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Development of Failure Master Curve for Asphalt Mastics Characterization

Pouya Teymourpour

Hussain Bahia

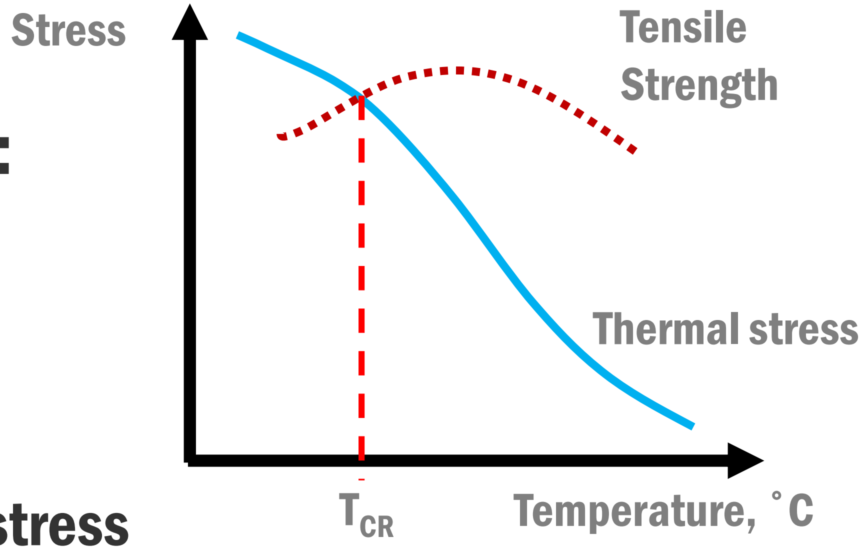
University of Wisconsin-Madison

Outline

1. What controls cracking ?
2. Strain or stress
3. Bitumen or mastic
4. What controls mastic cracking behavior ?
5. Summary

Introduction: Thermal Cracking

- Low temperature cracking is a major distress in many regions.
- Thermal stress buildup due to:
  - Restriction of thermal strain
  - Excessive brittleness
  - Increase in stiffness
  - Decrease in the ability to relax stress



- Current understanding: Thermal stress exceeds tensile strength, thermal cracks will occur.

Motivation:

What controls Cracking ?

$$\sigma_{ij}(t) = \int_0^t E_{ijkl}(t-\xi)\frac{\partial \varepsilon_{kl}(\xi)}{\partial \xi}d\xi$$

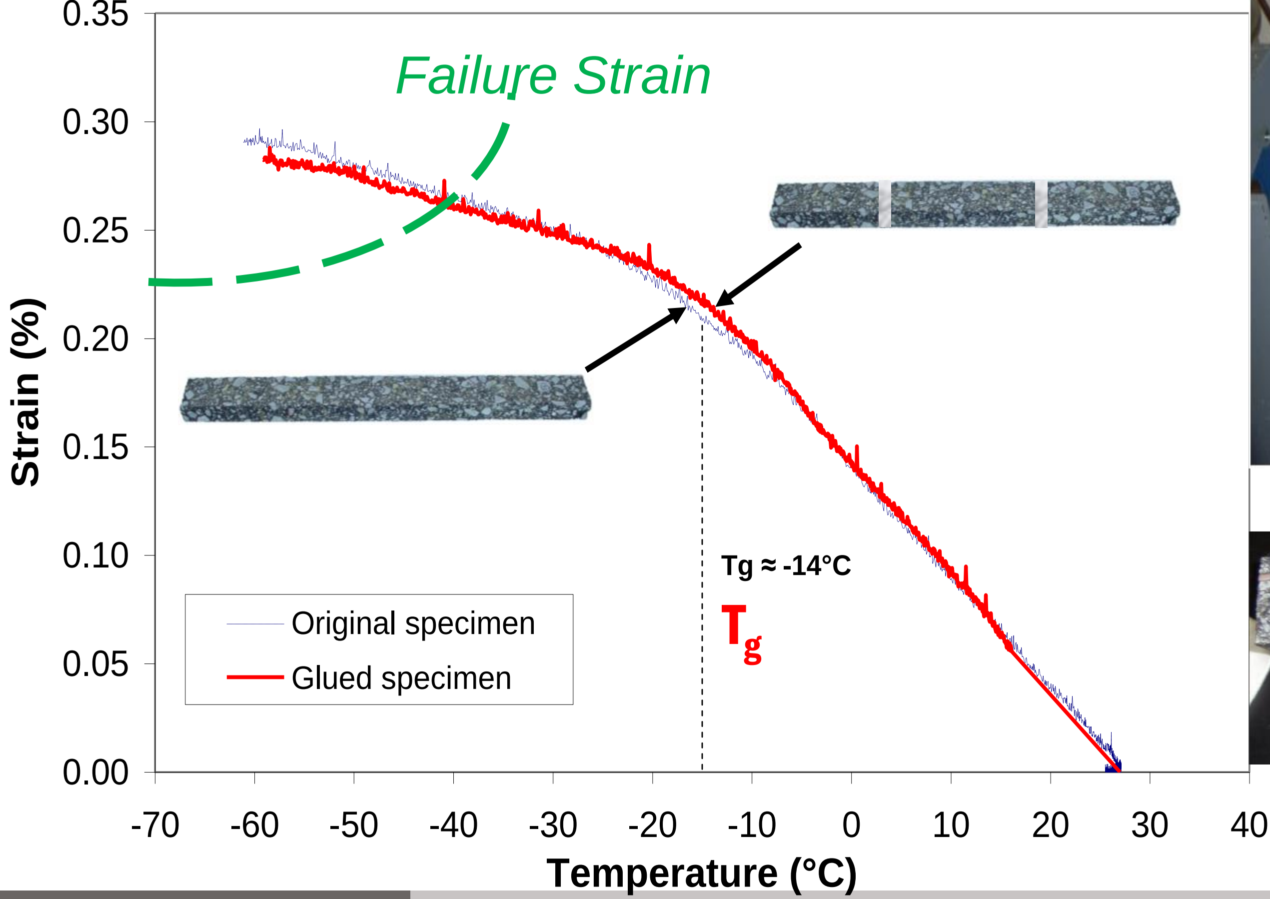
Thermal Stress

Thermal Strain- From T_g component: Coefficient of thermal contraction $\alpha(T)$ and T_g

