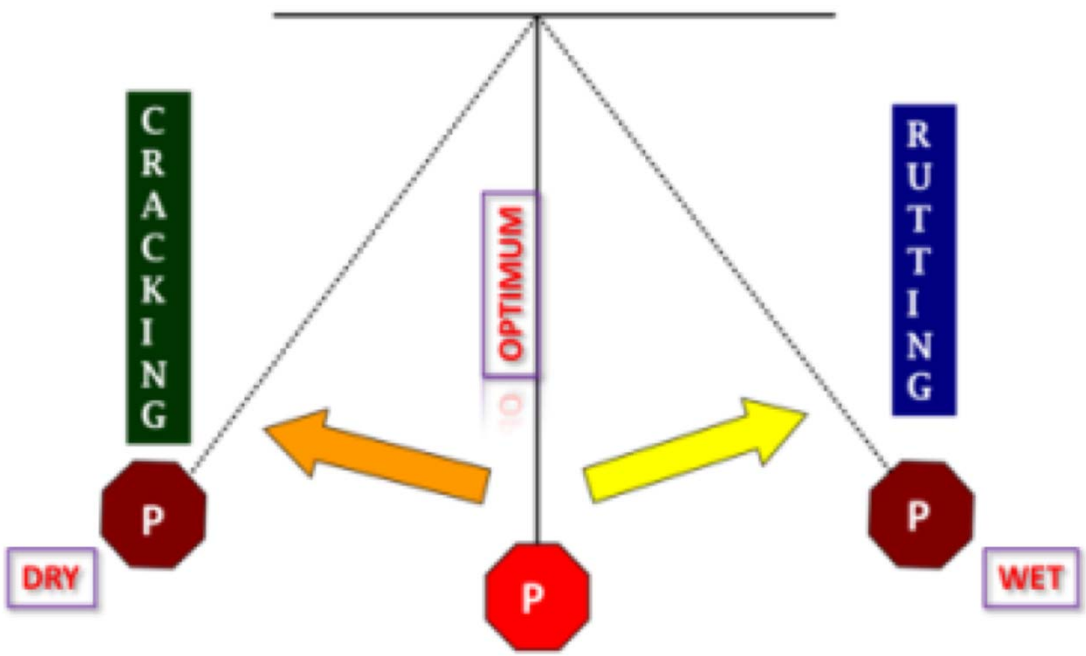
Optimized or Balanced Mix Design

- Crack Resistant
- Rut Resistant
- Resistant to Moisture Damage

Balanced Mix Design: ETG Definition

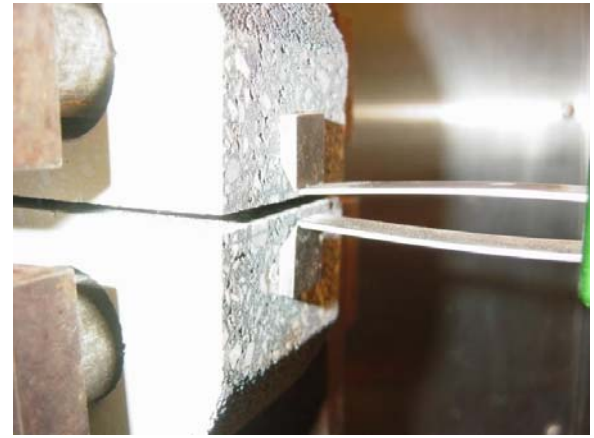
- Asphalt mix design using *performance tests* on appropriately *conditioned specimens* that address *multiple modes of distress* taking into consideration mix aging, traffic, climate and location within the pavement structure

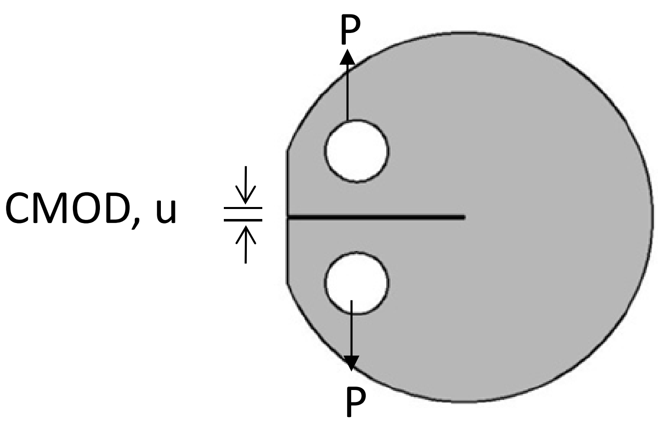


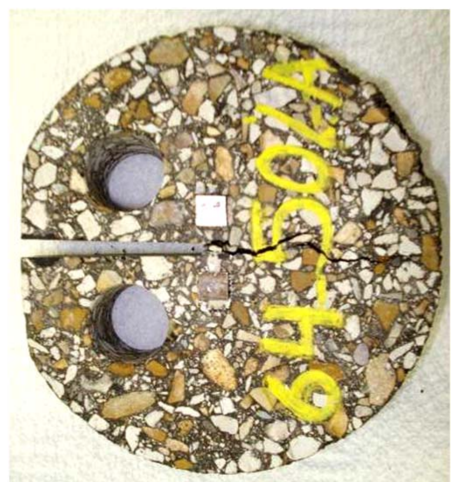
Performance Pendulum (Shane Buchanan, Oldcastle)

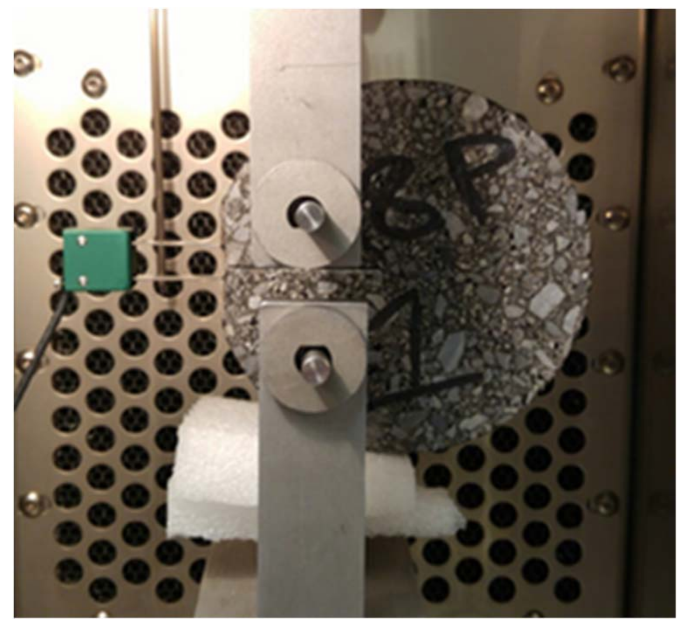
Disk-Shaped Compact Tension (DCT) Test

- ASTM D7313-13
- Loading Rate:
  - Crack Mouth Opening Displacement
  - CMOD Rate = 1.0 mm/min
- Measurements:
  - CMOD
  - Load



