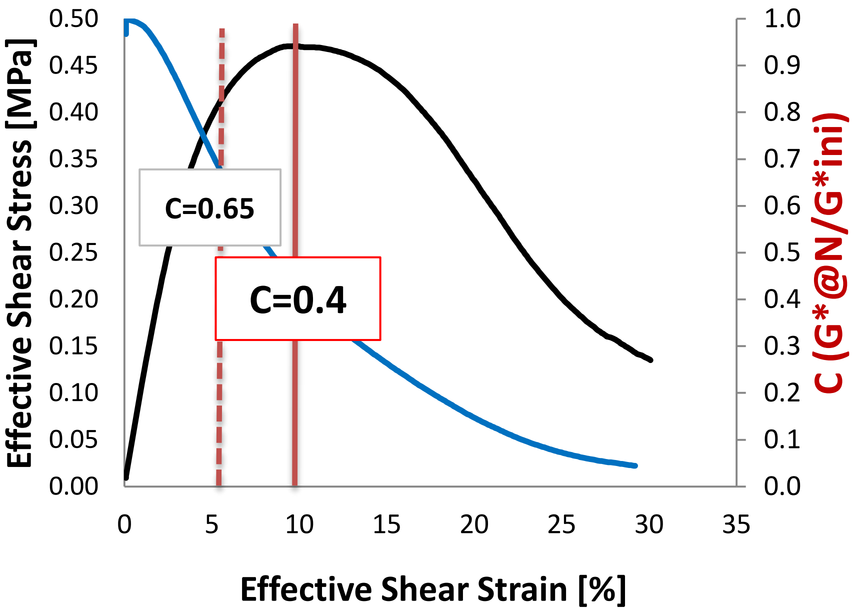
The "stepped" sweep was replaced with a "continuous" sweep.

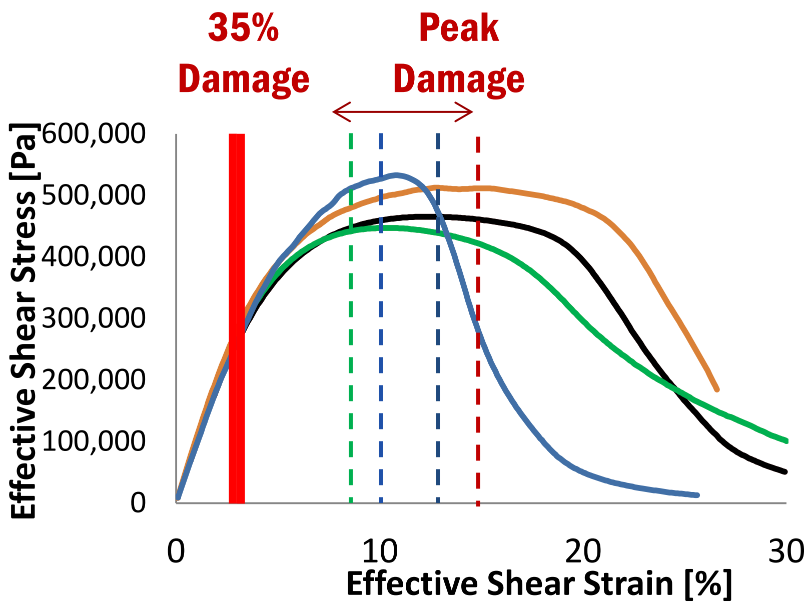
- Simpler to run with most rheometers



Current LAS Failure Criteria
(As described in current updated Procedure 3/2014)

- **AASHTO TP-101-12 uses VECD to calculate Nf at 35% reduction in initial modulus (C=0.65)**
- **Alternative failure criteria based on peak stress can also be used to relate the ultimate failure criteria to material response indicator**





ESTABLISHING RELATION TO FIELD PERFORMANCE

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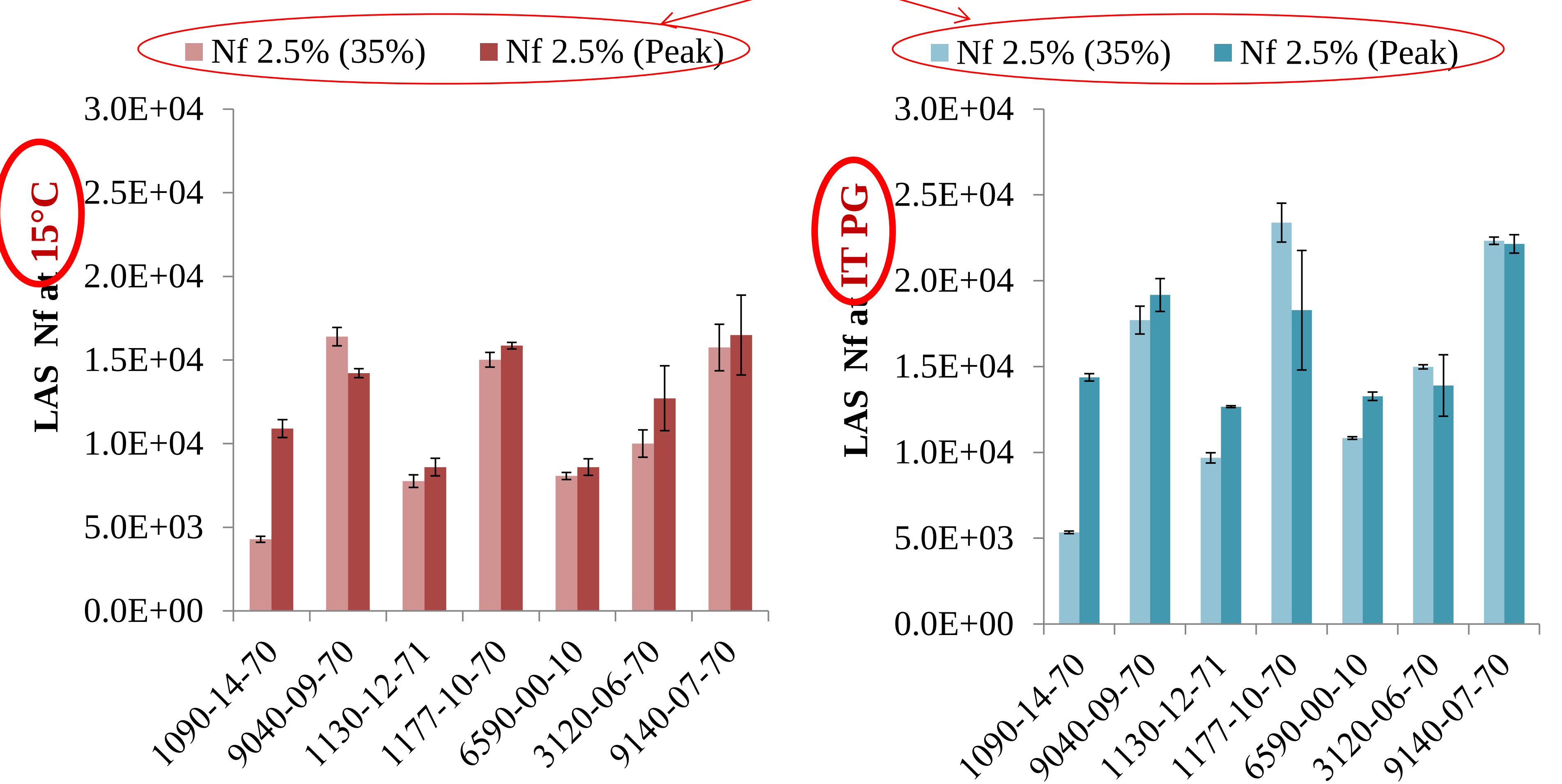
Effect of Traffic Volume and Binder Properties