This is a Strain-driven Mechanism; no strain= no stress

What about strain at Failure ?

Asphalt Mixtures Thermal Strain



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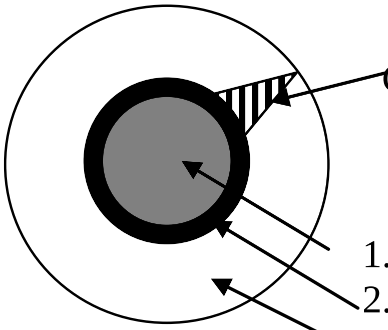
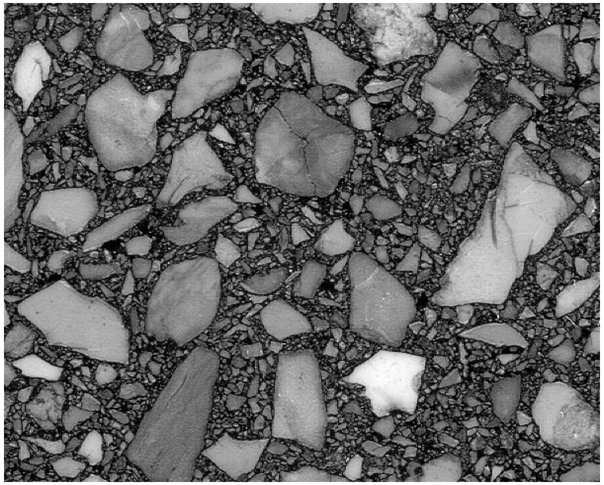
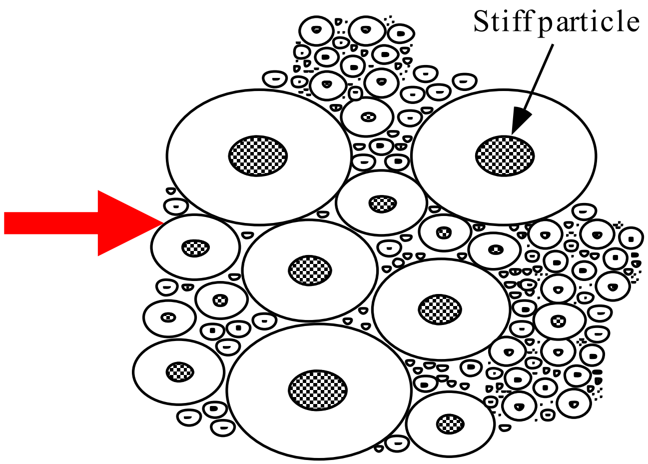
What controls Shrinkage: Bitumen or Mastics?

- ***Fillers & modifiers affect all aspect of bitumen behavior***







Important Filler Properties:
Geometry and Composition

Importance of Mastic in Thermal Cracking Prediction

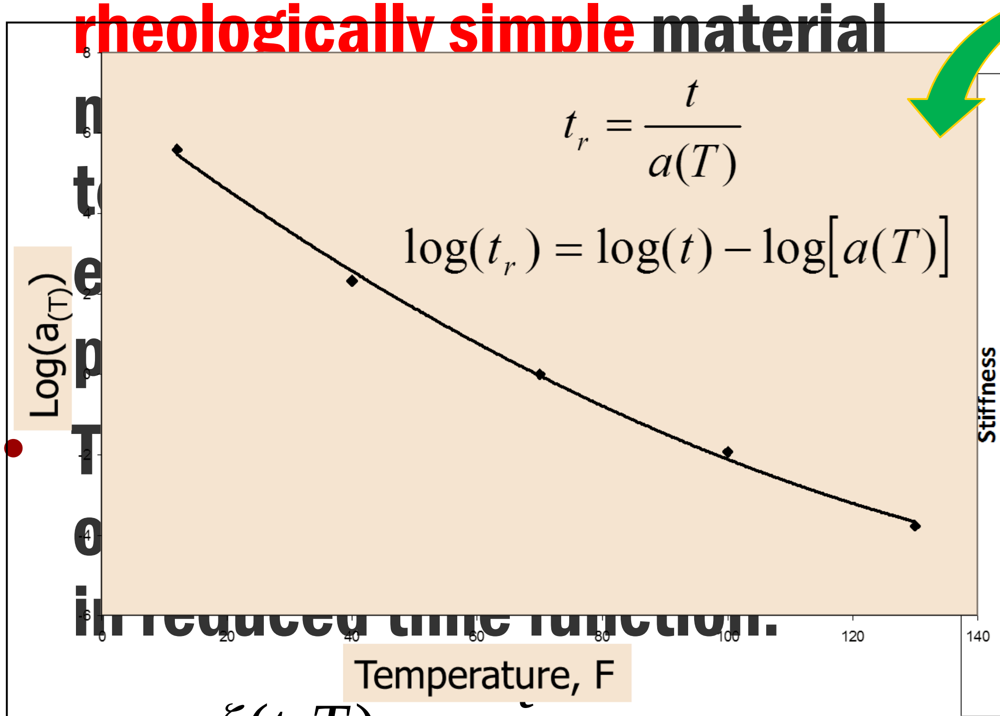
- Stiffening effect of mineral fillers has been observed in asphalt mastics and mixtures for many years (Anderson and Goetz (1973), Dukatz and Anderson (1980), Craus et al. (1978), Buttlar et al. (1999), etc.)
- Stiffening results from volume fraction of filler and physio chemical interaction between asphalt and filler.
- Cracking can be considered as an asphalt mastics related problem due to effects of mineral fillers on crack propagation and crack pinning

