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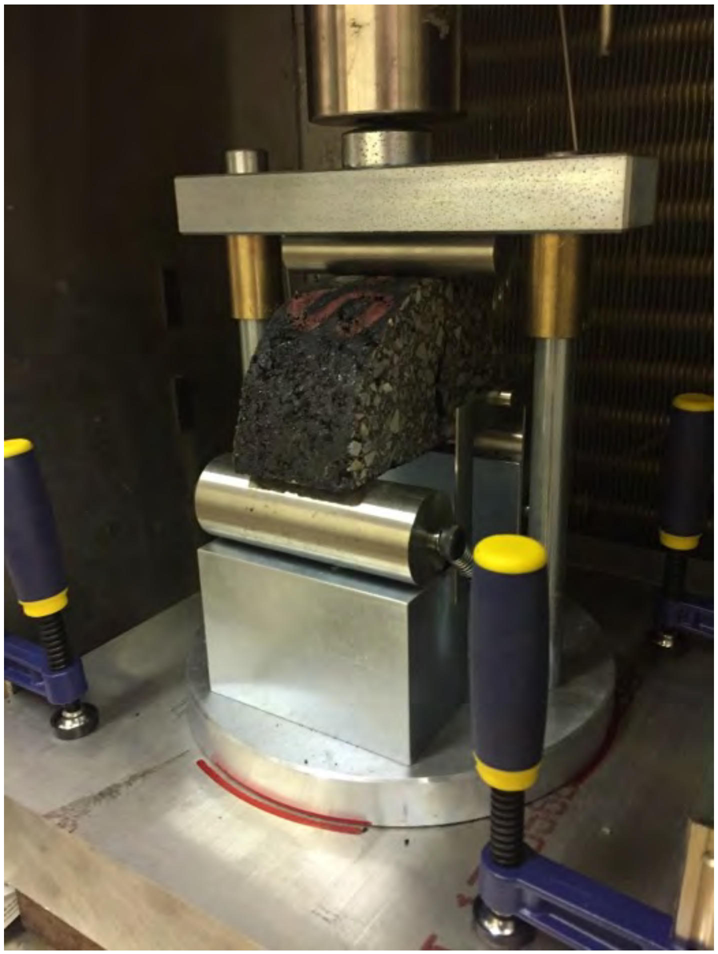
Semi-Circular Bending Beam Test:
Effect of Loading and Mix Parameters



NEAUPG

North East Asphalt User/Producer Group

Annual Meeting, October 19, 2017

Mansour Solaimanian,

Xuan Chen,

Pennsylvania State University

Outline

- A Review of Asphalt Concrete Fatigue Tests
- Semi-Circular Beam (SCB) Test
- PSU SCB Study and Preliminary Results
- Summary

Outline

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Lab Scale Tests

Monotonic Tests

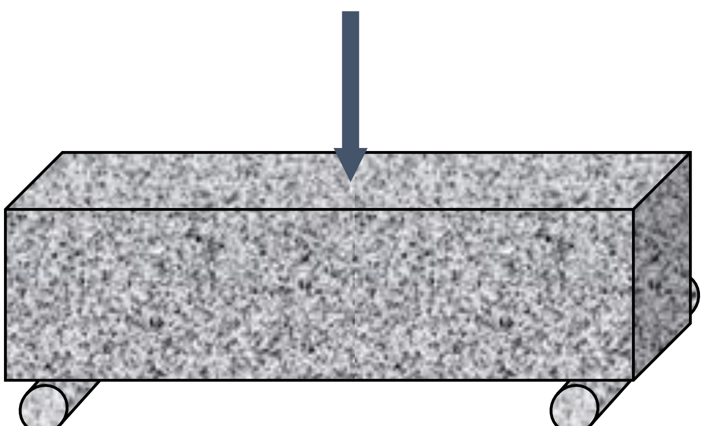
- Indirect Tensile
- Semi-Circular Beam
- Disk-Shaped Compact Tension

Cyclic Tests

- Four Point Bending Beam
- Indirect Tensile
- Uniaxial Push-Pull
- Texas Overlay

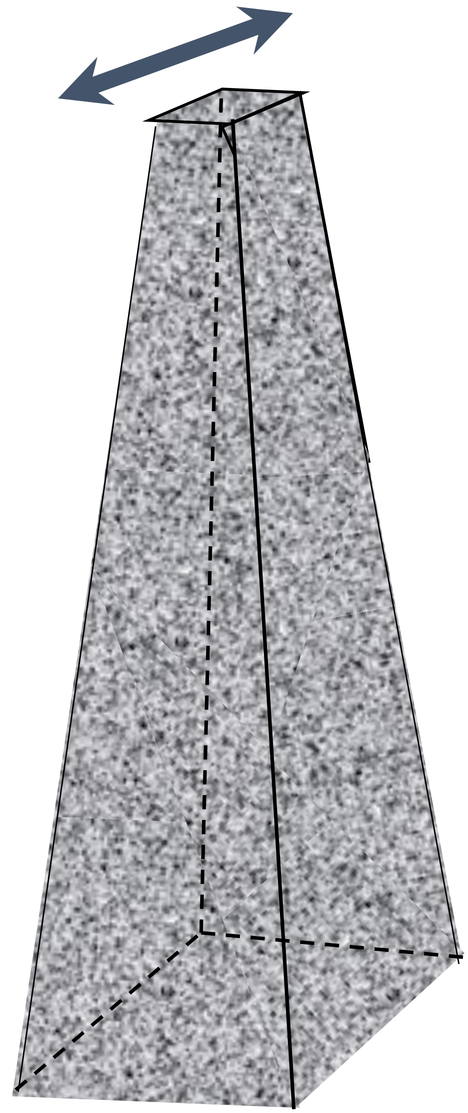
Picture Curtesy: IPC Global, Umass, Penn State

Lab Scale Tests (Cyclic Tests)



Bending Beam

Fatigue/Cantilever Trapezoid



Model Scale Accelerated Tests

- Third Scale Model Mobil Load Simulator (MMLS3)

Test Tracks and Full Scale Tests

NCAT Track

Picture Curtesy: NCAT

…and ALF, HVS, MLS, ….

Penn State Track

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Background on SCB

- Early Work on Rocks (Chong and Kuruppu, 1984)
- Introducing SCB for Asphalt Testing (Molenaar, 2000 & 2002)
- Further Research (Mohammad et al., 2004) - LA
- Further Research – IFIT (Alqadi et al., 2015) - IL
- Implementation in Specs (Mohammad et al., LTRC, 2016)

SCB Test Apply on Rocks (Initial Application)

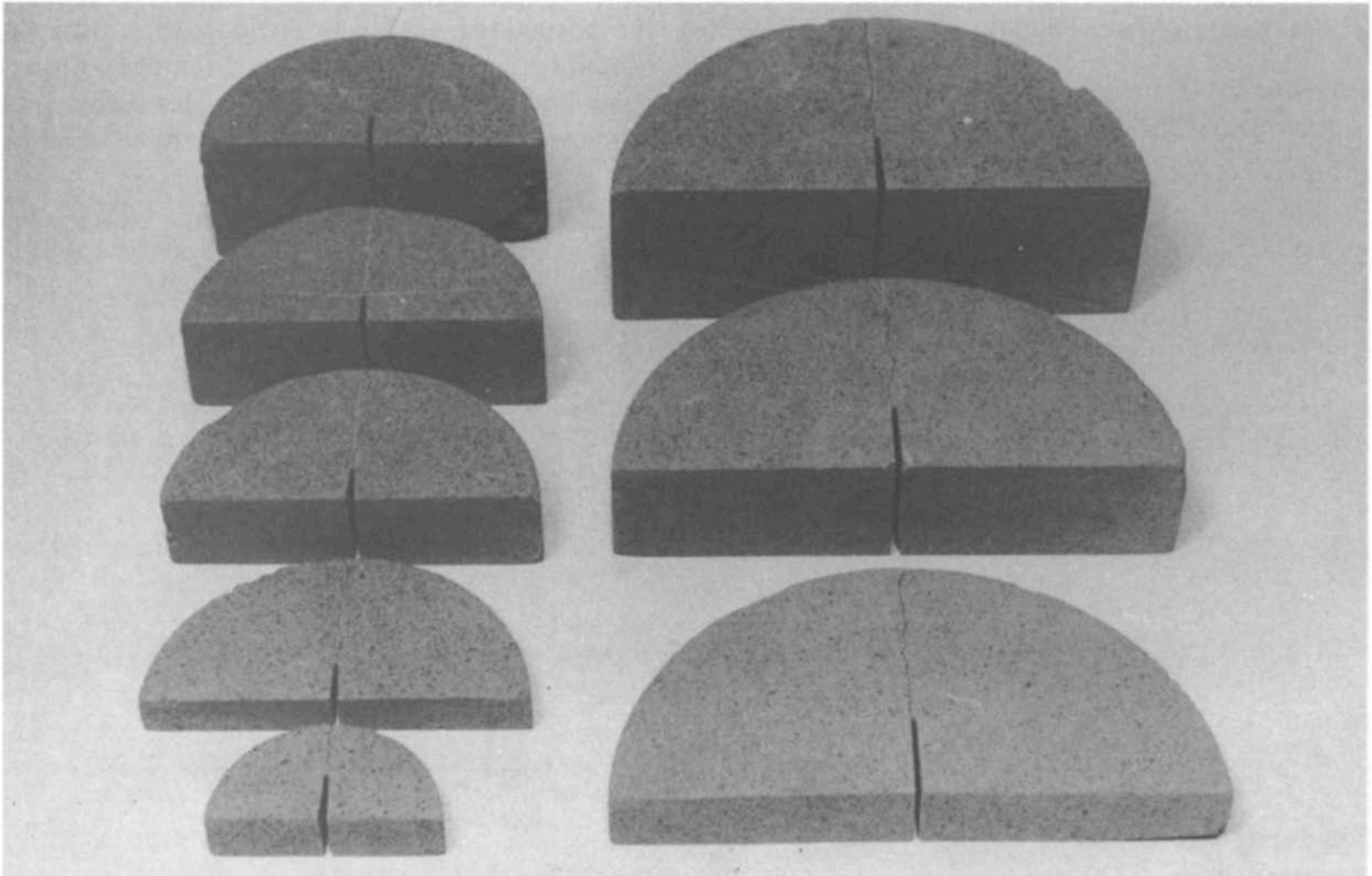


Photo Source: Lim et al. 1984

SCB Test Applied to Rocks

SCB Testing of Granite Rock

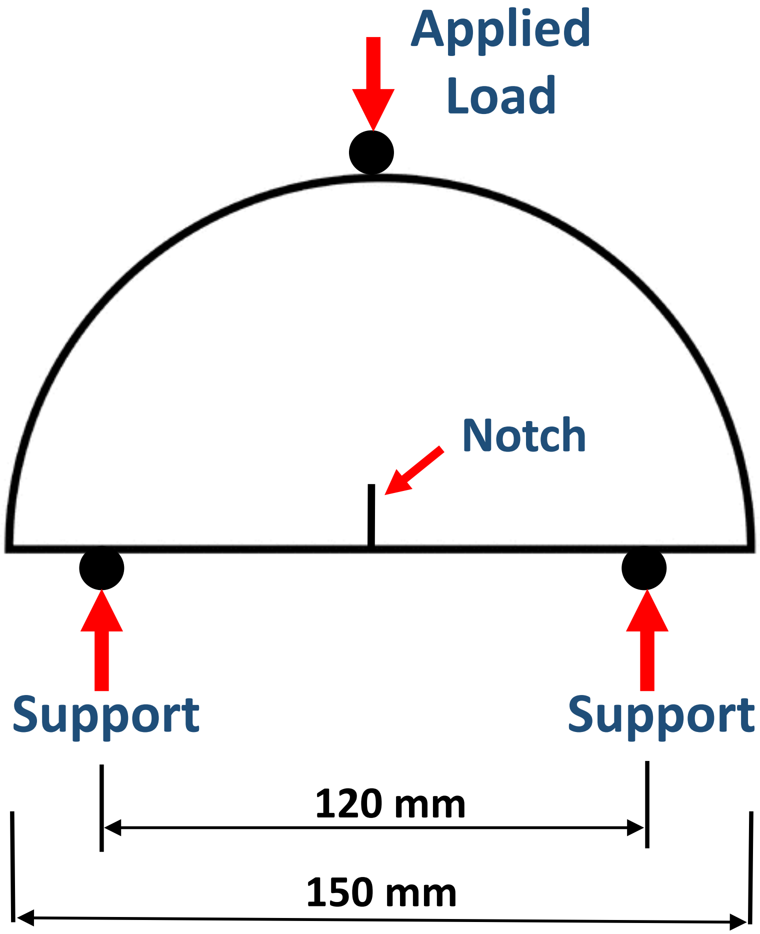
Photo Source: Dynamic Behavior of Materials, Vol.1

