Advanced Characterization and Modeling of Asphalt Materials

University of Wisconsin–Madison

Advanced Characterization and Modeling of Asphalt Materials
ARC Workshop – January 2015

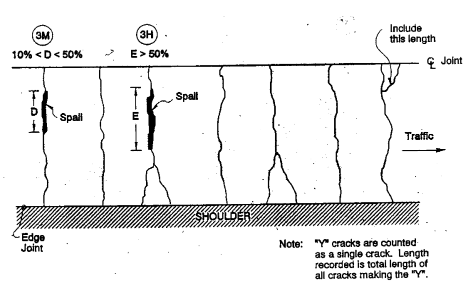
Damage Resistance Characterization

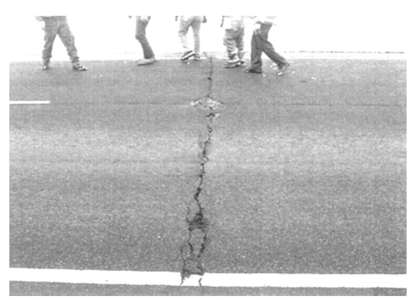
– Rutting Resistance
  - Multiple Stress Creep and Recovery
– Fatigue Resistance
  - Linear Amplitude Sweep Test (LAS)
– Fracture Testing
  - BBR-SENB

Outline

Problem Statement

- Thermal cracking of pavements remains one of the most challenging distress in pavements to predict, and reduce, in North America.





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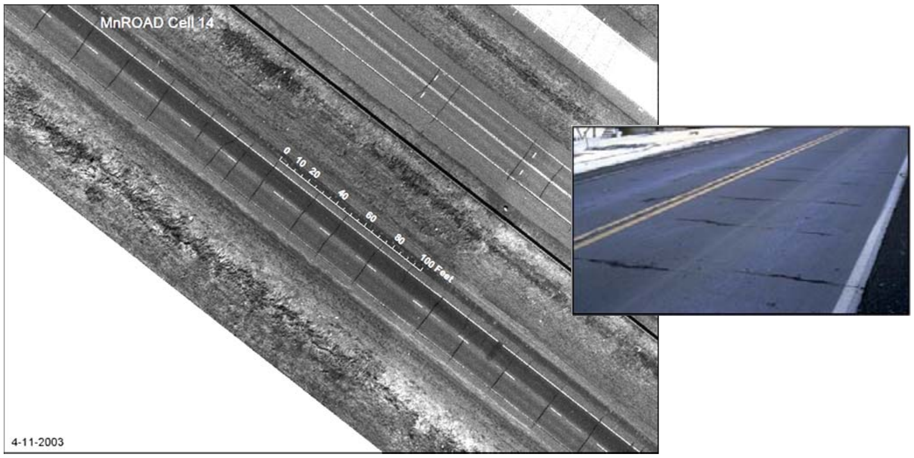
Thermal Cracking on MinRoad
15 Years after PG grading implemented !



*Marasteanu (2009)

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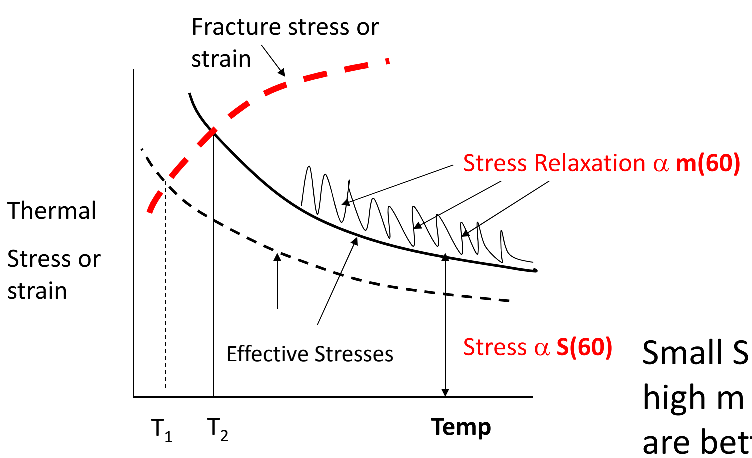
What causes thermal cracking?



Small S(60)
high m (60)
are better

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Background: Problem Statement

PG Testing Methods

- The binder S(60) and m (60) measured with the Bending Beam Rheometer (BBR) can estimate stress /strain build up, but not fracture
- Neat asphalts strength / strain tolerance values correlate highly with S(60) and m(6).
- However additives (polymers and extender oils) have significant effects on fracture properties of binders.
- Need for a testing system that is simple and effective in measuring fracture properties.

