Warm Mix Asphalt
Laboratory Characterization

Warm Mix Asphalt

Technical Working Group Meeting (WMA TWG)

December 12-13, 2007 Baltimore, Maryland

FHWA Office of Infrastructure R&D

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WARMMIXASPHALT.COM - Microsoft Internet Explorer

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Address http://www.warmmixasphalt.com/

NAPA first brought warm-mix technology to the United States from Europe in 2002, sparking intense interest among hot-mix asphalt producers, contractors, researchers, and government agencies. Since that time, new technologies have been developed in the United States.

Research

Several warm-mix asphalt demonstration projects have been constructed around the country. In addition, research under way at NCAT includes several test sections on the **NCAT Test Track**. The Federal Highway Administration is partnering with NCAT on this research, both by providing funds and by supporting innovative approaches to warm mix.

In exploring whether warm mix is the wave of the future, we must address many questions.

- Can warm-mix pavements be opened to traffic quickly after construction?
- What are the performance characteristics of these pavements?
- In the case of technologies developed in other countries, can they be adapted to the U.S., where climate conditions are often more extreme?
- If the production temperature is lower, does that mean that the binder does not age as much?
- Will the potential for thermal cracking be reduced?
- Will the potential for rutting be different?
- Will the contractor have to use a different grade of asphalt binder?
- What changes for the mix design procedure will be required?
- Will the performance-graded binder in a warm mix perform differently from pavements produced at higher temperature?

Publications and Links

[About NAPA] [Inside NAPA] [Join NAPA] [All About Asphalt] [Calendar]

NAPA National Asphalt Pavement Association
5100 Forbes Blvd

Internet

intense interest among hot-mix asphalt producers, contractors, researchers, and government agencies. Since that time, new technologies have been developed in the United States.

- Can warm-mix pavements be opened to traffic quickly after construction?
- **What are the performance characteristics of these pavements?**
- In the case of technologies developed in other countries, can they be adapted to the U.S. climate extreme?

Mixture fatigue of various technologies has been completed

- **If the production temperature is lower, does that mean that the binder does not age as much?**

Certainly

- Will the potential for thermal cracking be reduced?
- Will the potential for rutting be different?
- **Will the contractor have to use a different grade of asphalt binder?**

Perhaps??

- What changes for the mix design procedure will be required?
- **Will the performance-graded binder in a warm mix perform differently from pavements produced at higher temperature?**

Two Separate Presentations

Warm Mix Asphalt
and
Laboratory Fatigue Performance

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Warm Mix Asphalt
and
Binder Specifications
in the PG System

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and
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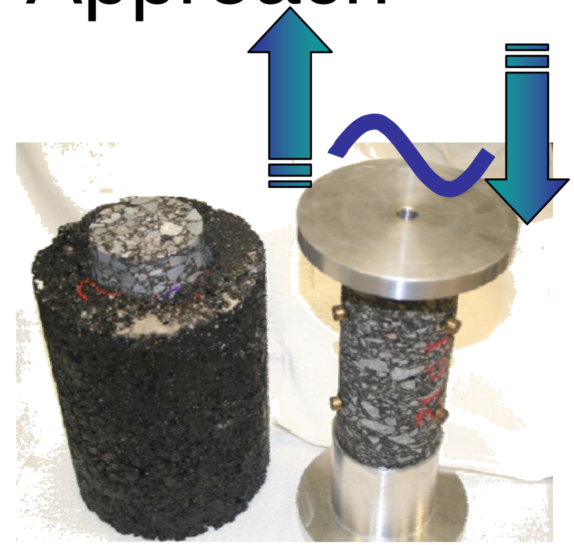
WMA Mixture Fatigue Characterization

- State-of-the-art-fatigue characterization
  - St. Louis WMA
    - Control
    - Sasobit
    - ~~Evotherm~~ **– remaining material in buckets has petroleum odor**
    - Asphamin
  - WAM Foam
- All mixtures were not long term oven aged per AASHTO R30.
  - Standard calls for compacted and cut samples are oven aged 120 hours at 85^{o}C after S.T.O.A.
  - Little/no concern for structural integrity with beam, but no experiments complete with cylindrical sample.

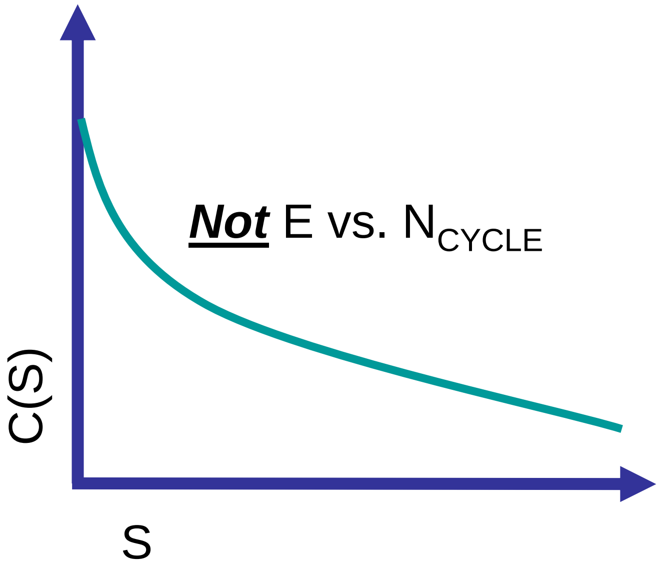
Cyclic ‘Push-Pull’ Fatigue Approach

- Holds greater promise for future than T312 flexural beam fatigue
- Test & Theory behind analysis present a more revealing description of the way damage grows in an asphalt mixture
- Sample can be made in Superpave gyratory compactor
- VERY compatible with SPT, modifications needed but possible



Cyclic 'Push-Pull' Fatigue Approach

- Raw data no different from AASHTO T312
  – N Cycles
  – Stress σ or strain ε control
- Goal is to find the damage characteristic curve *C(S) vs. S*
  – Interpretation is Loss in Modulus vs. Amount of Cracking Damage



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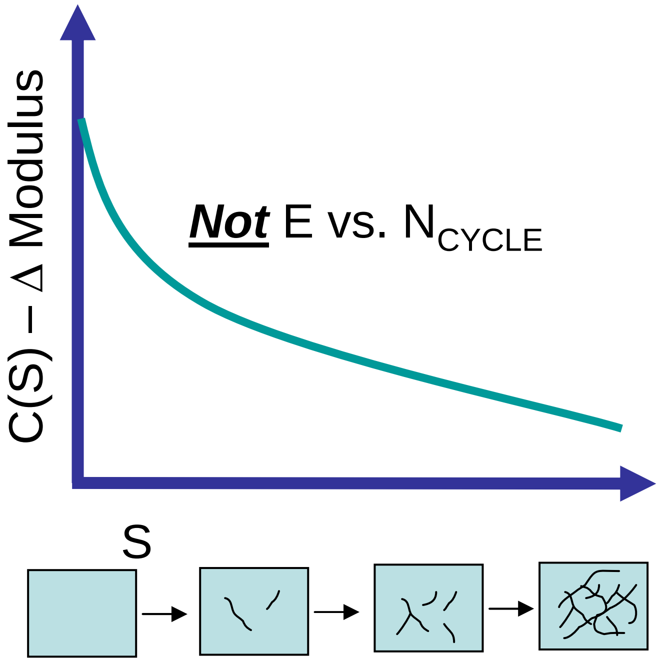
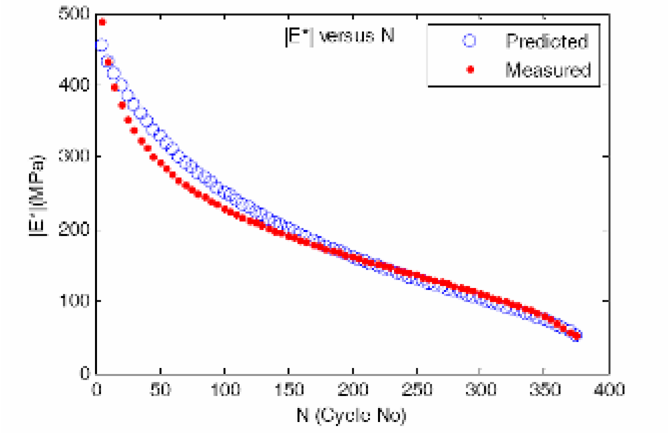
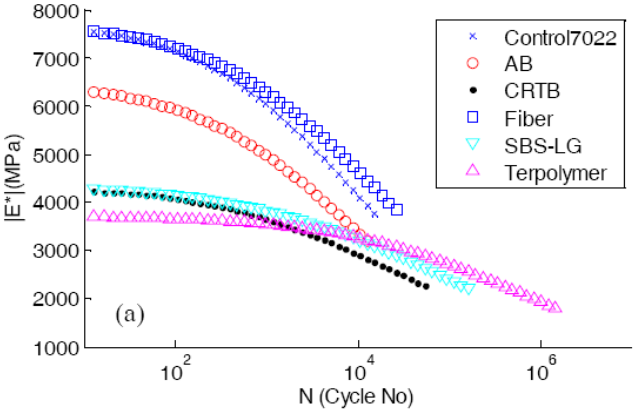


Cyclic 'Push-Pull' Fatigue Approach

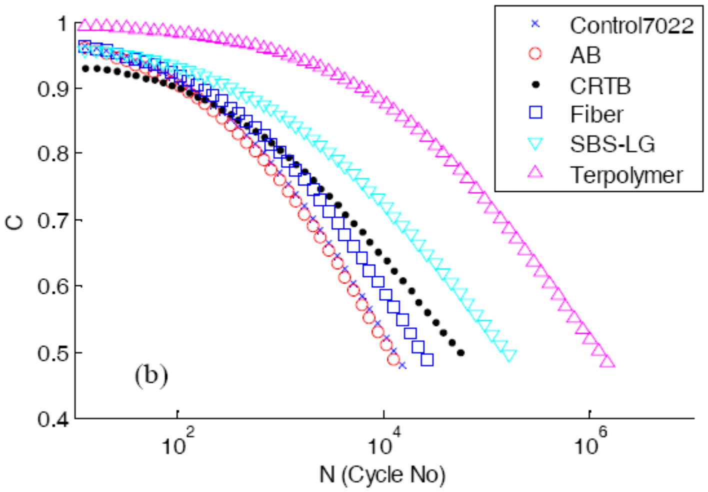
- Allows for an economized test program due to the theoretical underpinnings
- Results from a rapid and convenient cyclic test can be used to predict results under smaller stress or smaller strain
  - For example, a variety of mixtures can be virtually characterized at either 1,000με or 100με or any level desired.