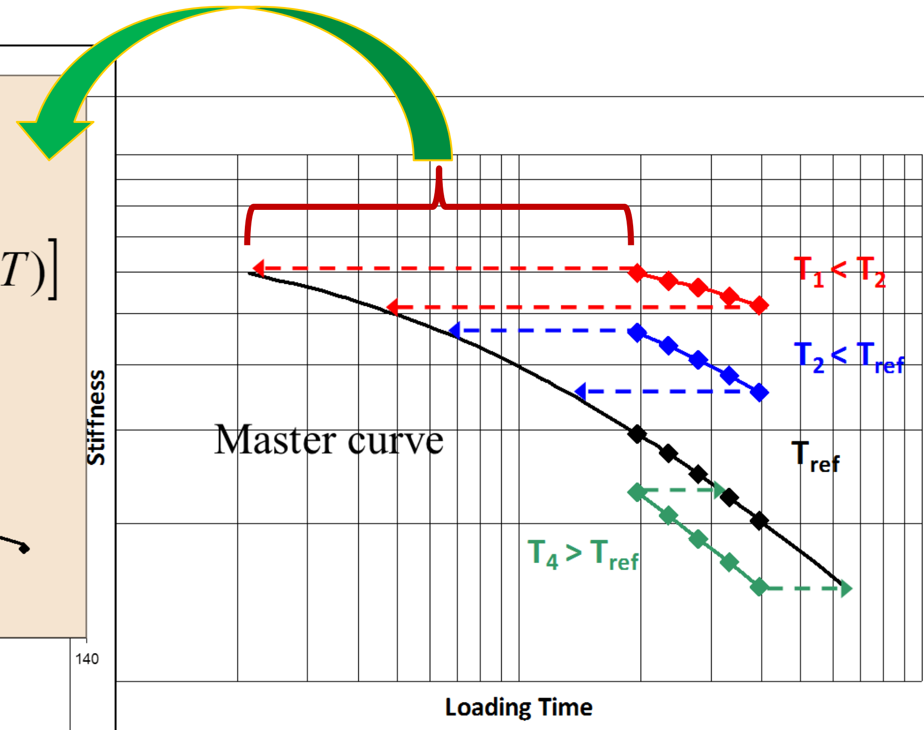
Importance of asphalt mastics in asphalt mixtures thermal cracking resistance is debated.

How to characterize Cracking: Time-Temperature Superposition Principle (TTSP)

- Asphalt is a **thermo-rheologically simple** material
- T … in reduced time function:

$$\xi(t,T) = \frac{t}{a_T(T)}$$





Application of Time-Temperature Principles on Fracture Properties of Asphalt-Aggregate Composites

- **Master curves** can be constructed for rheological properties of relatively homogenous materials at small strains.

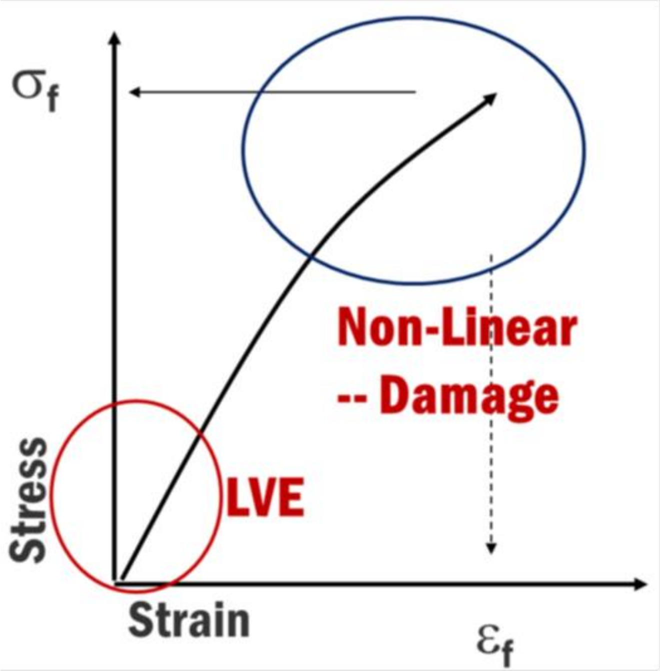
- Can this be applied to large strain **composite materials (Mastics) characterization**?

- Crack pinning of fillers
- Damage Propagation in Mastics

→ Complication of the behavior of asphalt mastics at high strains

Problem Statement: Stress and Strain in Failure Zone

- The binder S(60) and m(60) measured **with Bending Beam Rheometer (BBR)** can estimate stress / strain build up, but not fracture



- Neat bitumne strength / strain tolerance **values highly correlate** with binder stiffness
- However **mineral fillers** (binder-aggregate interaction) have significant effects on fracture properties of binders.