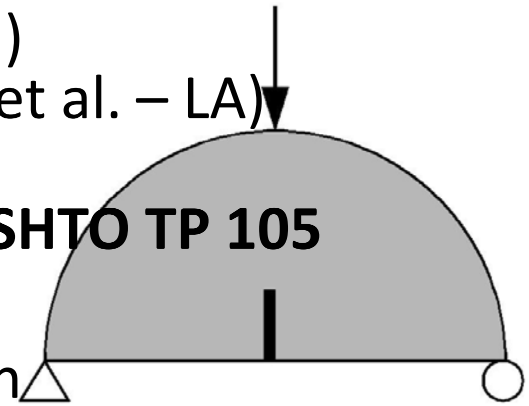


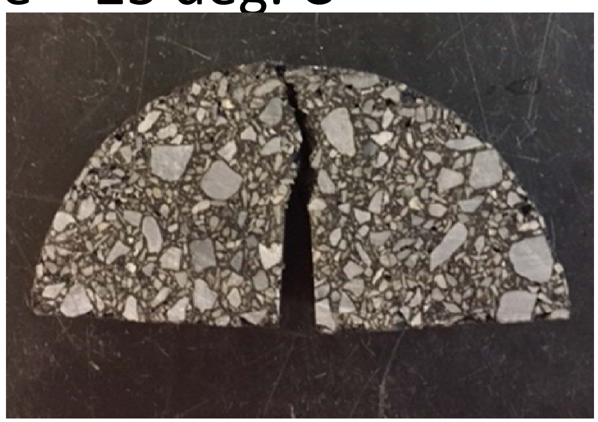


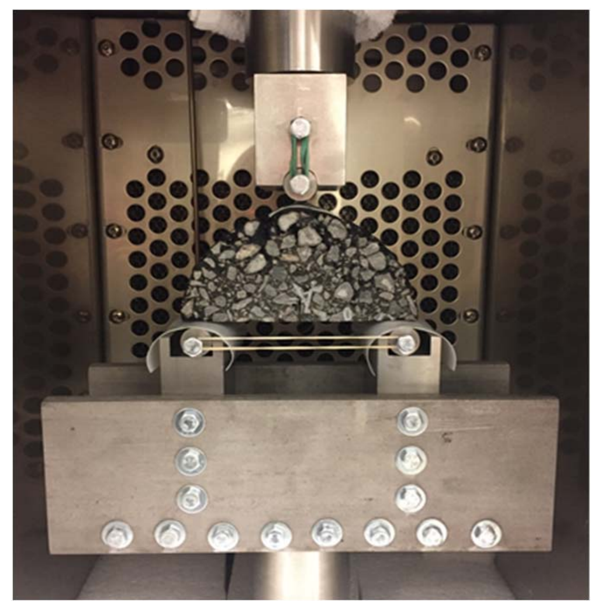


Semi-Circular Bend (SCB) Test

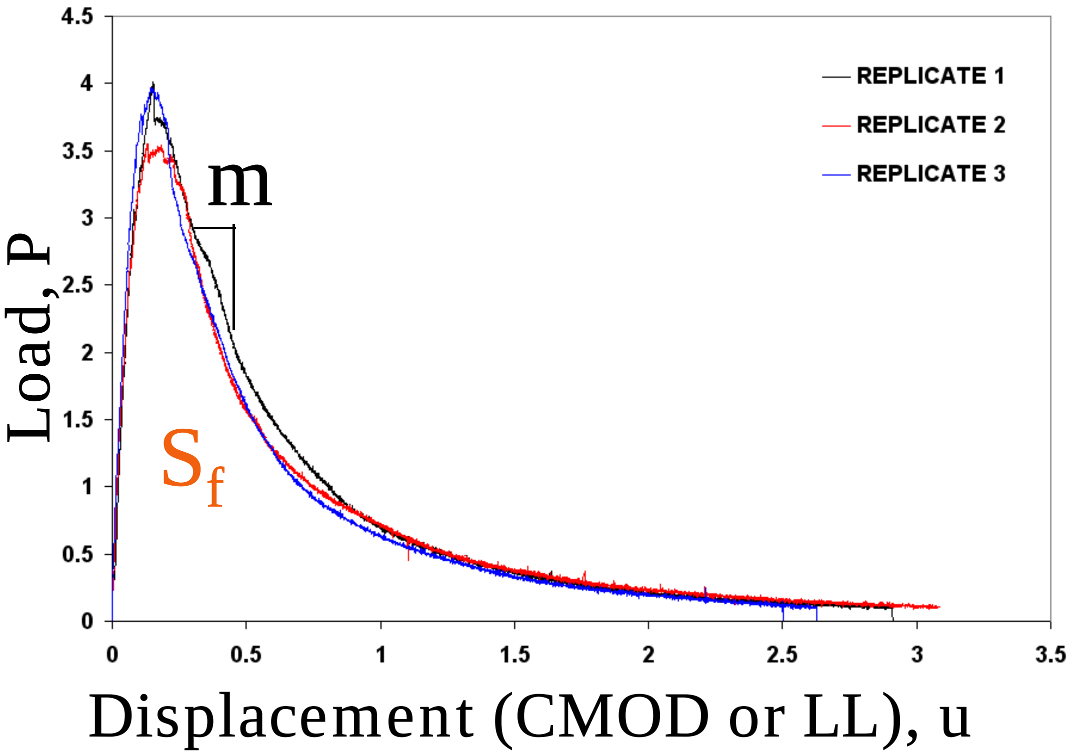
- Multiple variants exist
  - Early work in Europe
  - Simultaneous cold (Marasteanu et al. – MN) and intermediate temperature (Mohamed et al. – LA) versions
  - **Recent work from Al-Qadi et al. (IL) → AASHTO TP 105**
- AASHTO TP 105 (I-FIT)
  - Line load control, loading rate = 50 mm/min
  - Test temperature = 25 deg. C
- Measurements:
  - Displacement
  - Load
- Outcomes
  - Fracture Energy
  - Flexibility Index (FI)

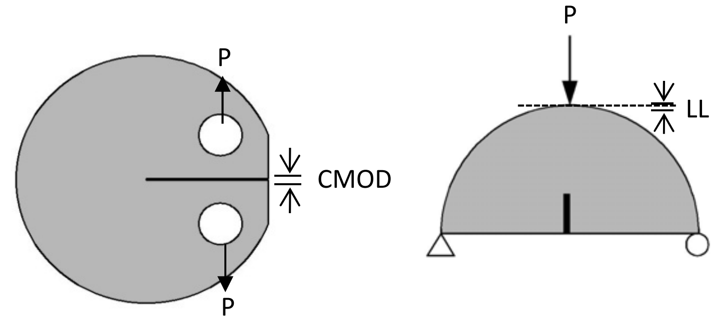






Fracture Parameters





Fracture work: Area under Load-Displacement curve

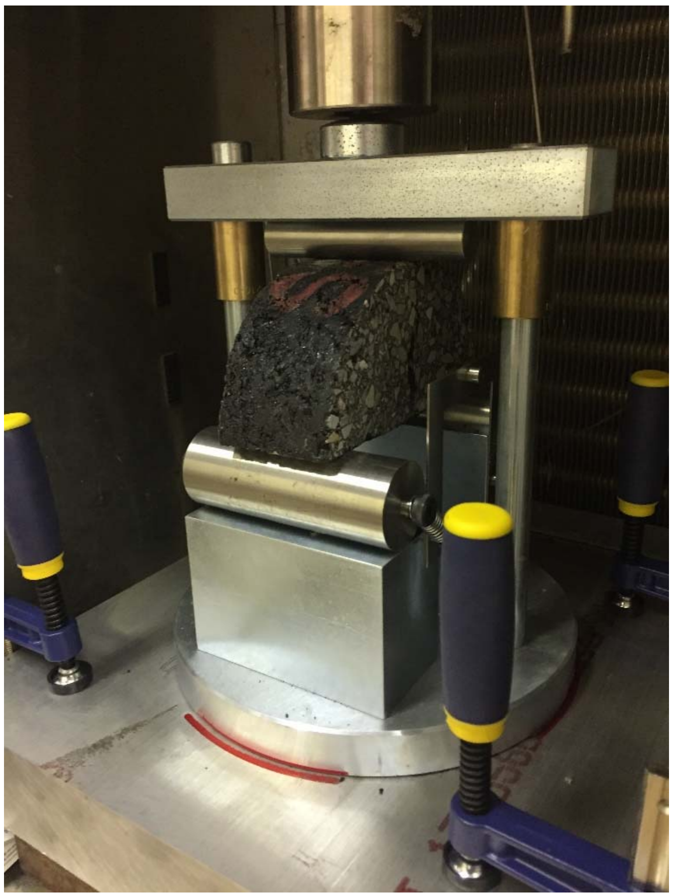
Fracture Energy, G_f: Energy required to create unit fracture surface

$$G_f = \frac{\text{Fracture Work, } S_f}{\text{Fracture Area}}$$

Flexibility Index, FI:

$FI = G_f / m$

Choosing A Fatigue Test for Long Life Asphalt Pavement (LLAP)



Mansour Solaimanian, Ph.D., P.E.
Pennsylvania State University
August 2nd, 2017

Scott Milander
Pezhouhan Kheiry
Xuan Chen
Saman Barzegari
Ilker Boz

Today's Talk

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

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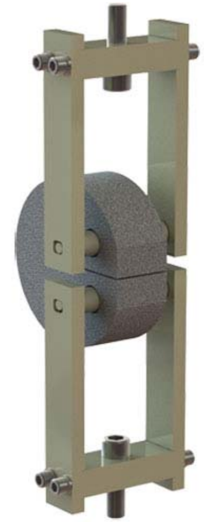
Lab Scale Tests

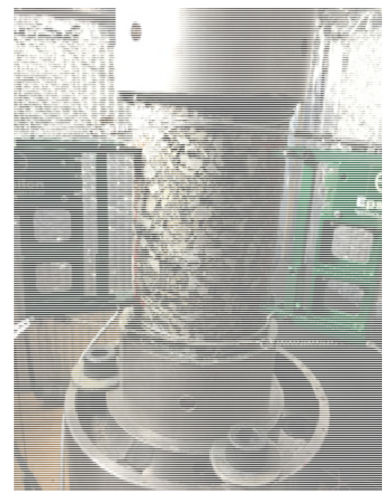
Monotonic Tests

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



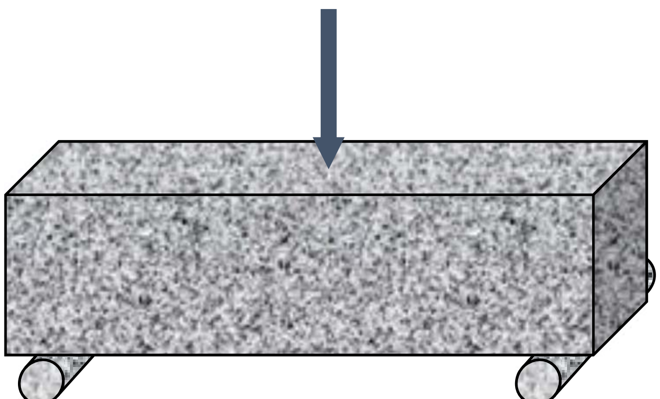
Cyclic Tests

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



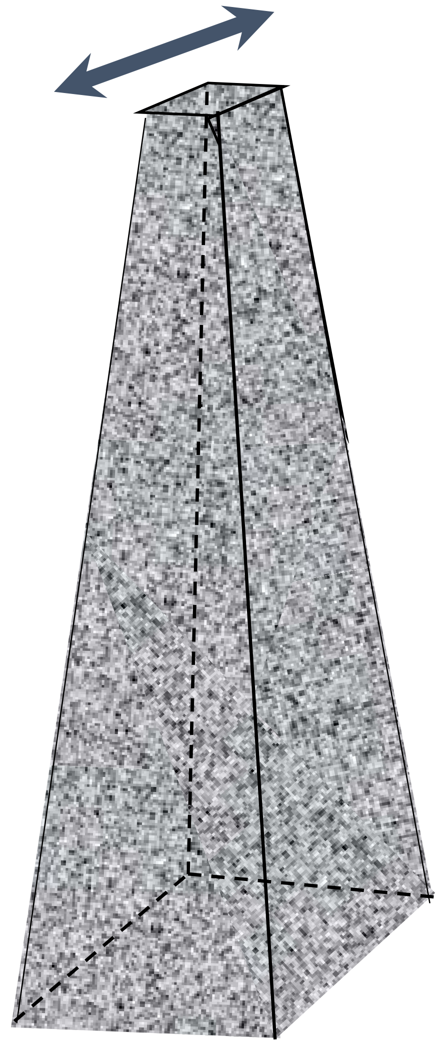
Picture Curtesy: IPC Global, Umass, Penn State

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, ….