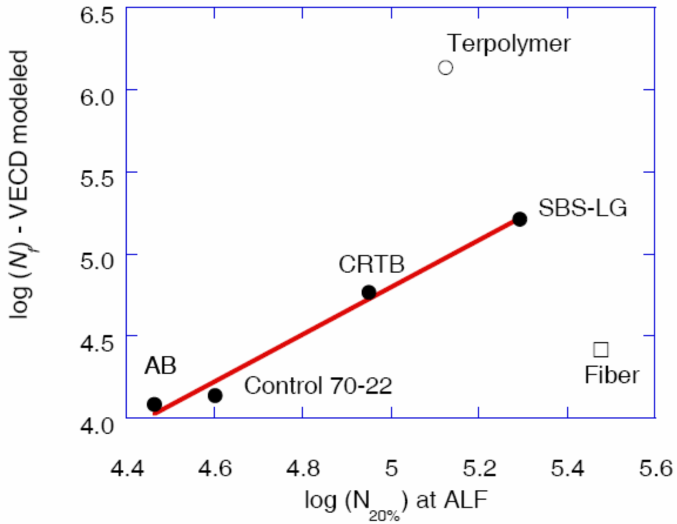




Cyclic ‘Push-Pull’ Fatigue Approach

- Analysis has been completed for ALF materials and normalized to 150με strain control

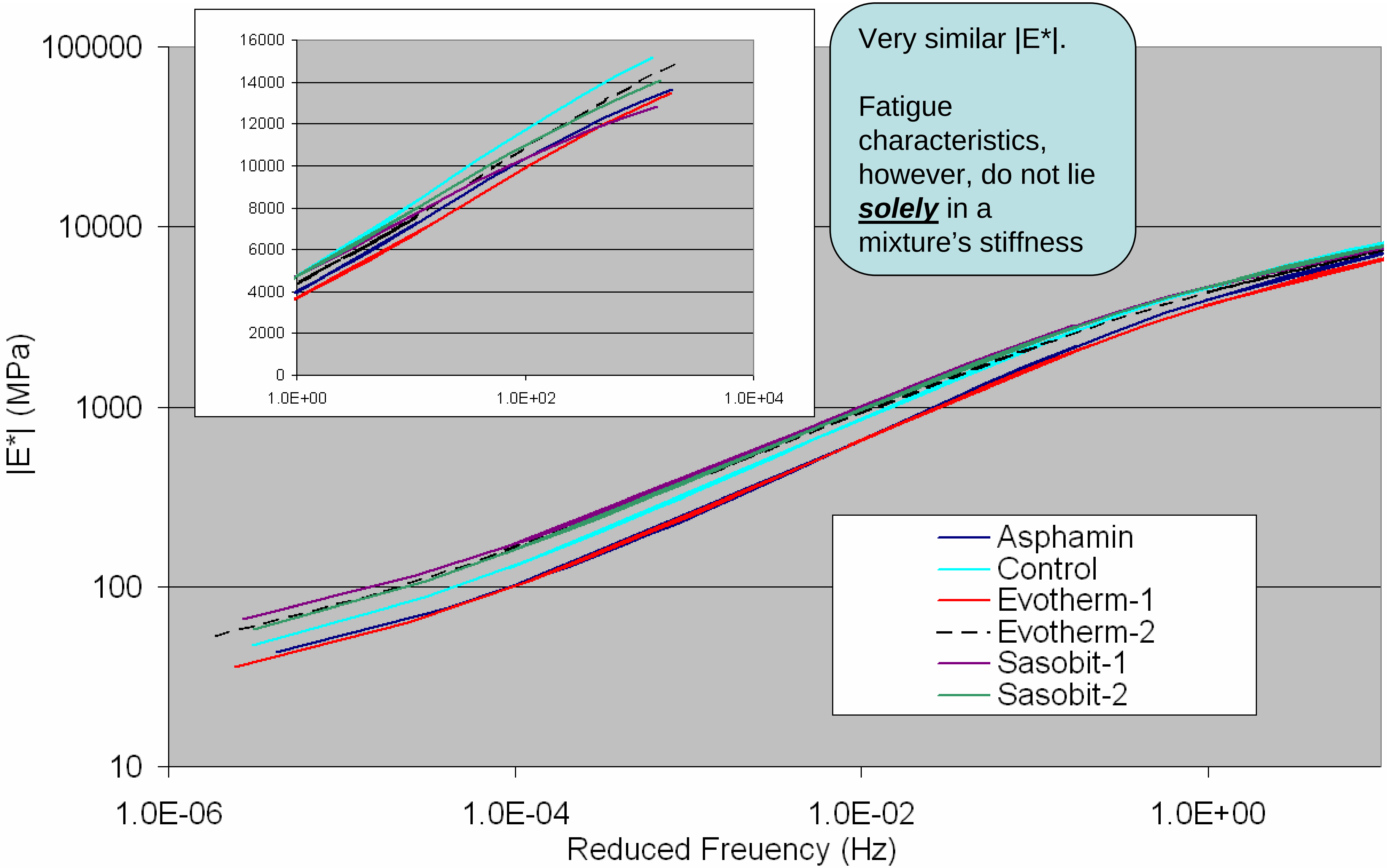




St. Louis WMA Trial
Fatigue Characteristics

Results - Nondestructive |E*|

- St. Louis WMA Trials

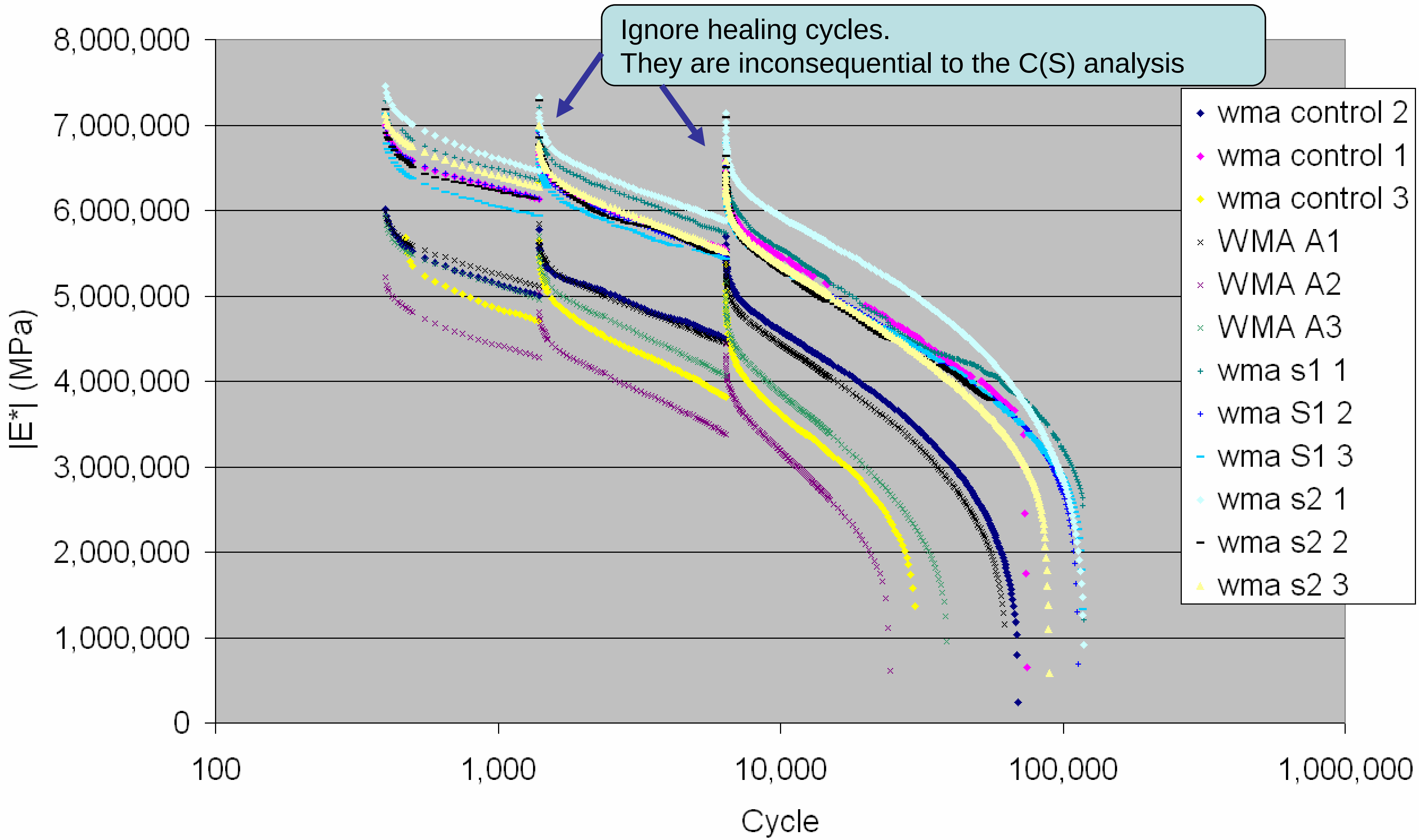


Very similar |E*|.

Fatigue characteristics, however, do not lie ***solely*** in a mixture's stiffness