Study Focus:

- Development of suitable **failure characterization of mastics** by constructing **fracture master curves** using Single Edge Notched Bending (SENB)
- Assessment of the **sensitivity of the mastic fracture** properties (e.g., strain at failure), to changes in loading **time and temperature**

Mineral Filler Selection

1. Surface Area of Fillers
2. Rigden Voids (Size Distribution):

Name	Code	RV (%)	BET (m^2/g)	SG (g/cm^3)
Basalt Vesicular	BV1	37.80	10.21	2.79
Cisler Granite	CSG	32.75	2.17	2.66
Hydrated Lime	HL	52.80	21.31	2.46

Place plunger in dropping block and seat on guides

Raise to drop height and let fall freely, repeat 100 times.

$$\%Voids = \left(1 - \frac{m \times 10^3}{\pi \times r^2 \times \rho \times h}\right) \times 100$$

- m = mass of compacted filler
- r = inner radius of the cylinder
- ρ = Specific gravity of filler
- h = Height of compacted filler.

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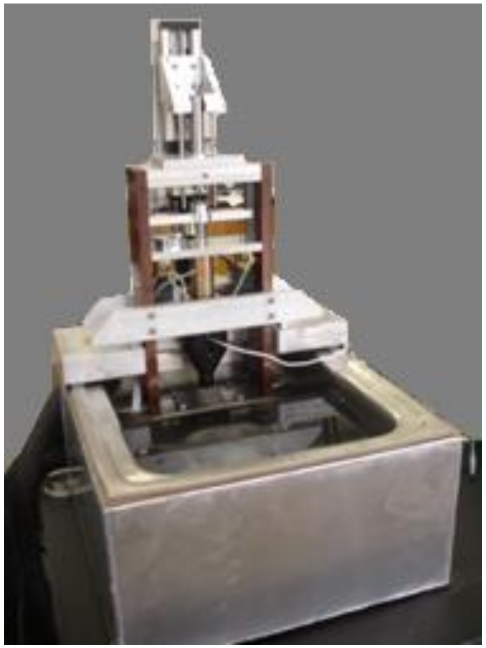
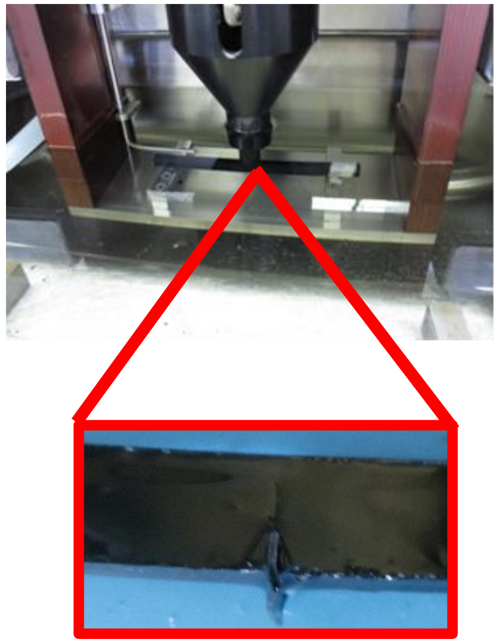
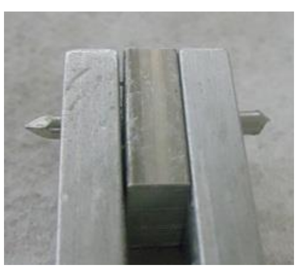
BBR-SENB System







- Evaluates:
  - Binder/Mastic low temperature fracture properties
- Modification of BBR by:
  - Deflection-controlled instead of load controlled.
  - Notched samples
- Used in this study to measure importance of **mastic strain at failure** in <u>low temperature cracking</u>.

Can we Construct Fracture Master Curve?

- 1 Binder Type
  - PG 64-22
- 2 Filler Volume Fractions: 20 % and 35%
- 3 different Loading Rates: 0.04 mm/s, 0.01 mm/ and 0.0025 mm/s
- 5 Different Temperatures:
  - -6, -9, -12, -18, -24 °C
- 3 Mineral Filler Types

Name	Code	RV (%)	BET (m^2/g)	SG (g/cm^3)
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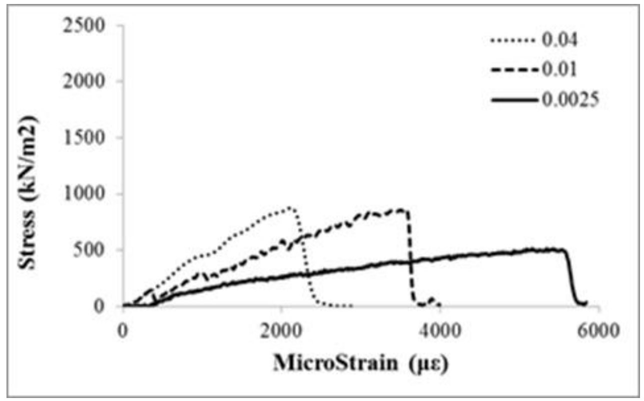
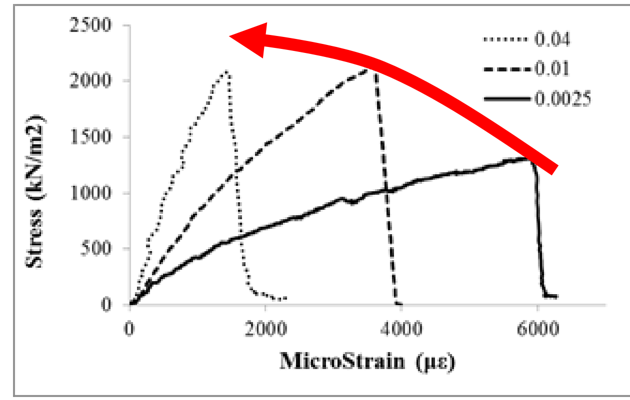
BBR-SENB Loading Rate & Temperature