- Fatigue damage can happen due to the following factors:
  - Poor binder fatigue resistance at specific strain levels
  - High traffic volume
  - Combination of both
- Analysis should consider traffic volume.

Recent WisDOT Study for Implementing the Linear Amplitude Sweep Results

Differences in failure criteria results



Bahia, H., Tabatabaee, H., Mandal, T., & Faheem, A. (2013). *Field Validation of Wisconsin Modified Asphalt Binder Selection Guidelines-Phase II.* Madison: Wisconsin Department of Transportation.

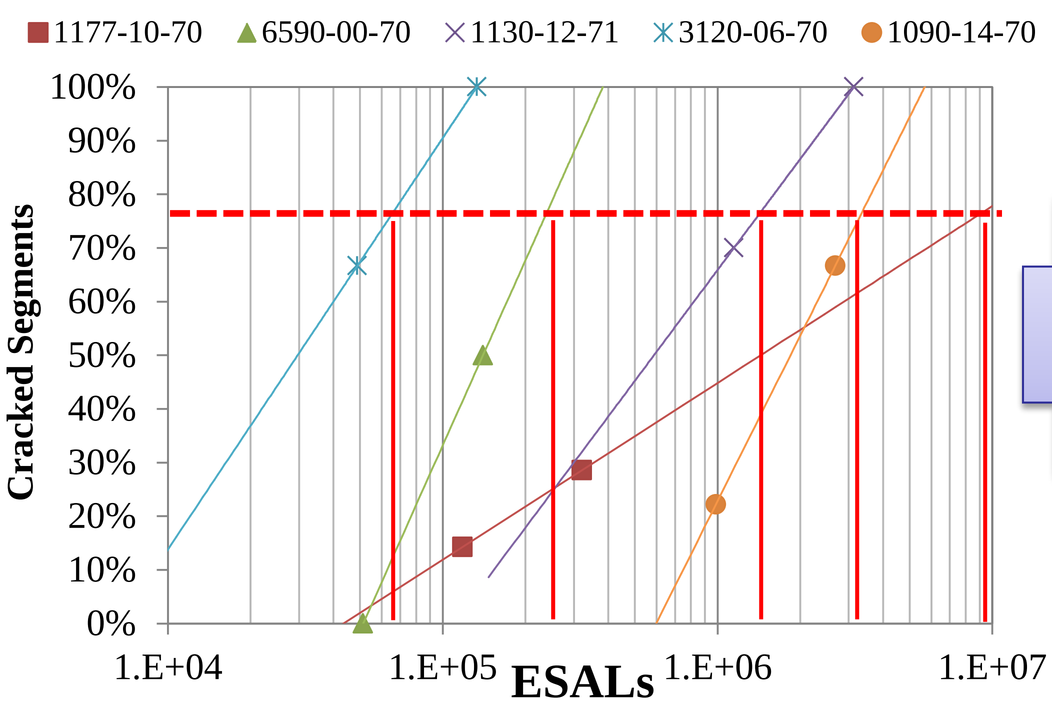
Relating Field Fatigue Damage to LAS (WisDOT Study)

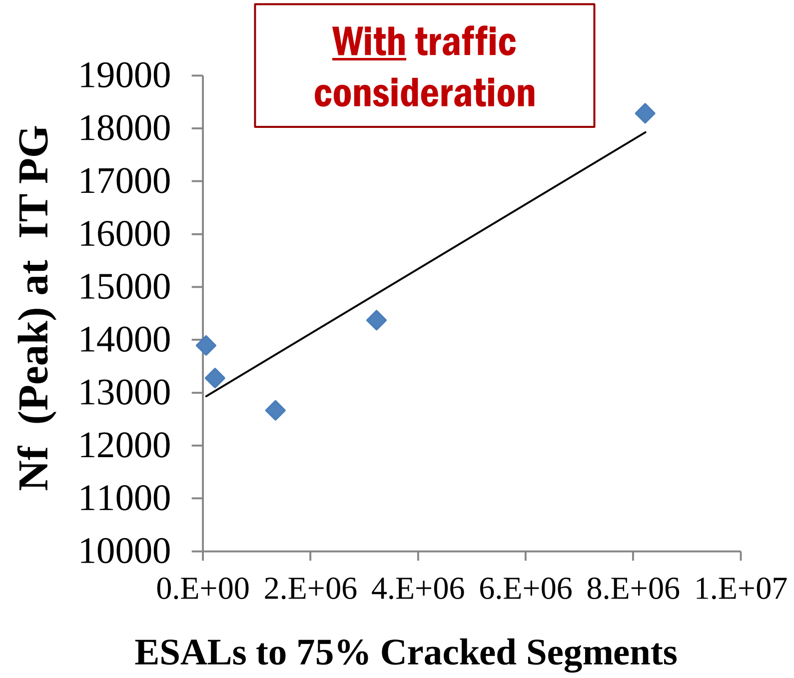
- By comparing field performance to LAS results it was found that:
  - Best relation established when LAS performed at the <u>**project's local required Climatic PG intermediate temperature (IT).**</u>
    - Defined in LTPPBind Software with 98% Reliability Level
  - Considers variations in binder performance based on local climatic conditions.
  - Field damage was <u>normalized to traffic</u> (next slide)