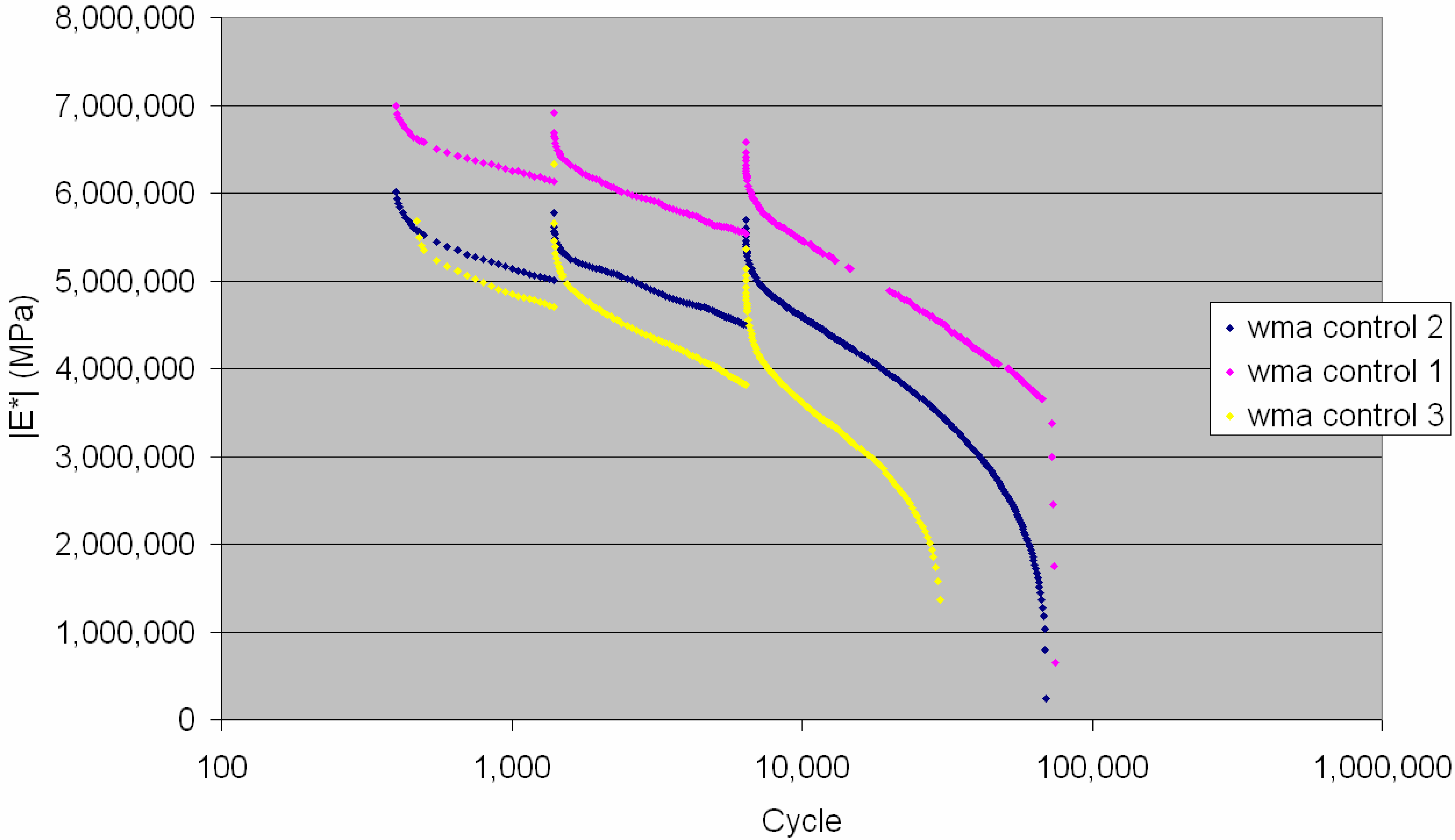
Results – Raw Fatigue Data

- St. Louis WMA Trials – All replicates / mixes



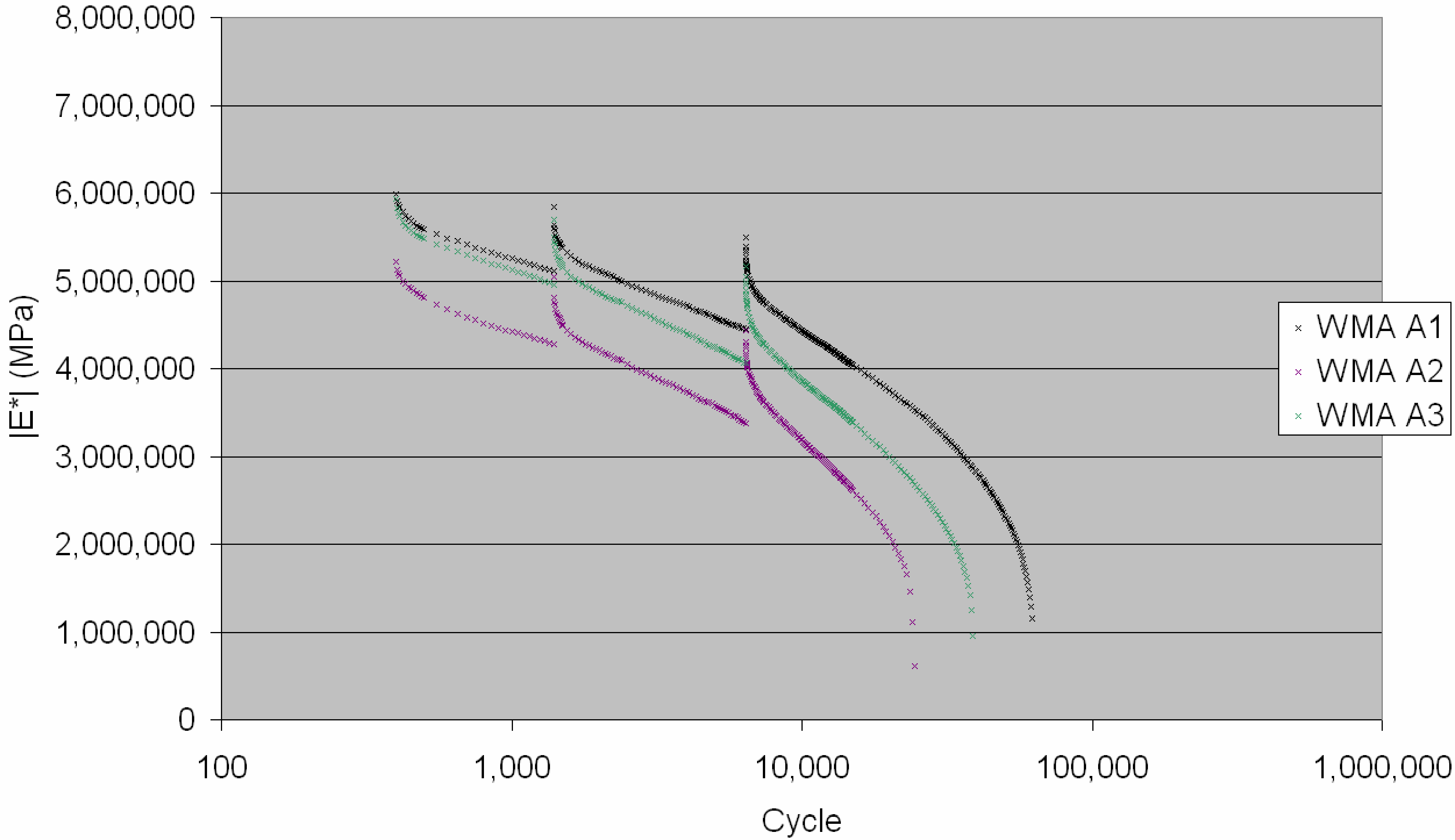
Results – Raw Fatigue Data

- St. Louis WMA Trials – Control HMA replicates



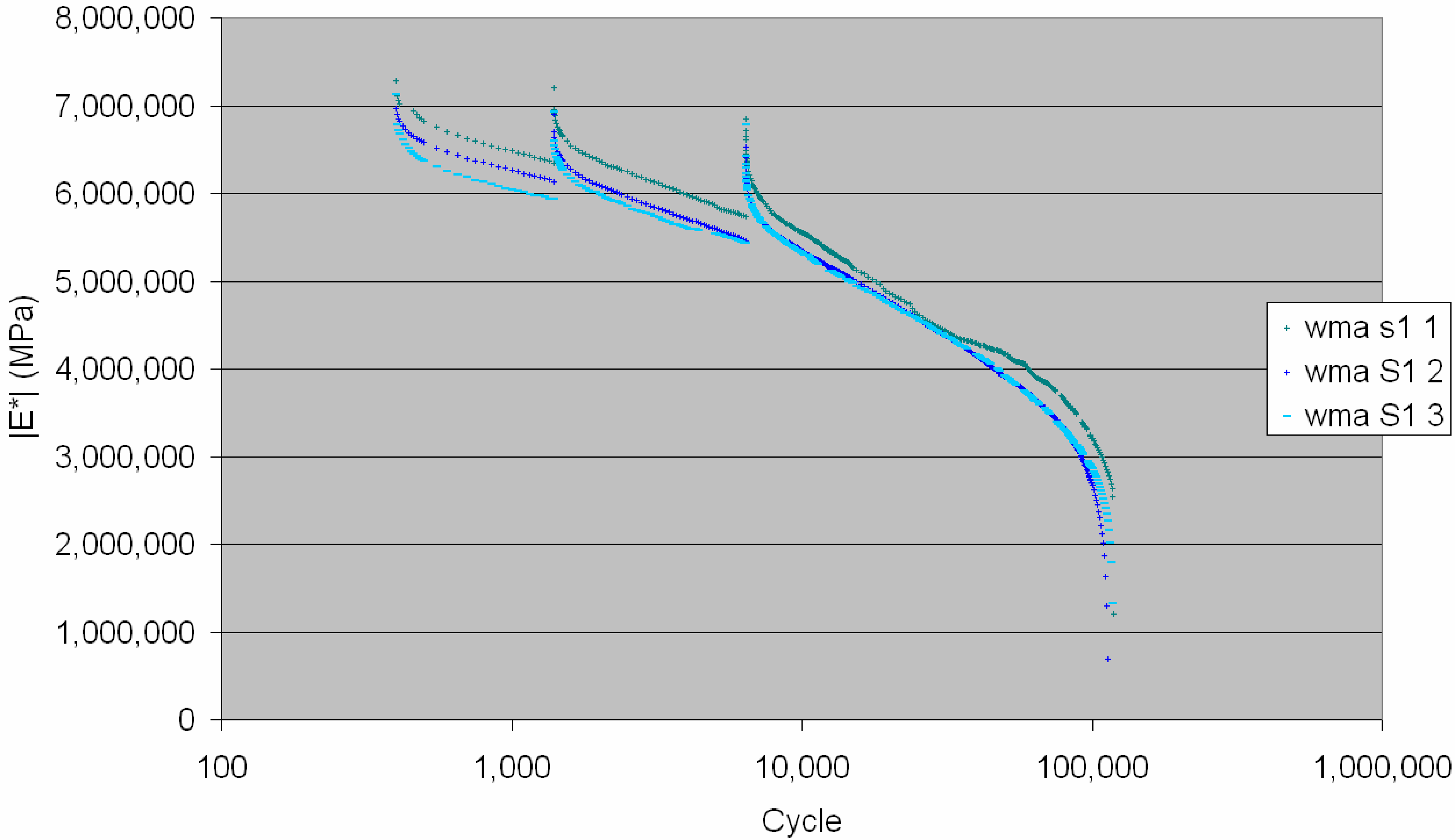
Results – Raw Fatigue Data

- St. Louis WMA Trials – Asphamin (only day)