SCB Test Applied to Rocks

Compression-Induced Fracture Surfaces and Failure Mechanism

Photo Source: Advances in Materials Science and Engineering Vol. 2014, Article 814504

SCB Test Setup

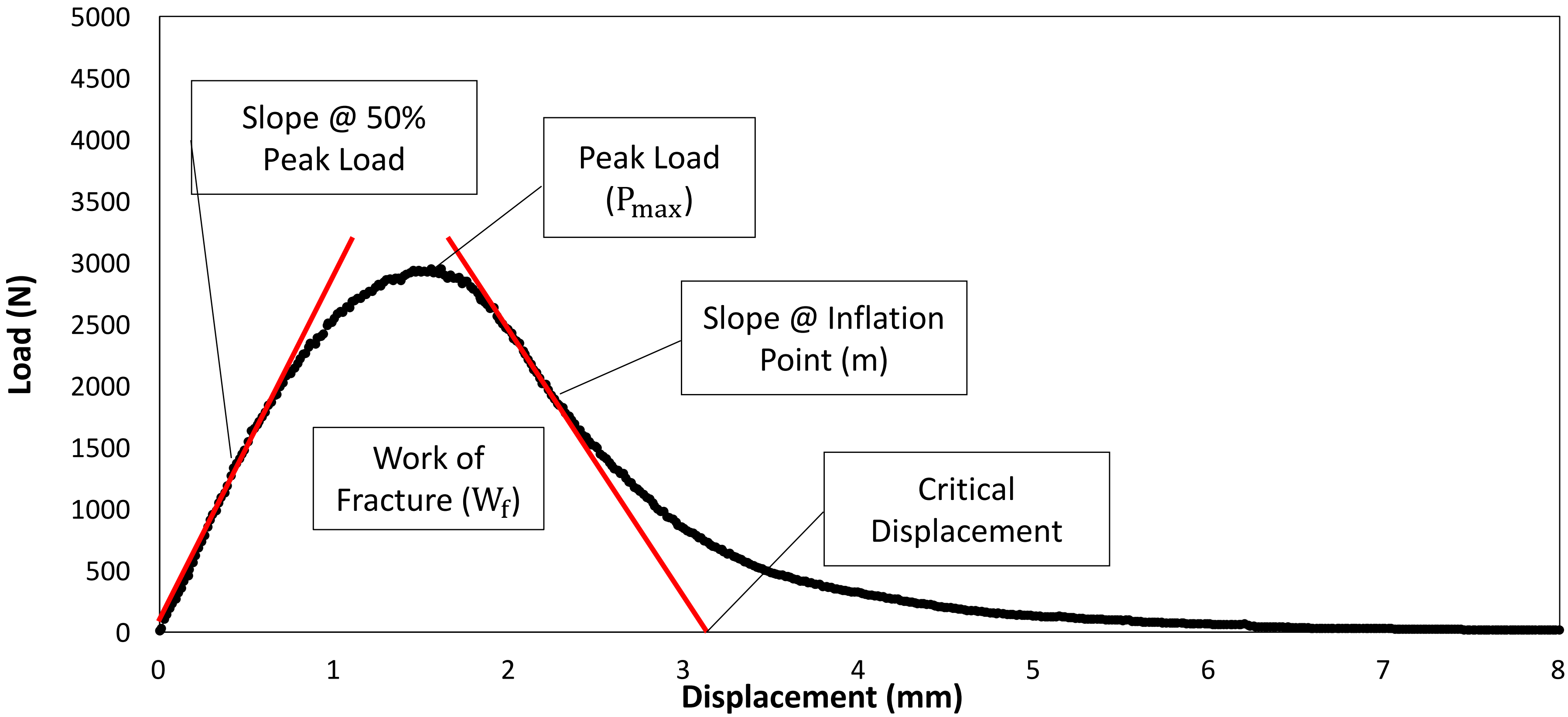


Specimen Thickness: **50** mm

Notch Depth: **15** mm

Notch Width: **1.5** mm

Parameters Used For Evaluation



Fracture Energy

$$G_f = \frac{W_f}{B \cdot L}$$

B: Specimen Thickness

L: Ligament Length

Flexibility Index

$$FI = A \times \frac{G_f}{abs(m)}$$

A: Constant

Stiffness Index

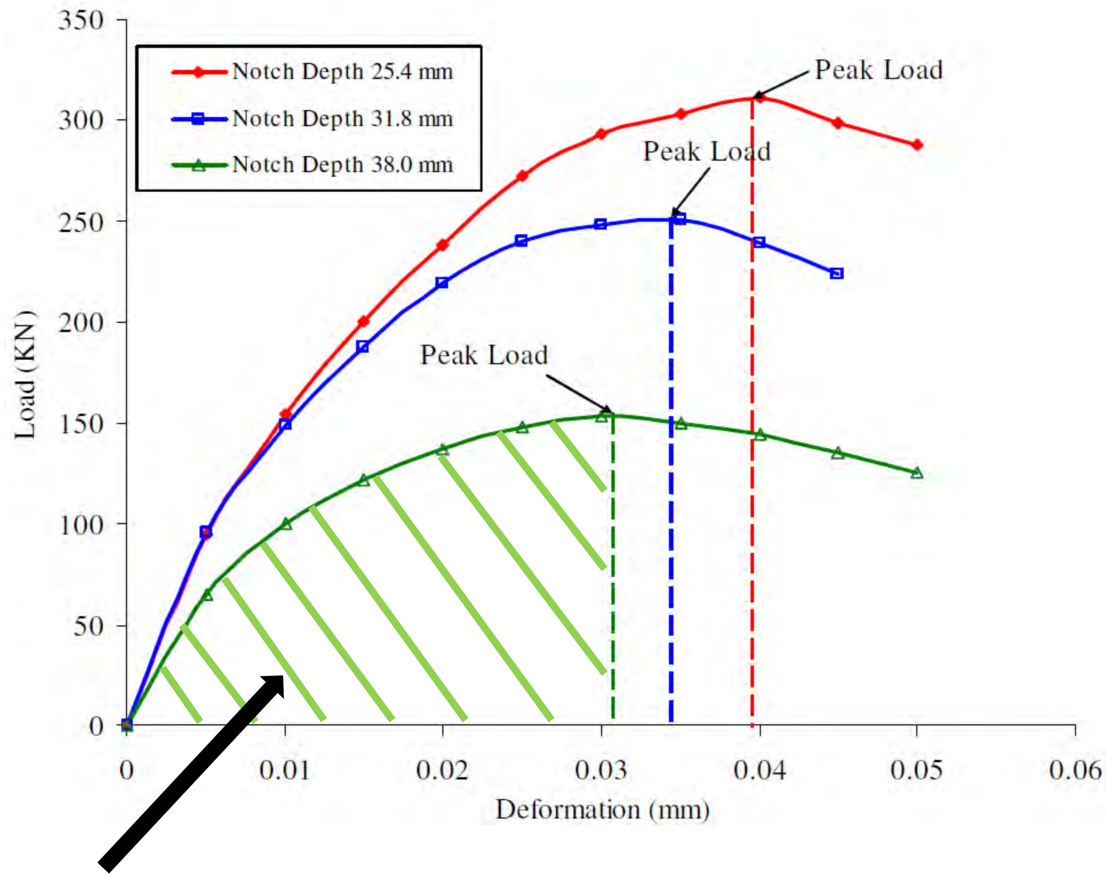
Slope @ 50% Peak Load in Pre-Peak Curve

Louisiana SCB Method (J Integral Concept)

Notch Depth:
25.4 mm

Notch Depth:
31.8 mm

Notch Depth:
38.0 mm



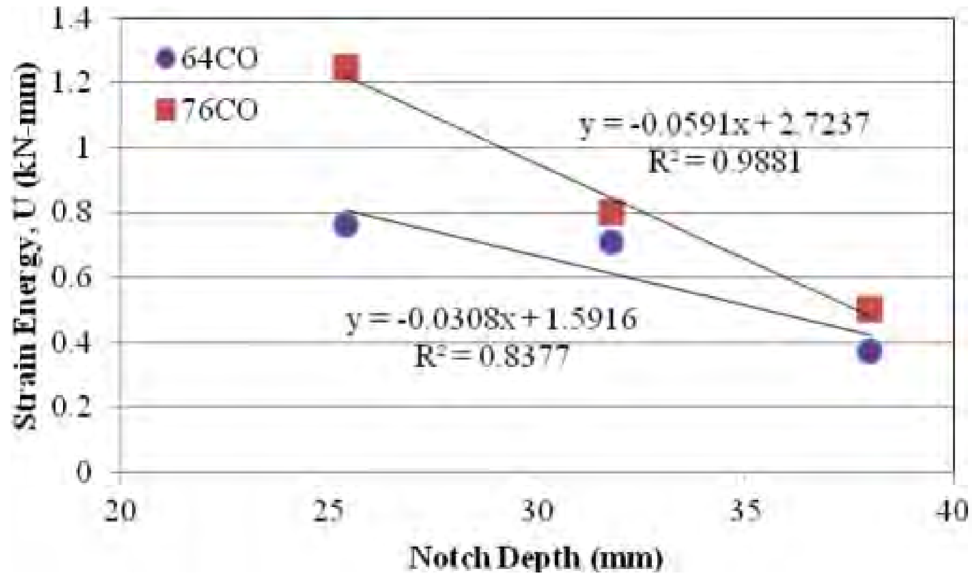
Strain Energy to Failure

Plot Source: Mohammad et al. 2012

Louisiana SCB Method (J Integral Concept)

$$J_c = -\left(\frac{1}{b}\right)\frac{dU}{da} = \left(\frac{U_1}{b_1} - \frac{U_2}{b_2}\right)\frac{1}{a_2 - a_1}$$

Where:
J_c = Critical strain energy release rate, KJ/m^2;
b = Specimen thickness, m;
a = Notch depth, m; and
U = Strain energy to failure, kN-m or KJ.



Plot Source: Elseifi et al. 2012

thickness: **50 mm**
multiple-notch depths (**25.4/31.8/38 mm**)

J_c : slope of the notch depth vs. strain energy plot

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Advantages of SCB Test

- Specimen Easily Prepared Using SGC or Field Cores
- Four Specimens from One Compacted Mix
- Easy to Perform and Simple to Analyze
- Possible To Perform Test Using Marshall-Type Stability Tester

- Good Correlation to Field Performance??

Current Issues

- What Test Parameters to Use?
  - **What test temperature?**
  - **How fast to test?**
  - **What pass/fail criteria?**
  - **Sensitivity to Mix Parameters**
  - **Short-term aged or long-term aged mix?**
  - **Test repeatability and reproducibility?**

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INVESTIGATE

- Effect of **Test Temperature**
- Effect of **Loading Rate Range**
- Effect of **Aging (short term vs long term)**
- Effect of **Binder Content and Binder Stiffness**
- Effect of **Voids**

Test Temperature

I-FIT Protocol: Fixed Temperature for All Mixes, i.e. 25°C

Proposed Protocol: Using ***Effective Temperature*** Concept

NCHRP 704: A Performance-Related Specification for HMA

$$T_{\text{eff}} = -13.995 - 2.332(\text{Freq})^{0.5} + 1.006(\text{MAAT}) + 0.876(\sigma\text{MMAT}) - 1.186(\text{wind}) + 0.549(\text{sunshine}) + 0.071(\text{rain})$$

Harrisburgh is around **18**°C

Freq: Loading Frequency, Hz;
MAAT: Mean Annual Air Temperature, °F;
***σ*MAAT**: Standard Deviation of the Mean Monthly Air Temperature;
Rain: Annual Cumulative Rainfall Depth, inches;
Sunshine: Mean Annual Percentage Sunshine, %; and
Wind: Mean Annual Wind Speed, Mph.