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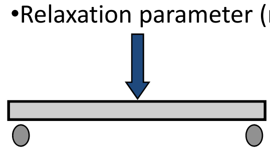
PG Testing Methods for Low Temperature Cracking

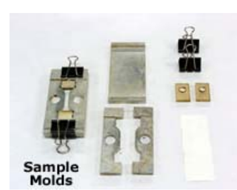
Bending Beam Rheometer (BBR)

- •Creep Stiffness (S)
- •Relaxation parameter (m-value)



Direct Tension Test (DTT)

- •Strain tolerance(ε_f)



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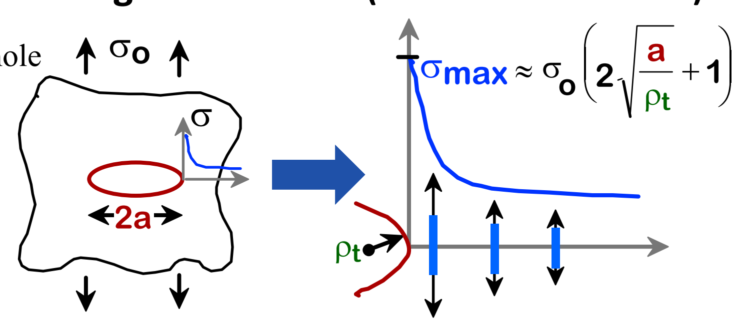
How to measure Fracture:
Basics of Fracture Science -Strength and Flaws

- Fracture strength is function of cohesive forces holding atoms together (E).
  - Theoretical cohesive strength of brittle and elastic material is ~ E/10
  - => Experimentally E/100 to E/10,000
- Griffith (1920s) proposed that difference is due to microscopic flaws amplifying local stress and producing stress concentration.

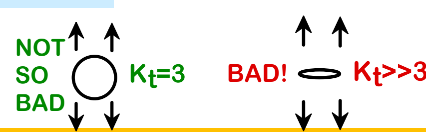
How can Aging affect
Strength and Flaws (stress Concentrators)

Elliptical hole in a plate:



Stress conc. factor: $K_t = \sigma_{max} / \sigma_o$

Large K_t promotes failure:



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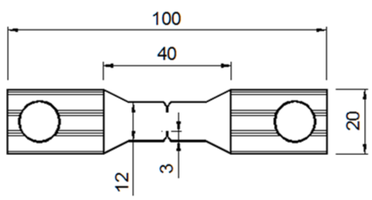
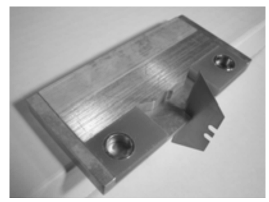
Fracture tests in tension
Double Edge Notch Tension Test (DENT)

- **Andriescu and Hesp (2004)** tested binders at 20°C to predict fatigue cracking in asphalt mixtures. Essential work of fracture (**EWF**) method by dividing strain energy into essential work of fracture (w_e) and plastic work of fracture (w_p)

•**Zofka and Marasteanu (2007)** compared DENT and DTT for 9 binders

-Results showed that DENT produces better repeatability than DTT and it can be used to estimate critical cracking temperatures of binders





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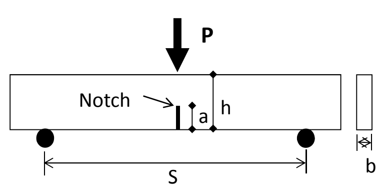
Fracture Testing in Bending

- T. Hoare and S. Hesp, "Low-Temperature Fracture Testing of Asphalt Binders: Regular and Modified Systems." Transportation Research Record 1728, pp. 36-42, (2000).
- E. Chailleux, and V. Mouillet, "Determination of the low temperature bitumen cracking properties: fracture mechanics principle applied to a three points bending test using a non-homogeneous geometry," ICAP Proceedings, Quebec, (2006).



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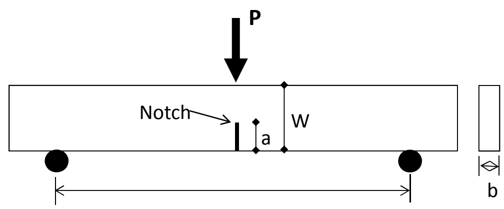
Background- Extensive Research Using SENB



Lee and Hesp (1994)
Anderson et al. (2001)
Hoare and Hesp (2000)
Hesp (2003)
Olard and Di Benedetto (2004)
Chailleux and Mouillet (2006)
Chailleux et al. (2007)
Not using the BBR!!