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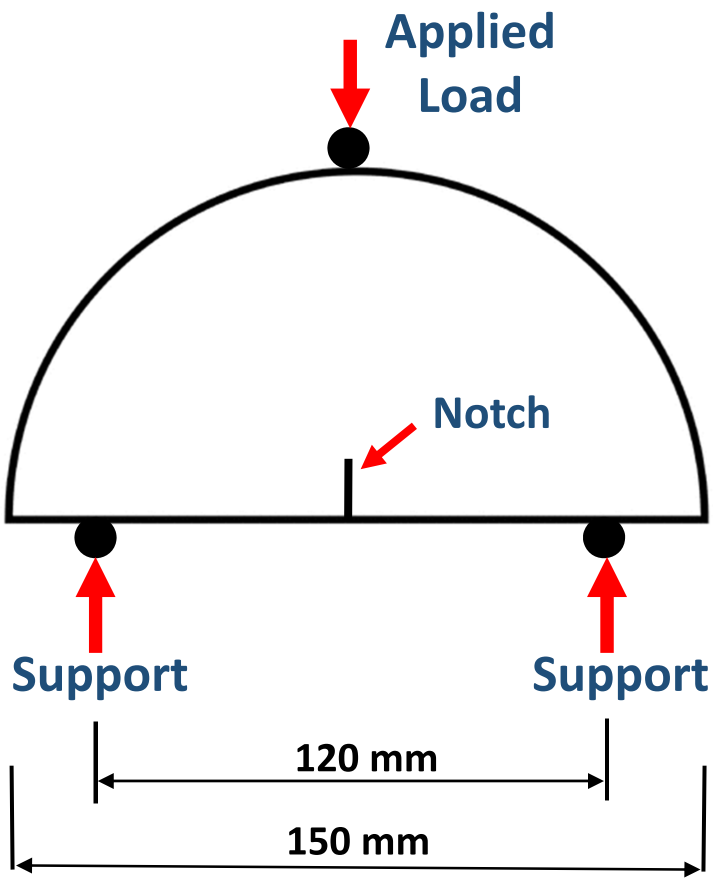
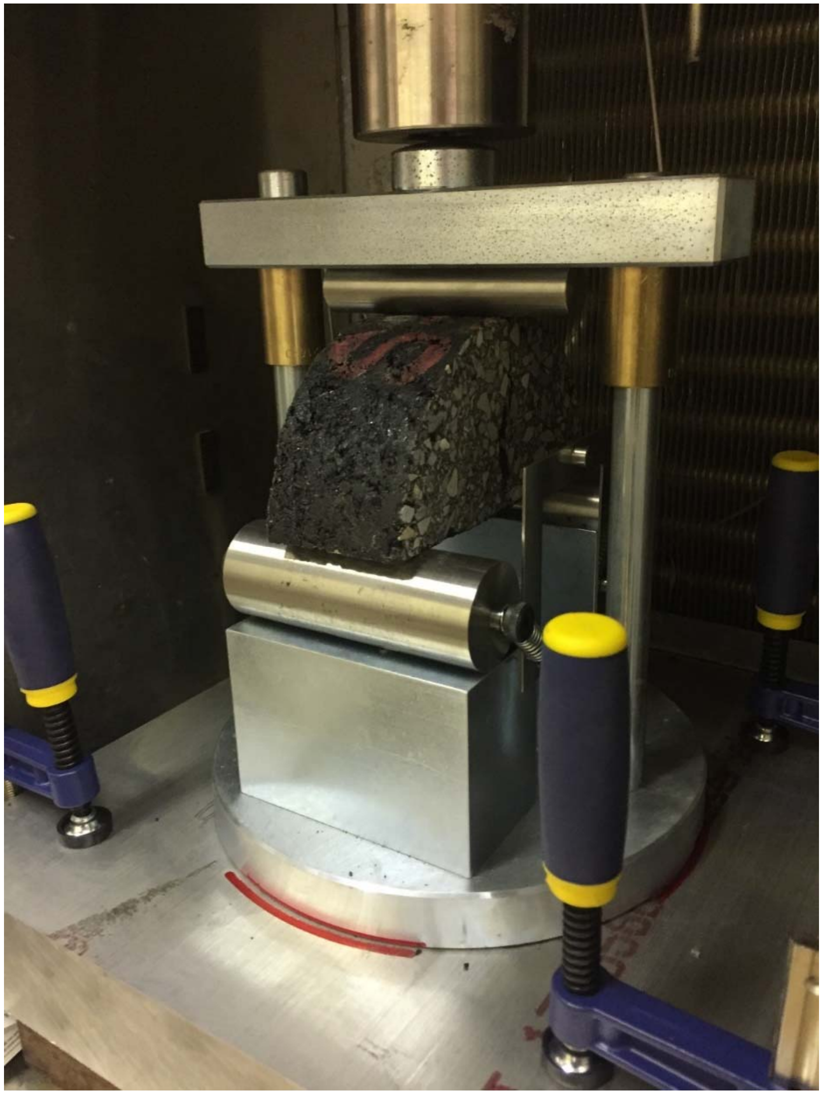
Background on SCB

- 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 Setup



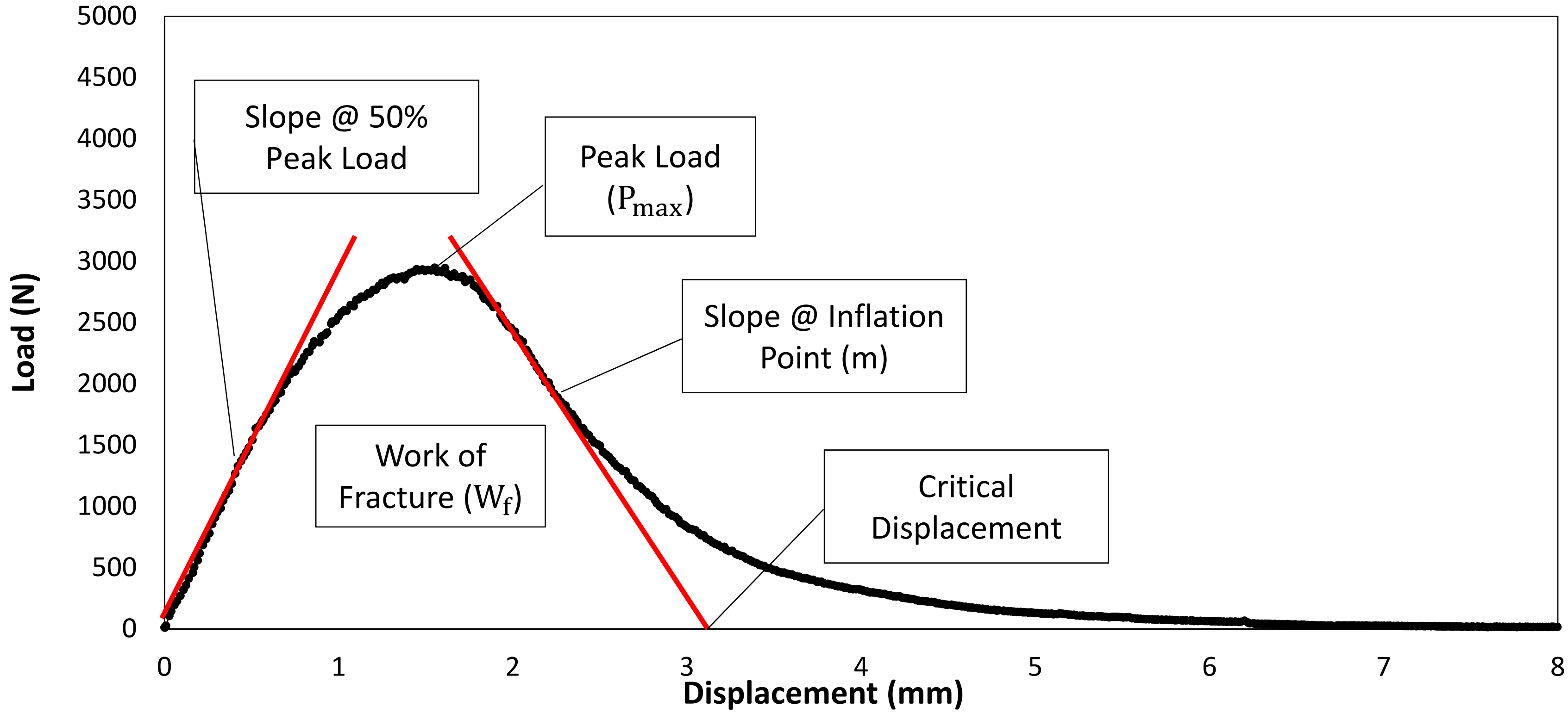


Specimen Thickness: 50 mm

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

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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 Has Been Reported. (Limited Data so far)?

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Current Issues

- In the SCB test, do we know the answer to these?
  - **What test temperature?**
  - **How fast to test?**
  - **What is good versus poor performance?**
  - **What pass/fail criteria?**
  - **Test short-term aged or long-term aged mix?**
  - **Test variability and how to reduce variability?**

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Study Objectives

- 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**

Use data to establish Temperature – Loading Rate **Master Curve** and Propose the **Final SCB Test Protocol**

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:

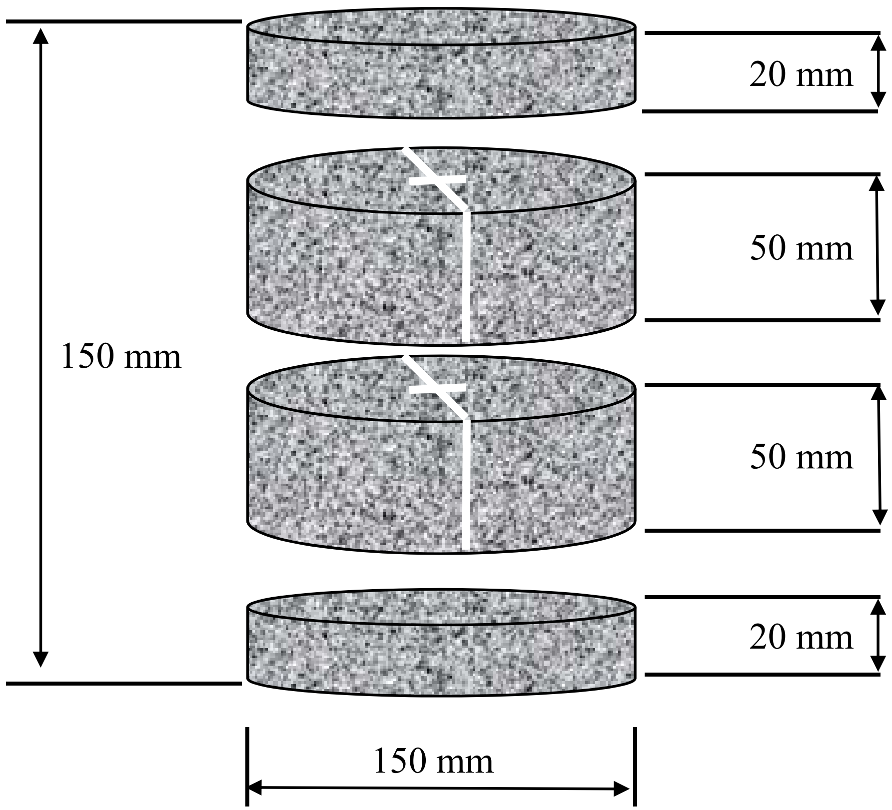
- 50 mm/min (too fast, not enough data points, higher COV)
- 0.5 mm/min (too slow, affected by creep)

