

4PBB - Four Point Bending Beam

3rd 4PBB Conference

17-18 September 2012, Davis, CA, USA

Laboratory Evaluation of Fatigue and Flexural Stiffness of Warm Mix Asphalt

Presented
by
John Harvey

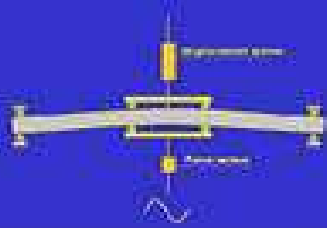
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BACKGROUND

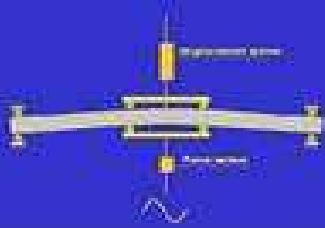
Fatigue

- structural distress attributed to accumulated damage under repeated load applications

Fatigue in Asphalt Concrete

- arises from repeated tensile strains resulting due to traffic loading
- Fatigue characterization – high tensile strains at the bottom (thin layer) or at the surface (thick layer) of the asphaltic layer





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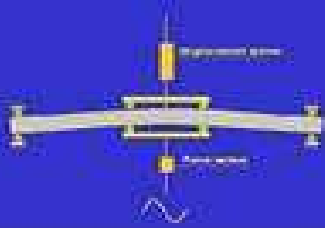
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BACKGROUND

Flexural Stiffness

- mix property linked to material response and load-spreading ability
- influenced by mix components, loading time (or frequency) and temperature
- flexural stiffness characterization – influenced by mix mechanical properties i.e. cohesive and adhesive properties (mixture stiffness)
- mixture stiffness - fundamental in the determination of fatigue behavior (fatigue life)





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WARM MIX ASPHALT (WMA)

Why alternative Materials such as WMA?

- sustainability, improved performance and durability.....among others

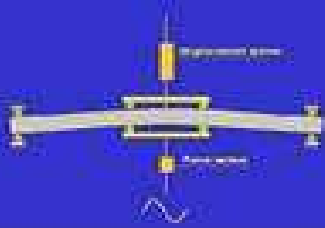
Interest in WMA

- technical and economic benefits such as, reduced fume generation, low fuel usage, worker health safety, increased usage of recycled asphalt concrete pavement (RA)

1st :Technological advancement must equal sustainable living???

2nd: Alternative materials evaluation must equal rational evaluation!





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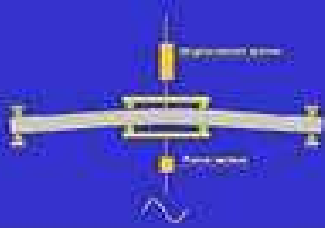
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FATIGUE DAMAGE MODELS

- 3 Fatigue models – Wöhler approach, the dissipated energy approximation and fracture mechanics technique
- 4-Point Bending Beam test – under repeated flexure, maximum flexural tensile strain is at the outer most fibre of the beam specimen
- Fatigue relationships – number of load repetitions to failure is related to the tensile strain
- Laboratory fatigue testing – damage concept based on Miner MA 1945 i.e. *damage is an inverse of number of load repetitions to failure*





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FATIGUE DAMAGE MODELS:

Wöhler fatigue relationship

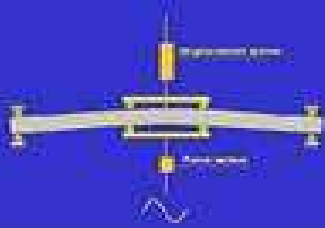
$$N_f = k_1 \cdot \left(\frac{1}{\varepsilon}\right)^n$$

- N_f – number of strain applications
- k_1, n – factors depending on mix composition and property
- ε – strain at the bottom of the asphaltic layer

Note:

k_1 & n are influenced by loading time (freq.) and test temperature





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FATIGUE DAMAGE MODELS: dissipated energy approach

Van Dijk 1977

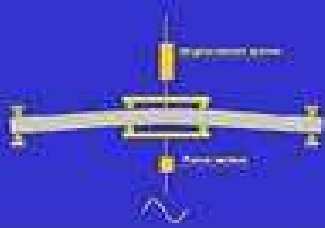
$$W_N = A (N_f)^Z$$

- N_f – number of strain applications
- A, Z – experimentally determined coefficients
- W_N – cumulative dissipated energy to failure

Note:

A & Z are influenced by loading time (freq.) and test temperature





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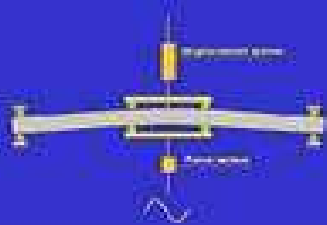
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Description of mix types

HMA Surface mix (Control mix)	WMA Surface mix (Trial mix)
10% RA 60/70 (Control1)	10% RA 60/70 Chemical Additive
10% RA 60/70 (Control1)	10% RA 60/70 Foam
10% RA 60/70 (Control 1)	10% RA 60/70 Organic Additive
20% RA 80/100 Plastomer (Control 2)	20% RA 80/100 Plastomer and Chemical Additive
20% RA 80/100 Elastomer (Control 3)	20% RA 80/100 Elastomer and Organic Additive

- All mix types – Surface Mix Types (2 surface binders, 2 asphalt binder modifiers, 3 WMA technologies and 2 RA contents)





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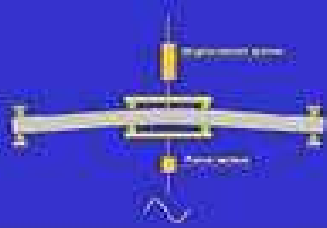
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Description of mix types

- Asphalt Binders – 60/70 pen and 80/100 pen
- Asphalt Binder 80/100 pen modified – Elastomer SBS (A-E2) or Plastomer EVA (A-P1)
- SBS combined with Organic additive technology
- EVA combined with chemical additive technology
- 60/70 pen – unmodified
- RA stockpiles – RA1 (-16mm) and RA2 (-8mm)