Bahia, H., Tabatabaee, H., Mandal, T., & Faheem, A. (2013). *Field Validation of Wisconsin Modified Asphalt Binder Selection Guidelines-Phase II.* Madison: Wisconsin Department of Transportation.

Establishing DOT Specification
Considering Traffic Volume Variation

- **Fatigue damage is function of traffic volume.**
  - Calculated traffic volume loading leading to equal damage in all sections calculated
  - Damage levels from multiple surveys used to develop curves





More data points will be provided through pooled fund PG+ binder tests project

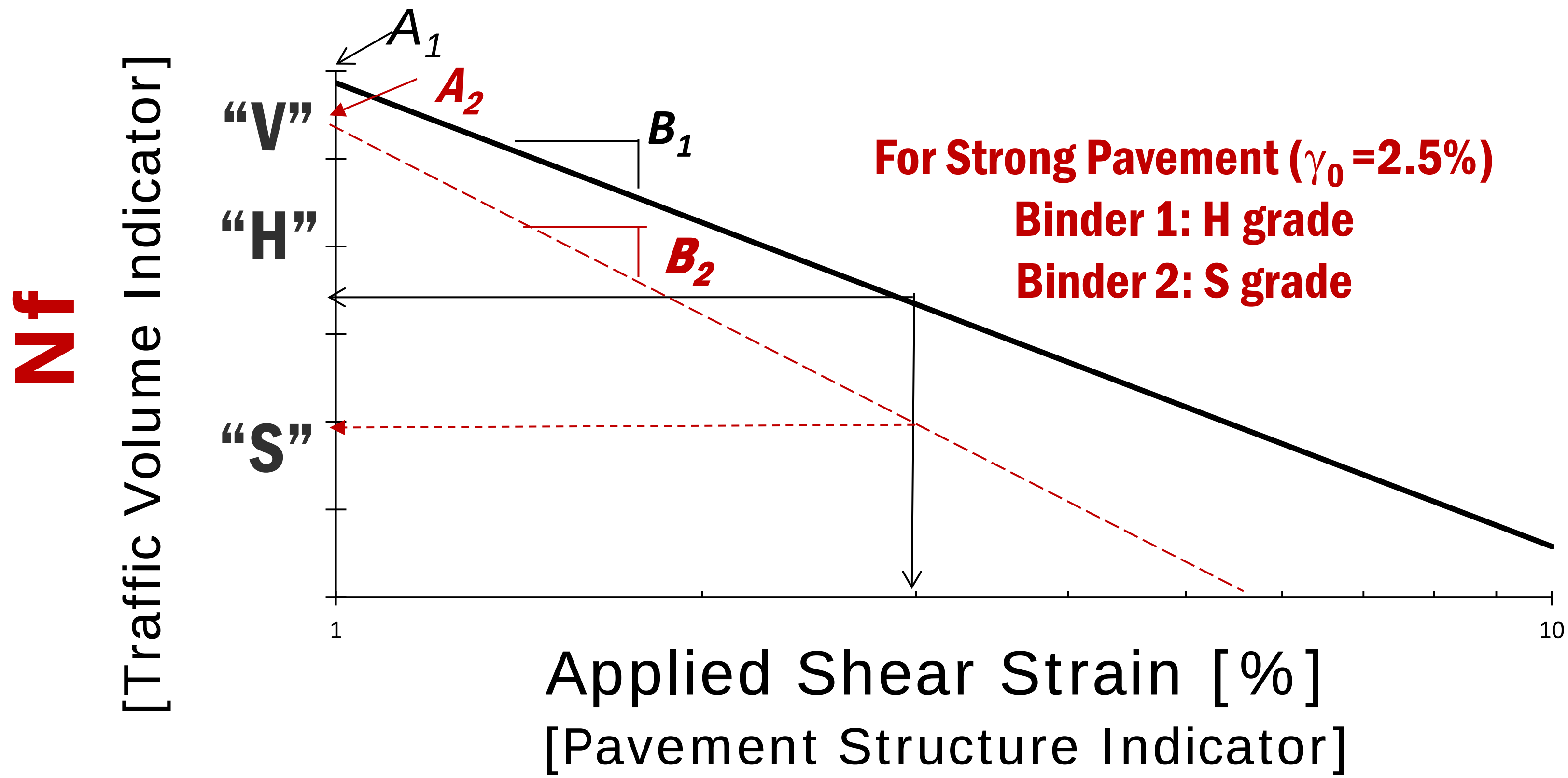
PROPOSED SPECIFICATION PROCEDURE

Proposed Procedure

1. Perform LAS on binder at Climatic Intermediate specification temperature
2. Calculate LAS Nf at 2.5 and 5% strain
   – Binder strain assumed ~50 times pavement strain (Masad et al. 2001)
   – For "strong" pavement 500 µstrain assumed (Binder strain=0.025 = 2.5%)
   – For "weak" pavement 1000 µstrain assumed (Binder strain= 0.050 = 5.0%)
3. Compare to Nf limit corresponding to design ESALS (using MP-19 or Superpave Mix Design definitions)