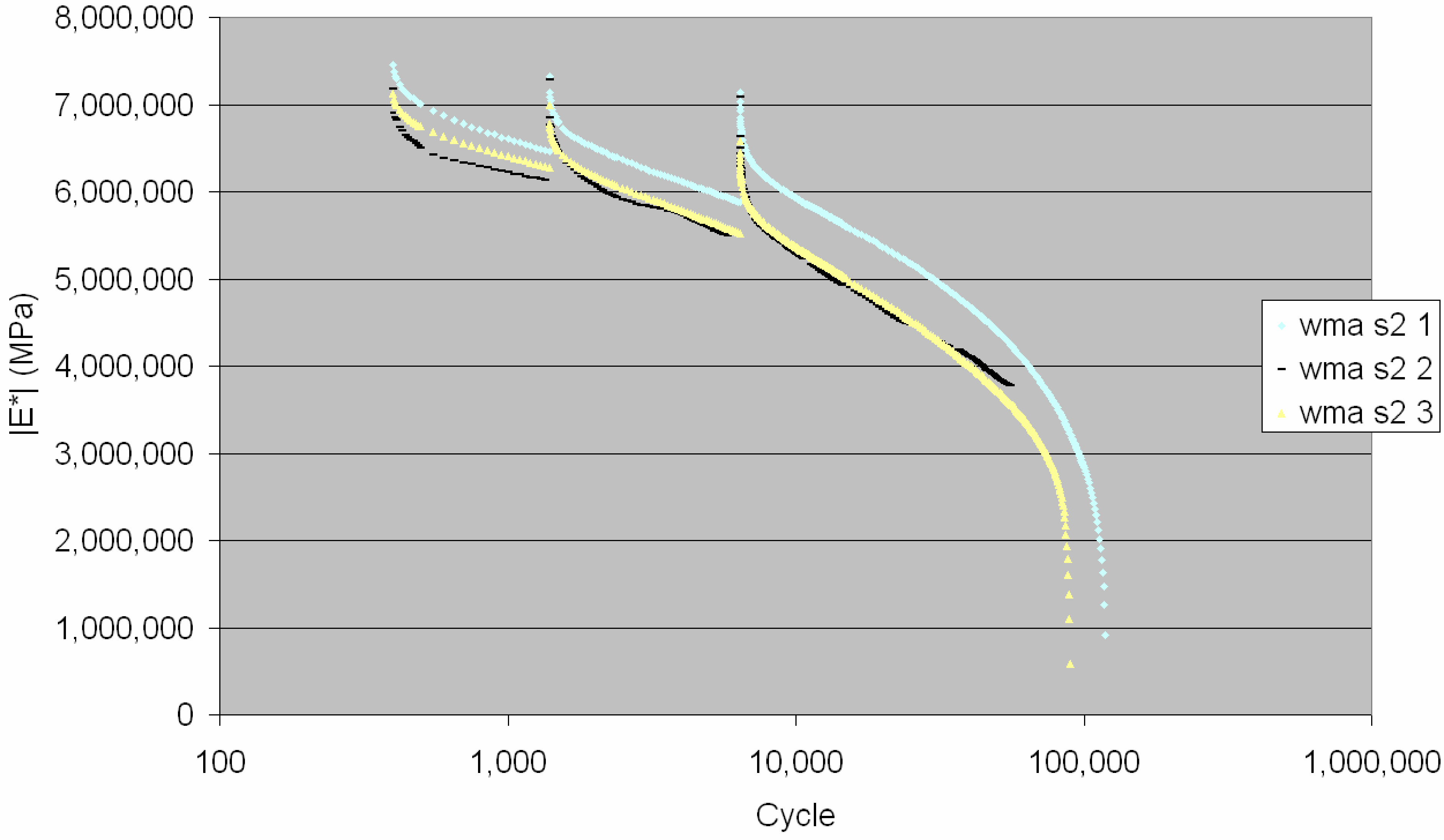
Results – Raw Fatigue Data

- St. Louis WMA Trials – Sasobit produced Hotter



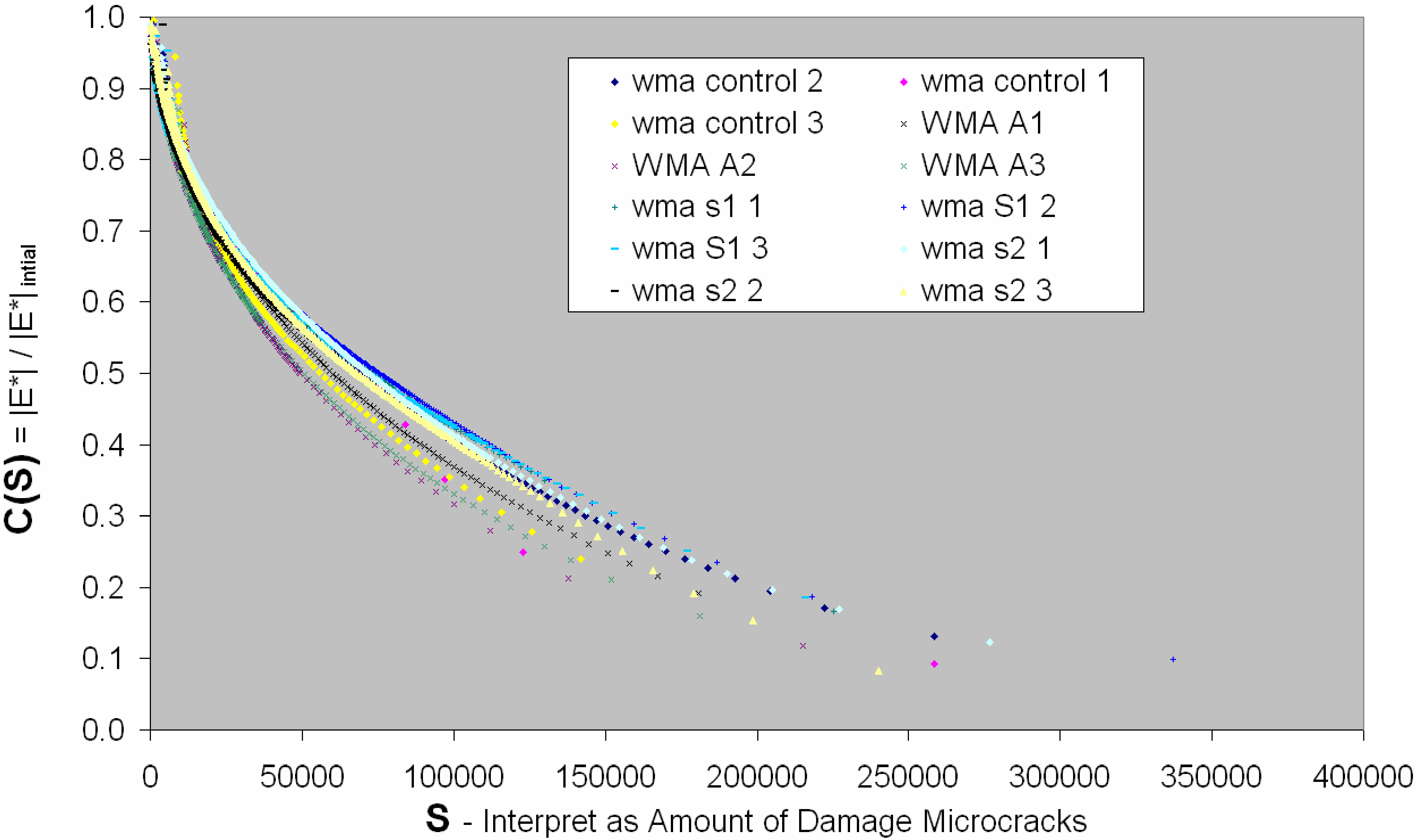
Results – Raw Fatigue Data

- St. Louis WMA Trials – Sasobit produced Cooler



Results – Fatigue Analysis

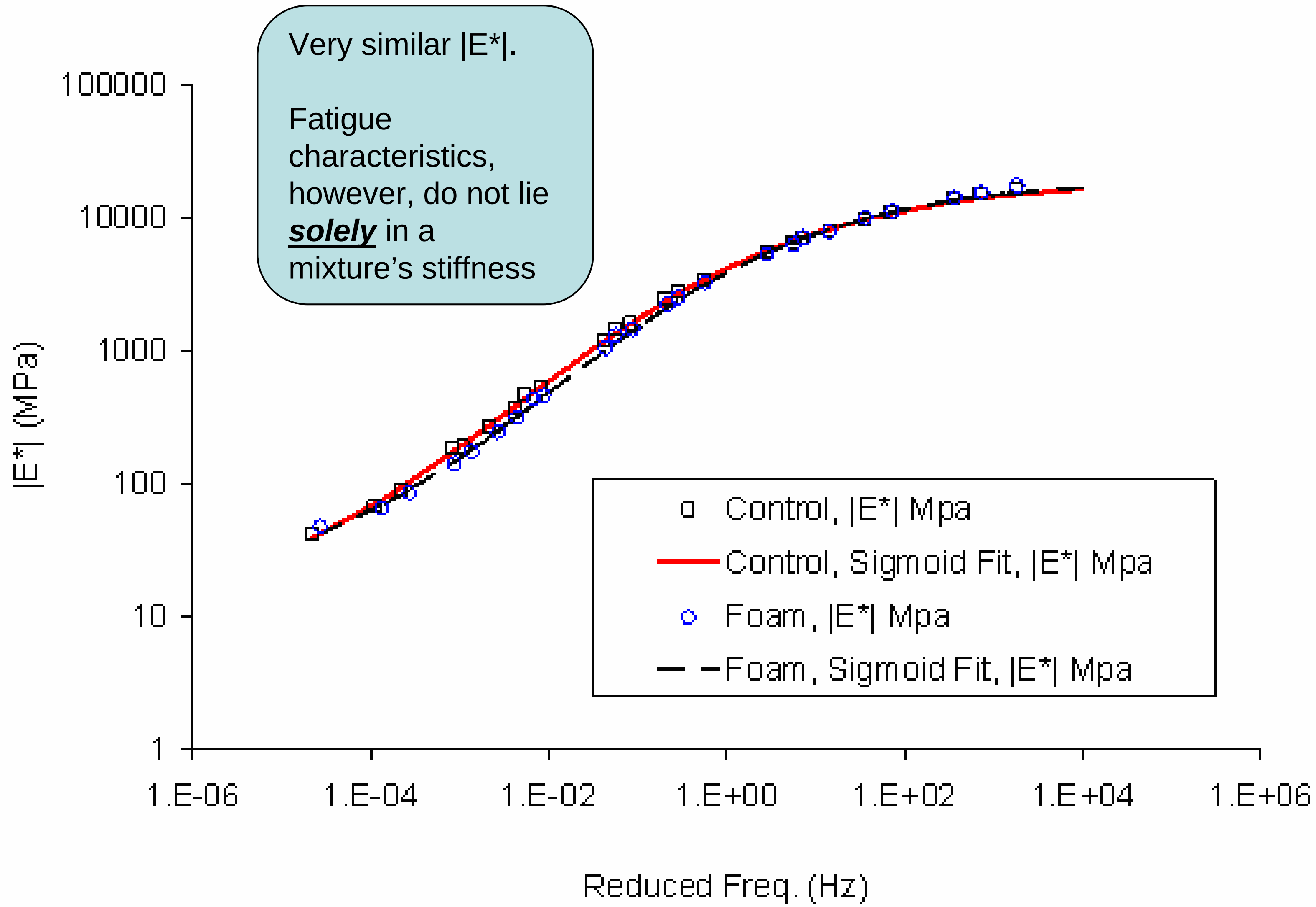
- St. Louis WMA Trials



WAM Foam
Fatigue Characteristics

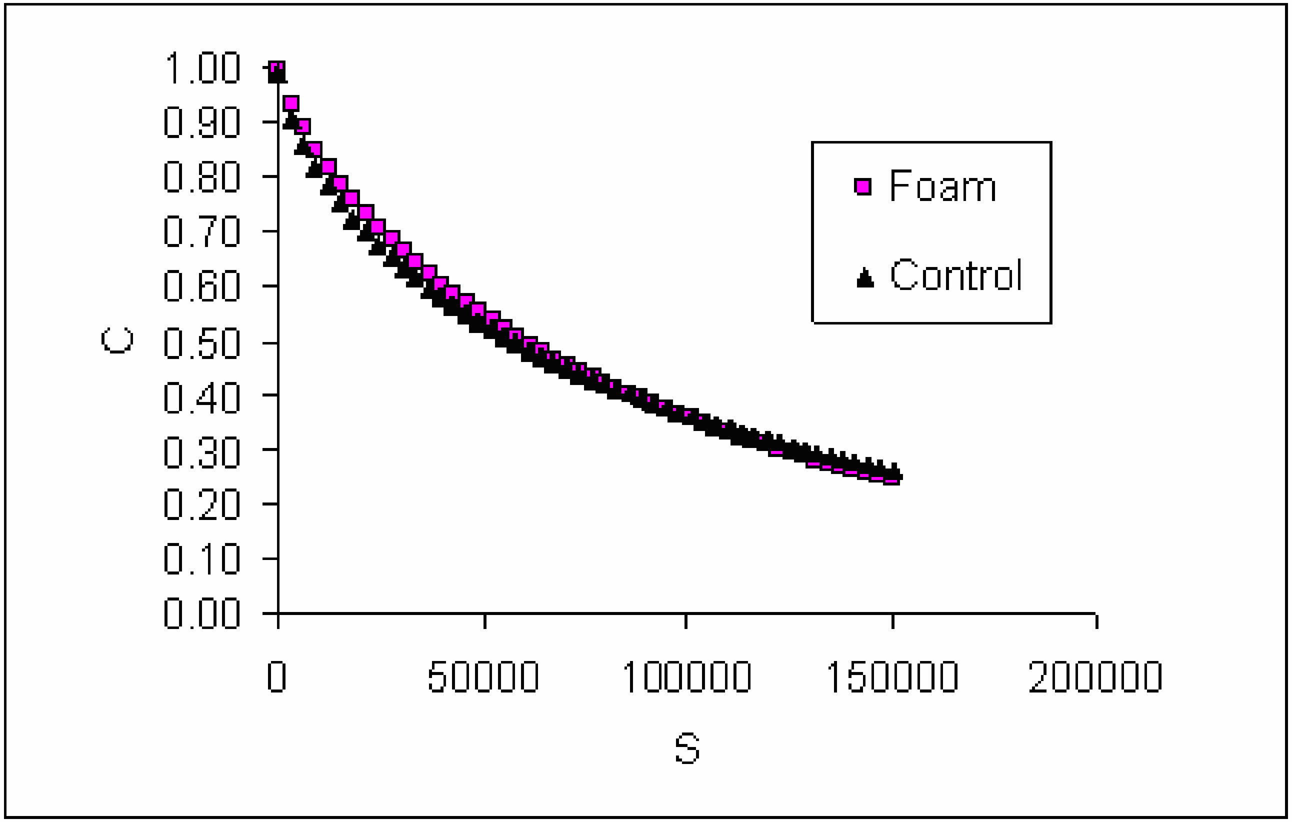
Results - Nondestructive |E*|

- WAM Foam



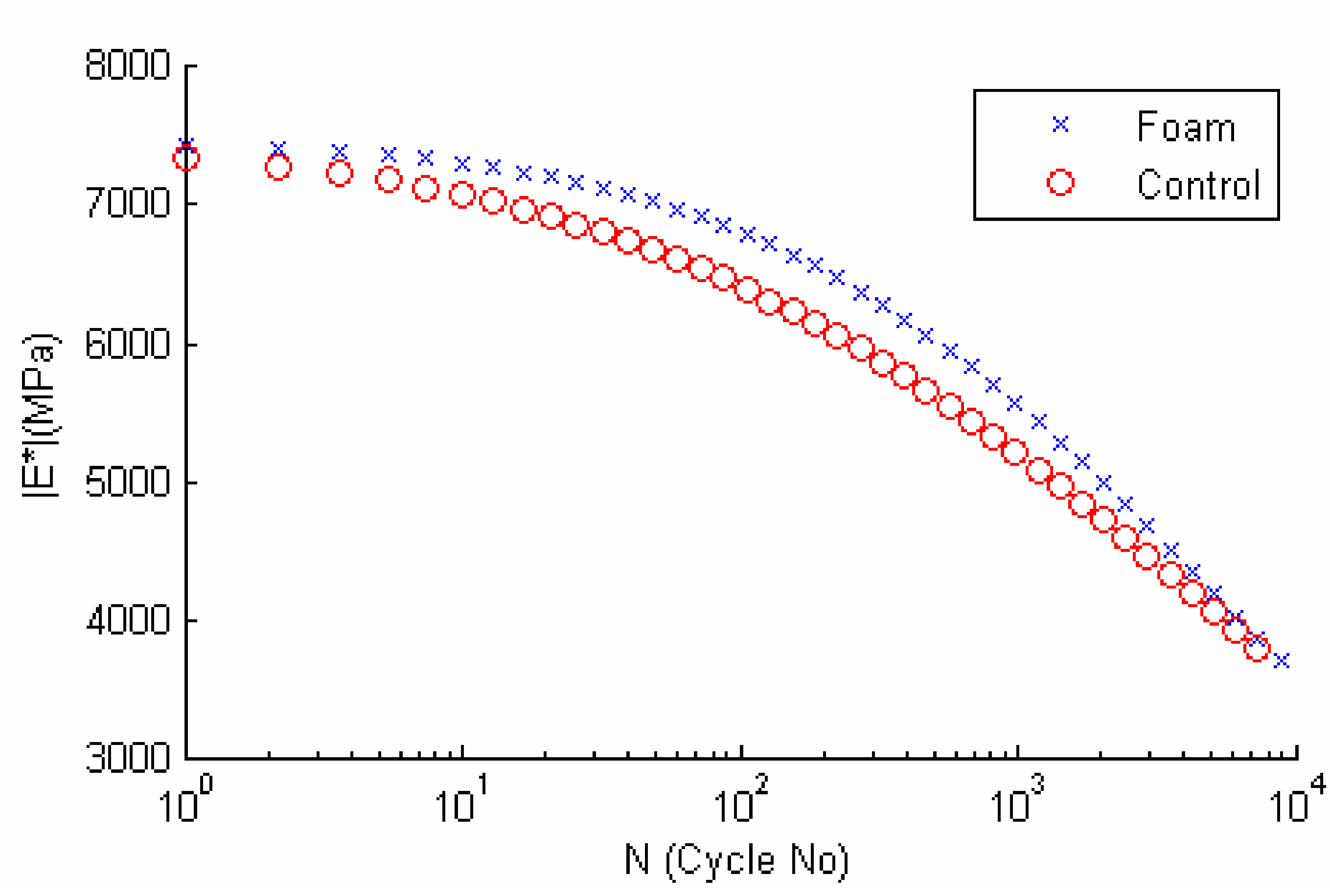
Results – Fatigue Analysis

- WAM Foam, Analysis of Raw Data
  - Still exhibits similar if not identical to conventional control mixture which was unfoamed with hard and soft binders preblended.



Results – Fatigue Analysis

- WAM Foam, 200$\mu\varepsilon$ strain control normalization



Overall WMA Fatigue Results

- WMA Fatigue without Long Term Aging
  - Little differences were seen between HMA and WMA technologies in the non destructive dynamic modulus |E*|