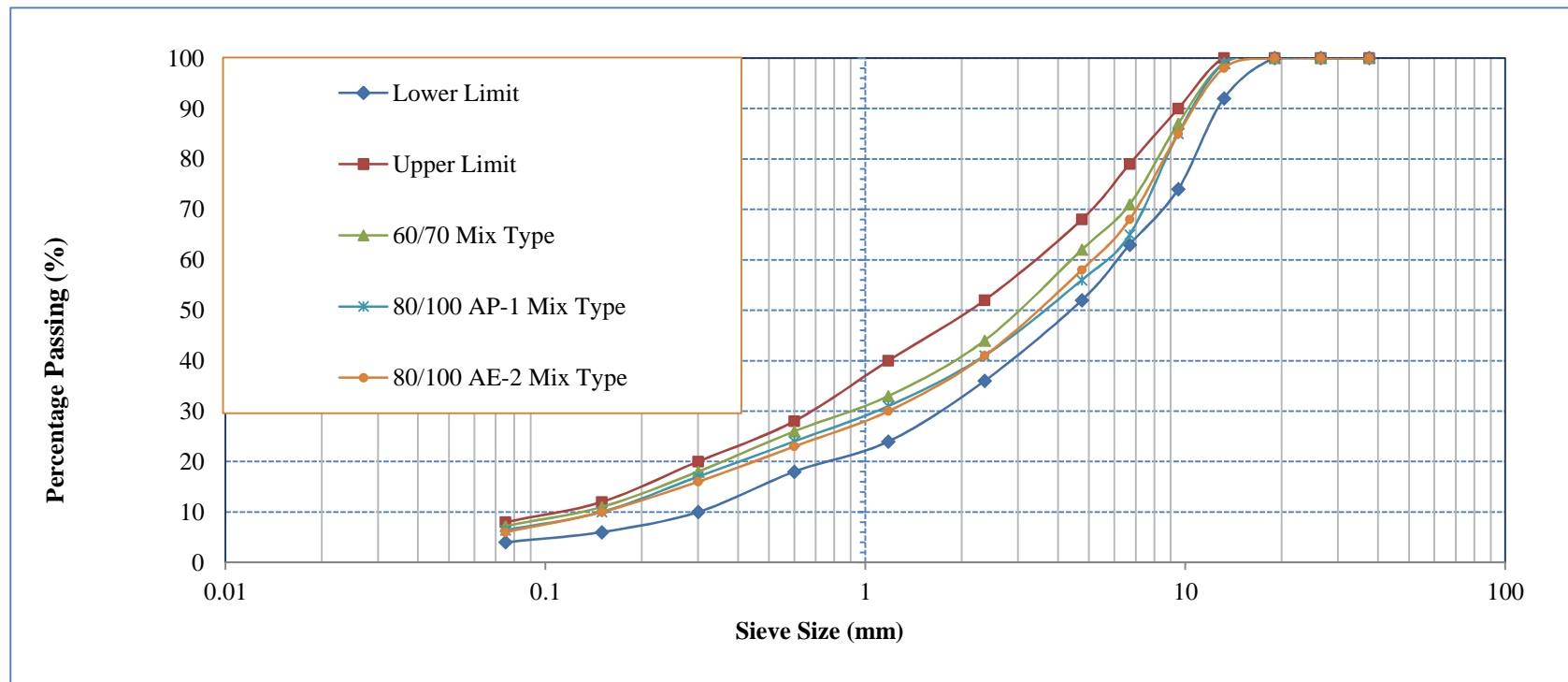


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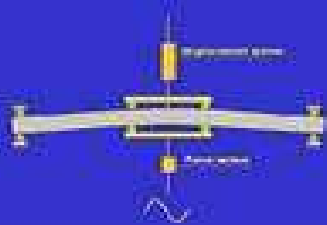
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Grading of mix types



- HMA grading Specifications were considered





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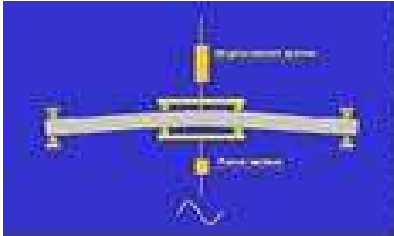
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Methodology

- All HMA mixes (control mixes) – produced at and above 160°C and compacted at and above 135°C (Unmodified) and 145°C (modified)
- All WMA mixes (trial mixes) – produced at 125°C (unmodified) and 135°C (modified) and then, compacted at 110°C (unmodified) and 120°C (modified)
- Compaction method – Two-drum roller compactor (compaction effort), metal mould mounted on concrete floor (confinement) at 35 passes simulating field compaction criterion





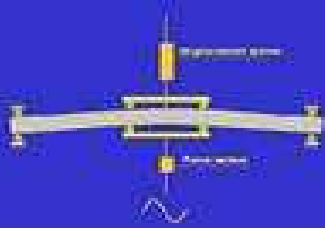
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Specimen preparation