Fatigue Law From LAS "A" and "B"
Two binders: 1:Modified, 2: Unmodified

Fatigue Law: $Nf = A(\gamma_0)^B$



Fatigue Law From LAS "A" and "B"
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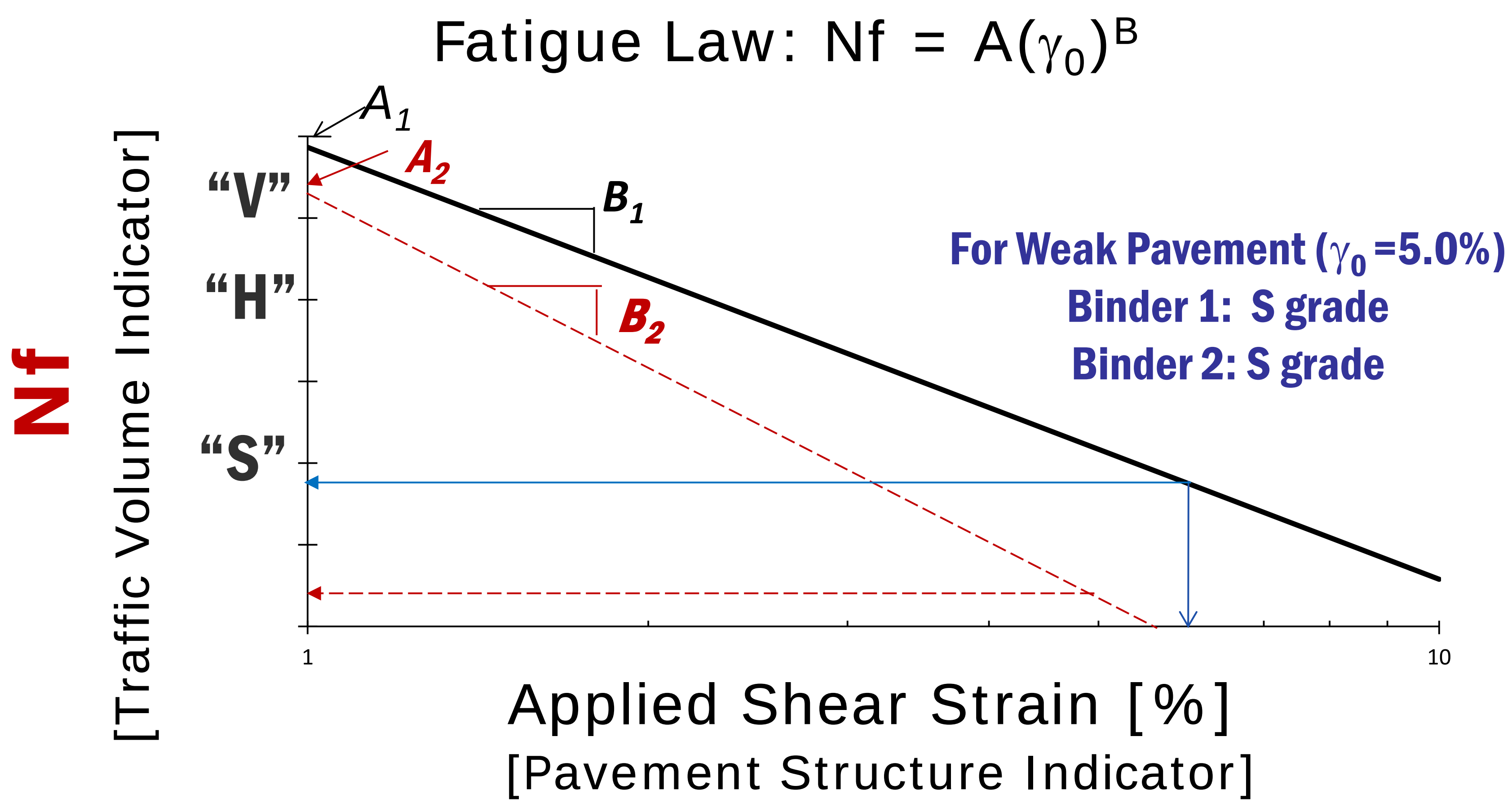


Advantages of Proposed Specification

- Can be performed on same sample as used for Superpave M320 grading.
- Calculation is very simple: $Nf = A(\gamma_0)^B$
- Considers traffic levels (using MP-19 or DOTs definitions)
- Considers pavement layer stiffness
  - Asphalt layer < 4 " : use 5.0% strain
  - Asphalt layer > 4 " : use 2.5 % strain
- Using existing framework for AASHTO MP-19 can facilitate integration and adoption

VALID G* TESTING RANGE

Determination of LAS Valid Temperature-Stiffness Range

- Binders were tested at 5, 10, 15, 25, and 35 C
- Photographs were taken from cracked surface and side (to check for geometry change)
- Time-temperature superposition was checked for VECD damage curves

- Data collected in collaboration between UW-MARC (Dr. Hussain Bahia, Dr. Hassan Tabatabaee) and NCSU (Dr. Cassie Hintz)

- LTPP and MnROAD Binders Tested
  - LTPP 340901
  - LTPP 090962
  - LTPP 370901
  - LTPP 370903
  - LTPP 370962
  - MnROAD C33 (Acid Modified)
  - MnROAD C35 (Elastomer Modified)

Bulging vs. Stiffness

- A relationship was observed between binder stiffness and the apparent geometry change (bulging).
- (red) : Too much bulging

At 10 rad/sec

Temperature (°C)	300903 |G*| 10 rad/sec (MPa)	370903 |G*| 10 rad/sec (MPa)	C35 |G*| 10 rad/sec (MPa)
35	0.41	0.67	0.42
25	2.14	4.50	2.39
20	4.46	10.38	5.21
15	8.76	21.95	10.64
10	16.15	42.49	20.27
5	27.99	75.36	36.08

At 10 Hz

Temperature (°C)	300903 |G*| 10 Hz (MPa)	370903 |G*| 10 Hz (MPa)	C35 |G*| 10 Hz (MPa)
35	1.49	2.44	1.38
25	6.50	13.15	6.70
20	13.90	30.99	15.21
15	21.95	51.07	24.87
10	36.83	88.23	43.26
5	58.33	140.36	70.45