  - Little differences seen in destructive fatigue characterization
  - If this were a double blind experiment, one would have a hard time determining which mixture was the conventional Hot Mix Asphalt and which was not.
- However, Long Term Aging needs to be investigated which may show larger differences between HMA vs. WMA and different WMA technologies

- Pause -

Warm Mix Asphalt
and
Binder Specifications
in the PG System

FHWA Office of Infrastructure R&D
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Binder Grading and Aging

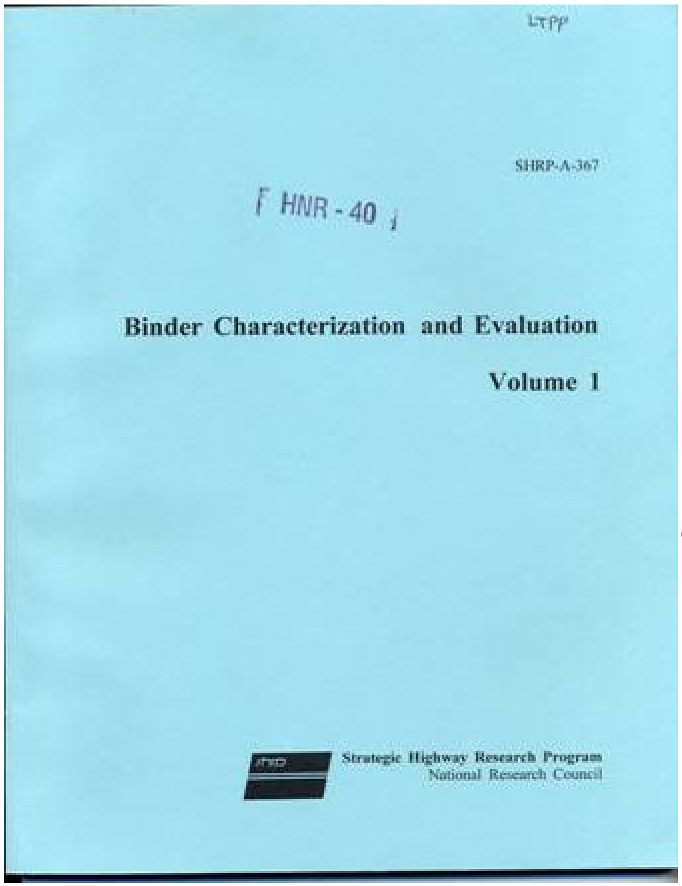
- In general, what is the sensitivity of binder rheology with changes in aging?

Binder Grading and Aging

- The high temperature grade is determined with binder aged under two conditions.
  - Original or Tank Condition
  - Rolling Thin Film Oven

Why do we do these two?
What does SHRP tell us?