Test Loading Rate

Current Protocol:

- 50 mm/min (too fast, not enough data points, higher COV)
- 0.5 mm/min (too slow, affected by creep)

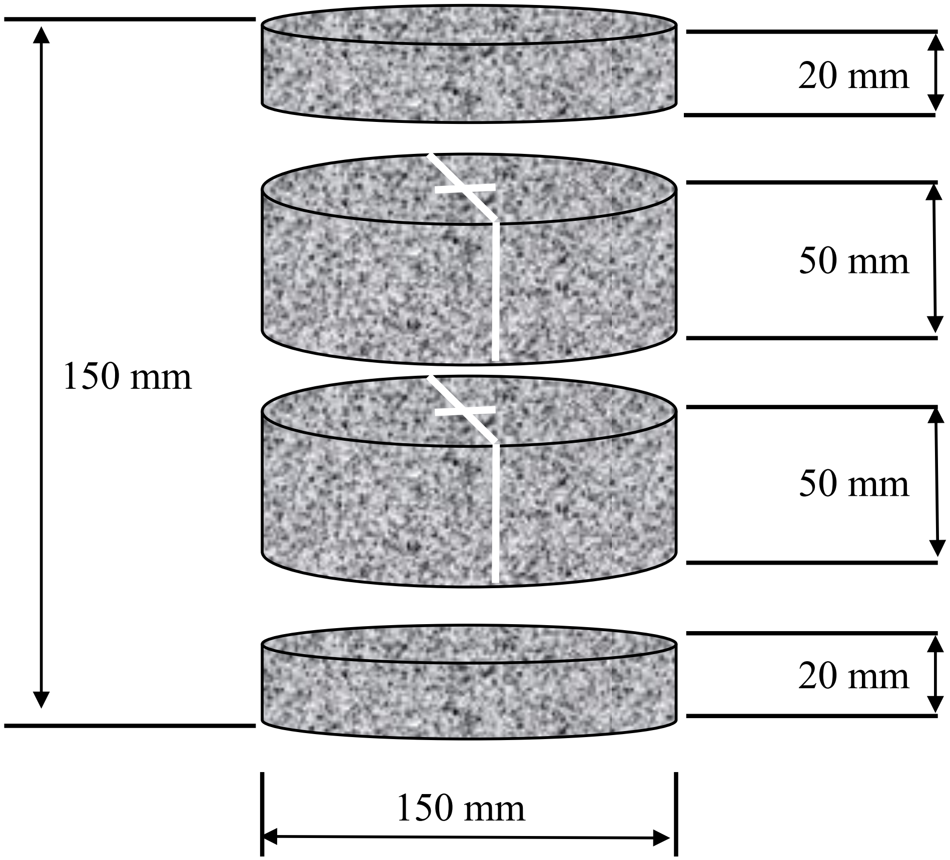
Findings:

- Loading rate between **5 to 20 mm/min** will minimize the effect of creep, and provide a reasonable range for FI for long term aged mix.

Specimen Preparation

- SGC Specimen or Field Cores
- Cut to Ensure Minimum AV Gradient
- Obtain Density
- Condition Specimens at Test Temperature
- Conduct Test

It Takes **3** days from Mixing to Obtain Results



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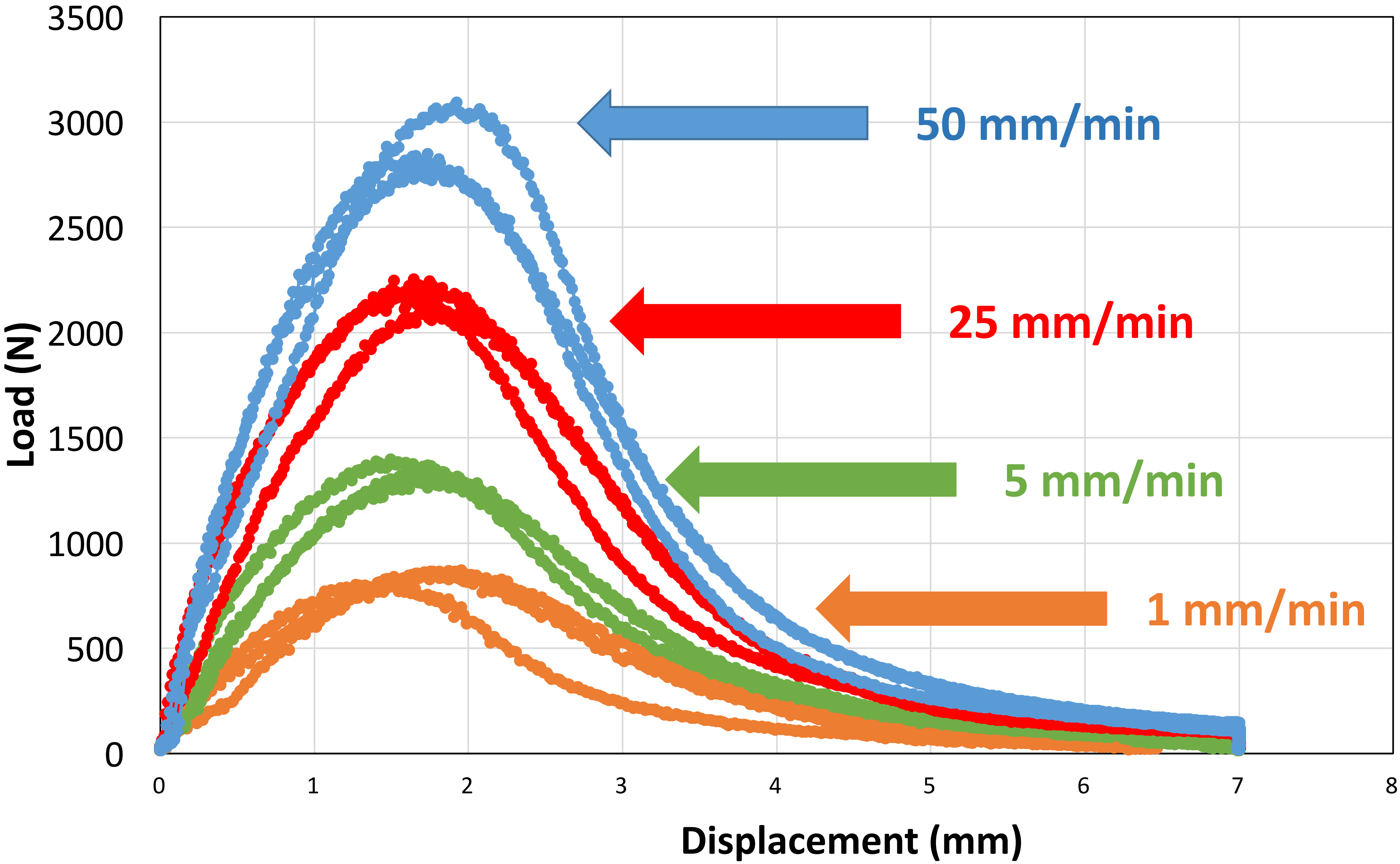
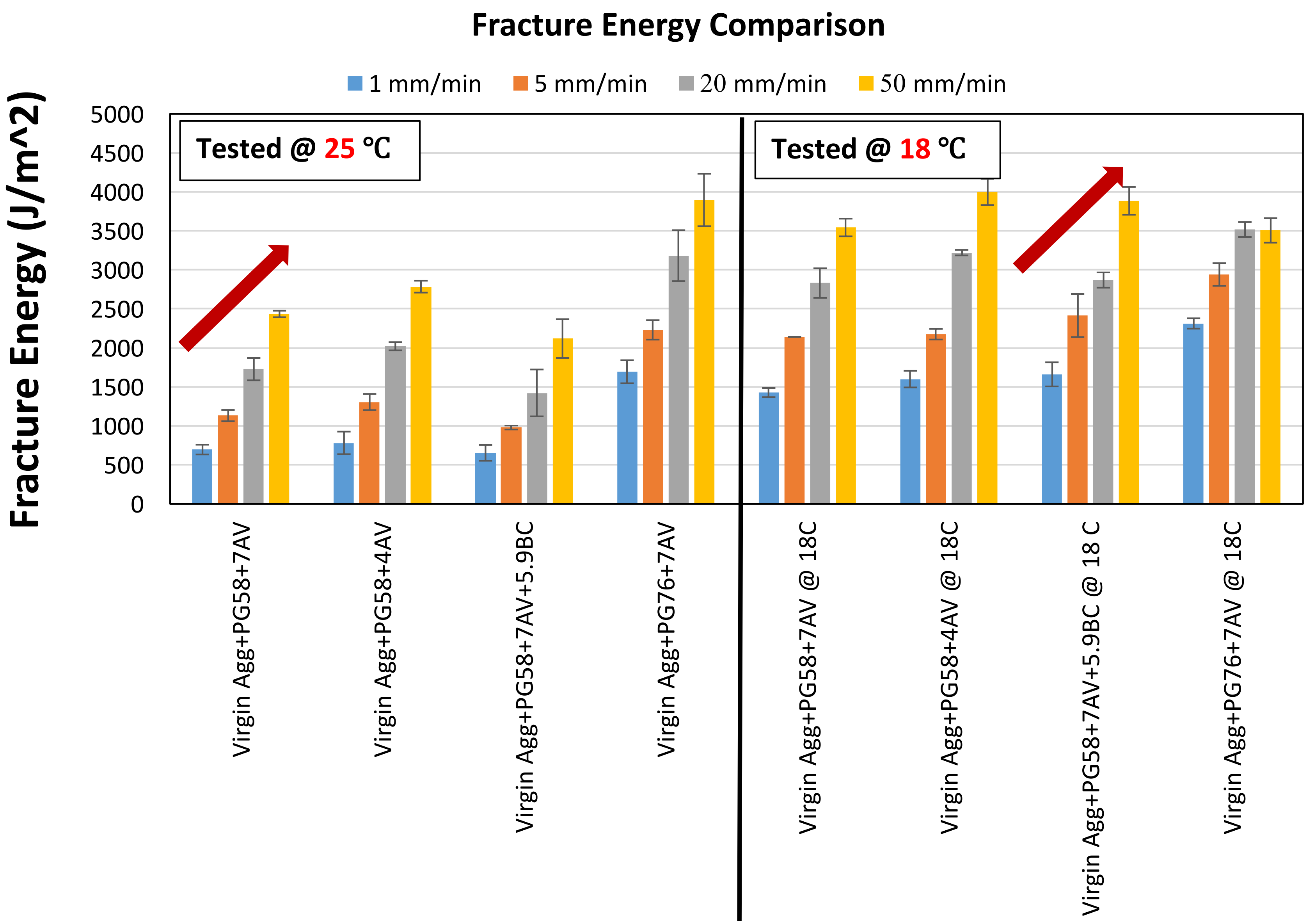
Specimens After Cutting
Ready for Testing

Specimens Before (L) / After (R) Testing

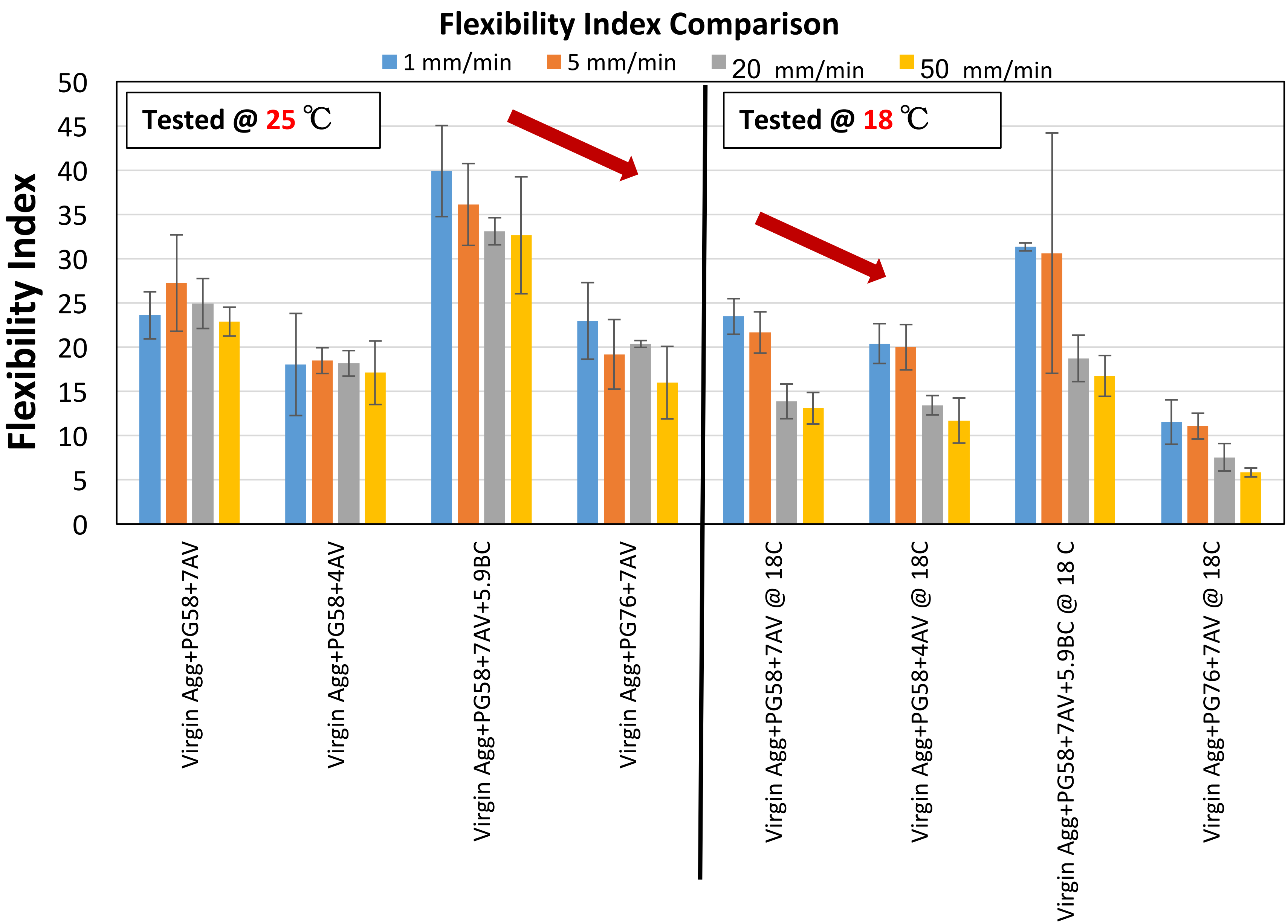
Typical Load vs Displacement Curves
3 Replicates, PG 58-28, 25°C