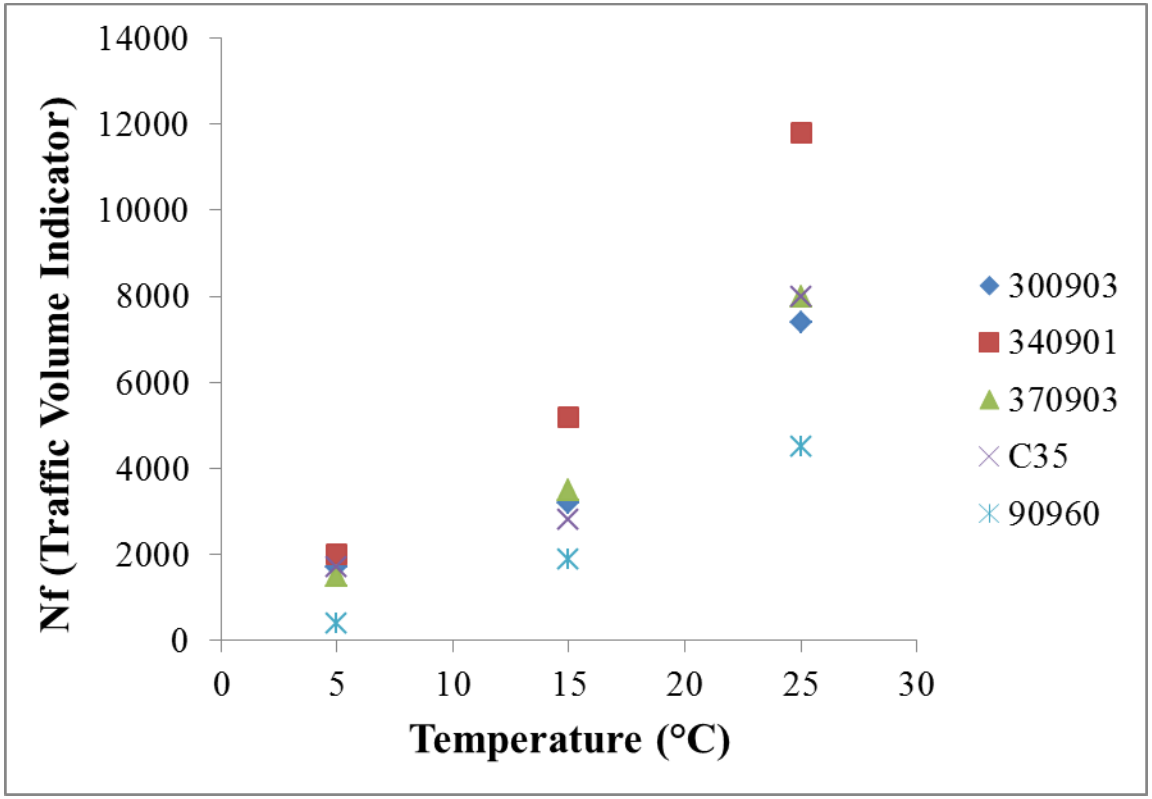
Applicable temperature Limits

- LAS targets cohesive fracture-based crack propagation
- At high temperatures geometry change and bulging initiates (observed in photos)
  - Max Temperature: G*>10 MPa at 10 Hz
    - Approximately 2.5 MPa at 10 rad/sec, based on binder
- At low temperatures excessive brittleness and adhesive failures occurs between DSR plates and binder specimen
  - Min Temperature: G*< 60 MPa at 10 Hz
    - Approximately 25 MPa at 10 rad/sec, based on binder

Easily determined from LAS standard frequency sweep step.