Proposed Protocol based on our results so far:

- Using 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.
- A set of tests (3 replicates) can be conducted within 5 minutes

Specimen Preparation

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

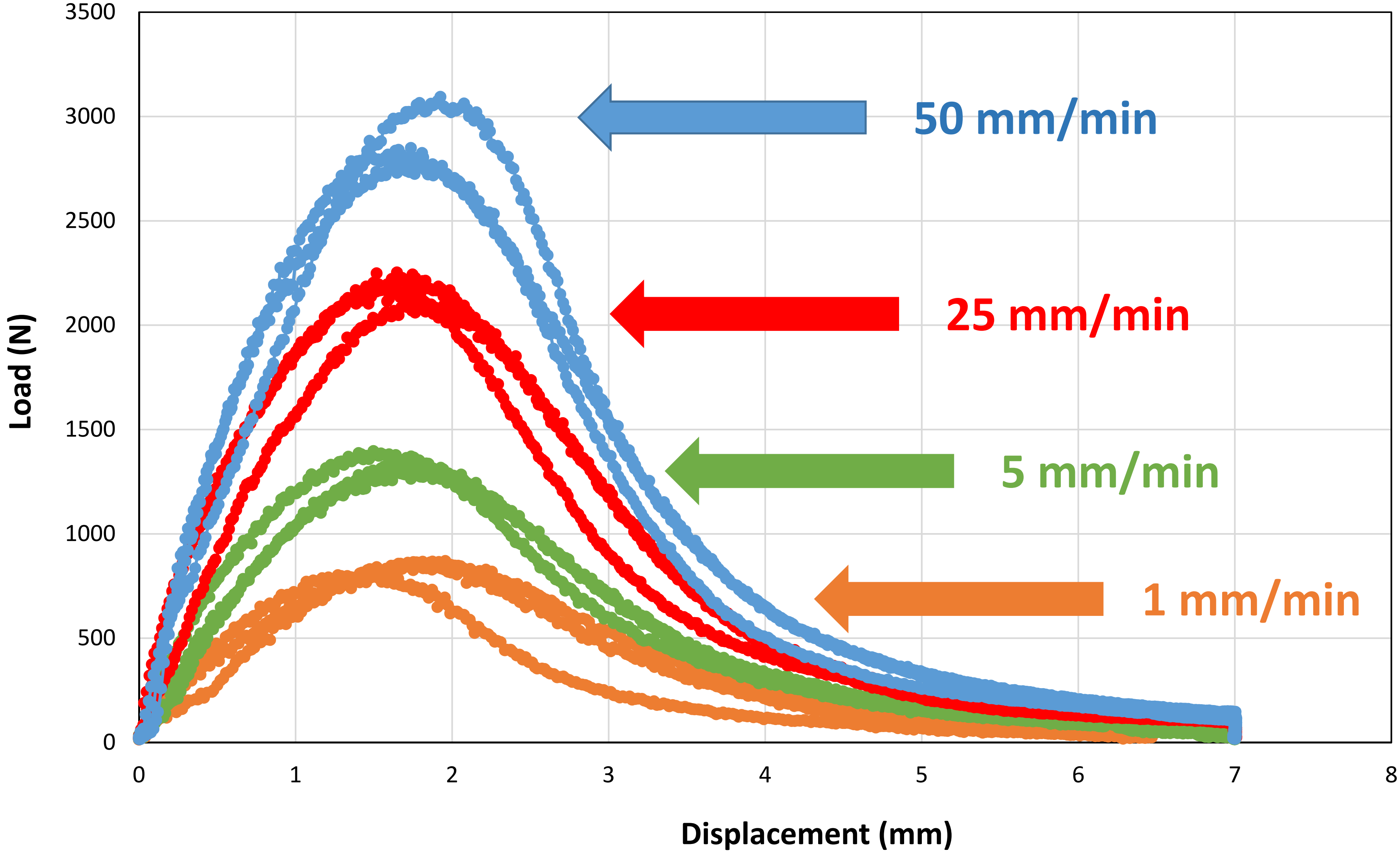


It Takes **3** days from Mixing to Obtain Results

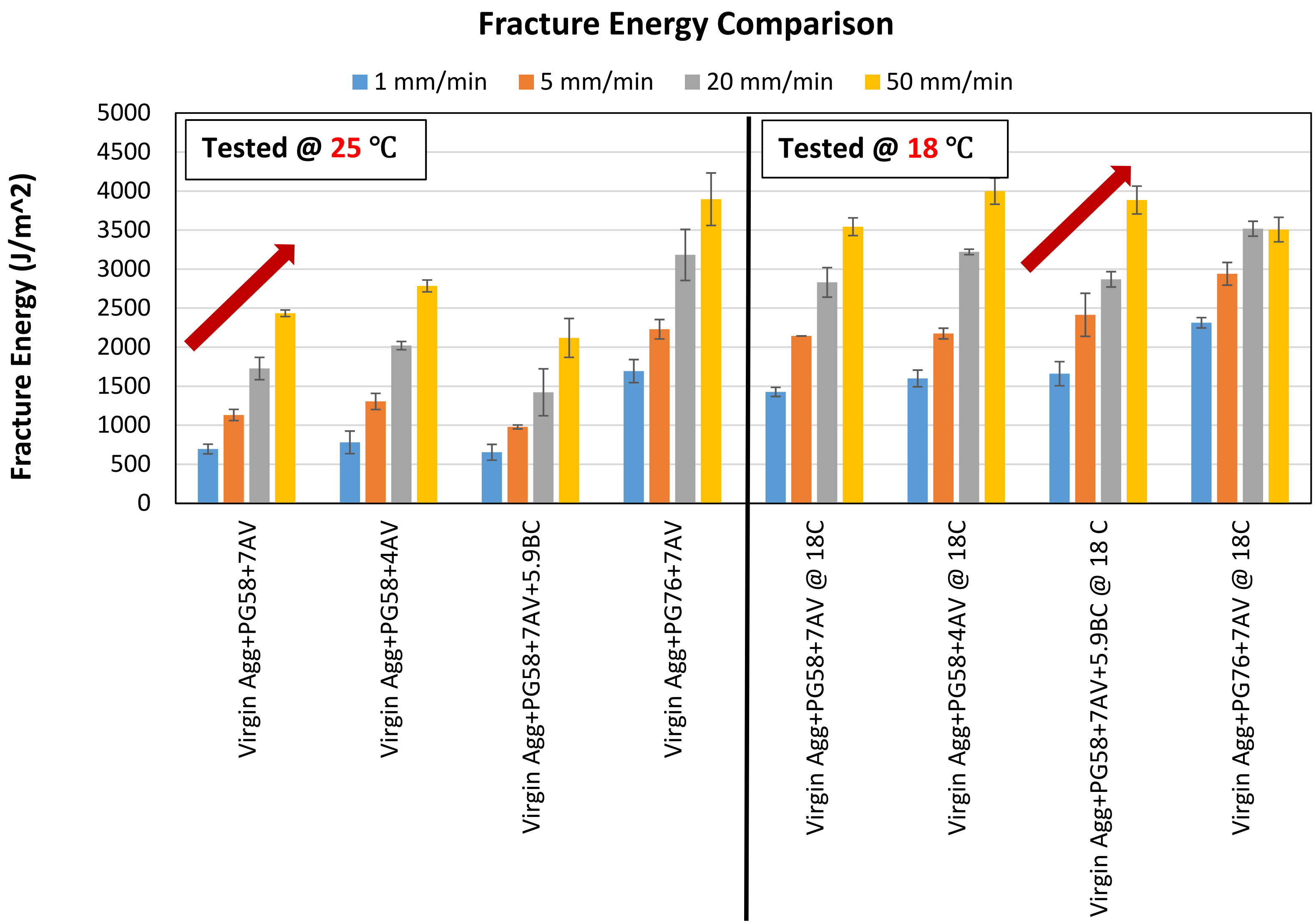
Specimens After Cutting
Ready for Testing