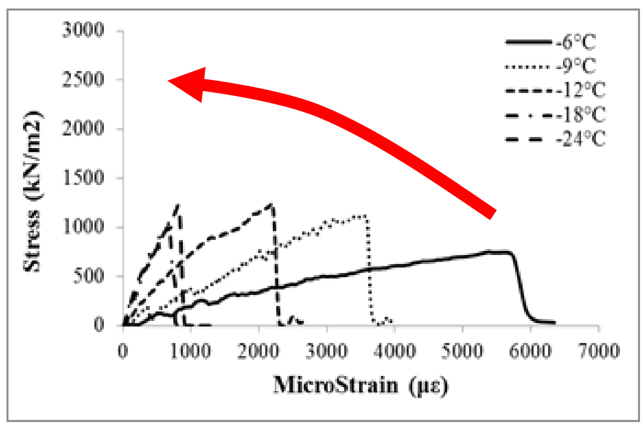
Binder | **Mastic**

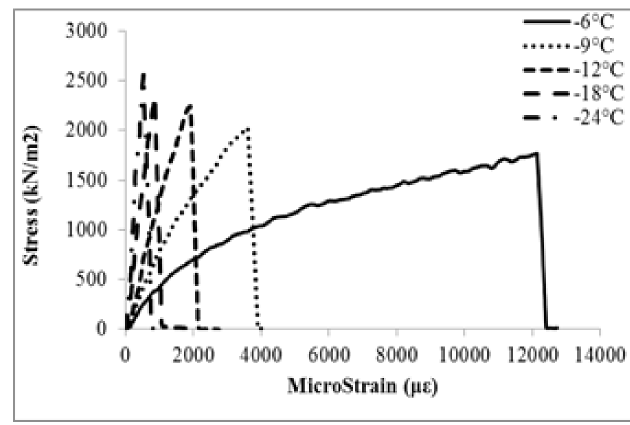
Effect of Strain Rate:



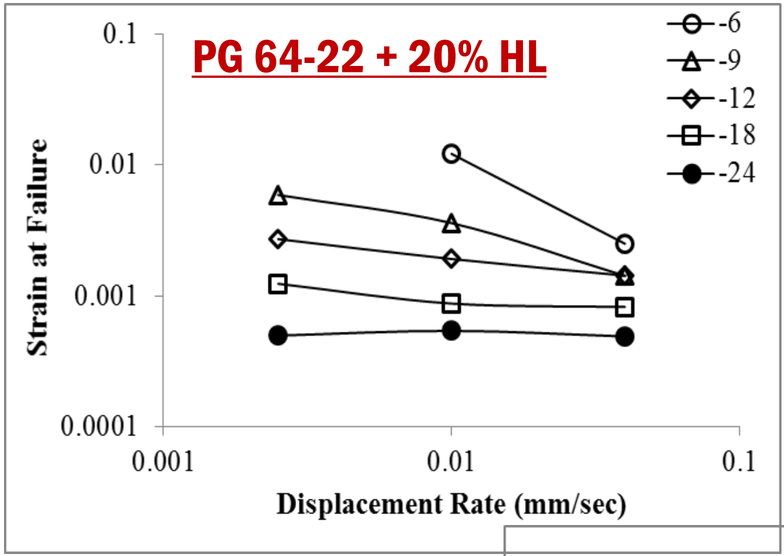


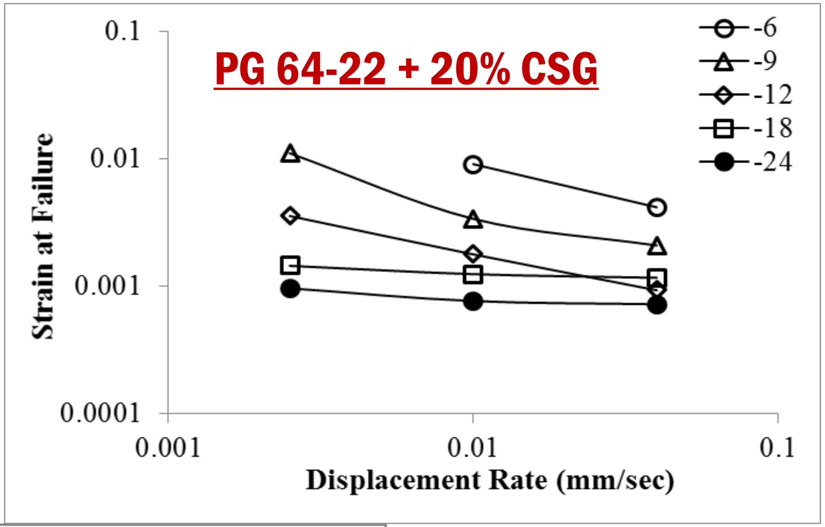
Effect of Temperature:

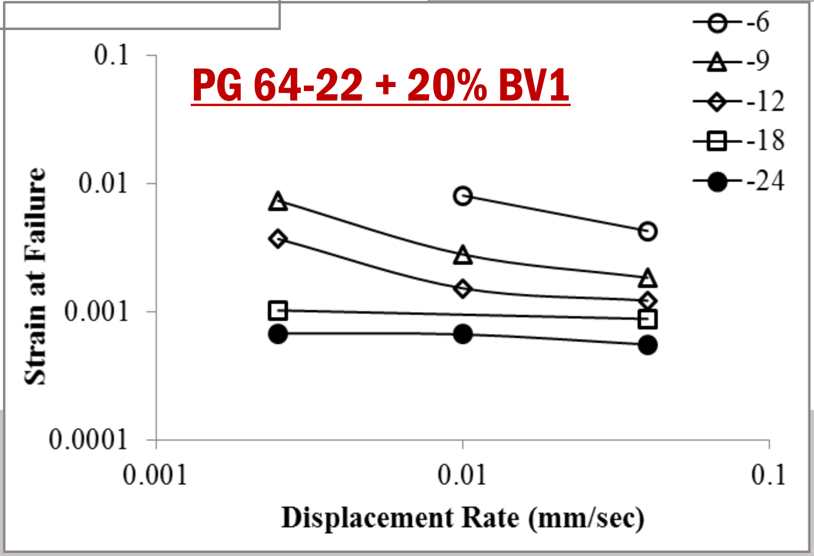




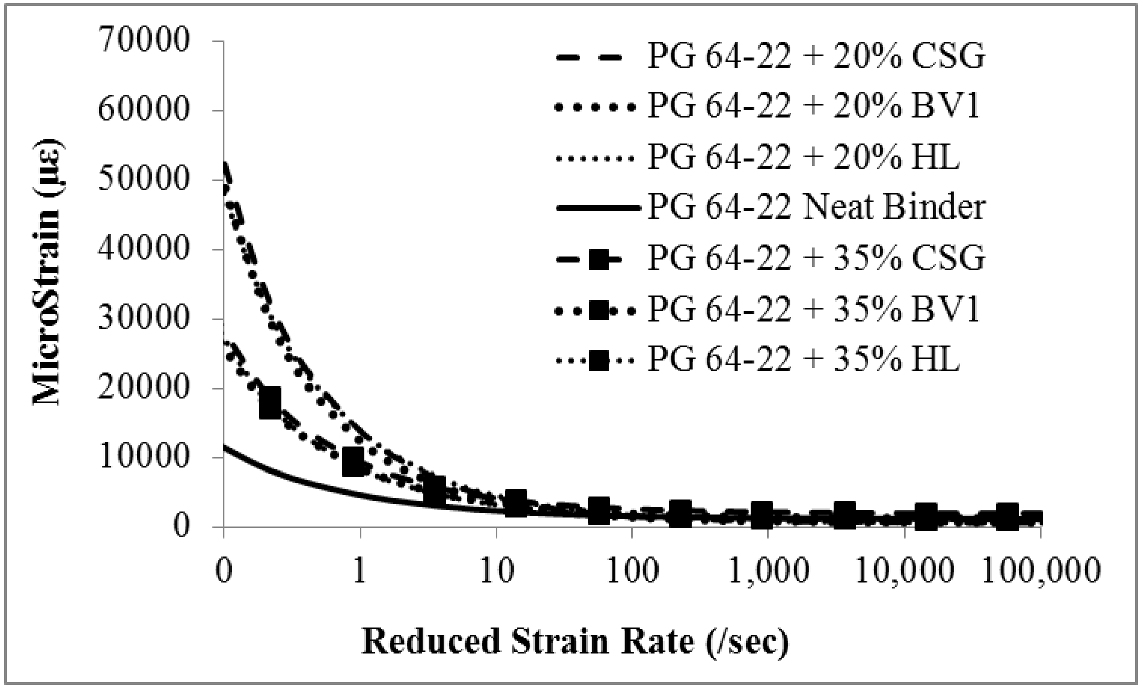
Time-Temperature Superposition Application
Strain at Failure