SHRP A -207



- *"A requirement that G*/sinδ be greater than 1kPa was added to the binder specification to protect against the possibility that the asphalt binder would contribute to tenderness during mixing and lay down. This could occur if the plant is operated so that the aging during TFO [...] and RTFO […] aging.* ***Reduced mixing temperature or wet aggregate can lead to significantly reduced aging during mixing and lay down.****"*
- *"The original material is tested for safety, to ensure pumpability of the binder in the mix plant, and to be certain the material is* ***stiff enough that tenderness is not encountered when minimal hardening occurs in the mix plant"***
- **Tenderness not performance?**

Binder Aging Experiments

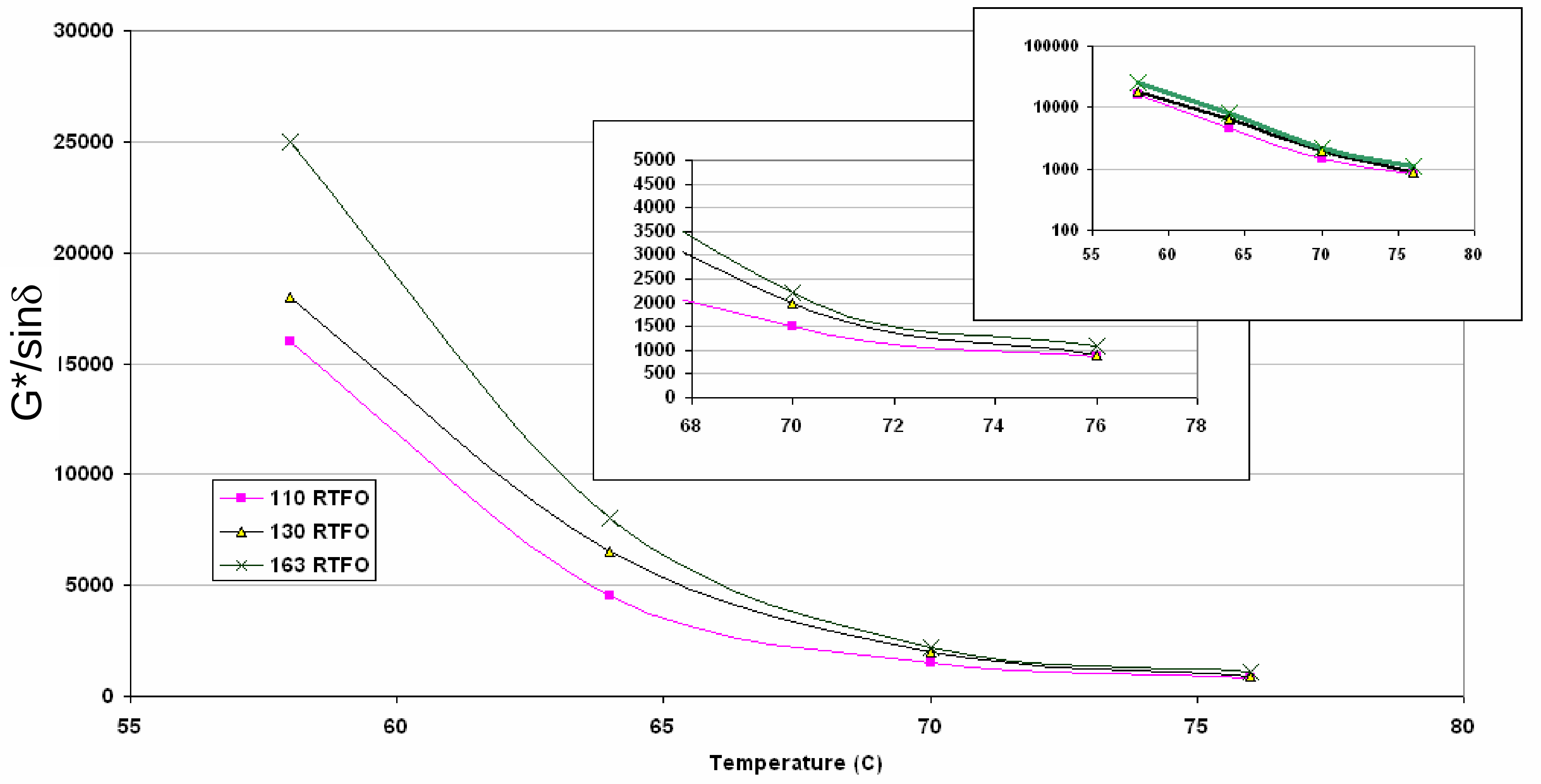
- Do we want to rely on the original condition grading (tenderness) to address Warm Mix Asphalt?
  - Seriously.
  - Does the community feel this is sufficient?
- To help answer some of these questions an aging study was pursued to quantify the change in asphalt binder under varying levels of short term aging temperature

Binder Aging Experiments

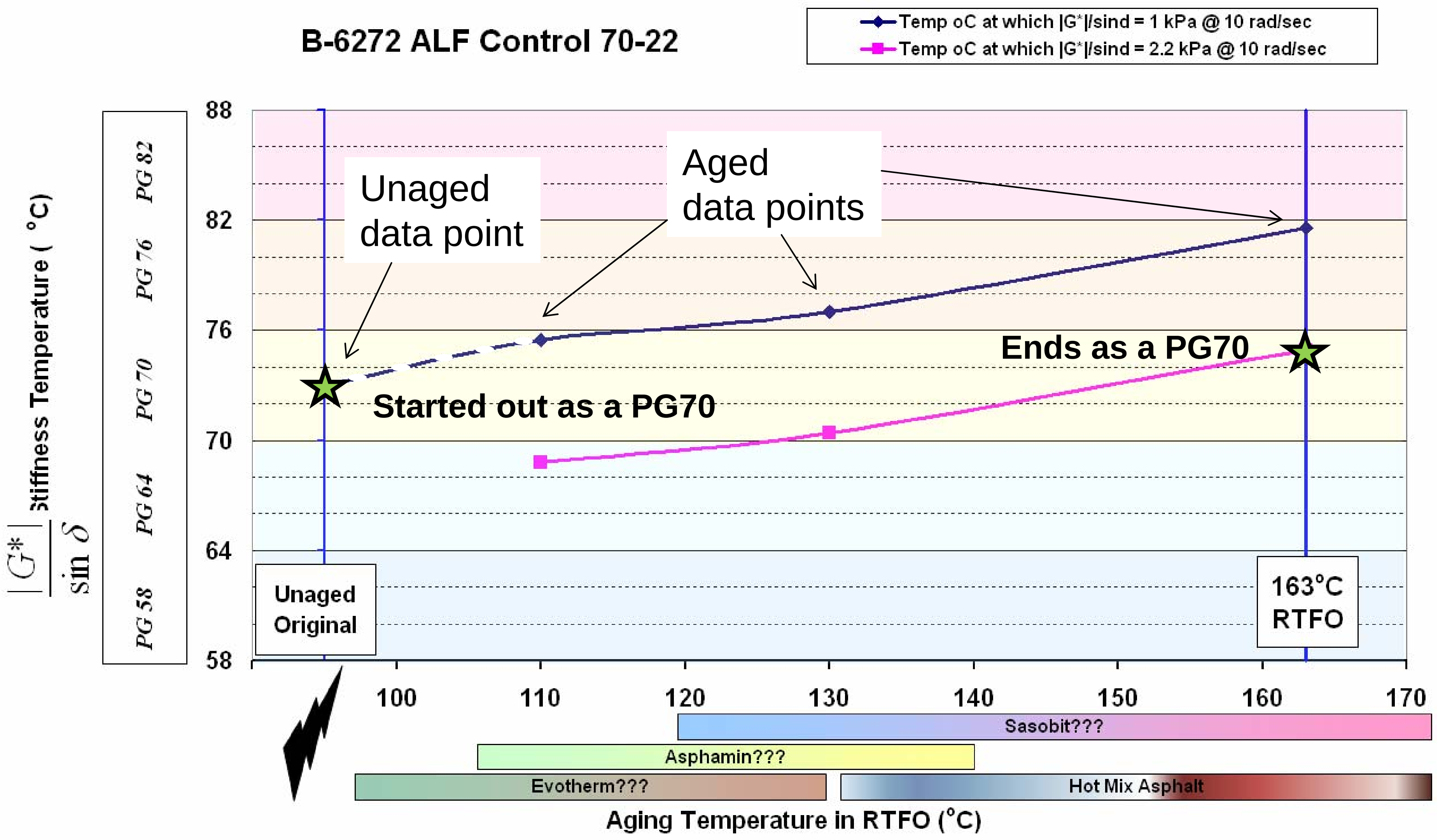
- Reduced Temperature RTFO Characterization
  - Unmodified FHWA ALF control binder (Venezuelan) plus Sasobit at two rates 1.5% and 3%
  - Hawaii DOT (unknown source) binder
  - Maryland DOT (Venezuelan) binder
  - AAM-1 and AAM-2 SHRP Binders with high paraffin as part of Sasobit low temperature TSRST characterization program
  - AAG-1 and AAD-1 SHRP California Valley and California Coastal both give wide differences in aging susceptibility
    - Age susceptible
    - Age resistant

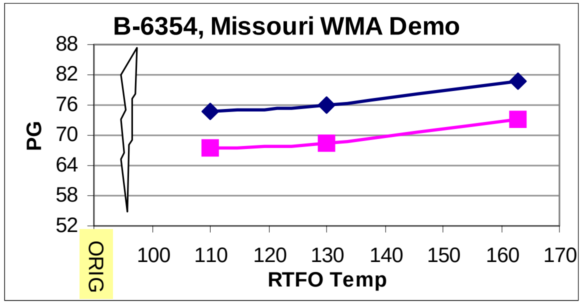
Schematic of Analysis

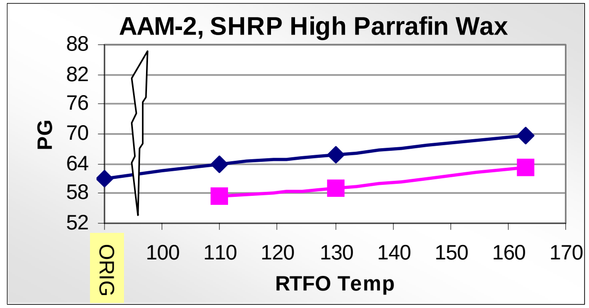
- Set RTFO oven at different temperatures & std. duration
- Characterize on DSR at 4 separate temperatures
- Interpolate to determine DSR temperatures where $G^*/\sin\delta$ reaches 1kPa & 2.2kPa at ω = 10 rad/sec