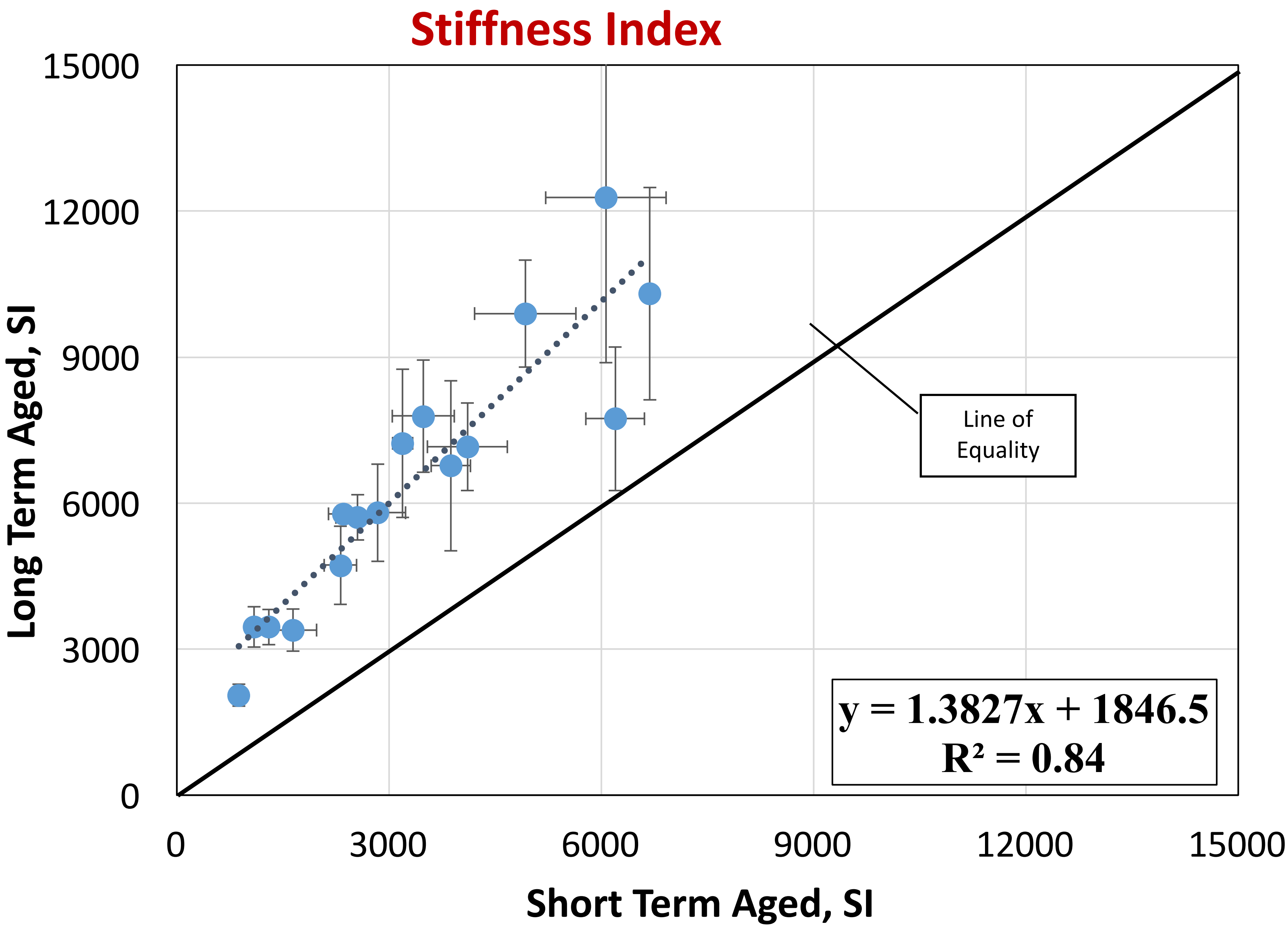
Temperature/Loading Rate Effects



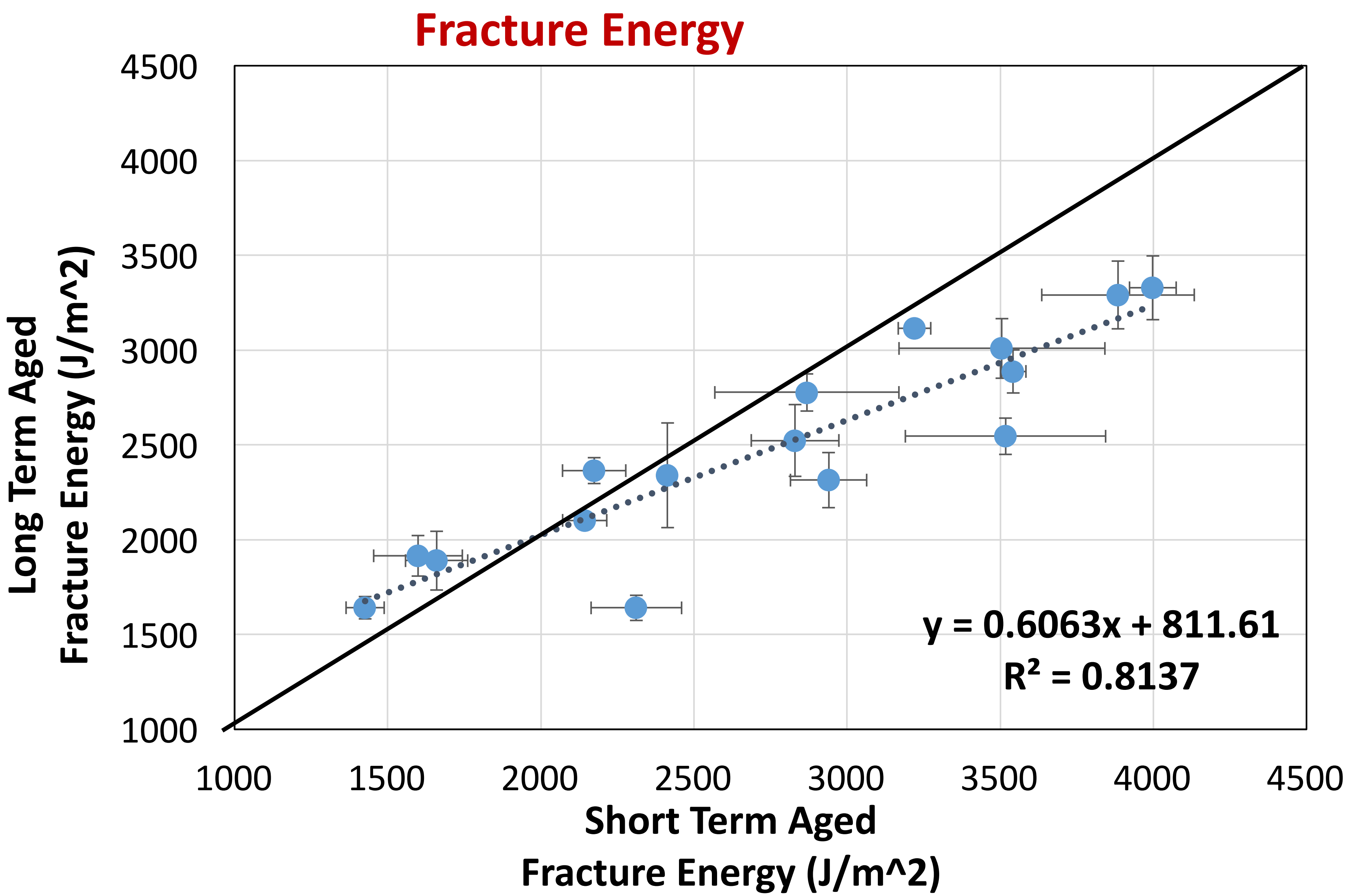
Temperature/Loading Rate Effects



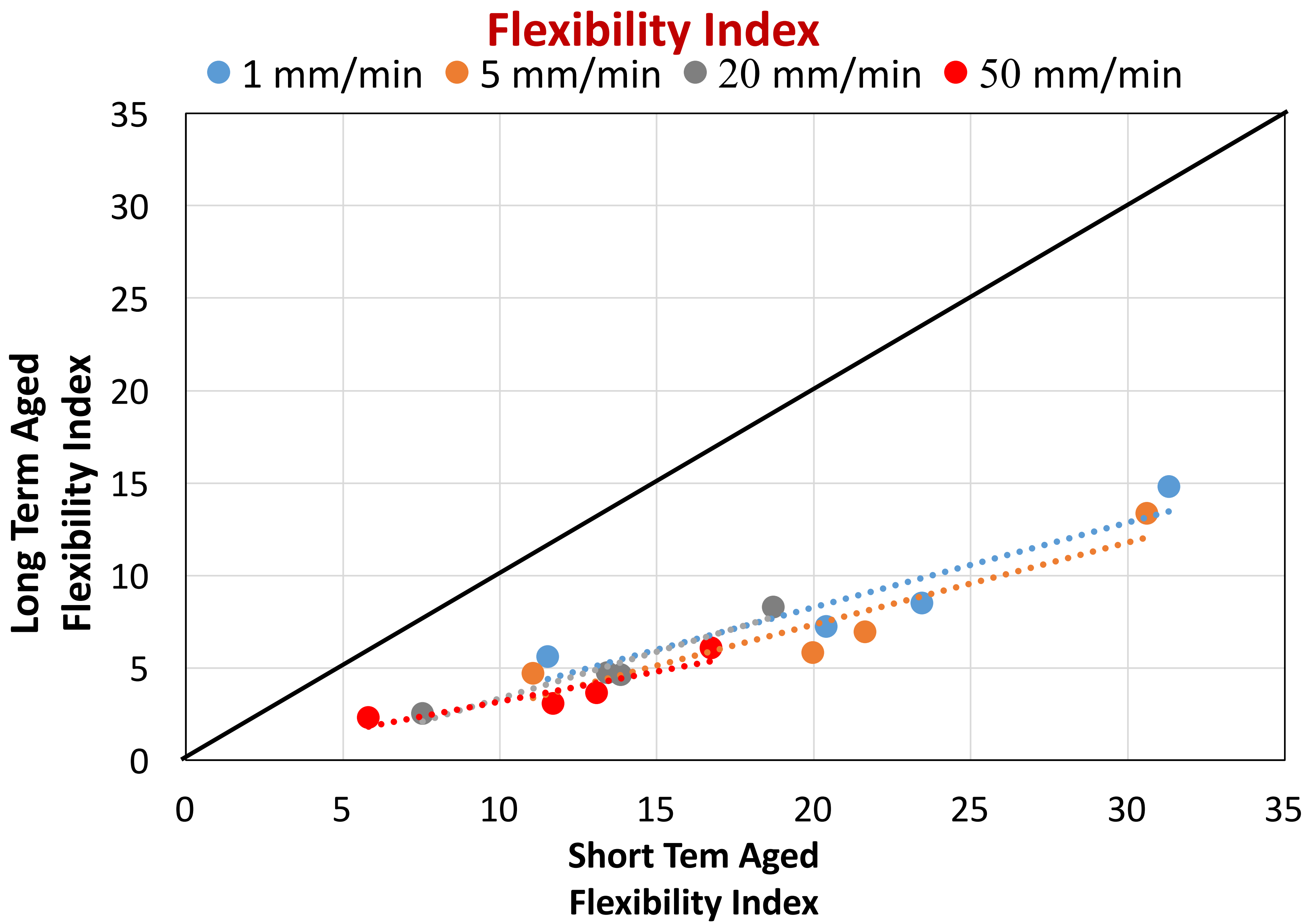
Stiffness Indices of Aged Mixes