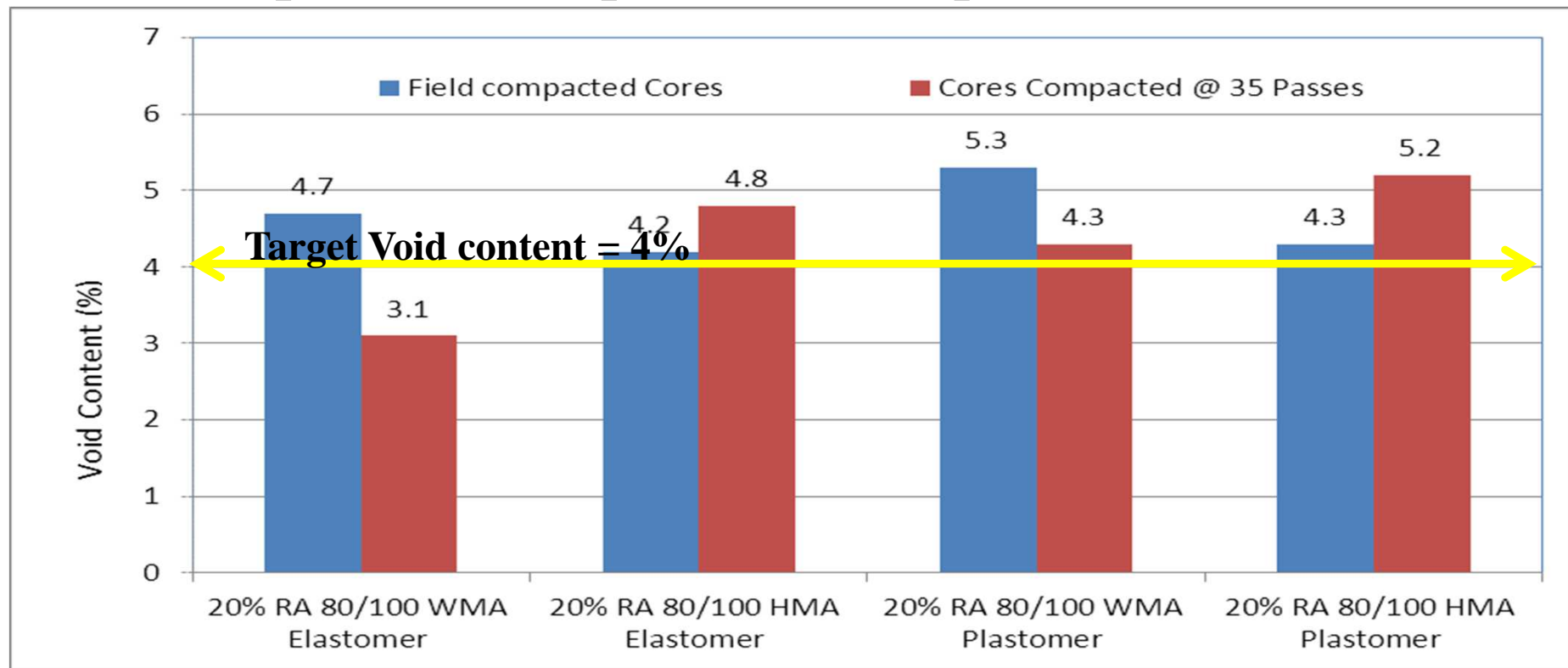


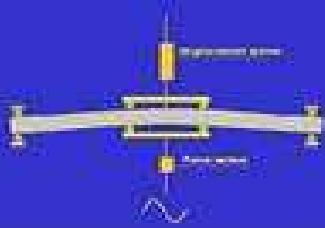
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Field Compaction vs. Specimen Compaction



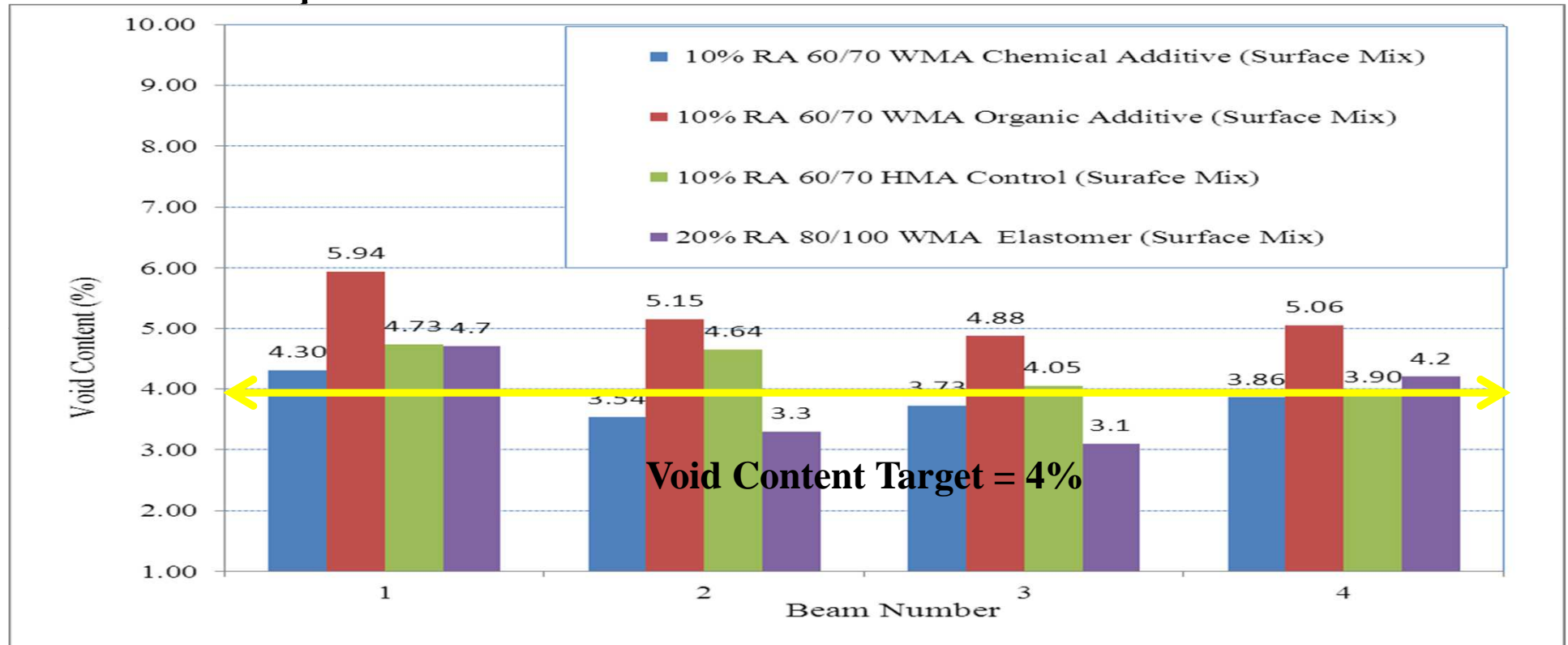


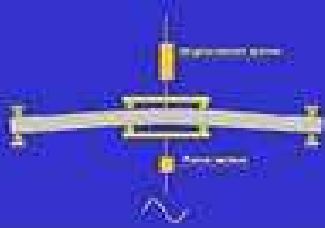
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Beam Compaction