Failure Parameter Within Applicable Temperature-Stiffness Range

- LTPP and MnROAD Binders Tested

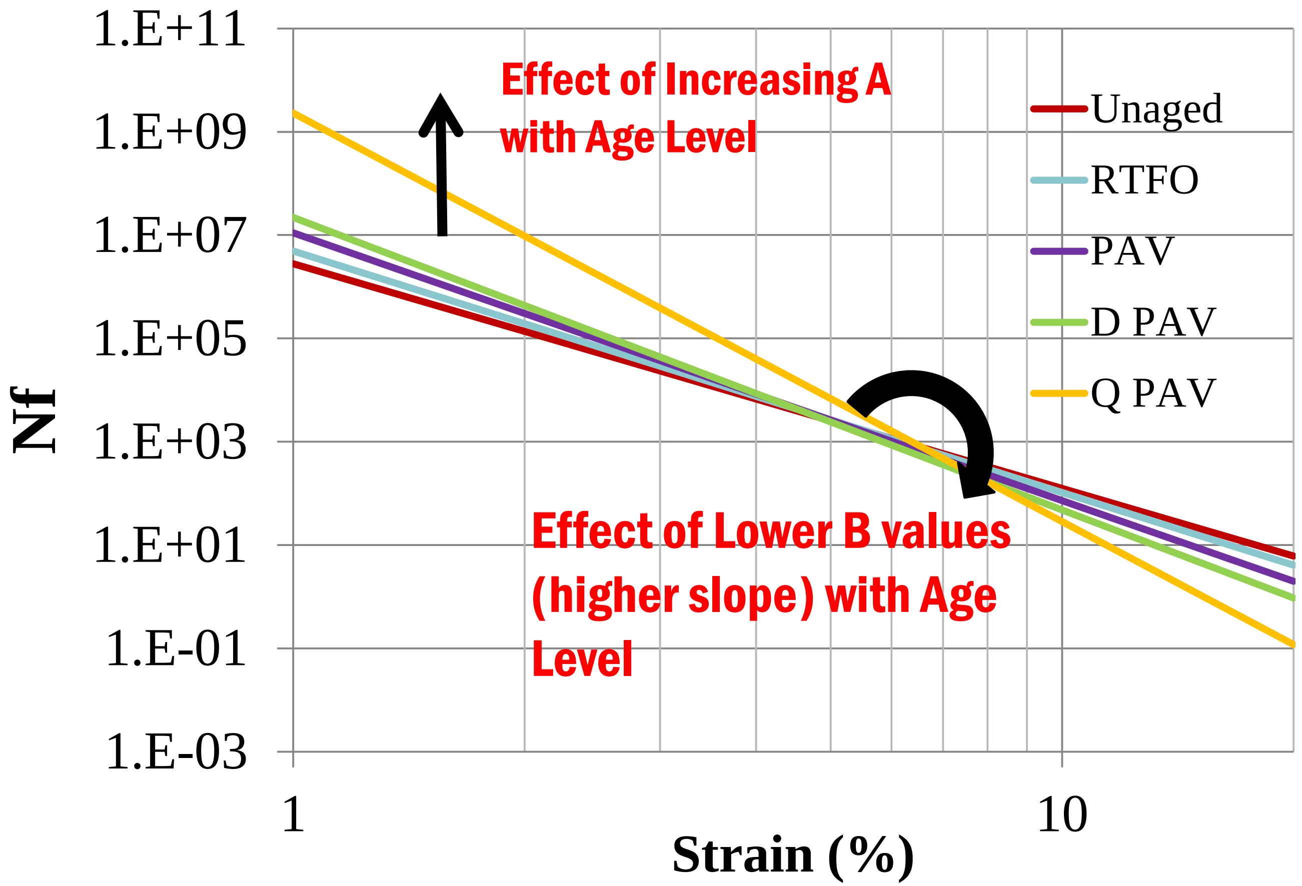


Increase in Testing Temperature (↑Temp)

↓

Increase in Failure Indicator (↑Nf)

Effects of Aging on Fatigue Life
Should we test RTFO or PAV?



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Keep it consistent with M320: Test PAV
Collect more data for future

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REVIEW OF RUGGEDNESS RESULTS

LAS Ruggedness Test (Review)

- Samples sent to 6 labs (listed alphabetically):
  - Asphalt Institute
  - FHWA Turner-Fairbanks
  - MTE Laboratories
  - North Carolina State University
  - University of Wisconsin
  - Utah DOT

Rheometer Used:

- Anton Paar Smartpave
- TA ARES
- TA Discovery Hybrid 3
- Malvern Kinexus

- Ruggedness test plan and analysis was performed in accordance to ASTM E1169-12a "Standard Practice for Conducting Ruggedness Tests"

Material and Method

- 3 binder types tested at at 19°C:
  - An RTFO aged Neat
  - An RTFO+PAV aged Neat
  - An RTFO+PAV aged Highly Polymer Modified

		Factor Levels	
Factor	Variable	Level 1	Level -1
T	Sample Loading temperature	60°C	70°C
S	Strain Amplitude	0.95·(0.1 to 30%)	1.05·(0.1 to 30%)
F	Frequency Accuracy	9.5 Hz	10.5 Hz
P	Sample Placement Method	Mold	Pour

Review of Ruggedness Results

- Nf values from new analysis method (Damage at Peak Stress) were rugged (p-value > 0.05) against effects of:
  - Loading Temperature
  - Frequency
  - Strain Amplitude
  - Sample type (pour vs. pallet)

Rugged?		F1-Loading Temp	F2-Strain Amplitude	F3-Frequency	F4-Sampling
Binder A	Lab 1	Y	Y	Y	Y
	Lab 2	Y	Y	Y	Y
	Lab 3	Y	Y	Y	Y
	Lab 4	Y	Y	Y	Y
	Lab 5	Y	Y	Y	Y
Binder B	Lab 1	Y	Y	Y	Y
	Lab 2	Y	Y	Y	Y
	Lab 3	Y	Y	Y	Y
	Lab 4	Y	Y	Y	Y
	Lab 5	Y	Y	Y	Y
Binder C	Lab 1	Y	Y	Y	Y
	Lab 2	Y	Y	Y	Y
	Lab 3	Y	Y	Y	Y
	Lab 4	Y	Y	Y	Y
	Lab 5	Y	Y	Y	Y

Conclusions and Recommendations

- The Linear Amplitude Sweep test (AASHTO RP 101) is shown to relate closely to observed field performance.
  - More data points needed to establish specification limits.

- Range of applicable temperatures and stiffness's defined.
  - Superpave Intermediate PG is suitable temperature for LAS test.

Next Steps

- Add additional field performance data to use in method shown for development specification Limits based on Mix Design categories (E-3, E-10, etc.) or AASHTO MP-19 framework (“S”, “H”, etc.).

- Draft a separate AASHTO procedure document for binder selection and specification limits.
  – Possibility exists to incorporate into current AASHTO M320 format

Acknowledgements

- This research was sponsored by the **Asphalt Research Consortium (ARC)**, which is funded by FHWA and WRI.
- Dr. Cassie Hintz for her research and collaboration with MARC in finalizing the LAS procedure.
- Dr. Hassan Tabatabaee for contribution to LAS ruggedness testing and establishing relation to field performance.
- Special thanks to all participating laboratories in ruggedness program:
  - Asphalt Institute
  - MTE Laboratories
  - Utah DOT
  - FHWA Turner-Fairbanks
  - North Carolina State University

Thank You!

Questions?