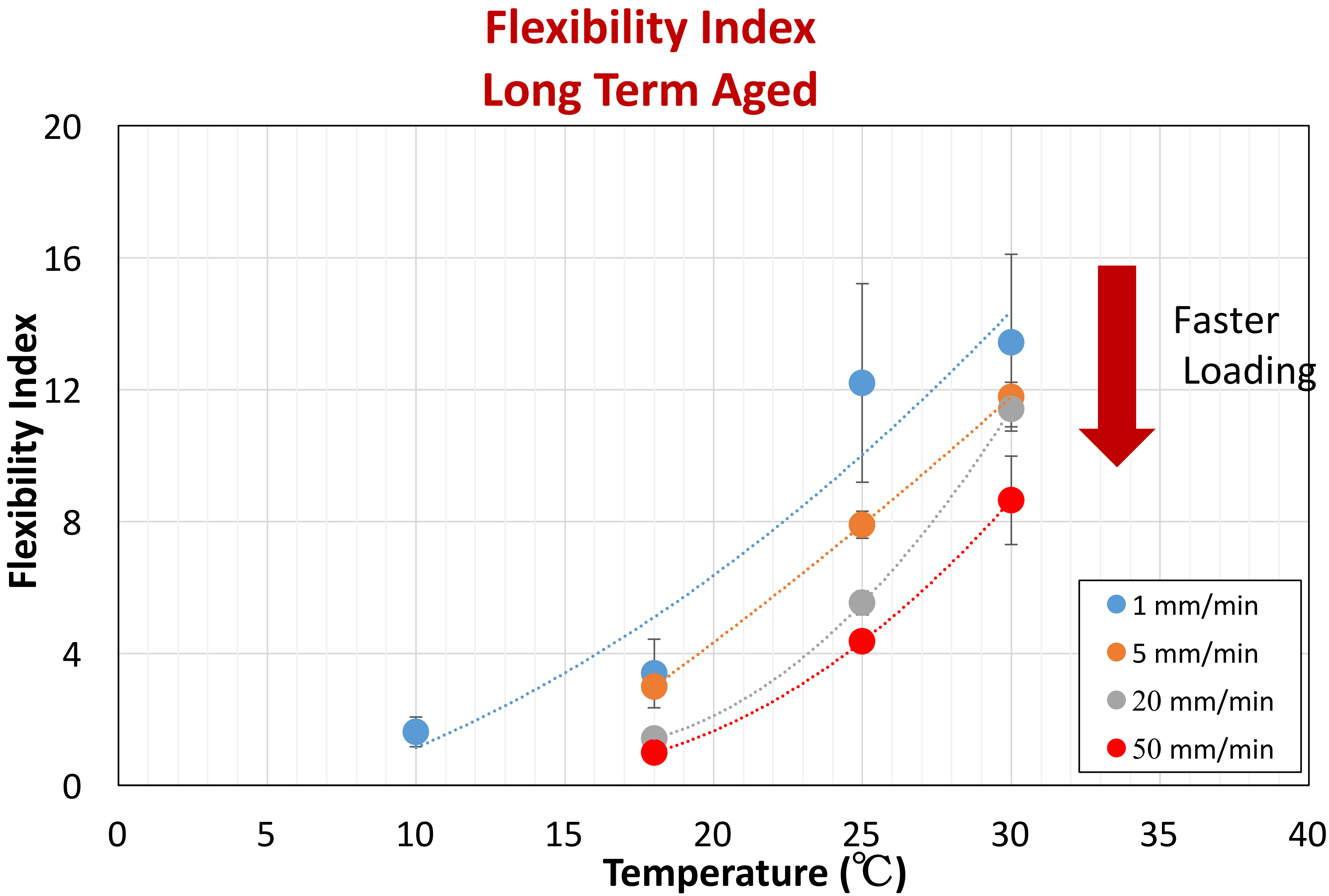
Facture Energy of Aged Mixes



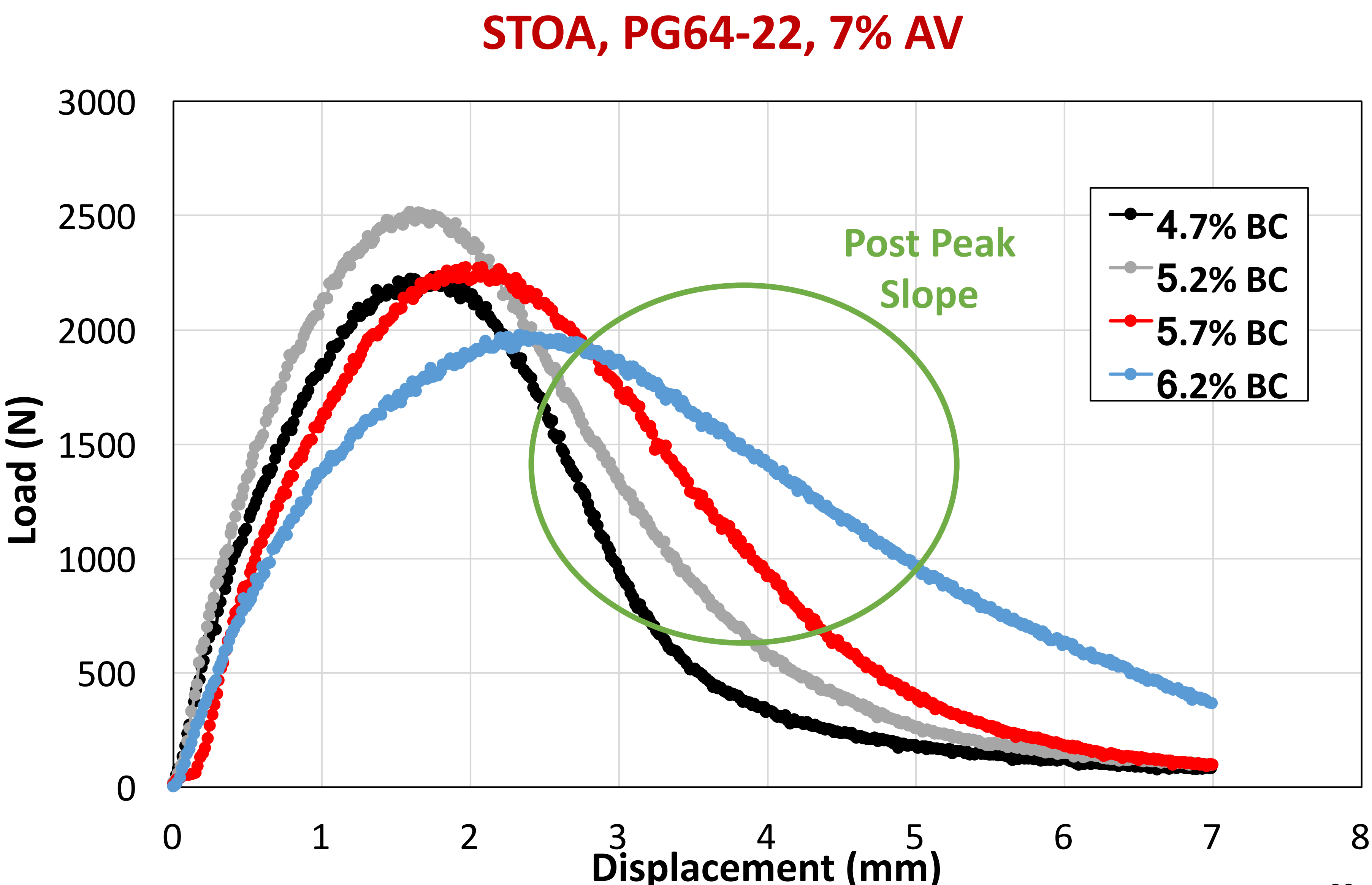
FI of Aged Mixes



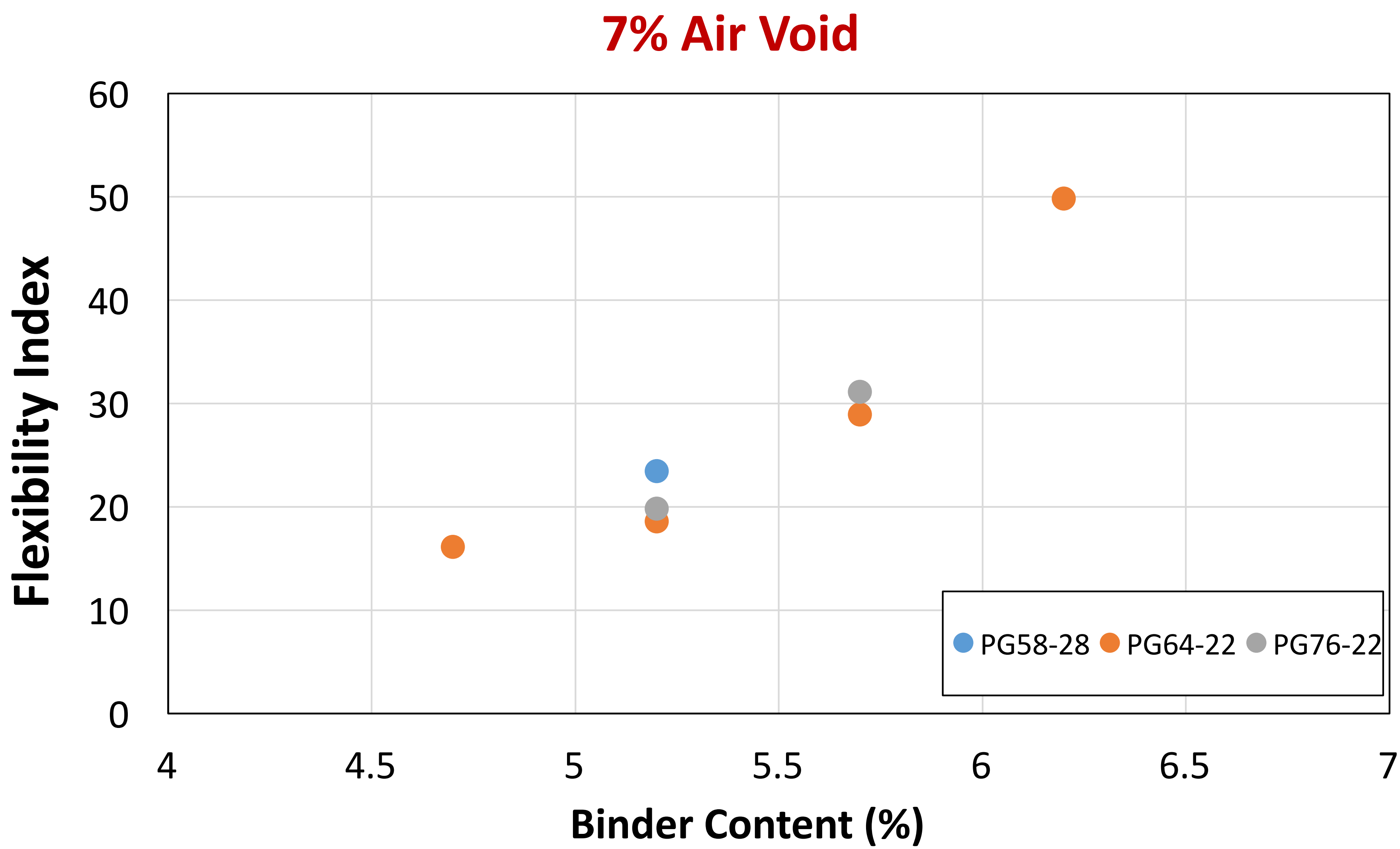
Temperature/Loading Rate Sweep in SCB



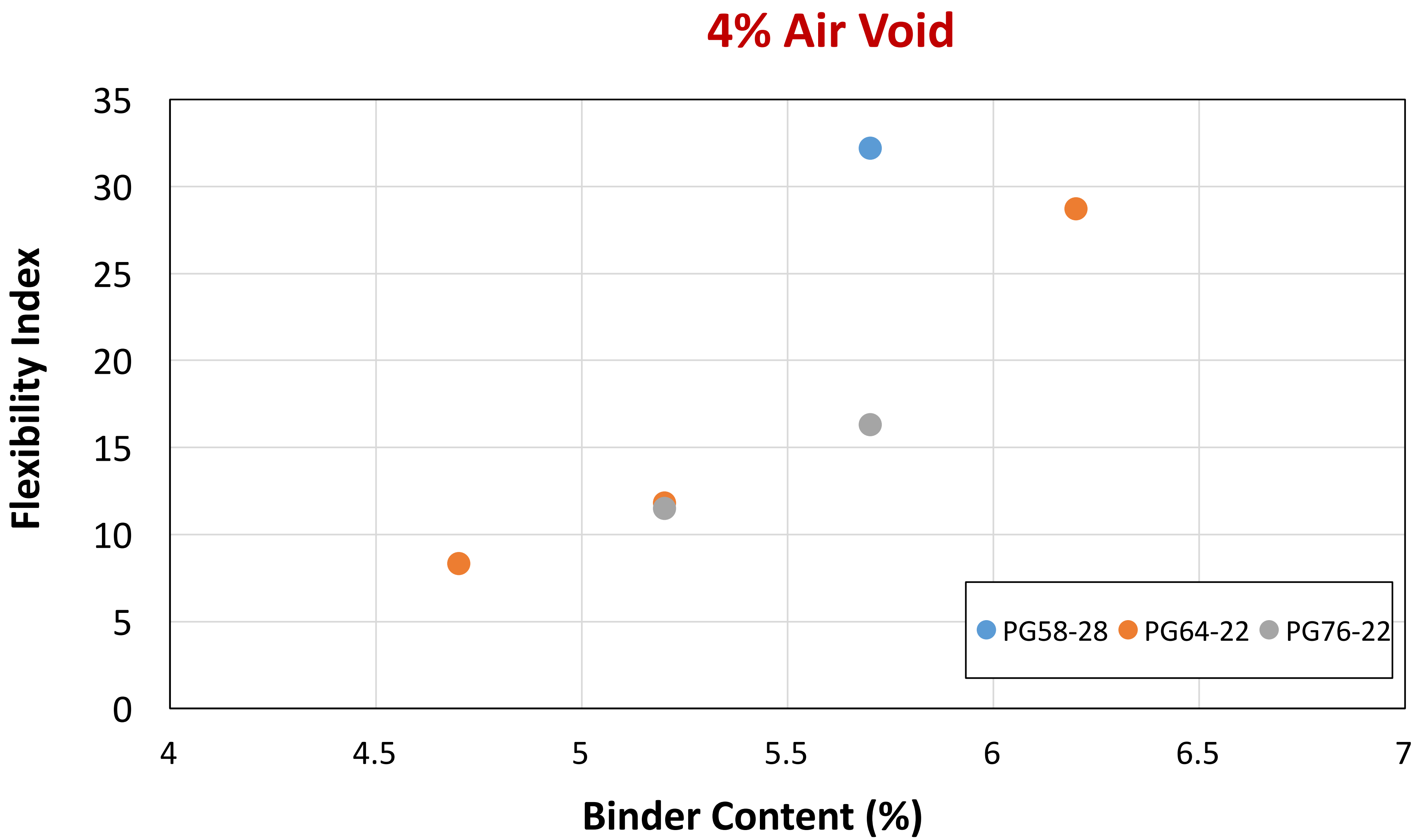