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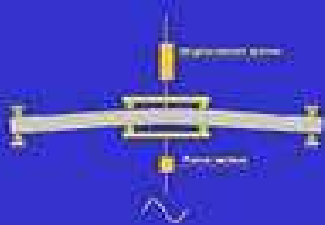
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Laboratory: Fatigue Testing

- Test temperature - 5°C and frequency - 10Hz using sinusoidal strain (as loading mode)
- 3 applied strains - $300\ \mu\epsilon$ (peak to peak) or $150\ \mu\epsilon$ (peak) as benchmark strain and 2 extra strains depending on the outcome at $300\ \mu\epsilon$ (peak to peak) a lower or higher strain was selected
- 50% reduction of the initial flexural stiffness as fatigue failure
- Initial flexural stiffness registered after 50 cycles from the start of test





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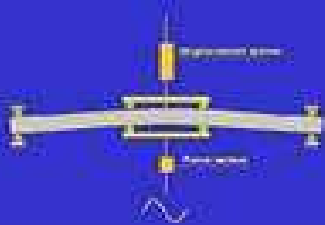
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Laboratory: Flexural Stiffness Testing

- different test temperatures – from 5°C to 25°C @ an interval of 5°C and frequency sweeps of 0.5Hz, 1Hz, 2Hz, 5Hz and 10Hz were applied per specimen for 300 cycles
- sinusoidal strain (as loading mode)
- Master curve was used to extrapolate flexural stiffness test data beyond test-ranges by applying the Arrhenius equation



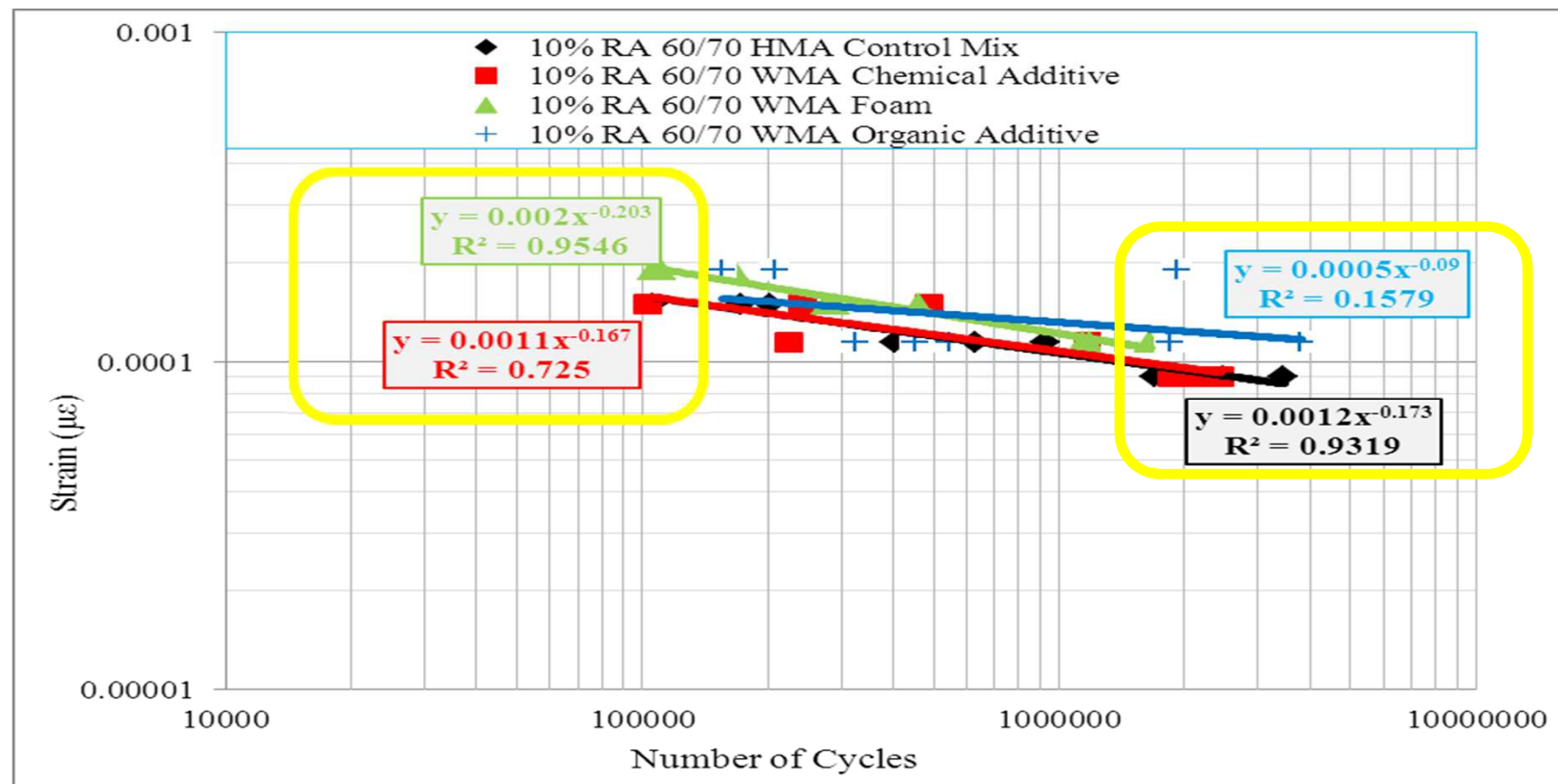


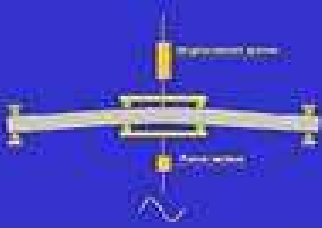
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10% RA 60/70 Fatigue Results: Strain vs. Nf