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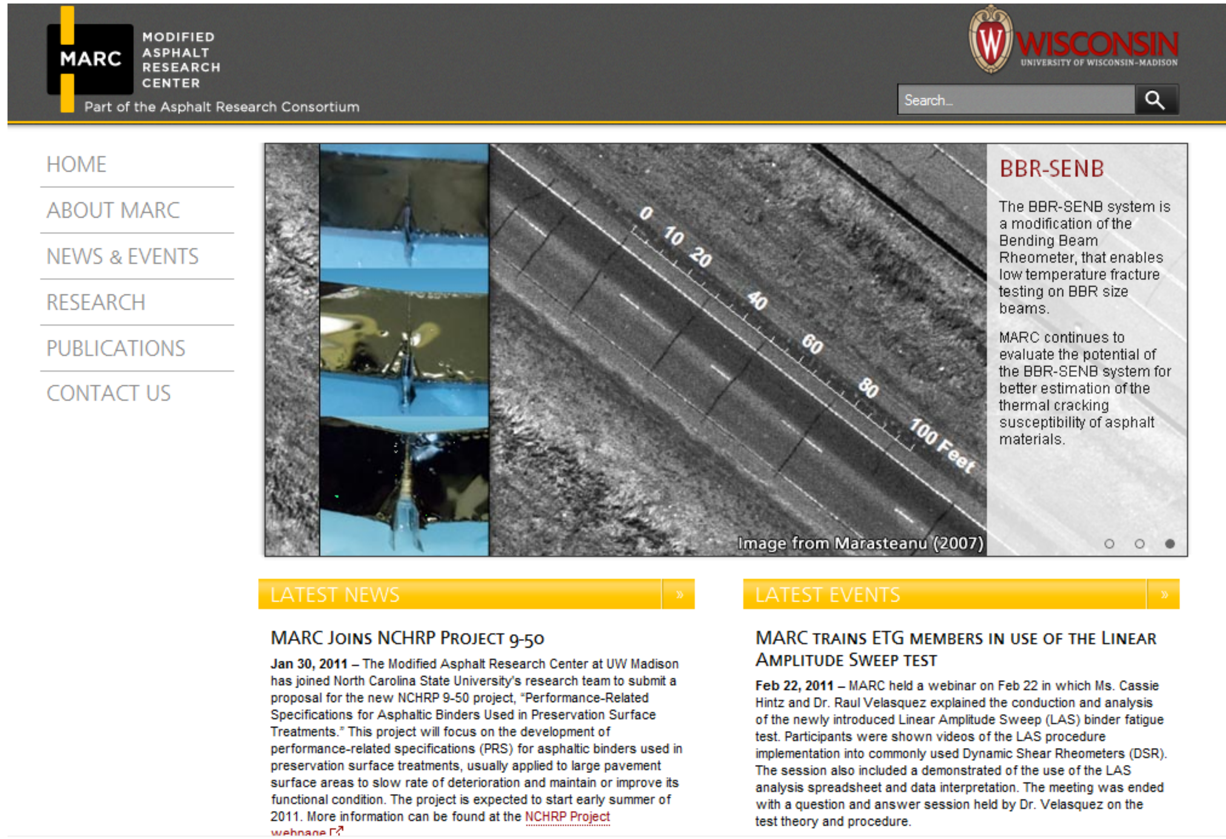

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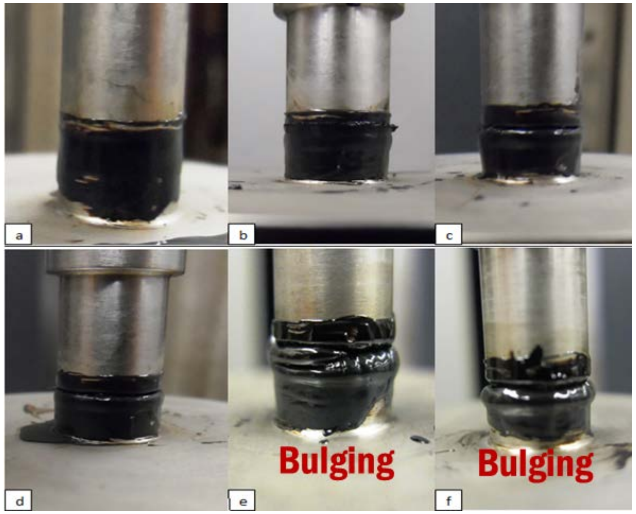
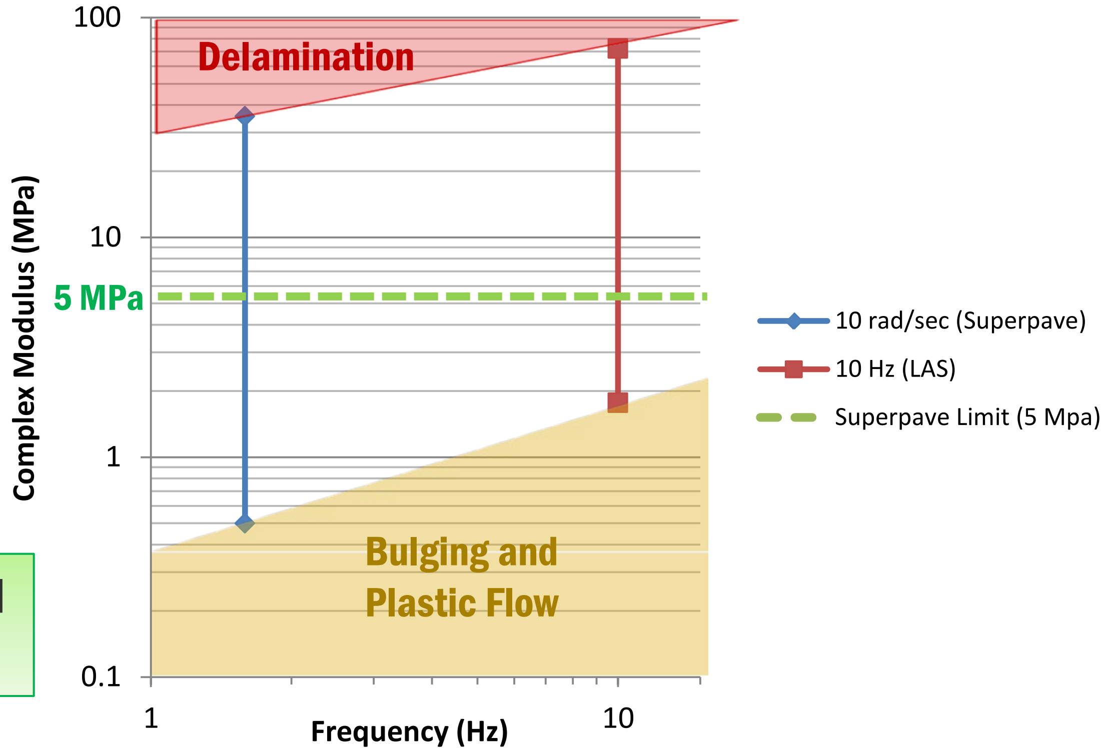
Image Analysis to Study Effect of Temperature on Failure Mechanism





PG intermediate temperature located in acceptable LAS Test Range

Easily determined from LAS standard frequency sweep step.