Effect of Binder Content



Effect of Binder Content



Effect of Binder Content



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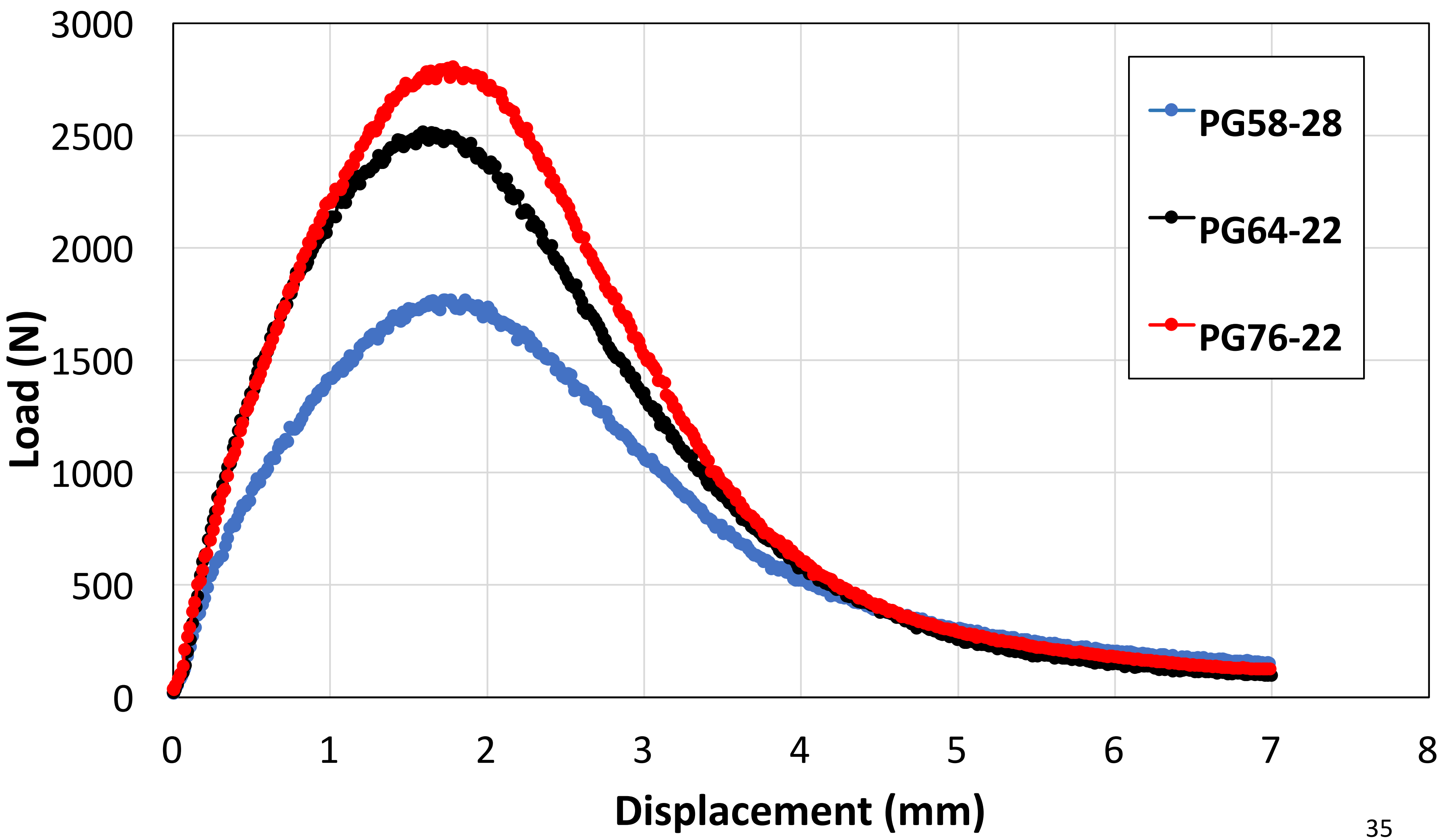
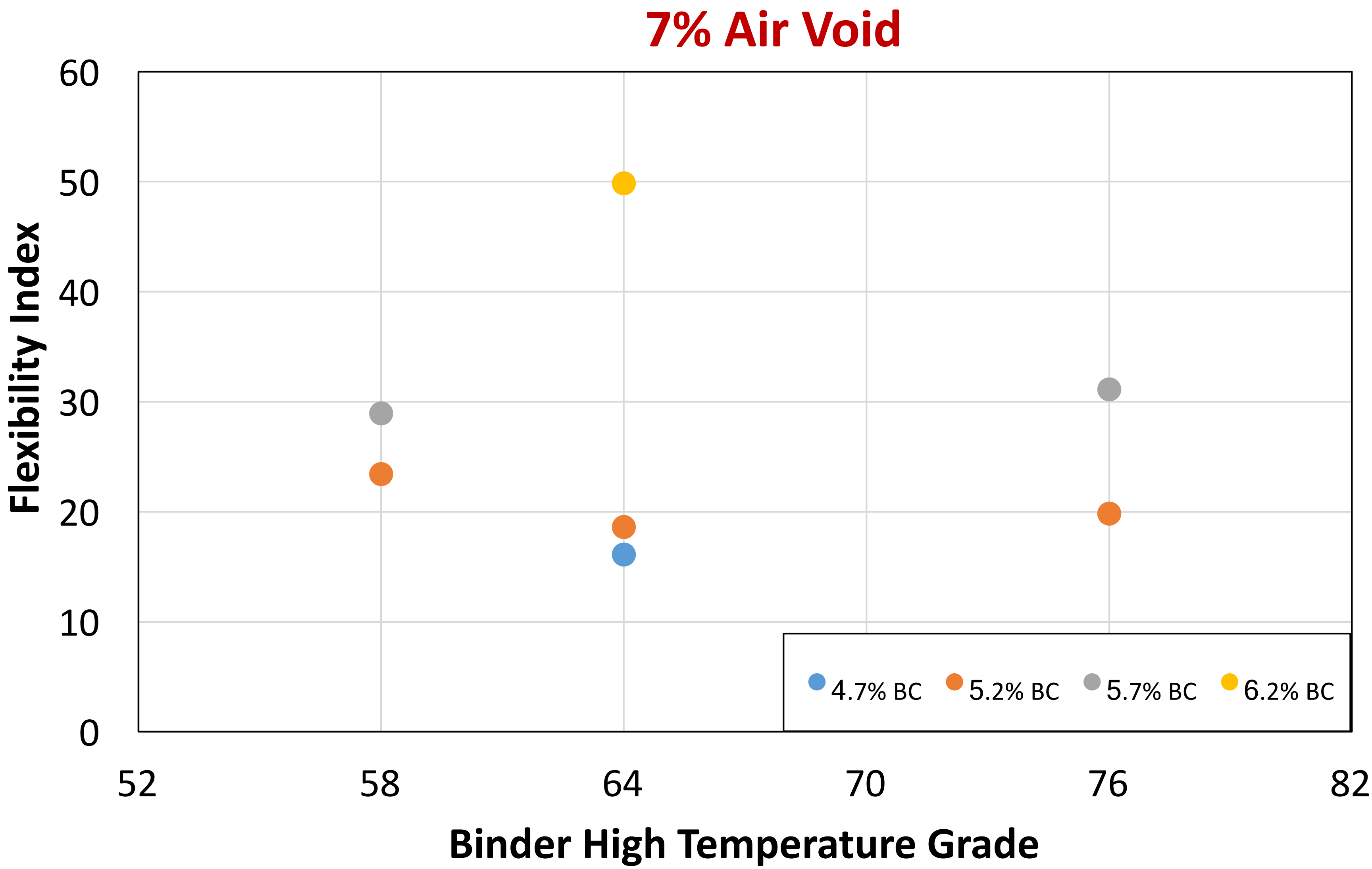
Effect of Binder Grade (Stiffness)