Motivation for Development of BBR-SENB

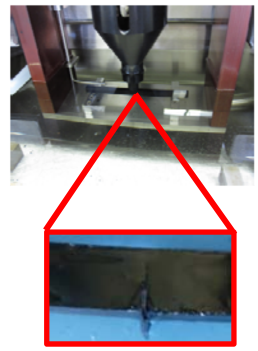
- BBR is very effective in controlling temperature, loading, and displacement, and allows high repeatability.
- SENB is an ASTM standard for metals and it has been used by Ontario DOT
- Currently an European standard for asphalt binders (CEN/TS 15963: 2010)
- Best choice is a BBR-SENB.

Modifications of BBR for BBR-SENB

Displacement-Controlled Mode

Step Motor

BBR system with a load cell with higher capacity



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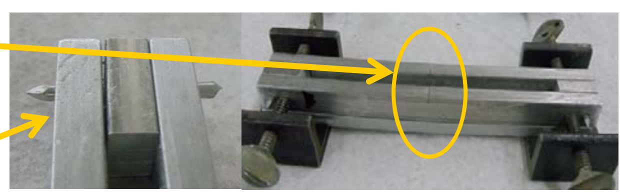
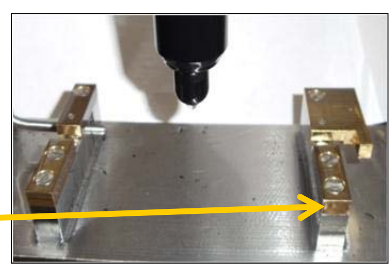
Modifications of BBR for BBR-SENB

BBR beam with a notch

Pins in molds to ensure proper notch preparation



Beam supports to ensure notch alignment



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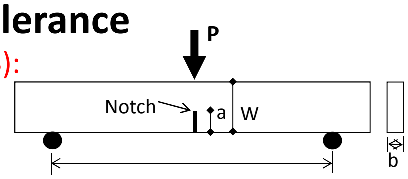
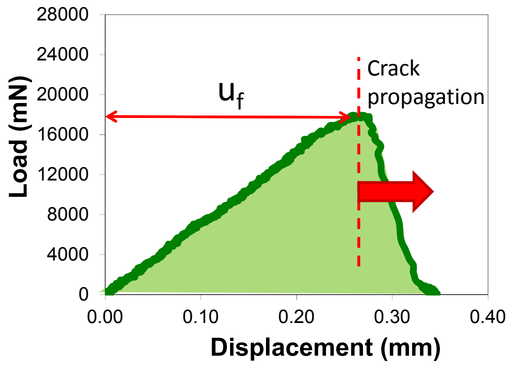
Modification of BBR to Measure Fracture Properties and Strain Tolerance

Single-Edge Notched Beam (BBR-SENB):

- •Failure Energy (G_f)
- •Deflection at fracture (u_f)