Specimens Before (L) / After (R) Testing

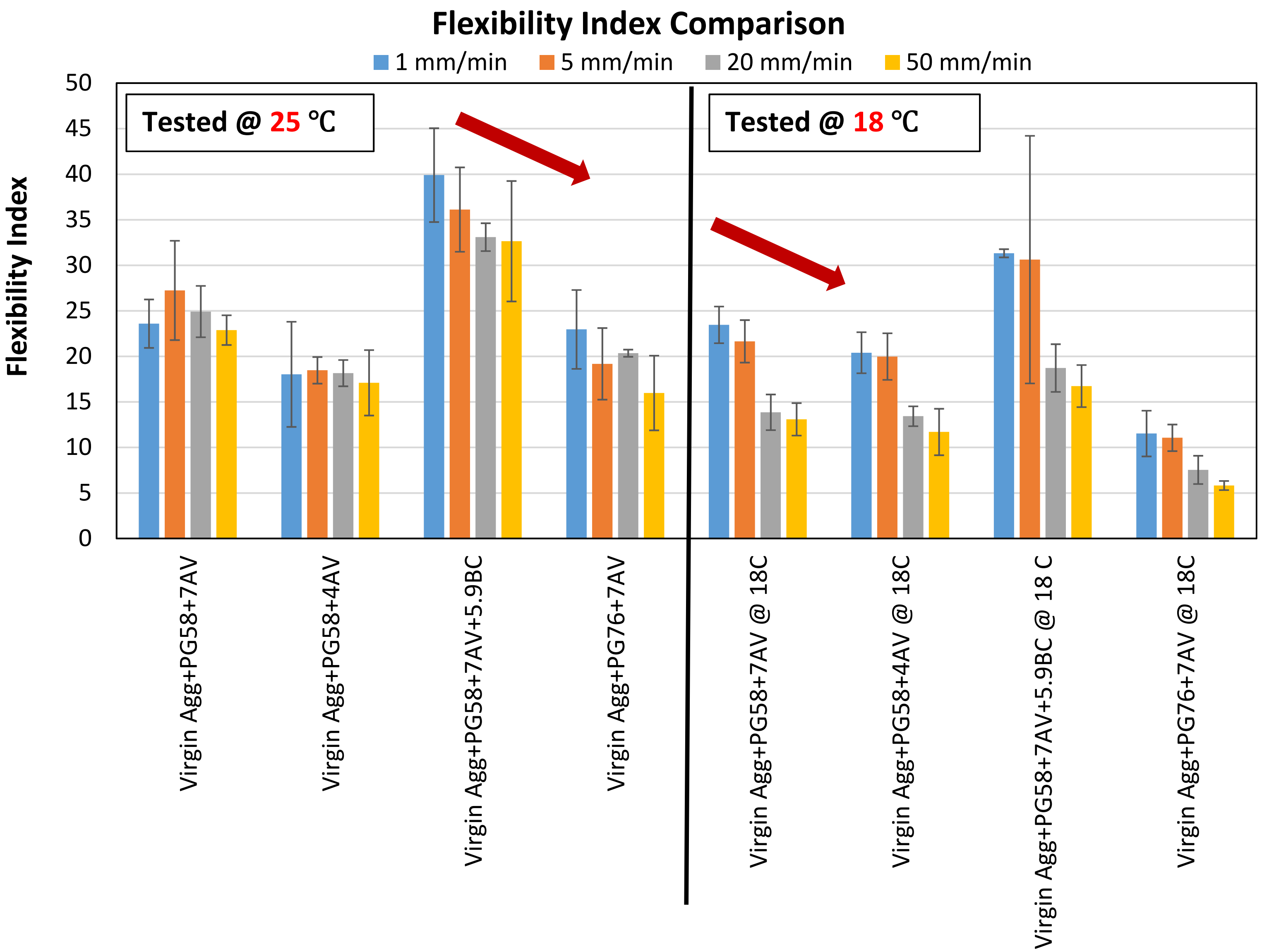
Typical Load vs Displacement Curves
3 Replicates, PG 58-28, 25°C