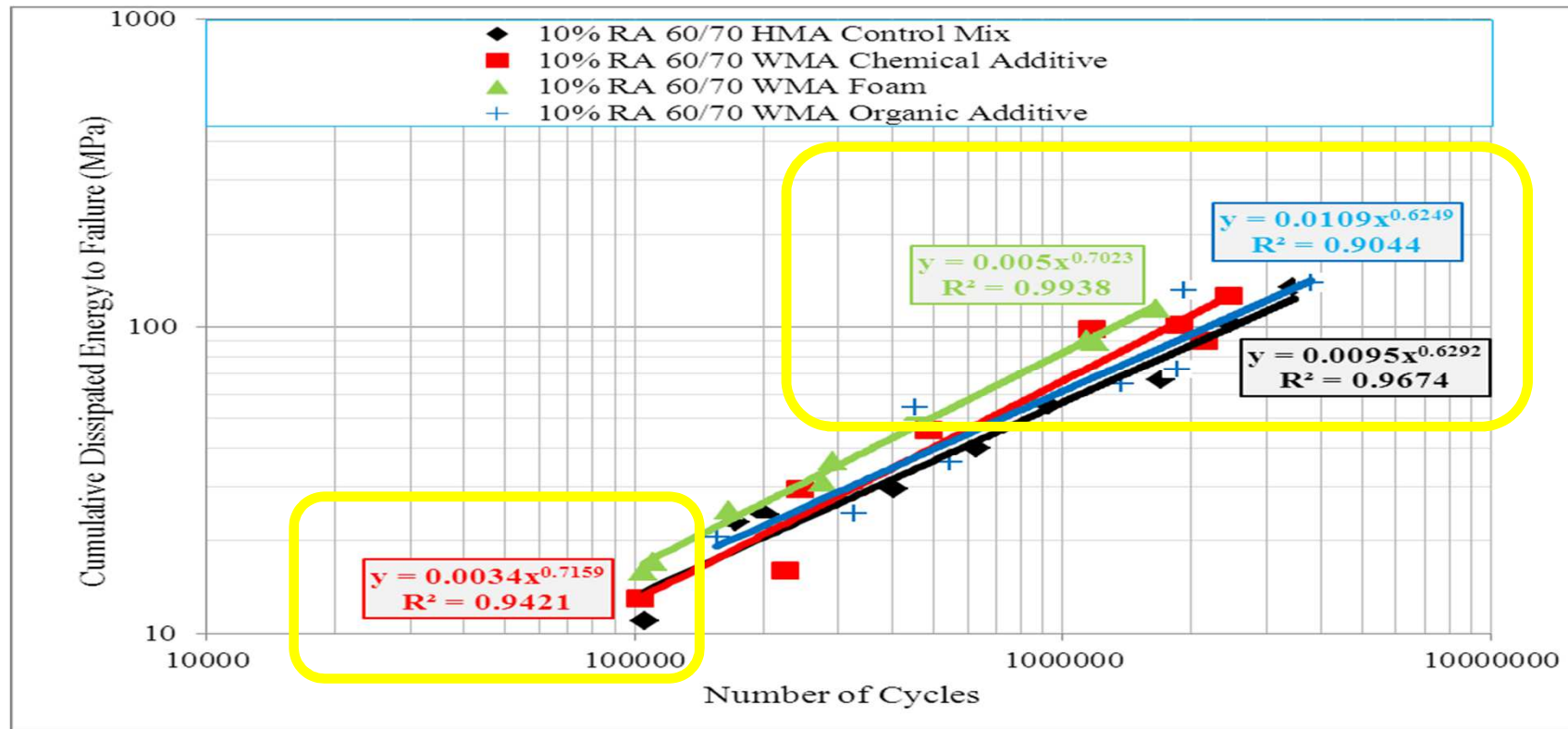


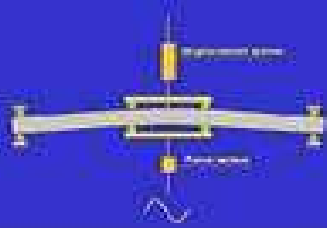
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10% RA 60/70 Fatigue Results: WN vs. Nf