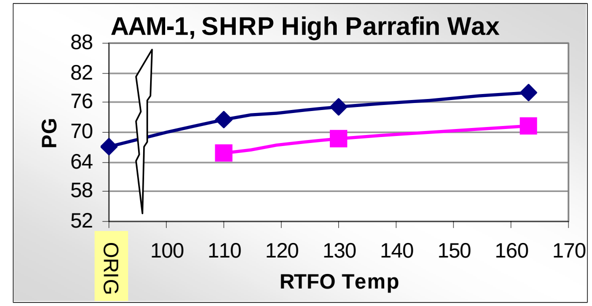


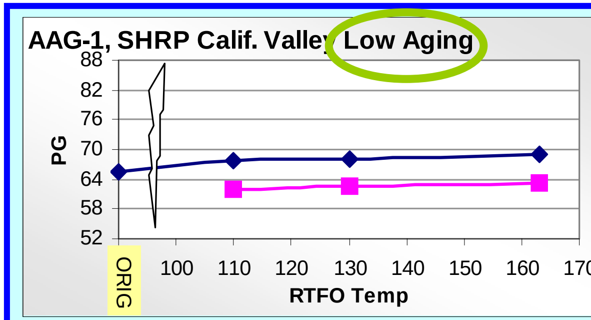
Typical Results

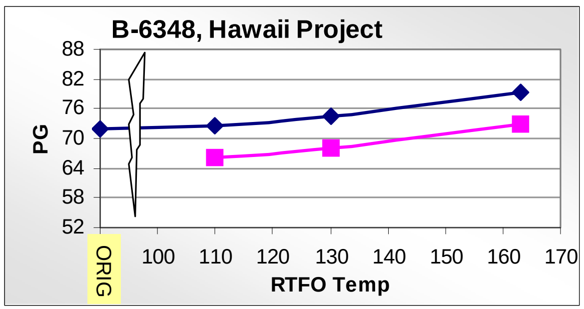


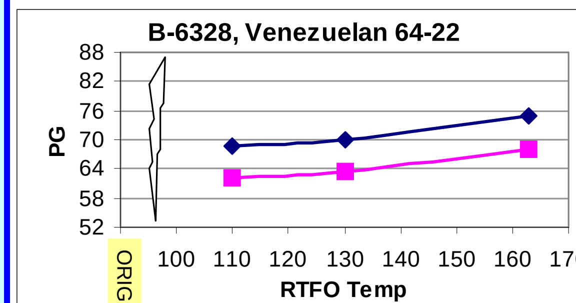

B-6354, Missouri WMA Demo
PG
88 82 76 70 64 58 52
ORIG
100 110 120 130 140 150 160 170
RTFO Temp

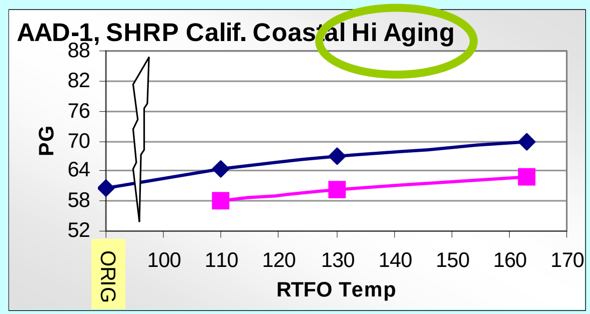

AAM-2, SHRP High Parrafin Wax
PG
88 82 76 70 64 58 52
ORIG
100 110 120 130 140 150 160 170
RTFO Temp

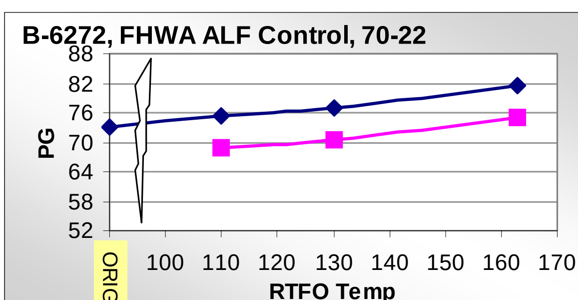

AAM-1, SHRP High Parrafin Wax
PG
88 82 76 70 64 58 52
ORIG
100 110 120 130 140 150 160 170
RTFO Temp

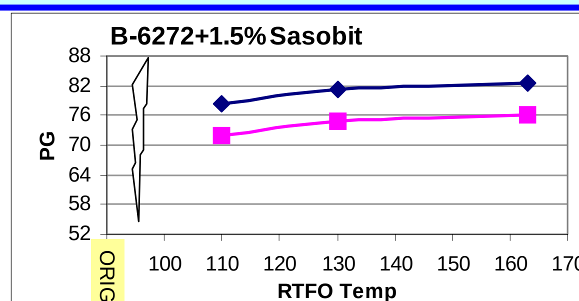

AAG-1, SHRP Calif. Valley Low Aging
PG
88 82 76 70 64 58 52
ORIG
100 110 120 130 140 150 160 170
RTFO Temp

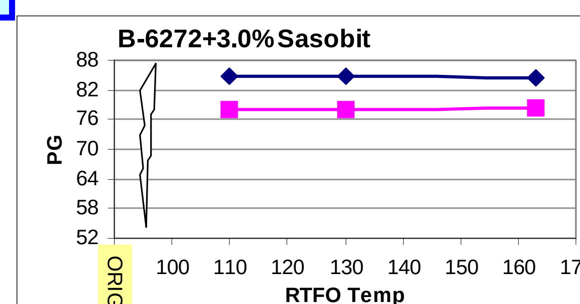

B-6348, Hawaii Project
PG
88 82 76 70 64 58 52
ORIG
100 110 120 130 140 150 160 170
RTFO Temp


B-6328, Venezuelan 64-22
PG
88 82 76 70 64 58 52
ORIG
100 110 120 130 140 150 160 170
RTFO Temp


AAD-1, SHRP Calif. Coastal Hi Aging
PG
88 82 76 70 64 58 52
ORIG
100 110 120 130 140 150 160 170
RTFO Temp


B-6272, FHWA ALF Control, 70-22
PG
88 82 76 70 64 58 52
ORIG
100 110 120 130 140 150 160 170
RTFO Temp


B-6272+1.5% Sasobit
PG
88 82 76 70 64 58 52
ORIG
100 110 120 130 140 150 160 170
RTFO Temp


B-6272+3.0% Sasobit
PG
88 82 76 70 64 58 52
ORIG
100 110 120 130 140 150 160 170
RTFO Temp

Overall Summary

Some binders had trouble coating bottles at 110C

PG52	PG58	PG64	PG70	PG76	PG82

	°C |G*|/sinδ = 1kPa				°C |G*|/sinδ = 2.2kPa			
Binder ID	Orig	110	130	163	Orig	110	130	163
B-6354, Missouri WMA Demo, 70-22		74.8	75.9	80.6		67.4	68.5	73.2
B-6348, Hawaii Project 70-16	72.0	72.5	74.4	79.3		66.2	68.1	72.9
B-6328, Venezuelan 64-22		68.8	70.0	74.8		62.2	63.4	68.1
AAM-1, SHRP High Parrafin Wax	67.1	72.6	75.3	77.9		65.9	68.8	71.4
AAM-2, SHRP High Parrafin Wax	60.9	64.0	65.8	69.8		57.5	59.1	63.2
AAG-1, SHRP Calif. Valley Low Aging	65.5	67.6	68.2	69.0		61.9	62.5	63.3
AAD-1, SHRP Calif. Coastal Hi Aging	60.5	64.5	67.0	69.7		57.9	60.2	62.8
B-6272, FHWA ALF Control, 70-22	73.0	75.5	77.0	81.6		68.8	70.4	74.9
B-6272+1.5% Sasobit		78.4	81.3	82.5		71.9	74.7	76.2
B-6272+3.0% Sasobit		84.9	84.7	84.6		77.9	78.0	78.4

Overall Summary

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B-6348, Hawaii Project 70-16	72.0	72.5	74.4	79.3		66.2	68.1	72.9
B-6328, Venezuelan 64-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	63.4	68.1
AAM-1, SHRP High Par	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	68.8	71.4
AAM-2, SHRP High Par	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	59.1	63.2
AAG-1, SHRP Calif. Valley Low Aging	65.5	67.6	68.2	69.0		61.9	62.5	63.3
AAD-1, SHRP Calif. Coastal Hi Aging	60.5	64.5	67.0	69.7		57.9	60.2	62.8
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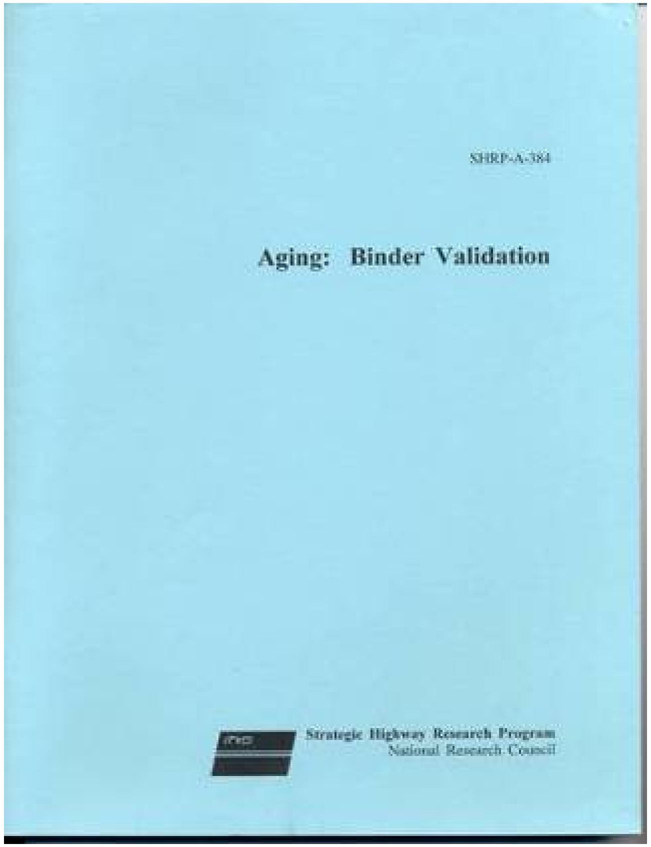
It Depends!