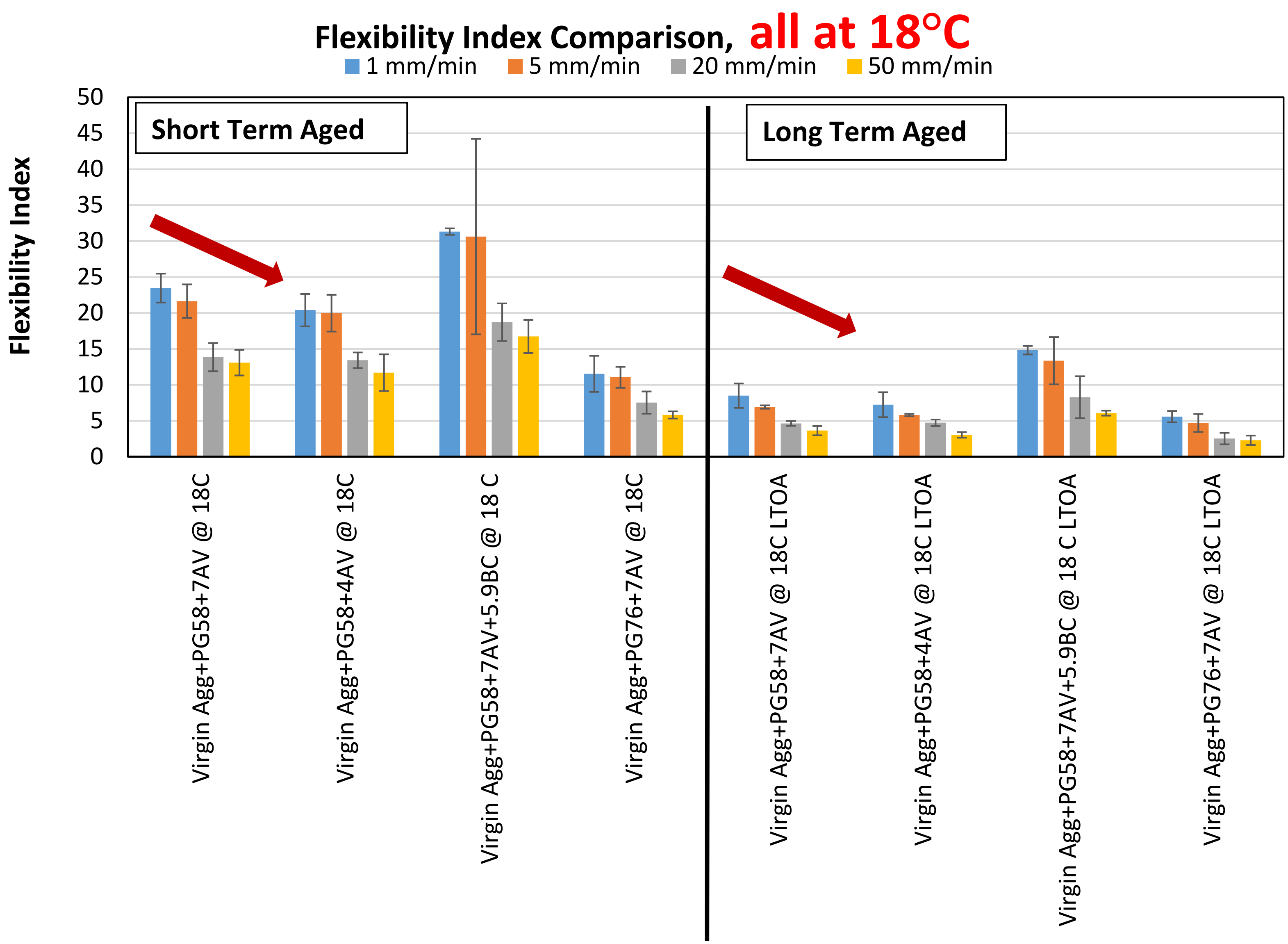
Temperature/Loading Rate Effects



Temperature/Loading Rate Effects



Aging Effect



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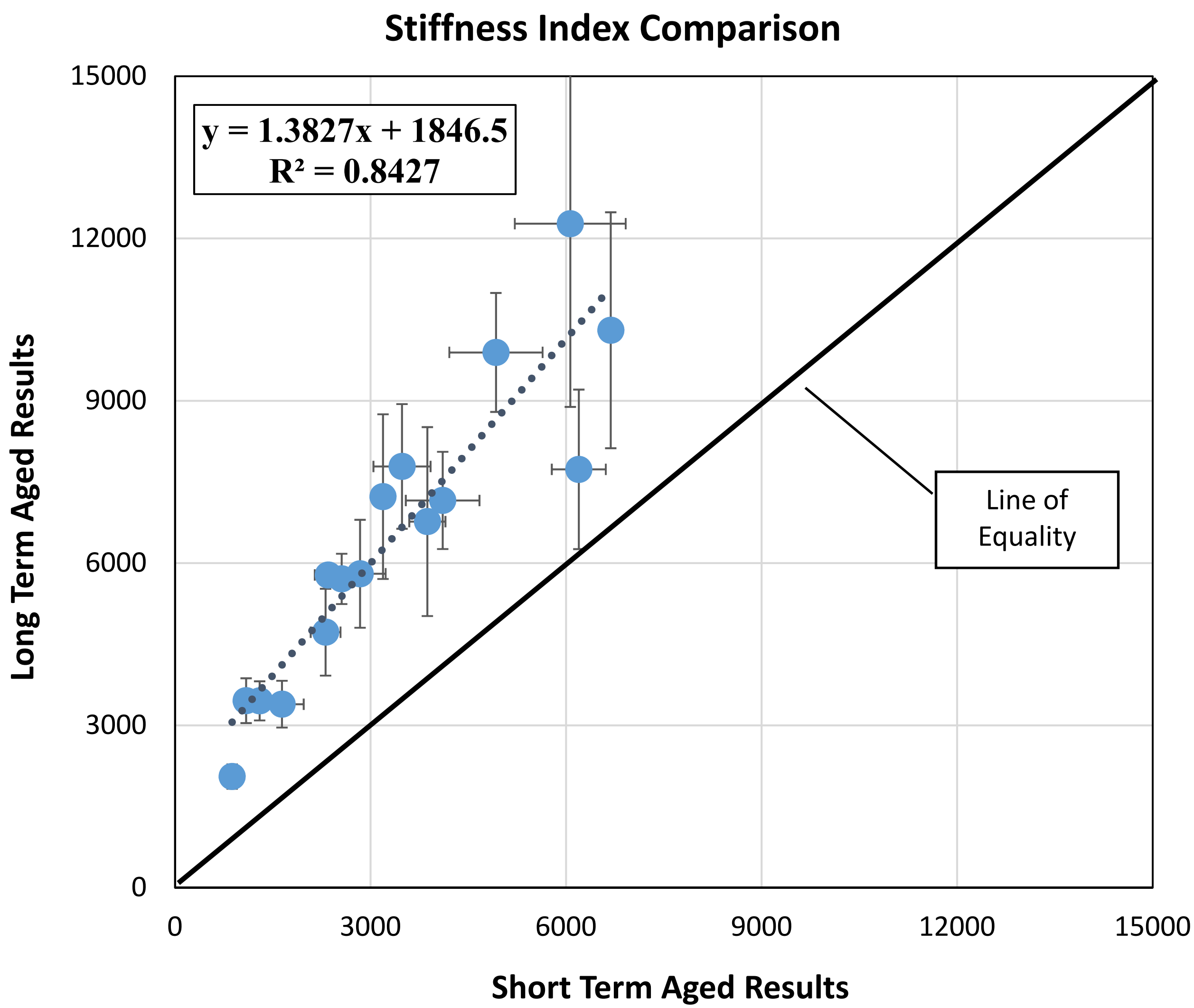