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Addition of LAS to MP-19 Table

Table 1—Performance-Graded Asphalt Binder Specification[a]

Performance Grade	PG 46			PG 52							PG 58				
	34	40	46	10	16	22	28	34	40	46	16	22	28	34	40
Average 7-day max pavement design temp, °C[b]	<46			<52							<58				
Min pavement design temp, °C[b]	>–34	>–40	>–6	>–10	>–6	>–22	>–28	>–34	>–40	>–46	>–16	>–22	>–28	>–34	>–40
Linear amplitude Sweep, TP101 Grade "S" Nf at 2.5 and 5% > 15,000 Test temp, °C	10	7	4	25	22	19	16	13	10	7	25	22	19	16	13
Linear amplitude Sweep, TP101 Grade "H" Nf at 2.5 and 5% > 19,000 Test temp, °C	10	7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7	25	22	19	16	13
Linear amplitude Sweep, TP101 Grades "V" and "E" Nf at 2.5 and 5% > 31,000 Test temp, °C	10	7	4	25	22	19	16	13	10	7	25	22	19	16	13

Same traffic grades (S, H, …)

Nf strain at 2 levels: "weak" or "strong"

Test at PG intermediate test temperature

Updated Analysis Method

- The following analysis is performed automatically once data is pasted into spreadsheet:

1. α is defined based on the slope of the frequency sweep (unchanged)
2. Calculate Damage for each increment as follows:

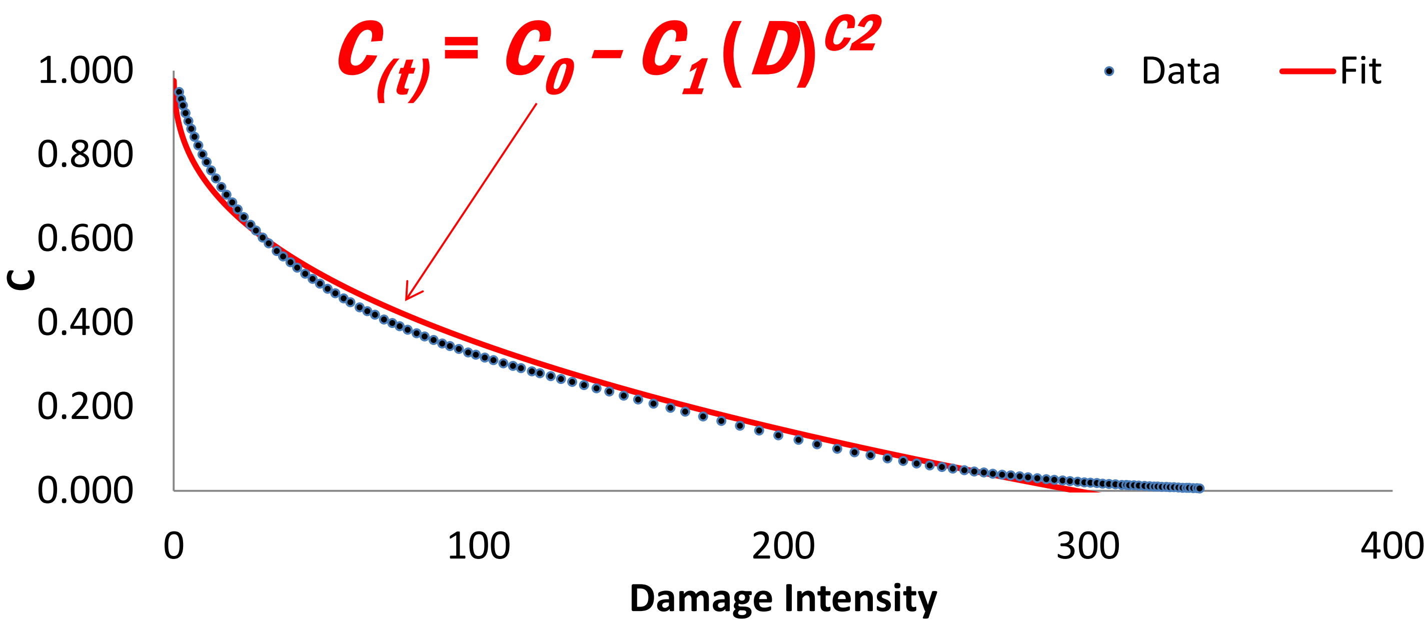
$$D(t) \cong \sum_{i=1}^{N} \left[\pi \gamma_0^2 (C_{i-1} - C_i)\right]^{\frac{\alpha}{1+\alpha}} (t_i - t_{i-1})^{\frac{1}{1+\alpha}}$$

Where:

$$C(t) = \frac{|G^*|(t)}{|G^*|_{initial}}$$

Determination of C1 and C2

3. **C1 and C2 parameters are calculated by fitting the following equation to the C vs. Damage curve:**



Updated Analysis Method

4. **Define failure damage level:**

$$D_f = \left(\frac{C_1 - C\ at\ Peak\ Stress}{C_1}\right)^{1/C_2}$$

5. **Calculate A and B for** $N_f = A(\gamma_{max})^{-B}$

$$A = \frac{f(D_f)^k}{k(\pi C_1 C_2)^\alpha}$$

$k = 1 + (1 - C_2)\alpha$

and

$B = 2\alpha.$

Analysis Spreadsheet

- **Spreadsheet automatically calculates A, B, and Nf.**

$$N_f = A(\gamma_{max})^{-B}$$

Sample:		Damage level:	0.582
Model:	$C(t) = C_0 - C_1(D)^{\wedge}C_2$		
C_0	C_1	C_2	Summed Error
1.000	0.103	0.399	0.166
τ_{max} (Pa)	903124		
α	$\lvert G^*\rvert_{initial}$	D_f	k
1.734	22350666.667	76	2.042
A	B	Applied Strain [%]	N_f
1.186E+06	-3.468	2.5	**49,416**
		5.0	**4,465**