Failure Strain Master Curves

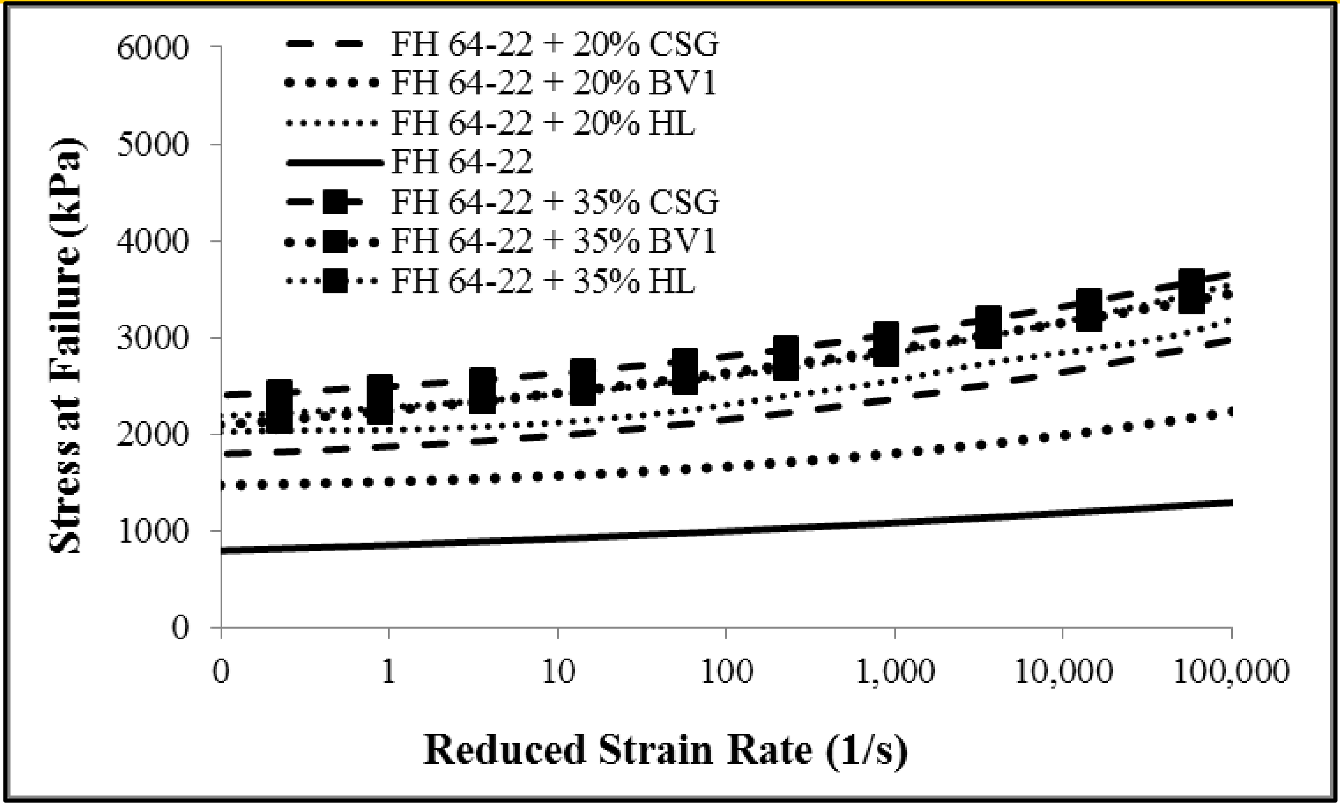


- Asphalt **mastics** have **different** fracture behavior than asphalt **binders**
- TTS principles **can be applied** to mastics
- The **volume fraction of filler** is a Main factor

$$F(f) = \varepsilon_{min} + (\varepsilon_{max} - \varepsilon_{min})\left[1 + \left({}^{f_c}/_{a_T f}\right)^k\right]^{-m/k}$$

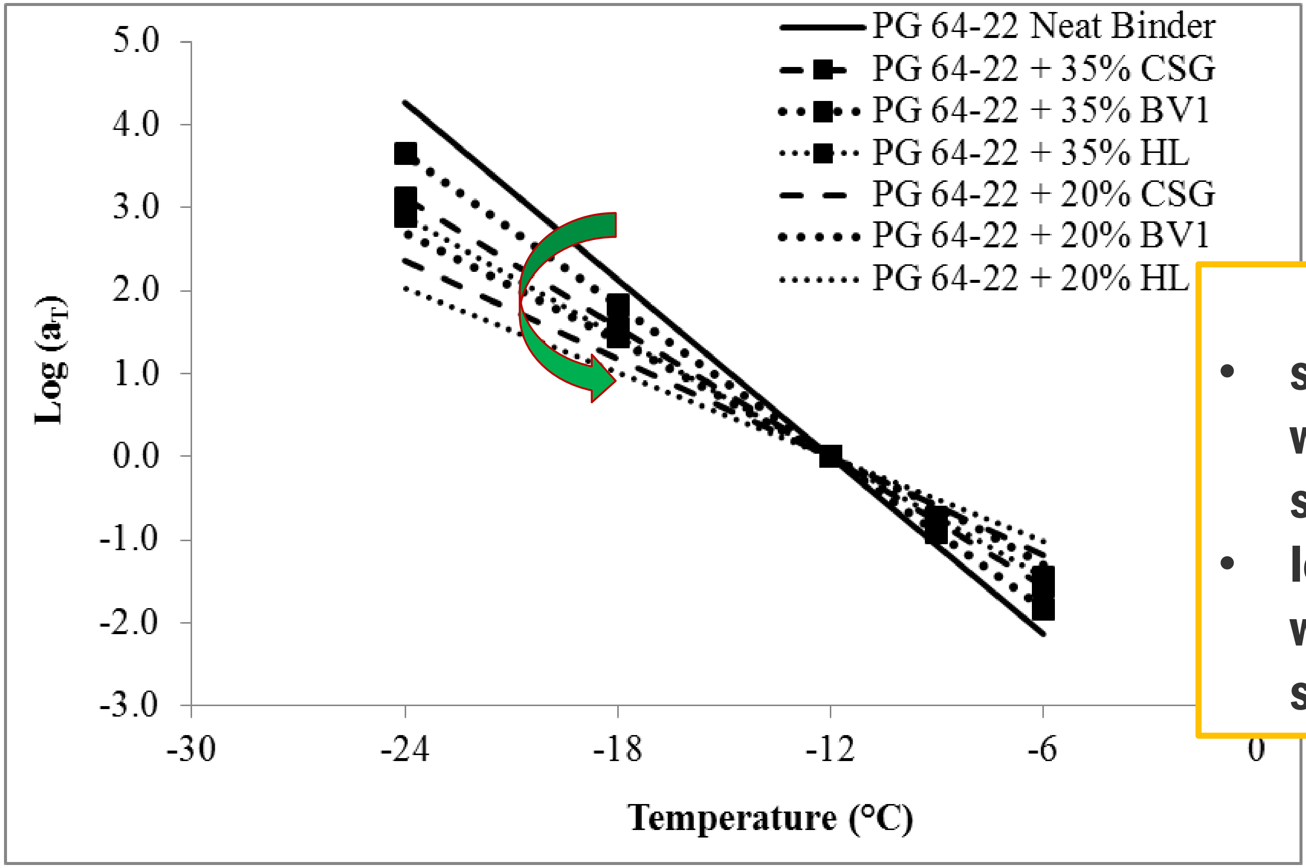
$$\log a_T = -c_1(T - T_0)/[c_2 + (T - T_0)]$$