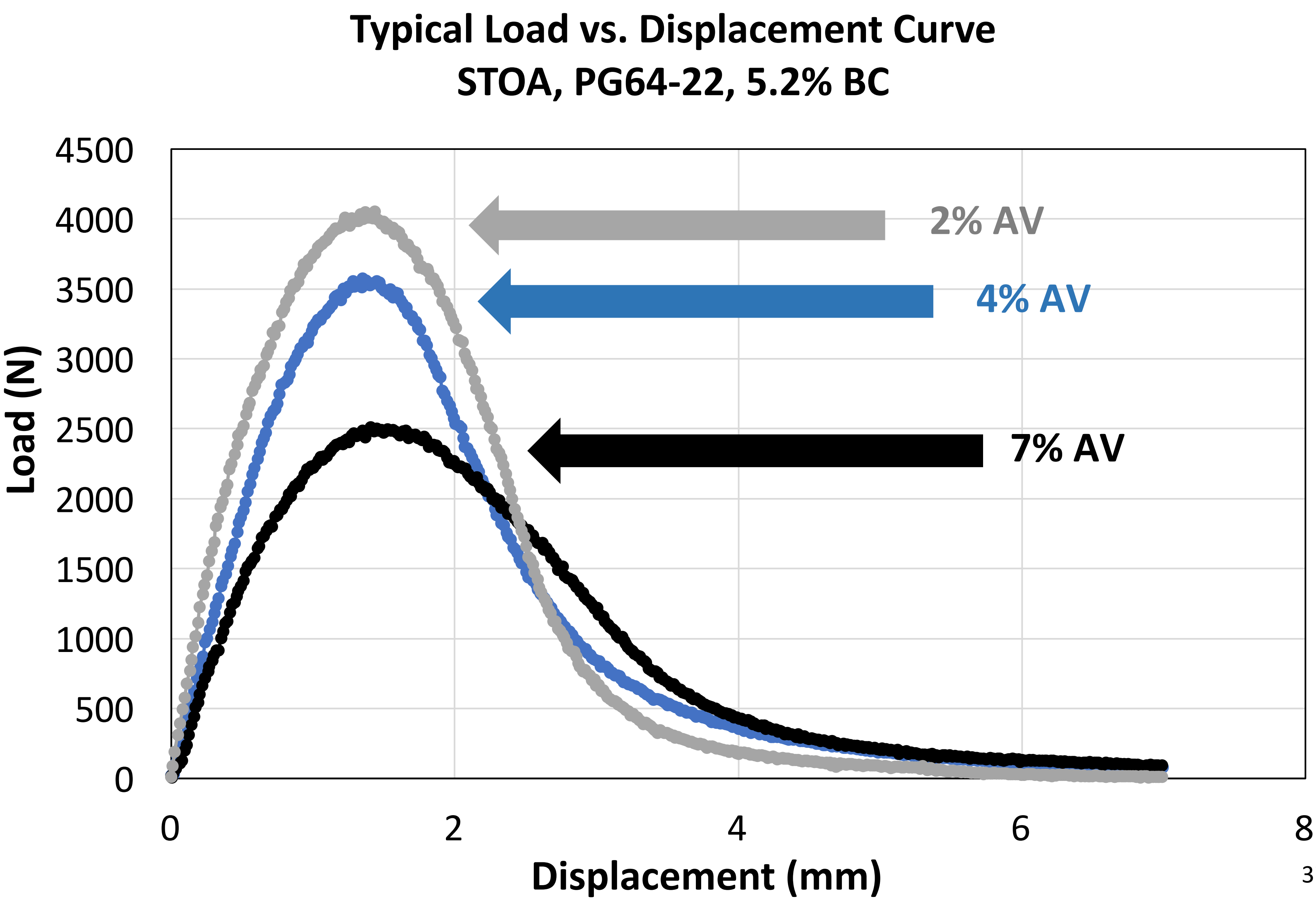
STOA, 7% AV, 5.2% BC



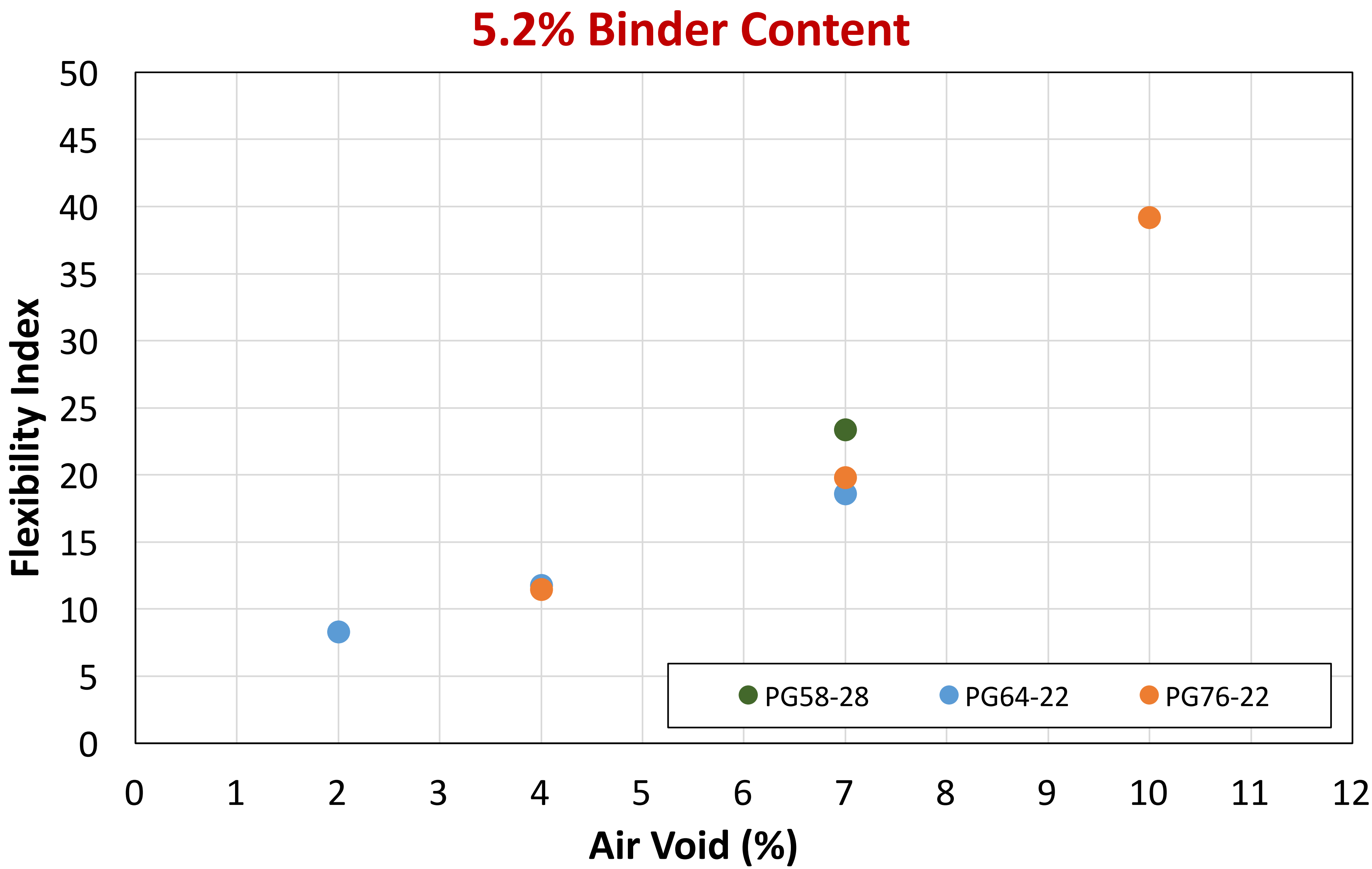
Effect of Binder Grade (Stiffness)