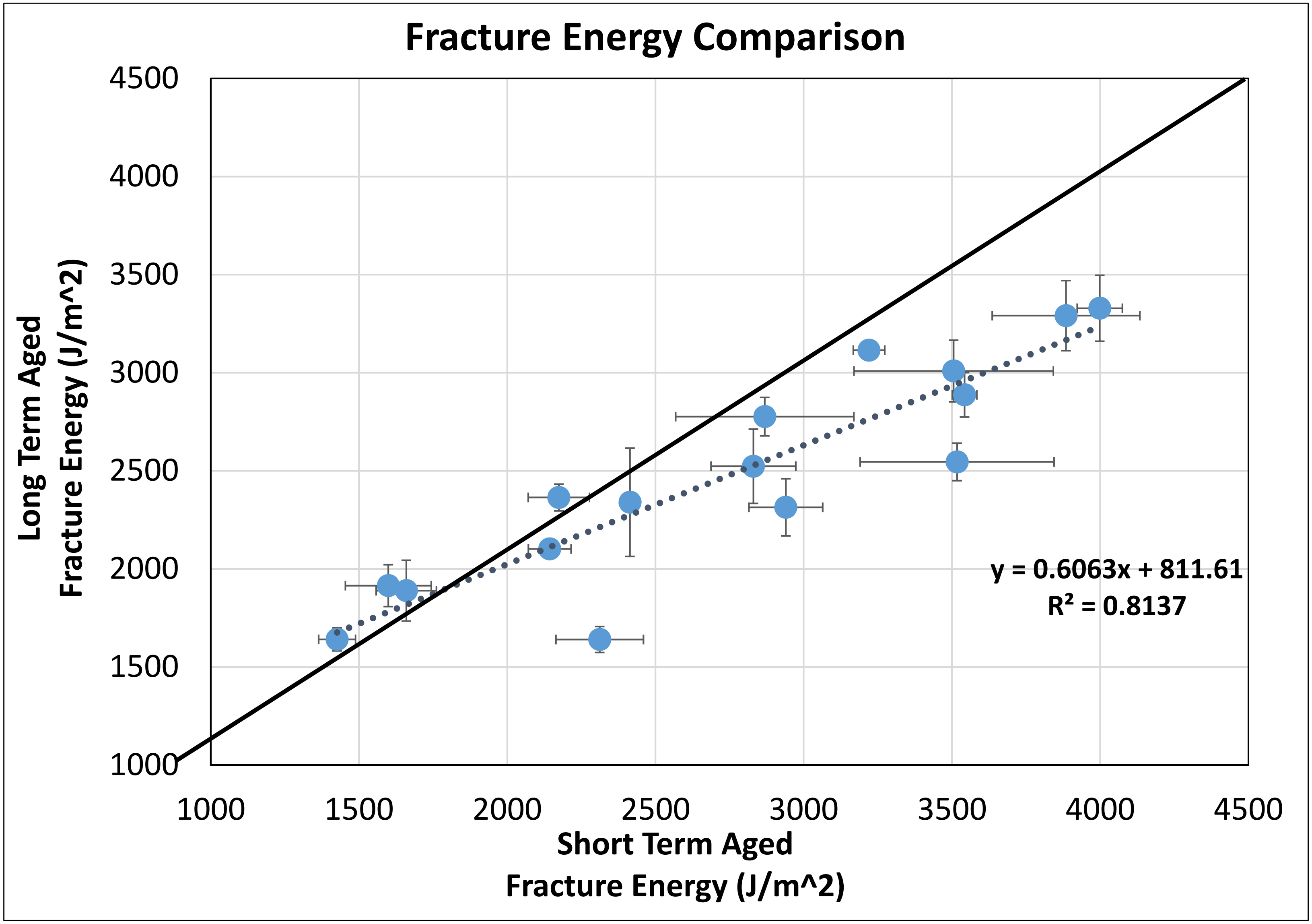
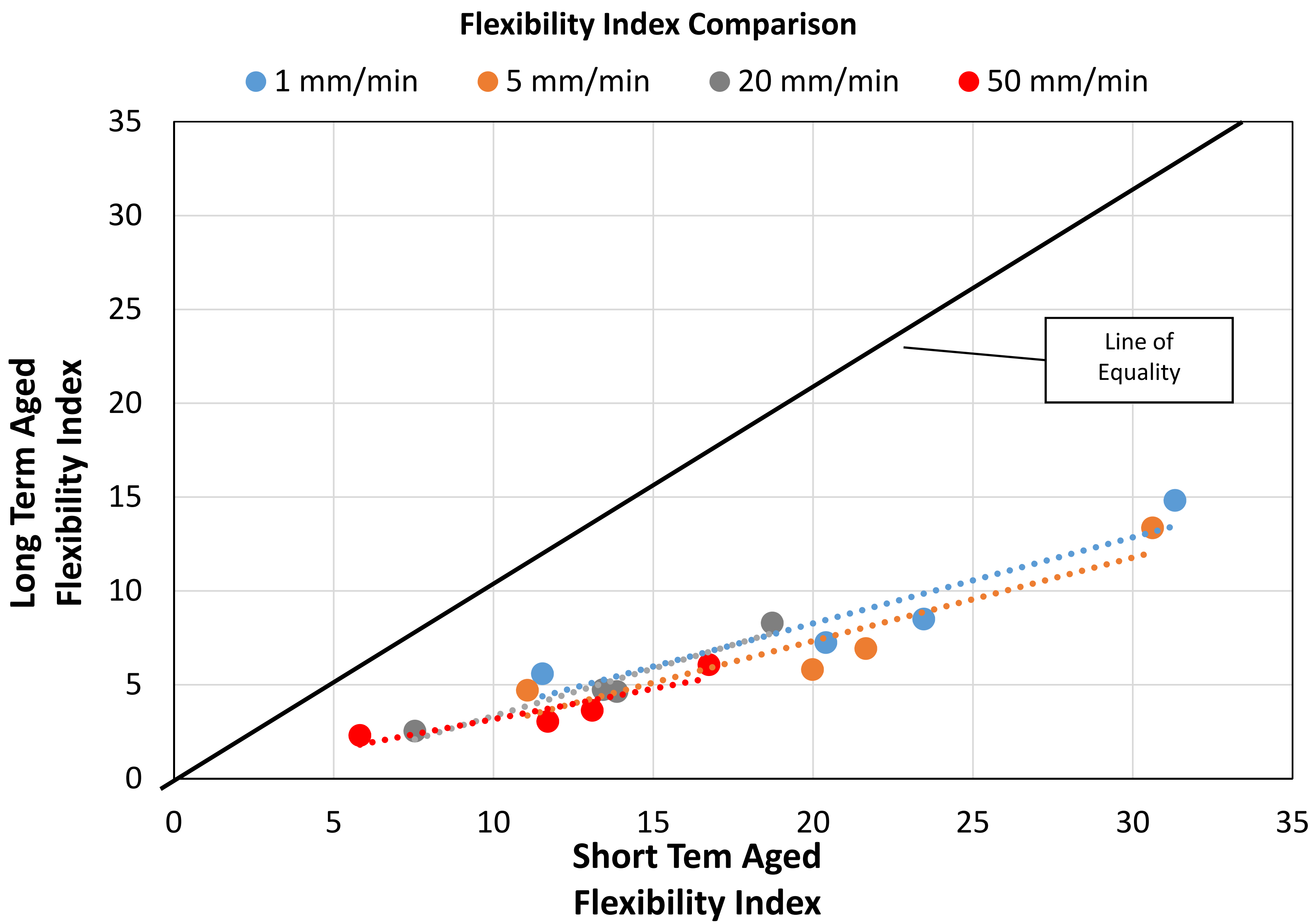
Correlate Stiffness Indices of Aged Mixes



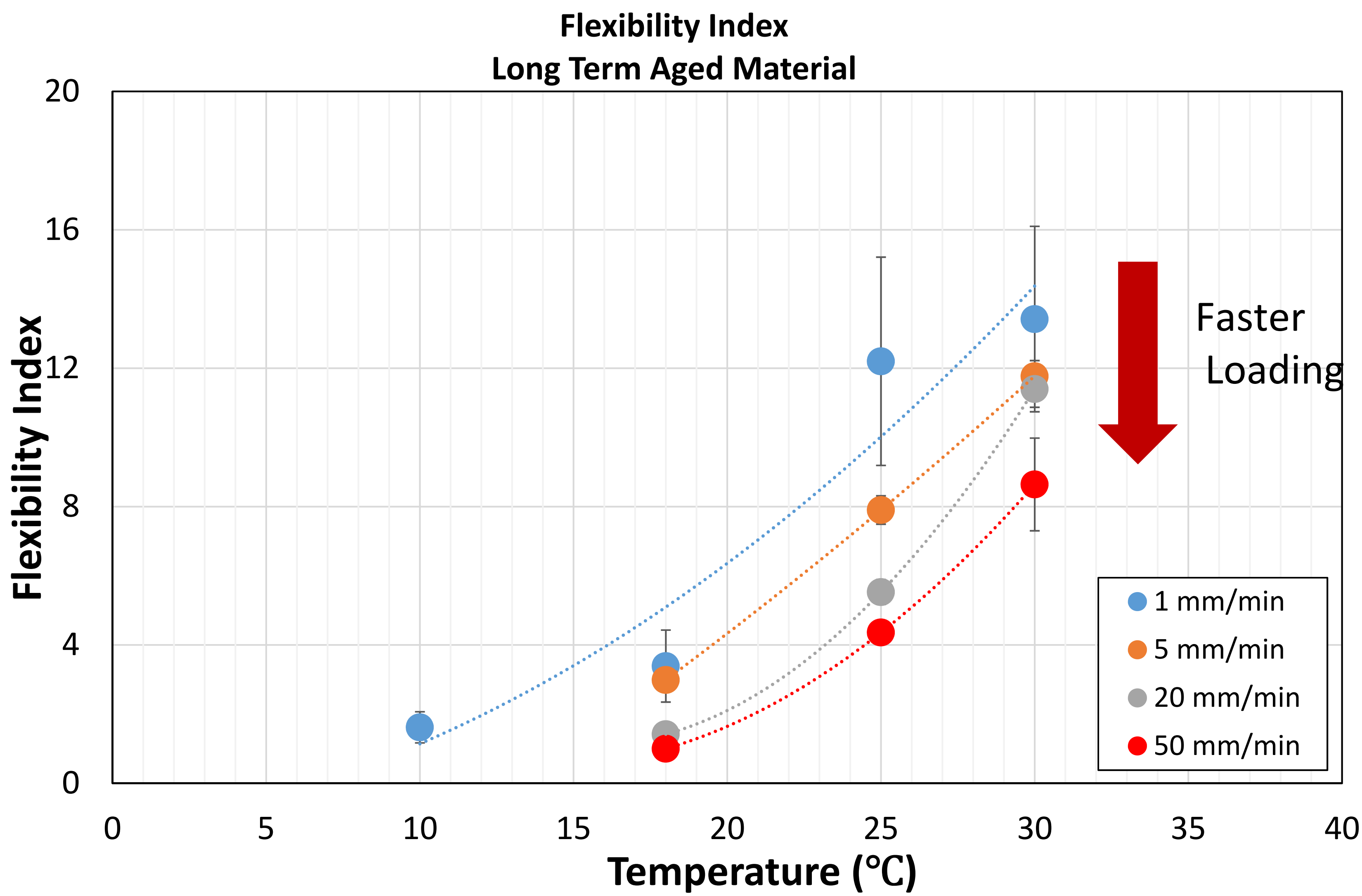
Correlating Facture Energy of Aged Mixes