Failure Stress Master Curves



- ✓ Failure stress is less sensitive to cooling rates .
- ✓ Suggesting consideration of failure strain as the main Characteristic

Temperature Shift Factors



Shift curves are :

- steeper for materials which failed at smaller strain, and
- less steep for materials which failed at larger strains

Failure Master Curves Sensitivity Analysis

Factor	Filler Type	Volume Fraction	Temperature (°C)	Deformation Rate (mm/sec)	Replicate
Level	3	2	5	3	2
Description	CSG BV1, HL	20%, 35%	-6, -9, -12, -18, -24	0.0025 0.01, 0.04	A B

Factor	Df	Sum Sq	Mean Sq	F value	Pr(>F)	Significance
Filler Type	2	5123053	5123053	2.3092	0.1294	N
Filler Volume Fraction	1	15273112	7636556	3.4422	0.0329	Y
Temperature	4	1494287770	373571943	168.3869	< 2.2e-16	Y
Displacement Rate	2	322264719	161132359	72.6301	< 2.2e-16	Y
Replicate	1	1860339	1860339	0.8385	0.3604	N

Filler type and Replicates are not significant

Summary of Findings

- **Mastic fracture master curves** can be developed and applied. **Time temperature superposition** remains **valid** for asphalt mastics (binders with mineral filler inclusion) **at large strains at failure**.

- Mastics have **significantly different** fracture behavior than binders
  - It is **better to test mastics** to predict mixture cracking

Summary of Findings

- Strain at failure is more sensitive to cooling rate than stress at failure → More emphasize should be placed on failure strain in areas where cooling rates vary significantly
- At **lower mastic strain rates** representative of low cooling rates typical of field cooling conditions, the **strain at failure of asphalt mastics** are found to be the **controlling factor** since the failure stresses are almost independent of strain rates (cooling rates)

Thank You!

Questions?

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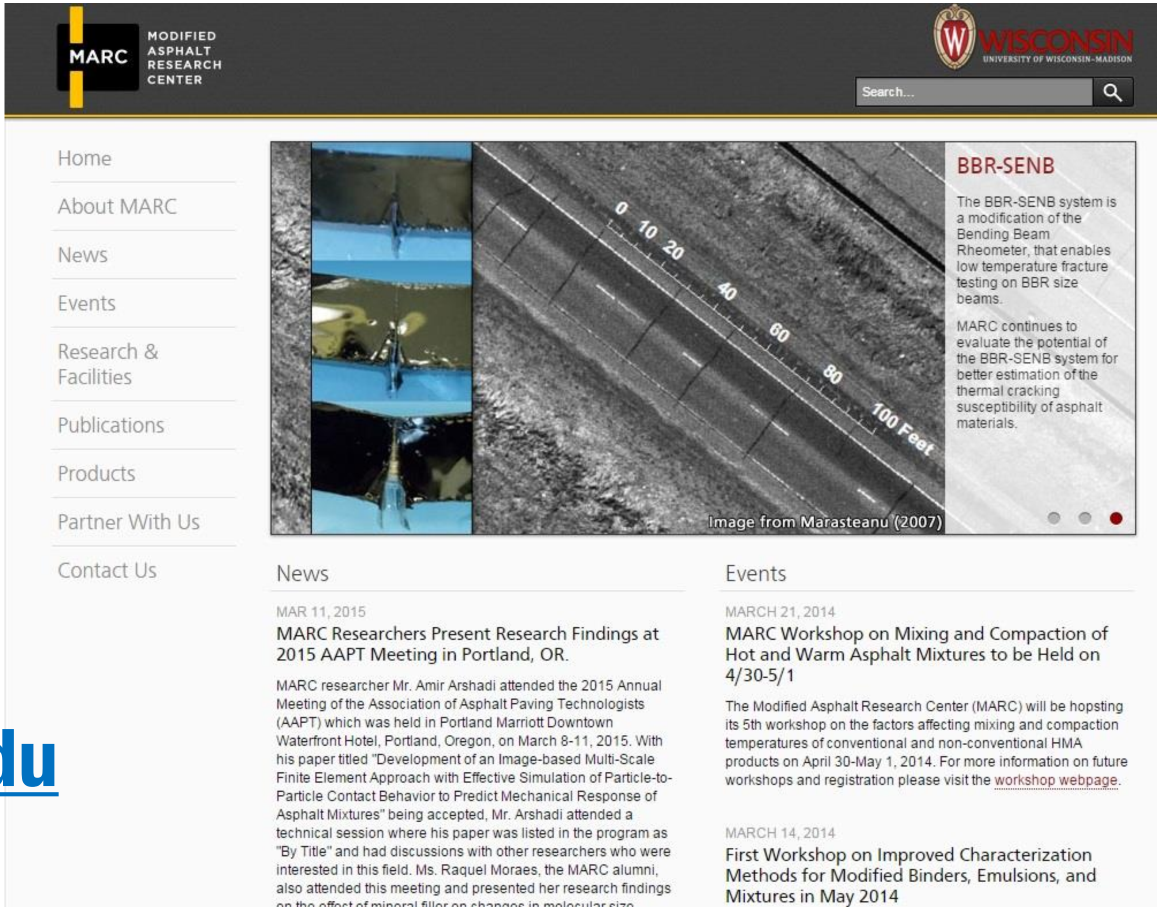

Hussain Bahia
bahia@engr.wisc.edu

Pouya Teymourpour
teymourpour@wisc.edu