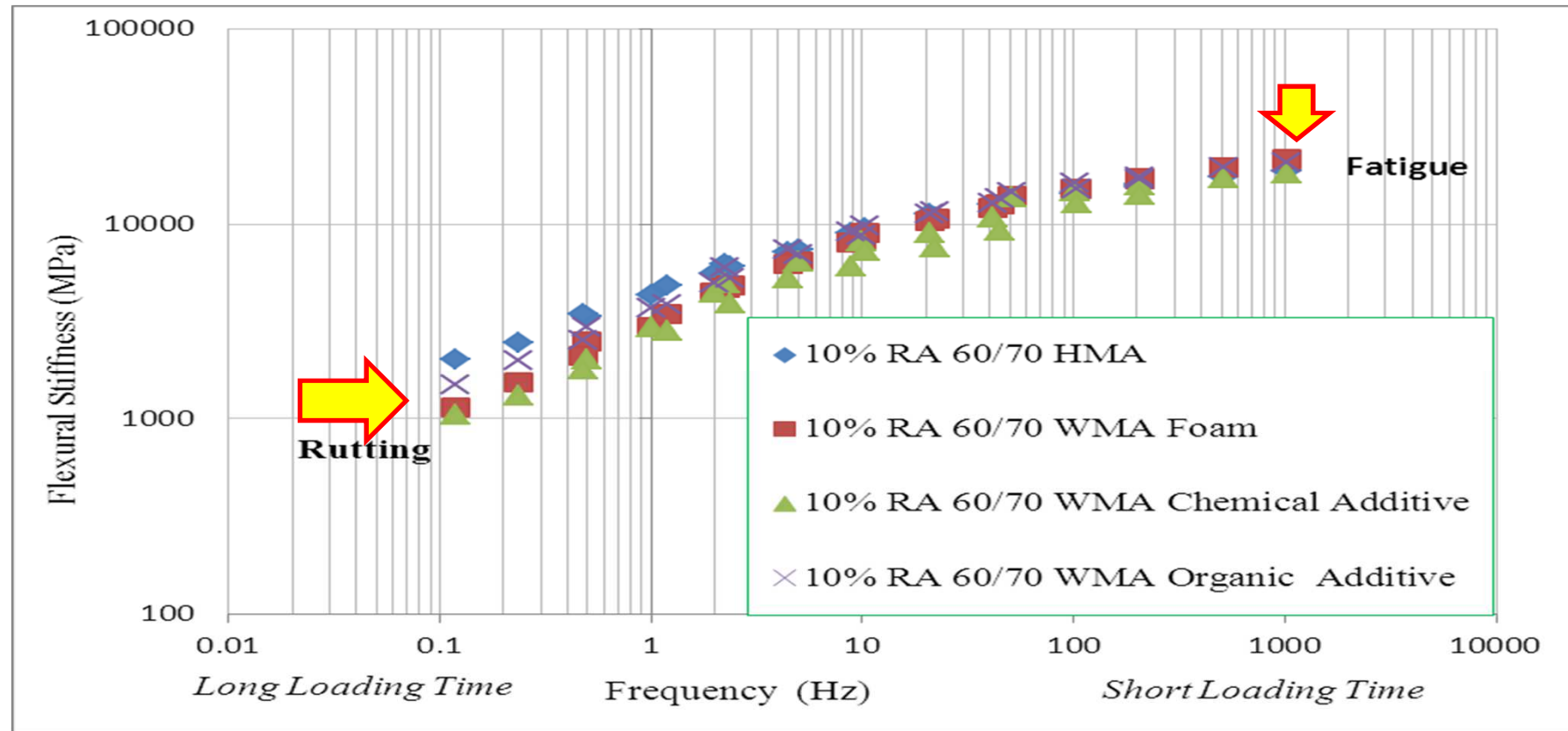


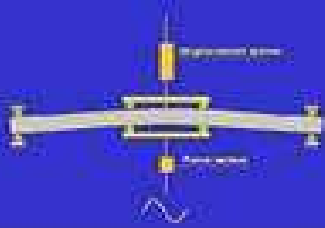
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10% RA 60/70 Flexural Stiffness



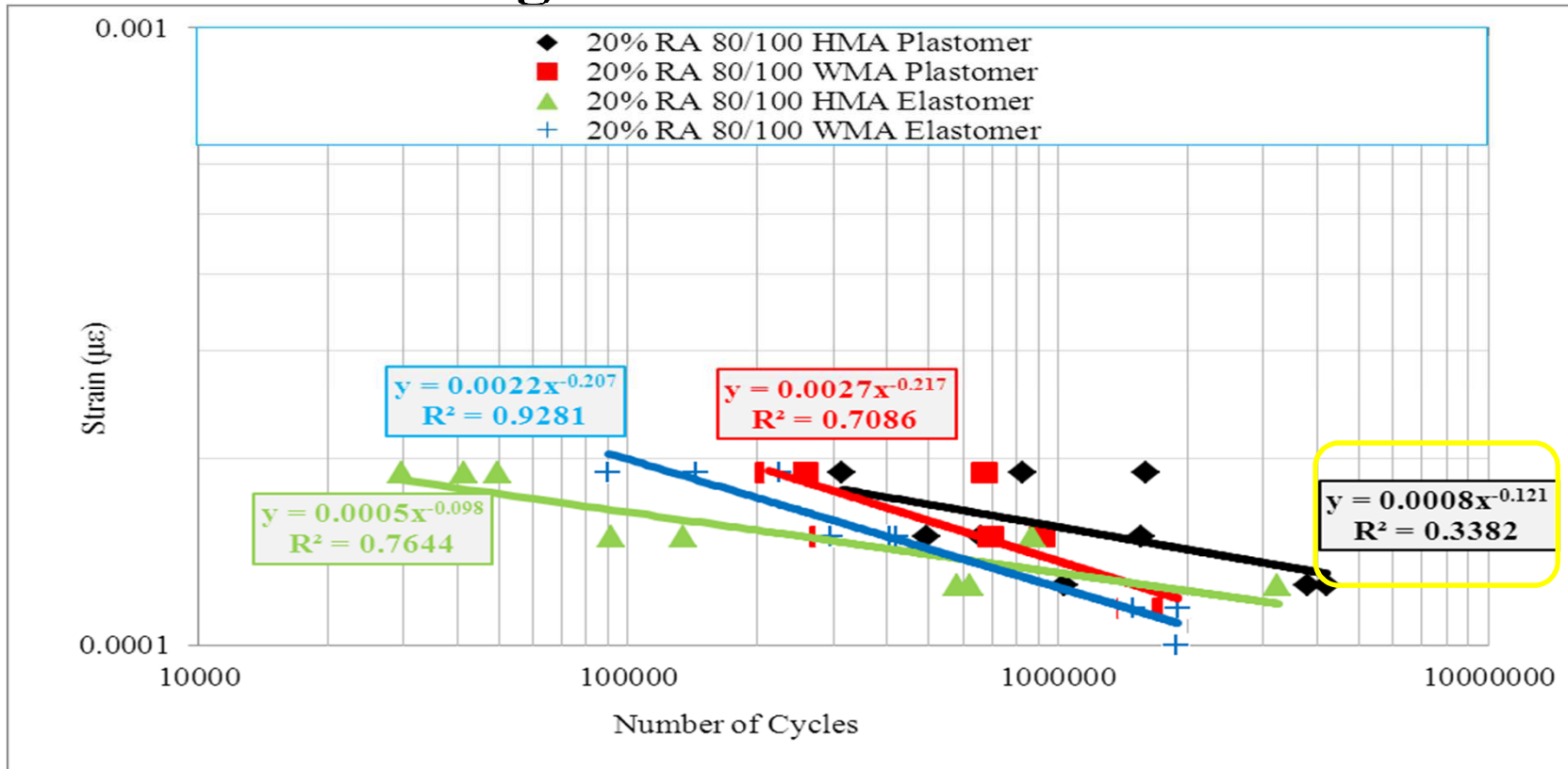


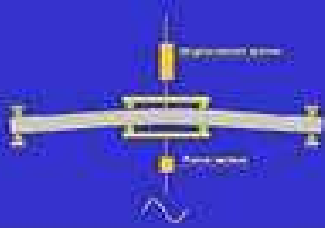
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20% RA 80/100 Fatigue Results: Strain vs. Nf