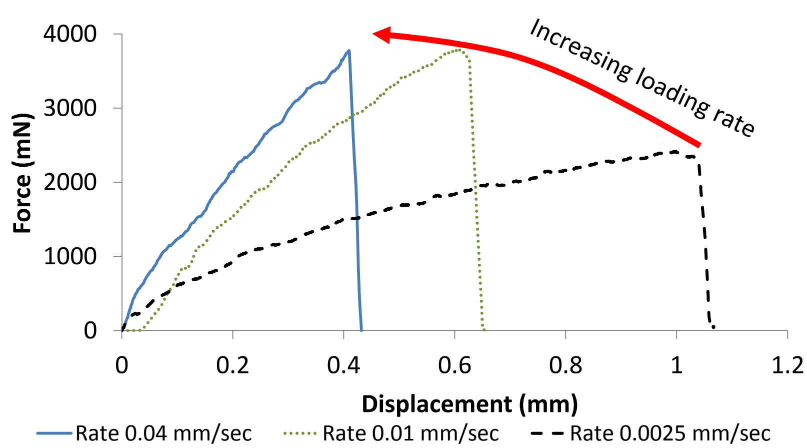




$$G_f = \frac{W_f}{A_{lig}}$$ Failure Energy

$$W_f = \int P du$$ Work

Effect of Loading Rate or Cooling Rate



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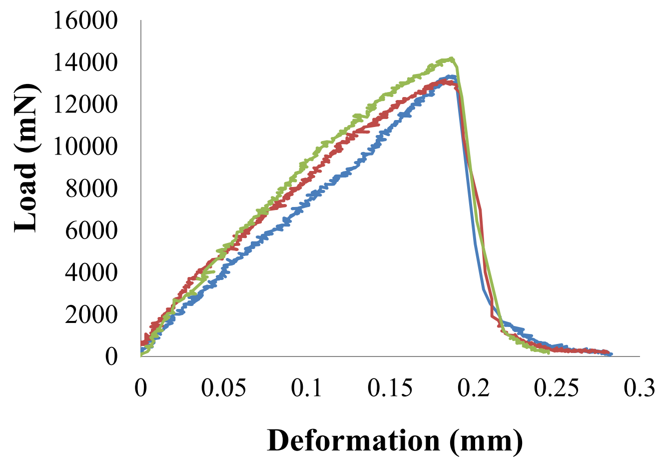
Repeatability of BBR-SENB



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Verification Study : Materials

- Asphalt binders collected from:
  - MnROAD (Minnesota, USA)
  - MN County Road 112 (Minnesota, USA)
  - Asphalt Research Consortium (ARC) project
  - Long Term Pavement Performance (LTPP) sections
- All binders were subjected to short-term aging using the Rolling Thin Film Oven (RTFO)

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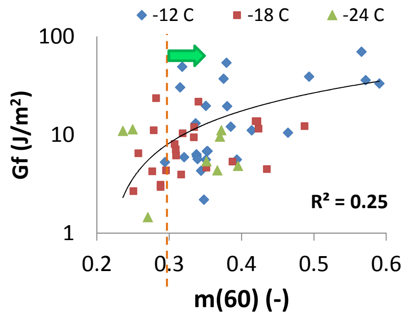
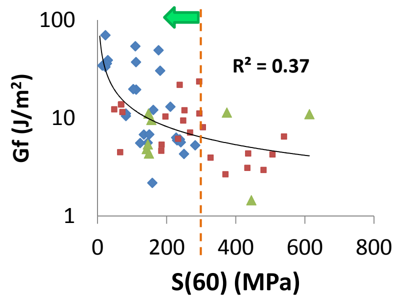
Comparing BBR and BBR-SENB





BBR m-value and S- value limits fail to distinguish between binders demonstrating low and high values of failure energy

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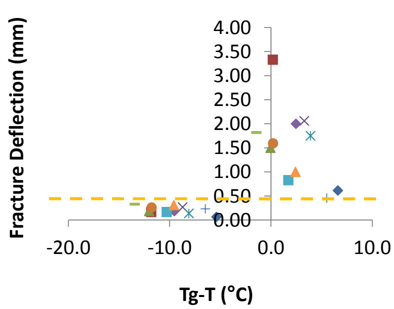
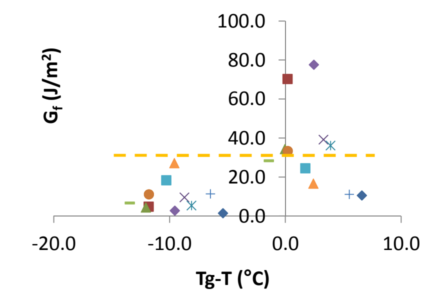
Selection of Performance Parameters for BBR-SENB – Can we detect brittleness- Tg ?





Fracture Energy and Fracture deflection are recommended for specifications or material selection

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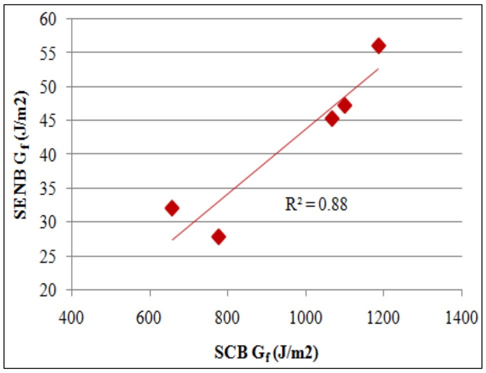
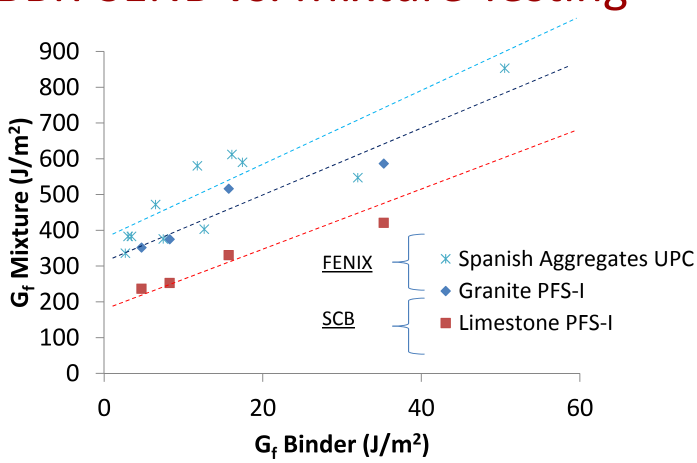
BBR-SENB vs. Mixture Testing