Aging and High Temp Spec Findings

- Reduction in RTFO temperature can have impact on binder properties
- By conventional grading some binders have different Original and RTFO grades - - but most were same in Original and RTFO
- Most binders loose a grade at a lower RTFO by both stiffness values 1 kPa and 2.2 kPa
  - 5 of 10 lost a PG grade when RTFO aged at 130^{o}C compared to 163^{o}C - but held that grade when RTFO aged at 110^{o}C
    - Of those 5, it was at most 1.9C away from next grade at 130^{o}C and 4.1^{o}C away from the next grade at 110^{o}C
  - 3 of 10 maintained PG grade when RTFO aged at 130^{o}C compared to 163^{o}C - but lost that grade when RTFO aged at 110^{o}C
    - Of those 3, it was at most 1.2^{o}C from next grade
  - 2 of 10 kept PG grade throughout – 3% Sasobit and California Coastal “low ager”

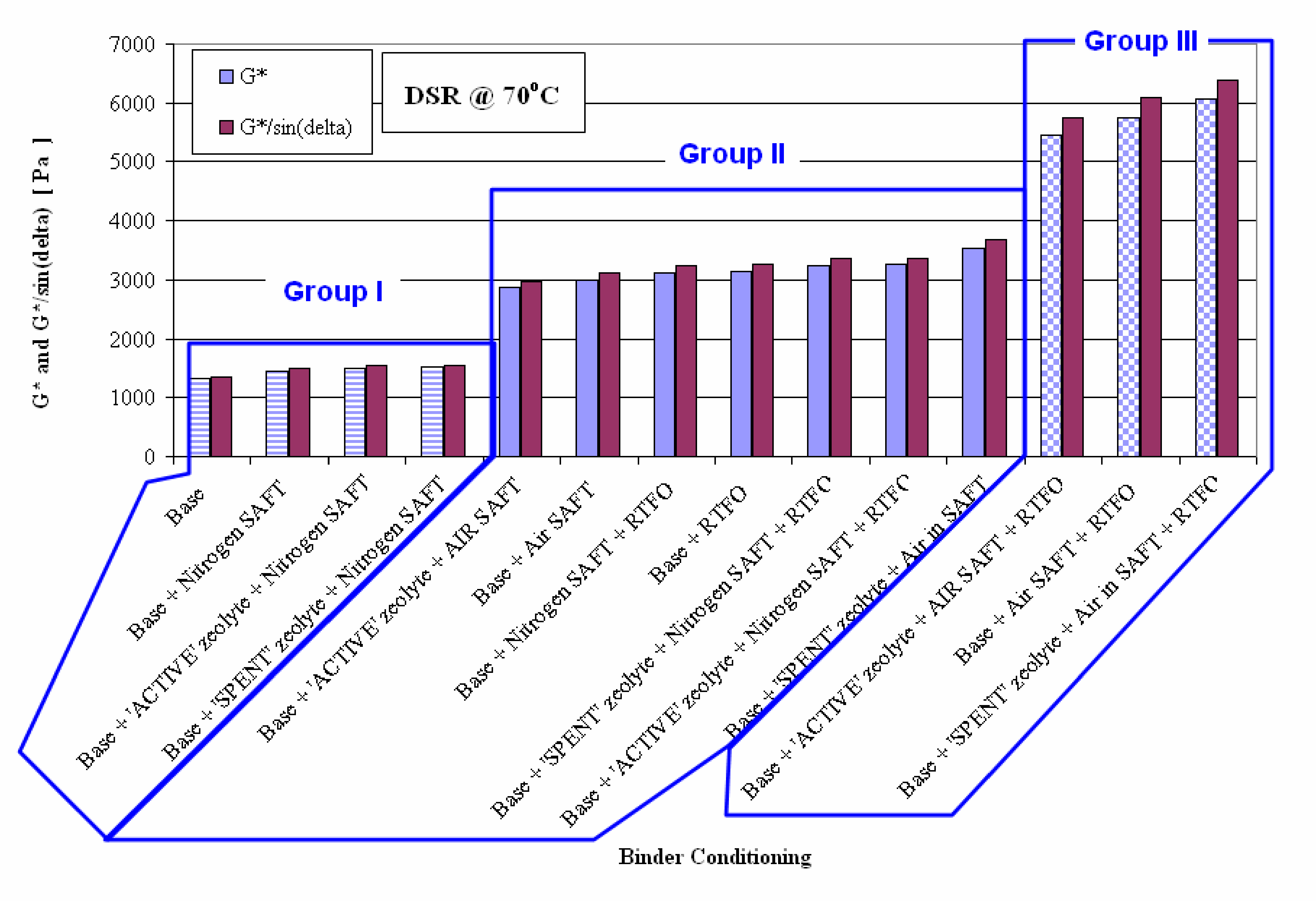
Aging and High Temp Spec Findings

- Would it be an overburden to check a binders loss of grade that is tailored to each technology’s temperature range?
  - Based on the amount of loss in grade from the RTFO conditions it seems fair to account for an expected softer binder by a half or whole grade.
  - ***[draw input from the TWG]***

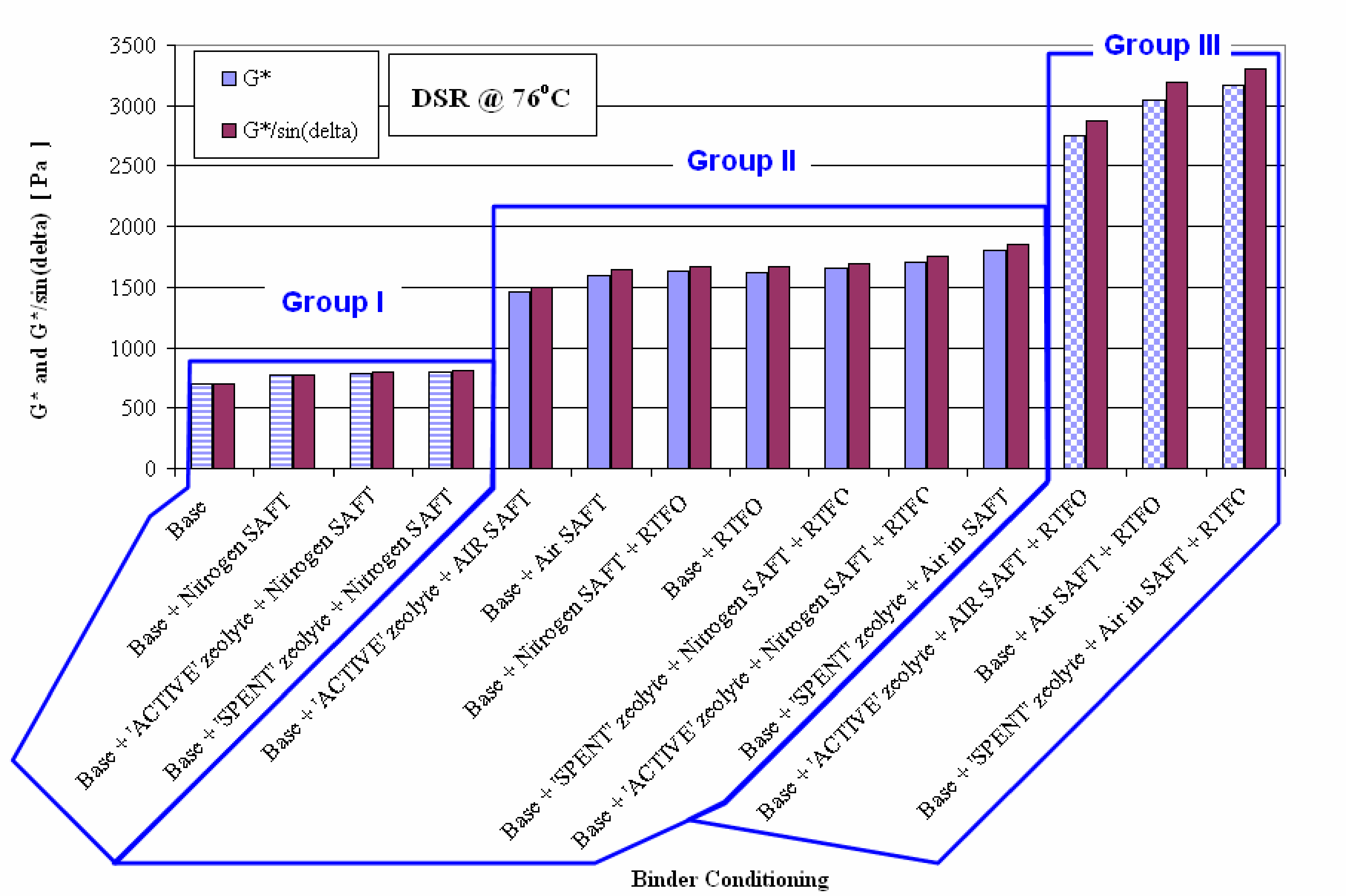


- "Recent research in SHRP contacts A-002A and A-003A suggest that the presence of aggregate decrease the viscosity of asphalt compared with bulk asphalt for equivalent aging times. The different in viscosity may be caused by the aggregate particles binding some of the oxidative functional groups formed and thereby preventing the formation of viscosity building species."
- "Aging of the asphalt alone and subsequent testing does not appear to adequately predict mixture performance because of the **apparent mitigating effect that aggregate has on aging.**"

Questions?
Comments?



G*
G*/sin(delta)
DSR @ 70°C
Group I
Group II
Group III
G* and G*/sin(delta) [Pa]
7000
6000
5000
4000
3000
2000
1000
0
Base
Base + Nitrogen SAFT
Base + 'ACTIVE' zeolyte + Nitrogen SAFT
Base + 'SPENT' zeolyte + Nitrogen SAFT
Base + 'ACTIVE' zeolyte + AIR SAFT
Base + Air SAFT
Base + Nitrogen SAFT + RTFO
Base + RTFO
Base + 'SPENT' zeolyte + Nitrogen SAFT + RTFC
Base + 'ACTIVE' zeolyte + Nitrogen SAFT + RTFC
Base + 'SPENT' zeolyte + Air in SAFT
Base + 'ACTIVE' zeolyte + AIR SAFT + RTFO
Base + Air SAFT + RTFO
Base + 'SPENT' zeolyte + Air in SAFT + RTFC
Binder Conditioning



G* and G*/sin(delta) [Pa]
3500
3000
2500
2000
1500
1000
500
0
G*
G*/sin(delta)
DSR @ 76°C
Group I
Group II
Group III
Base
Base + Nitrogen SAFT
Base + 'ACTIVE' zeolyte + Nitrogen SAFT
Base + 'SPENT' zeolyte + Nitrogen SAFT
Base + 'ACTIVE' zeolyte + AIR SAFT
Base + Air SAFT
Base + Nitrogen SAFT + RTFO
Base + RTFO
Base + 'SPENT' zeolyte + Nitrogen SAFT + RTFC
Base + 'ACTIVE' zeolyte + Nitrogen SAFT + RTFC
Base + 'SPENT' zeolyte + Air in SAFT
Base + 'ACTIVE' zeolyte + AIR SAFT + RTFO
Base + Air SAFT + RTFO
Base + 'SPENT' zeolyte + Air in SAFT + RTFC
Binder Conditioning