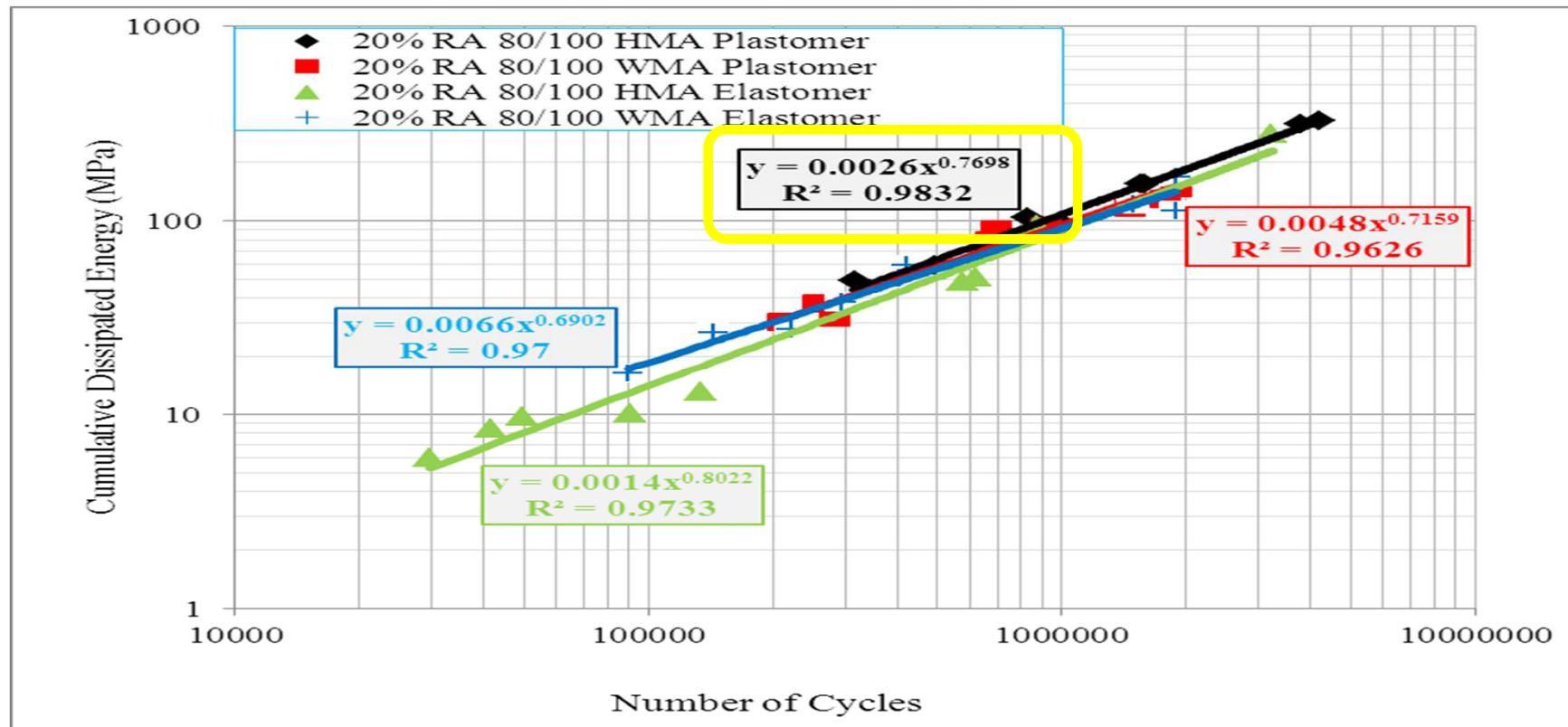


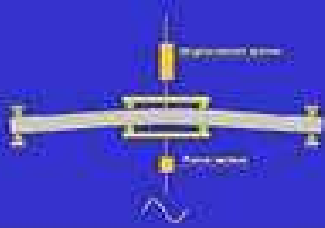
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20% RA 80/100 Fatigue Results: W_N vs. N_f