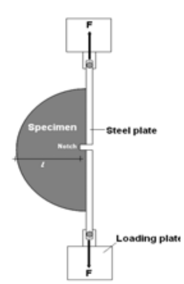
Semi-Circular Bending (SCB) Mixture testing of MnROAD materials conducted by *University Minnesota* as part of a Pooled Fund Study on Low Temperature Cracking- Phase II

Correlation shows that failure energy index from BBR-SENB testing is a good potential indicator of mixture performance

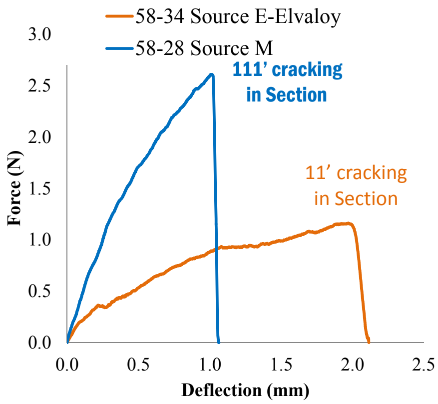
BBR-SENB vs. Mixture Testing



Fenix Test (Mixtures)



BBR-SENB vs. Field Performance



- Two binders from MN County Road 112 had similar G_f but very different u_f.
- Binder with lower u_f performed very poorly in field.
- Combined assessment of G_f and u_f needed.

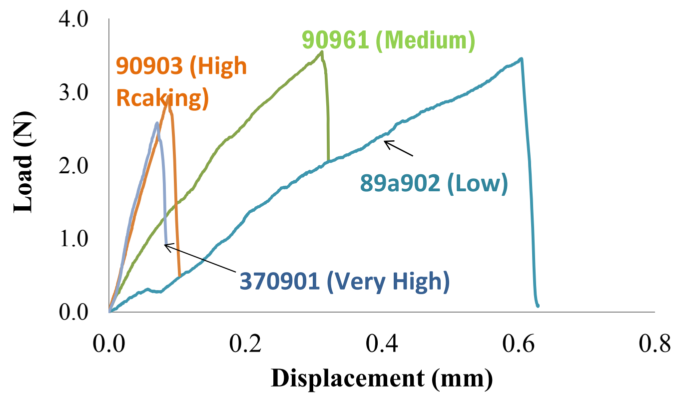
BBR-SENB vs. Field Performance

LTTP Sections

Section ID	No. of Cracks	Performance Grouping	PG	LT PG Grouping	G_f(J/m^2)	u_f (mm)	Testing Temp (°C)	SENB G_f Grouping	SENB u_f Grouping
350902	0	1	PG 64-22	2	34	0.89	-12	1	1
350903	0	1	PG 58-22	2	27.5	0.90	-12	1	1
340901	2	1	PG 64-22	2	24.5	0.60	-18	1	1
370964	0	1	PG 76-22	2	25	0.74	-12	1	1
370963	0	1	PG 64-22	2	27	0.64	-12	1	1
340902	0	1	PG 58-28	1	17.5	0.51	-18	1	1
370962	0	1	PG 76-22	2	14.5	0.44	-12	2	2
340961	11	2	PG 78-28	1	15.5	0.58	-18	2	1
370960	15	2	PG 76-22	2	8.5	0.25	-12	3	3
370901	29	3	PG 64-22	2	9.7	0.34	-12	3	3

BBR-SENB vs. Field Performance

LTTP Sections



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Final Remarks

- Binders of same low PG grade can have significantly different failure energy and deflection at fracture values measured at grade temperature.
  - Binders graded as PG (xx-28) showed a range of 5 to 80 J/m^2 measured at -12°C.
- Fracture properties of asphalt mixtures is highly influenced by fracture properties of binders
- Binders with high strain tolerance (u_f) perform better in field

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Final Remarks

- BBR-SENB is a good compliment to BBR as it can measure damage resistance behavior and strain tolerance of binders in brittle condition.
- BBR-SENB test is a relatively simple test that can be carried out in a time frame similar to current BBR test

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  - National Pooled Fund Study TPF-5(132): "Investigation of Low Temperature Cracking in Asphalt Pavements Phase-II"

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