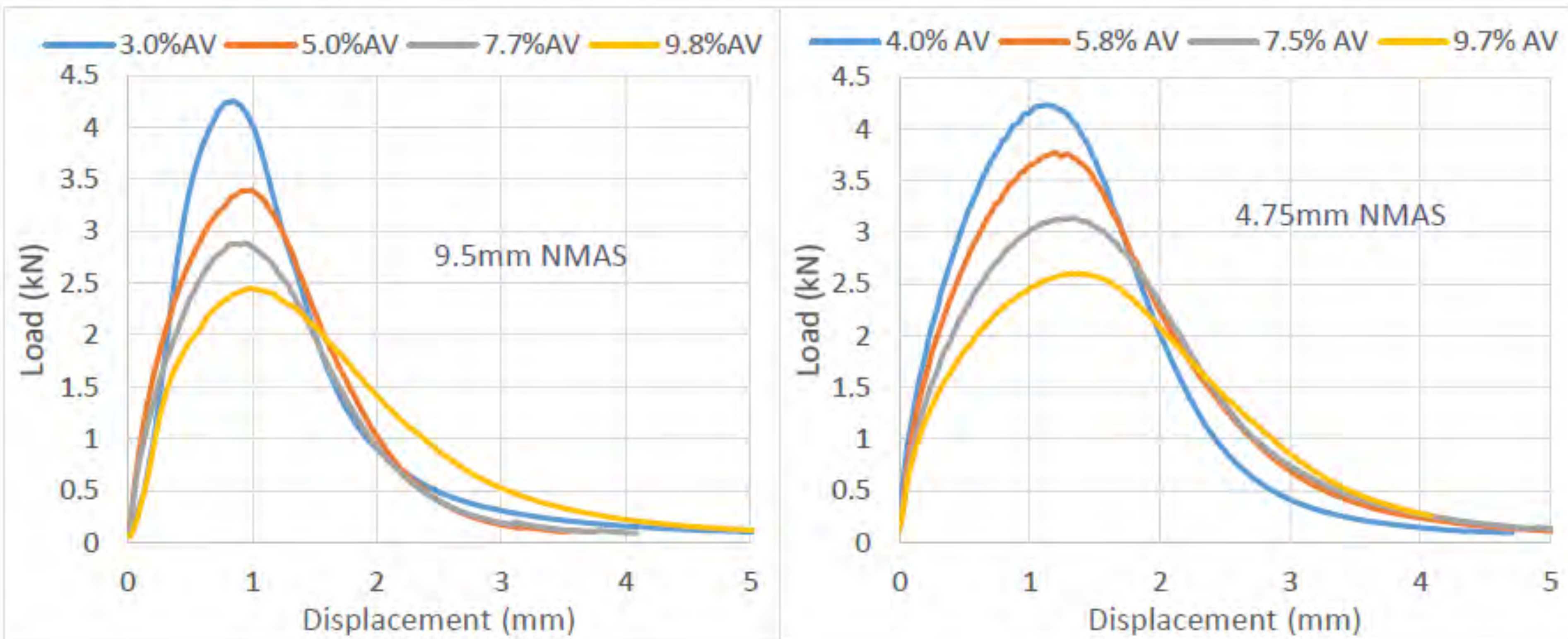
Effect of Air Void



Effect of Air Void

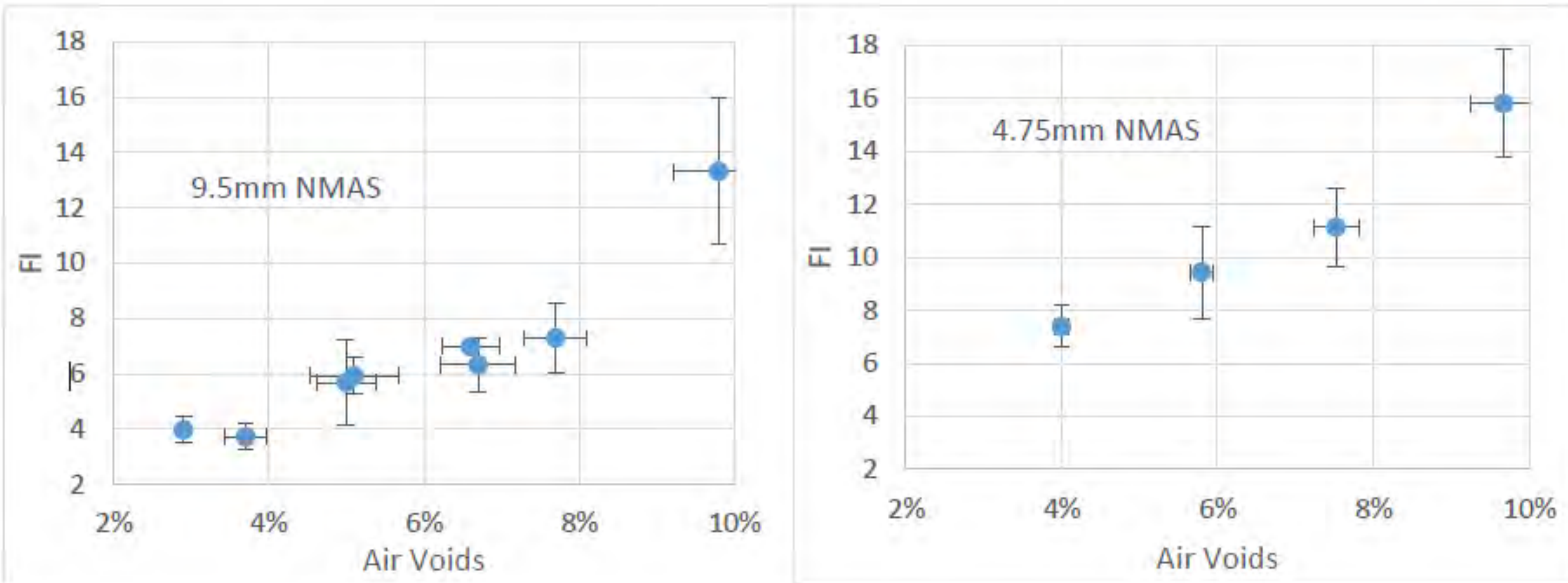


The Effect of Air Void Reported by UIUC



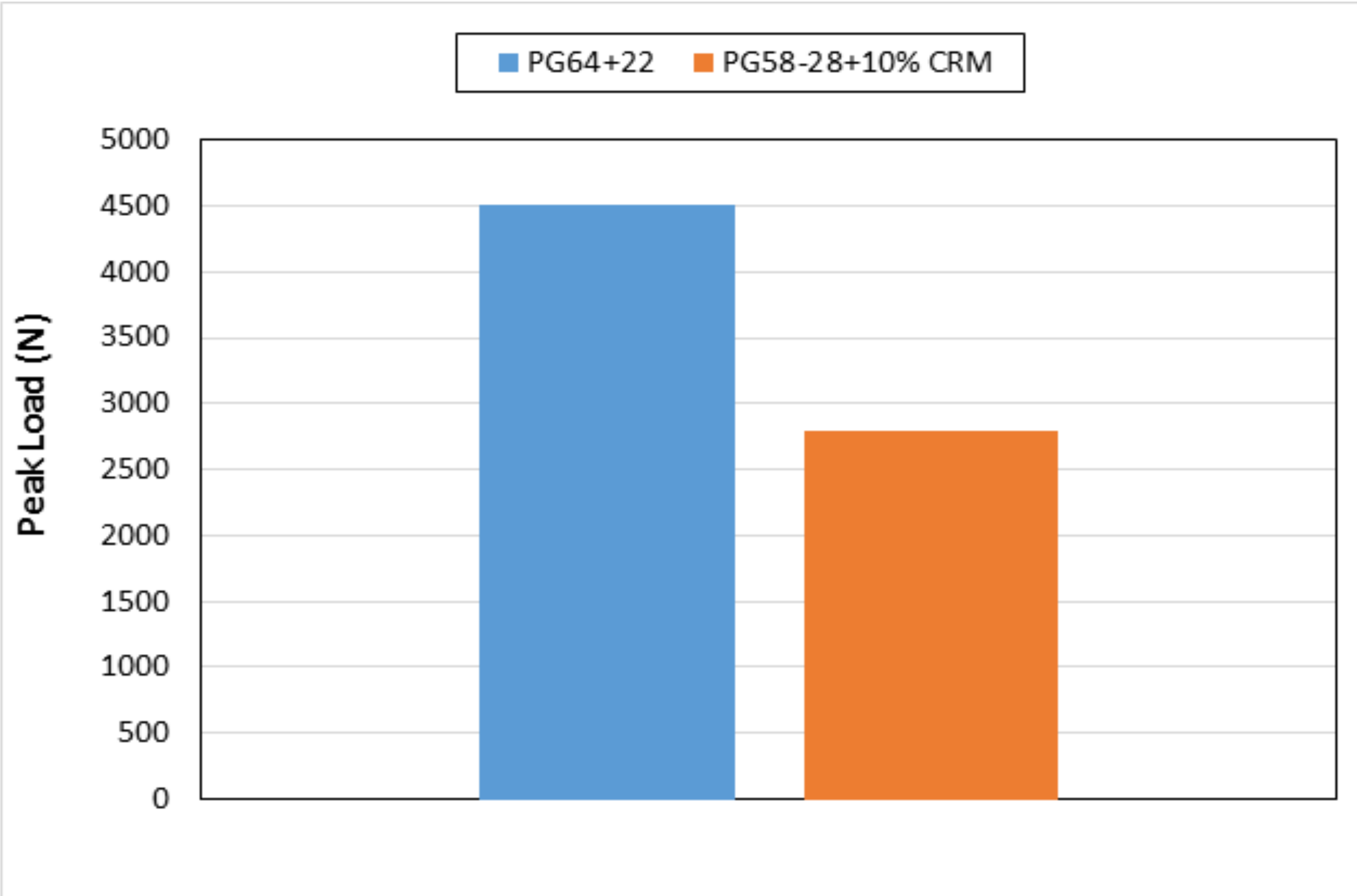
Source: Maxwell 2016

The Effect of Air Void Reported by UIUC

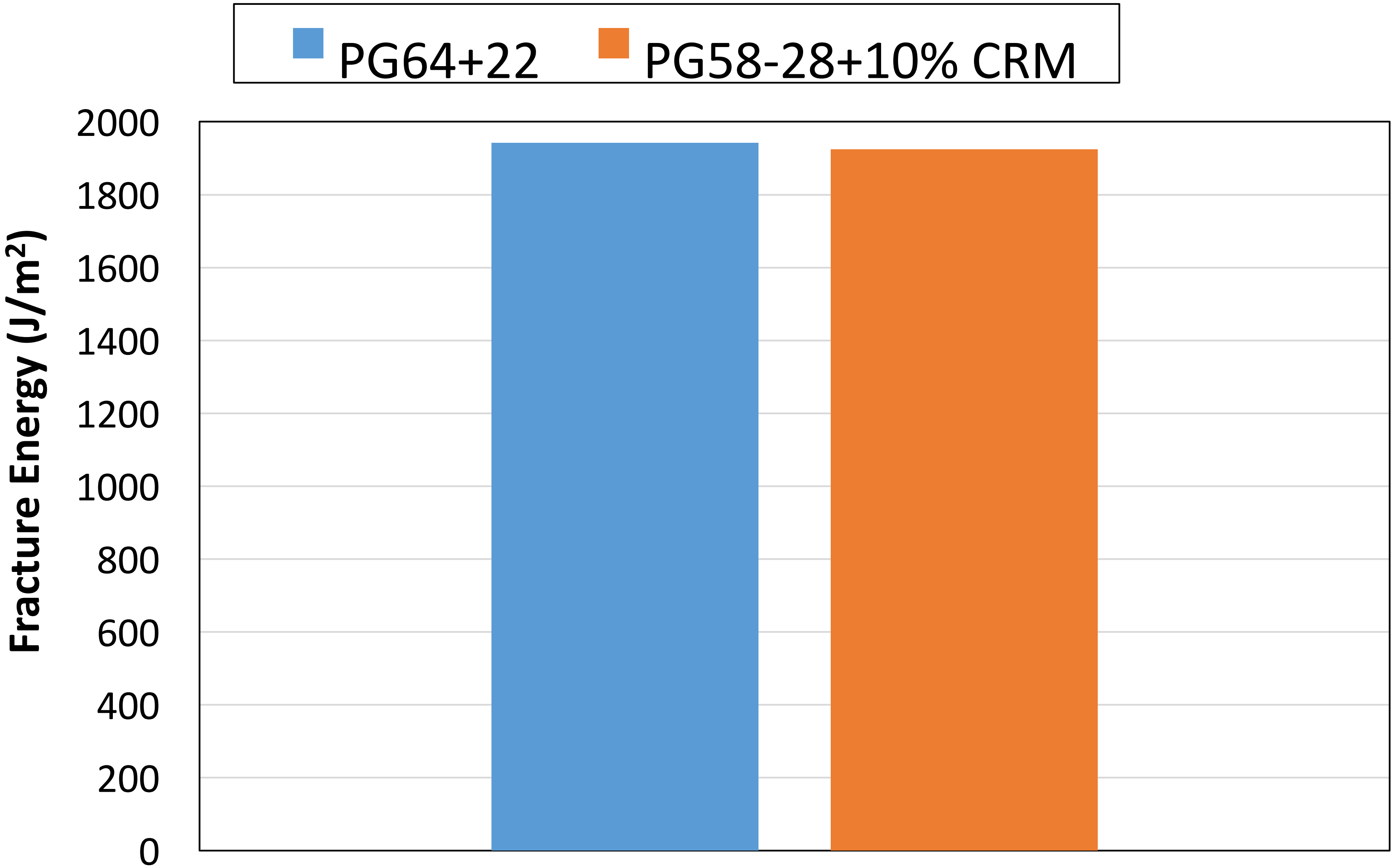


Source: Maxwell 2016

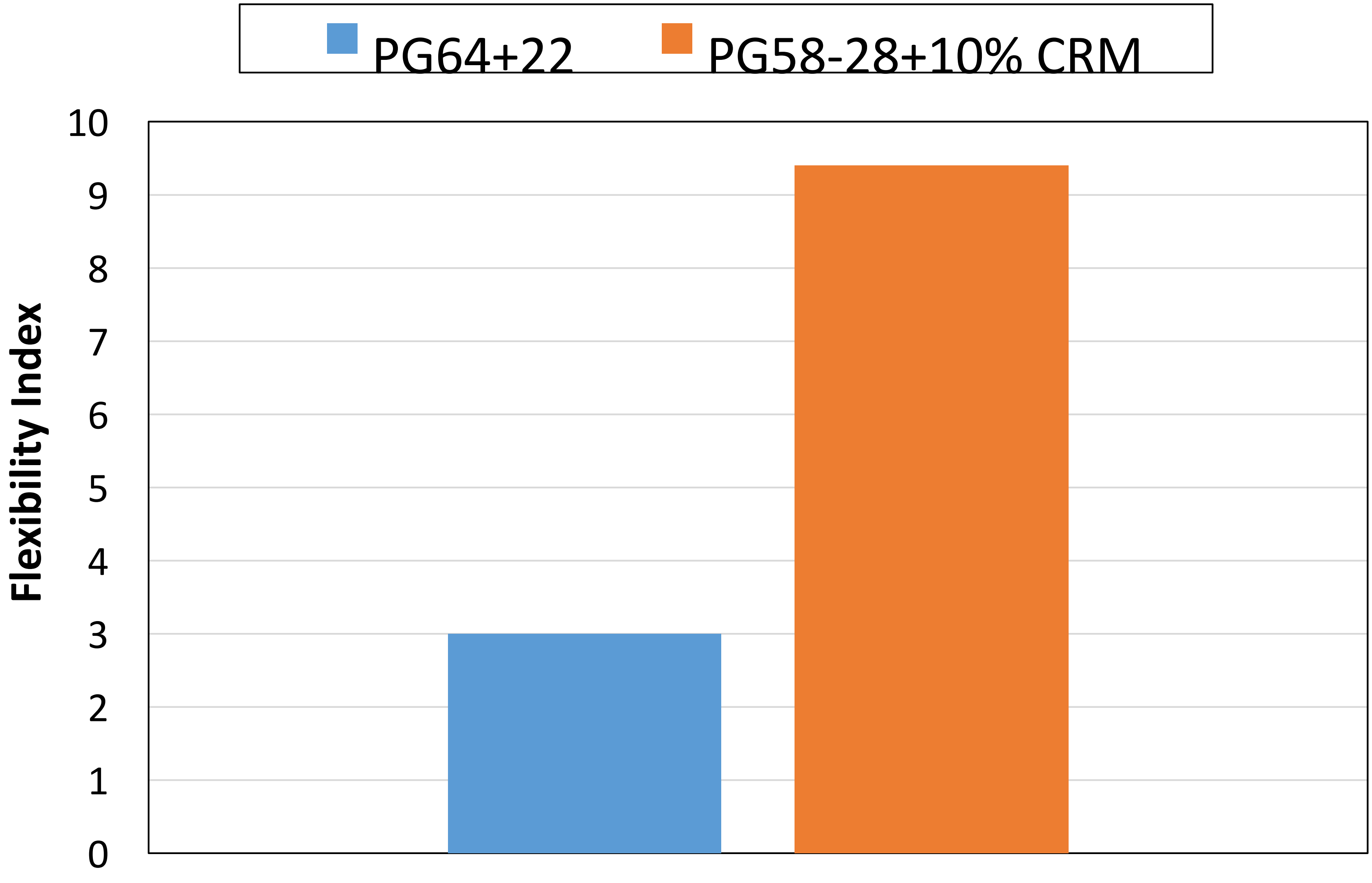
CRM Mixes – Peak Load (LTOA)



CRM Mixes – Fracture Energy (LTOA)



CRM Mixes – Flexibility Index (LTOA)



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Summary

- Higher loading rate → Lower FI
- Higher temperature → Higher FI
- Higher Binder Content → Higher FI
- Higher Air Void → Higher FI?
- Higher Aging → Lower FI
- Increase in Binder Stiffness (Grade)?
- CRM+PG 58 higher FI compared with PG 64

October 17, 2017

Thank you!

October 18, 2014