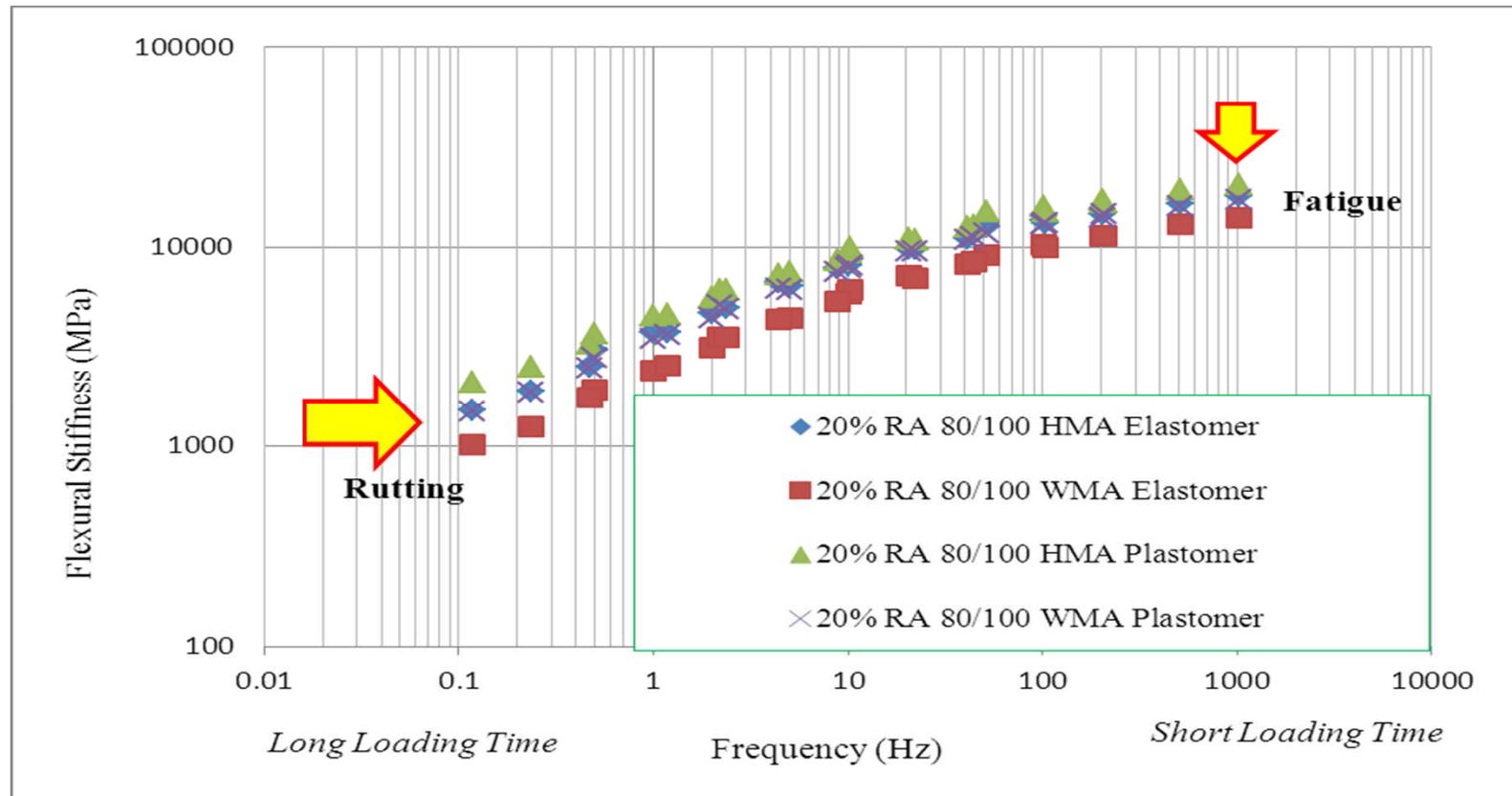


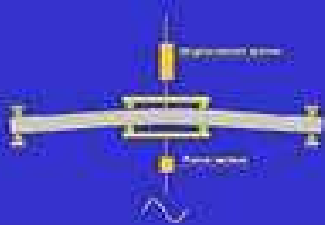
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20% RA 80/100 Flexural Stiffness





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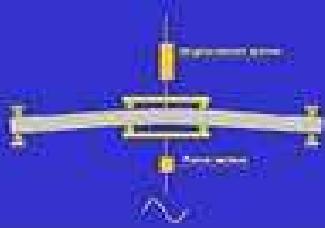
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Fatigue Models

Fatigue Models (Dissipated Energy Approach)				
Mix Type	A	Z	R-Sq.	$W_N = A (N_f)^Z$
10% RA 60/70 HMA Control	0.0095	0.6292	0.967	$W_N = 0.0095(N_f)^{0.6292}$
10% RA 60/70 Chemical Additive	0.0034	0.7159	0.942	$W_N = 0.0034(N_f)^{0.7159}$
10% RA 60/70 Organic Additive	0.0109	0.6249	0.994	$W_N = 0.0109(N_f)^{0.6249}$
10% RA 60/70 Foam	0.0050	0.7023	0.904	$W_N = 0.0050(N_f)^{0.7023}$
20% RA 80/100 Plastomer Control	0.0026	0.7698	0.983	$W_N = 0.0026(N_f)^{0.7698}$
20% RA 80/100 WMA Plastomer	0.0048	0.7159	0.963	$W_N = 0.0048(N_f)^{0.7159}$
20% RA 80/100 Elastomer Control	0.0014	0.8022	0.973	$W_N = 0.0014(N_f)^{0.8022}$
20% RA 80/100 WMA Elastomer	0.0066	0.6902	0.970	$W_N = 0.0066(N_f)^{0.6902}$





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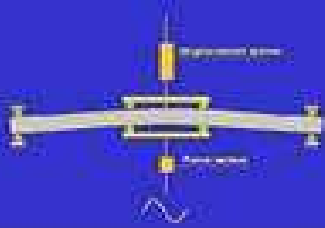
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CONCLUSIONS:

- Wöhler fatigue relationship (Strain vs. N_f) provides a better analytical fatigue evaluation compared to the dissipated energy approach (W_N vs. N_f)
- mix fatigue characterization should also include the evaluation of mix flexural properties as to correlate mix flexural properties to rutting as well as fatigue criteria
- evaluation of material performance necessitates the assessment of material properties in terms of durability and material response regarding area of application or service





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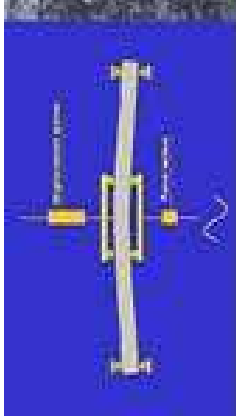
RECOMMENDATIONS:

Future Research;

- should consider an integrated approach of fatigue evaluation that incorporates fracture mechanics technique with its evaluation
- consideration of advancing present fatigue models, as to better the analysis and evaluation, is highly required especially with the ever increasing research innovations and newer material types

The challenges remain attainable – RESEARCH!





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