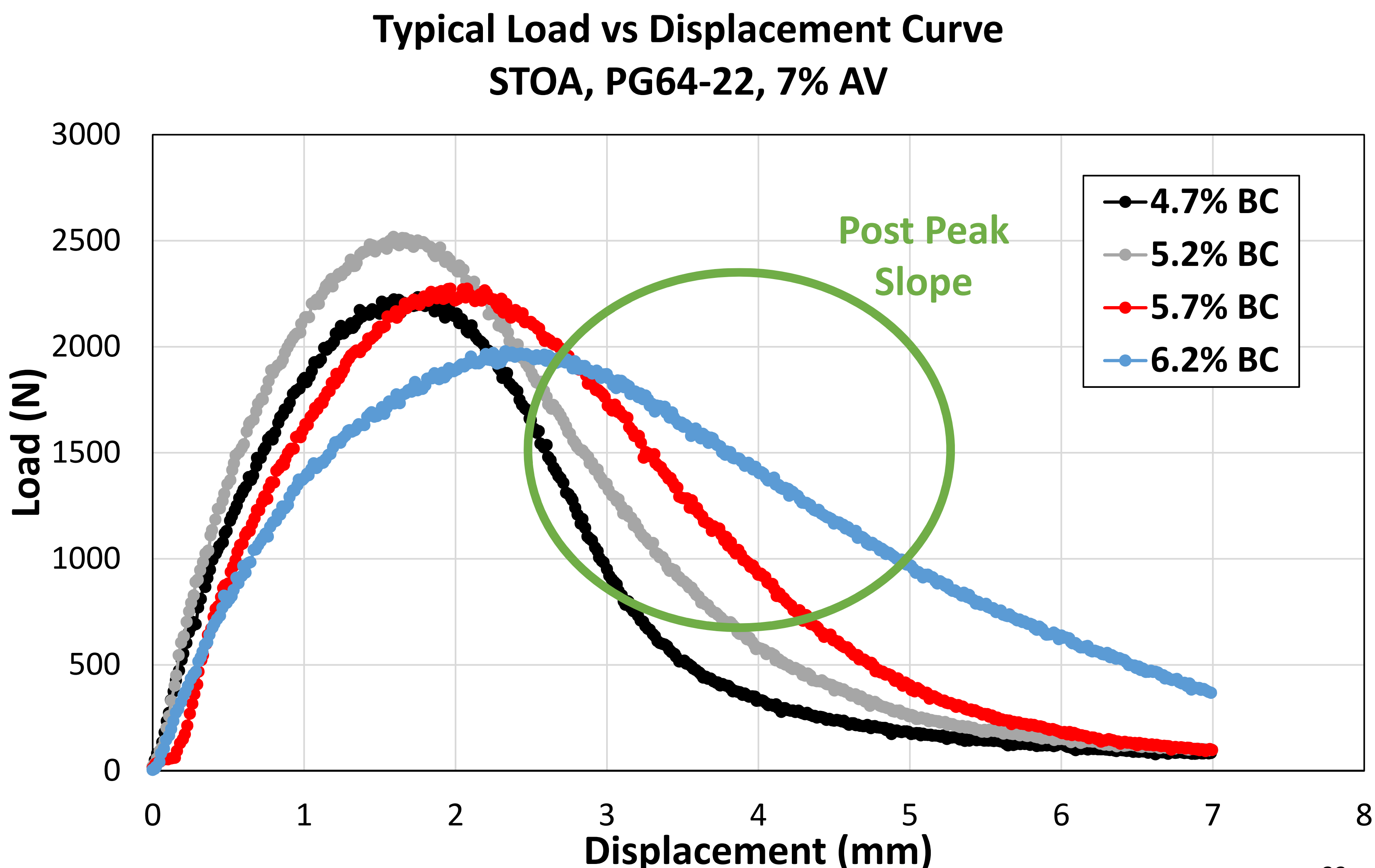
Correlating FI of Aged Mixes



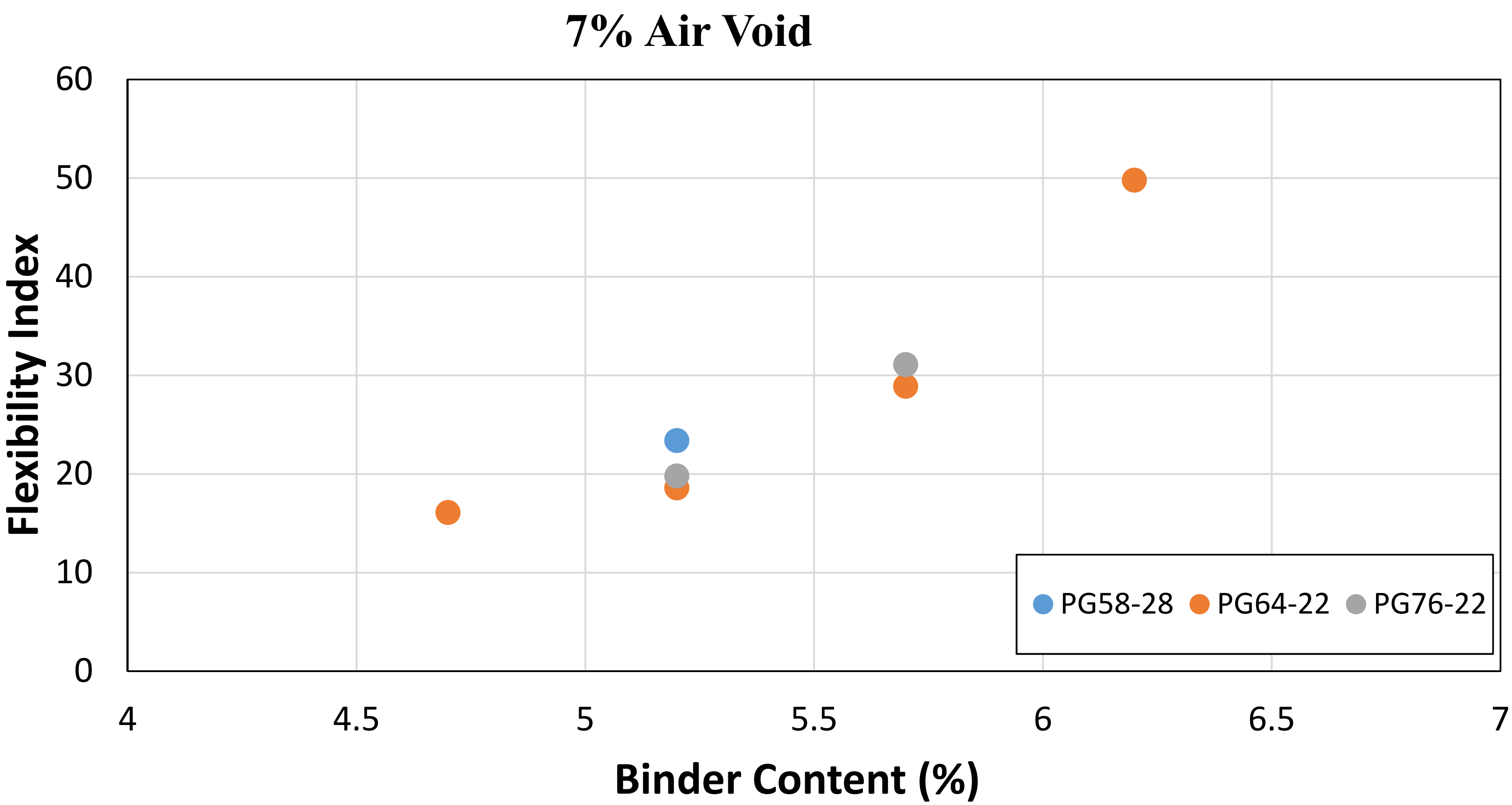
Temperature/Loading Rate Sweep in SCB



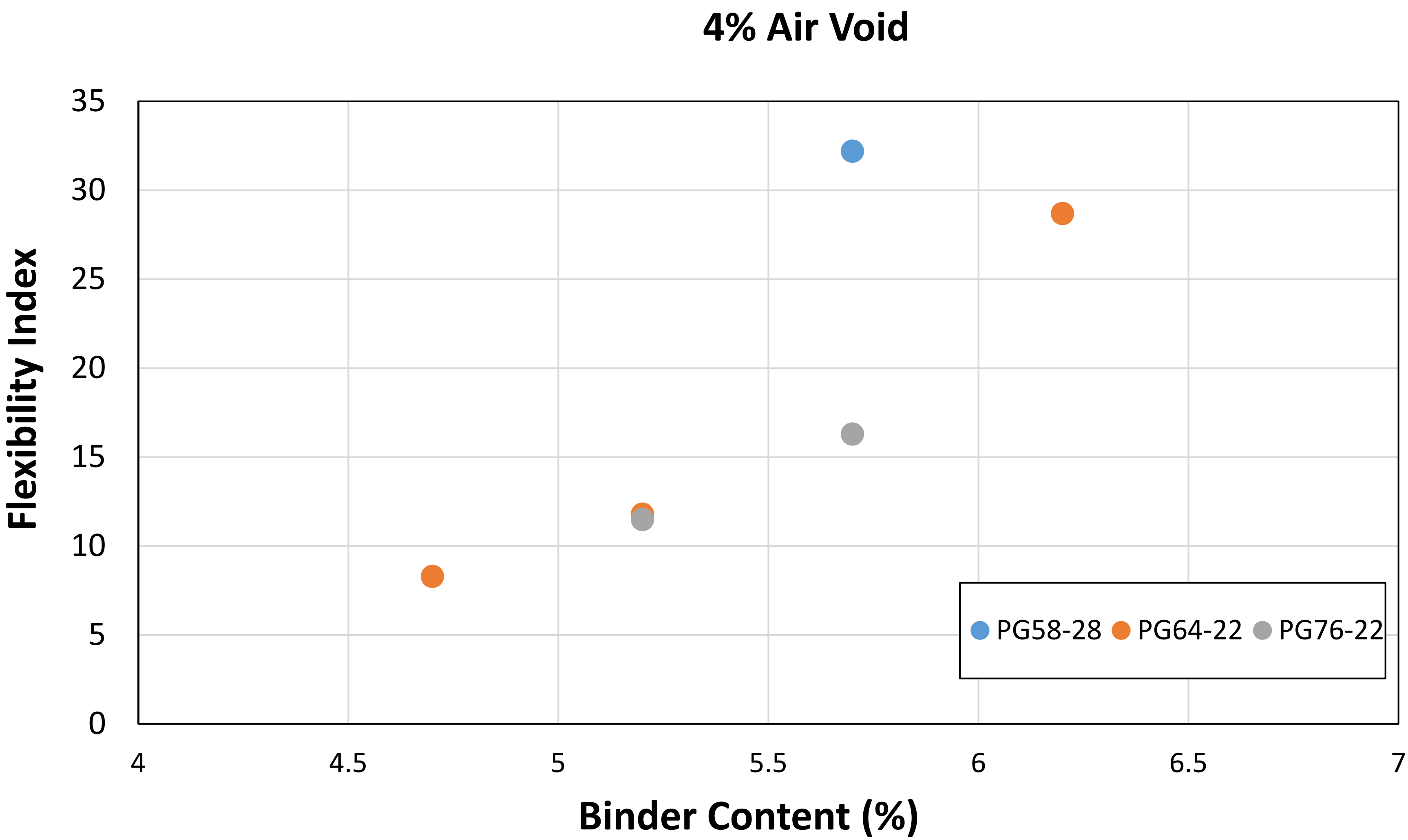
Effect of Binder Content



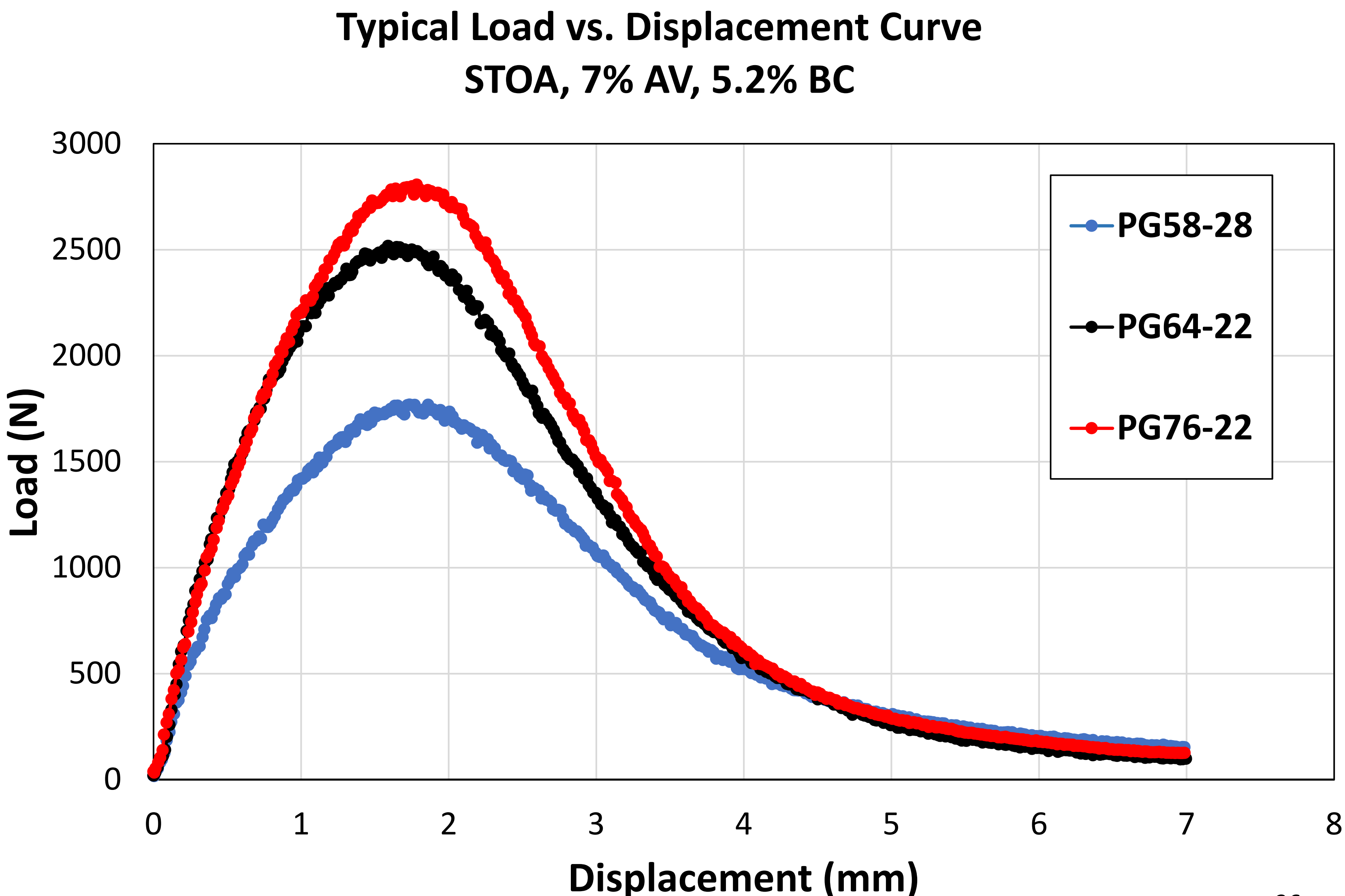
Effect of Binder Content



Effect of Binder Content



Effect of Binder Grade (Stiffness)



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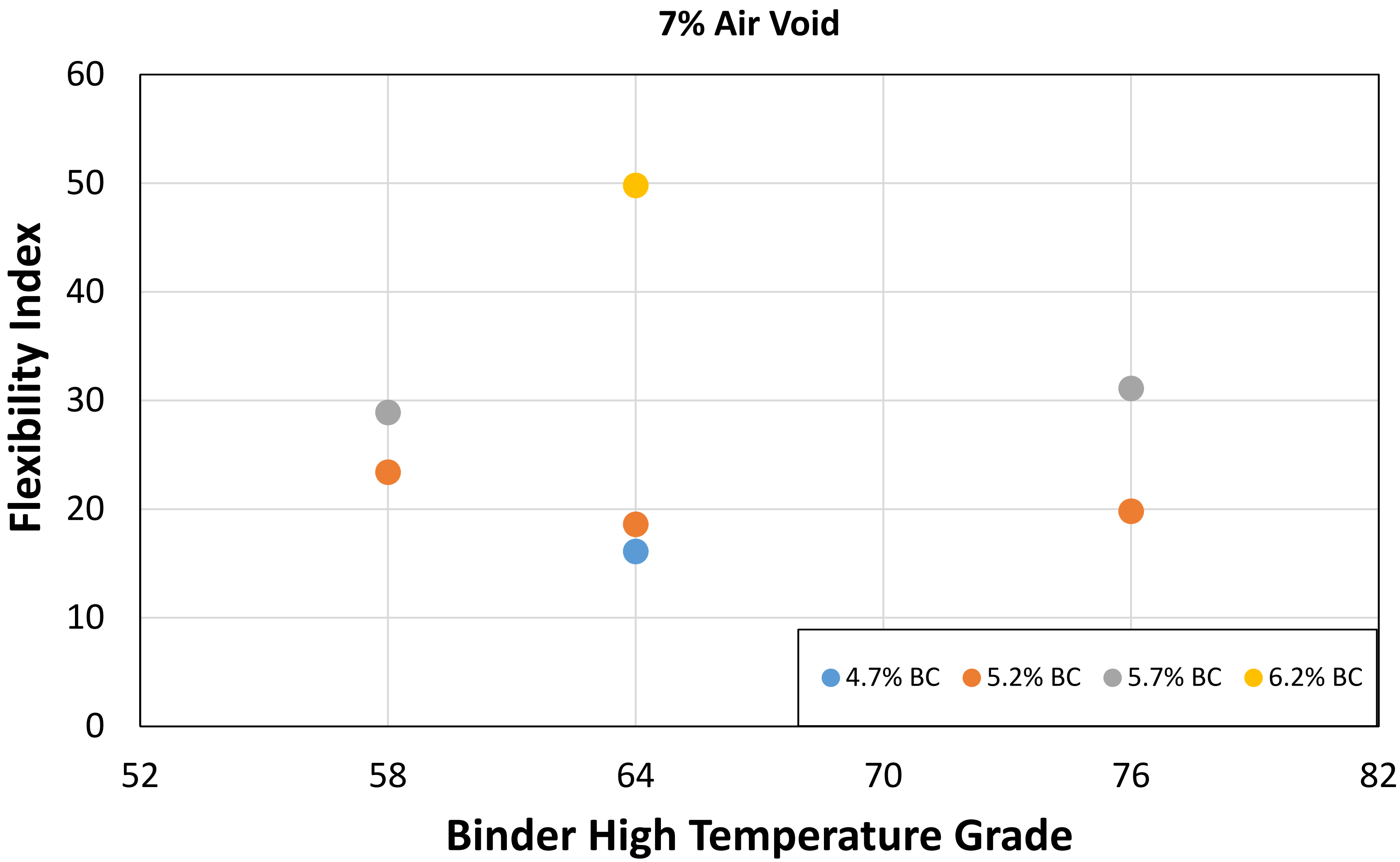

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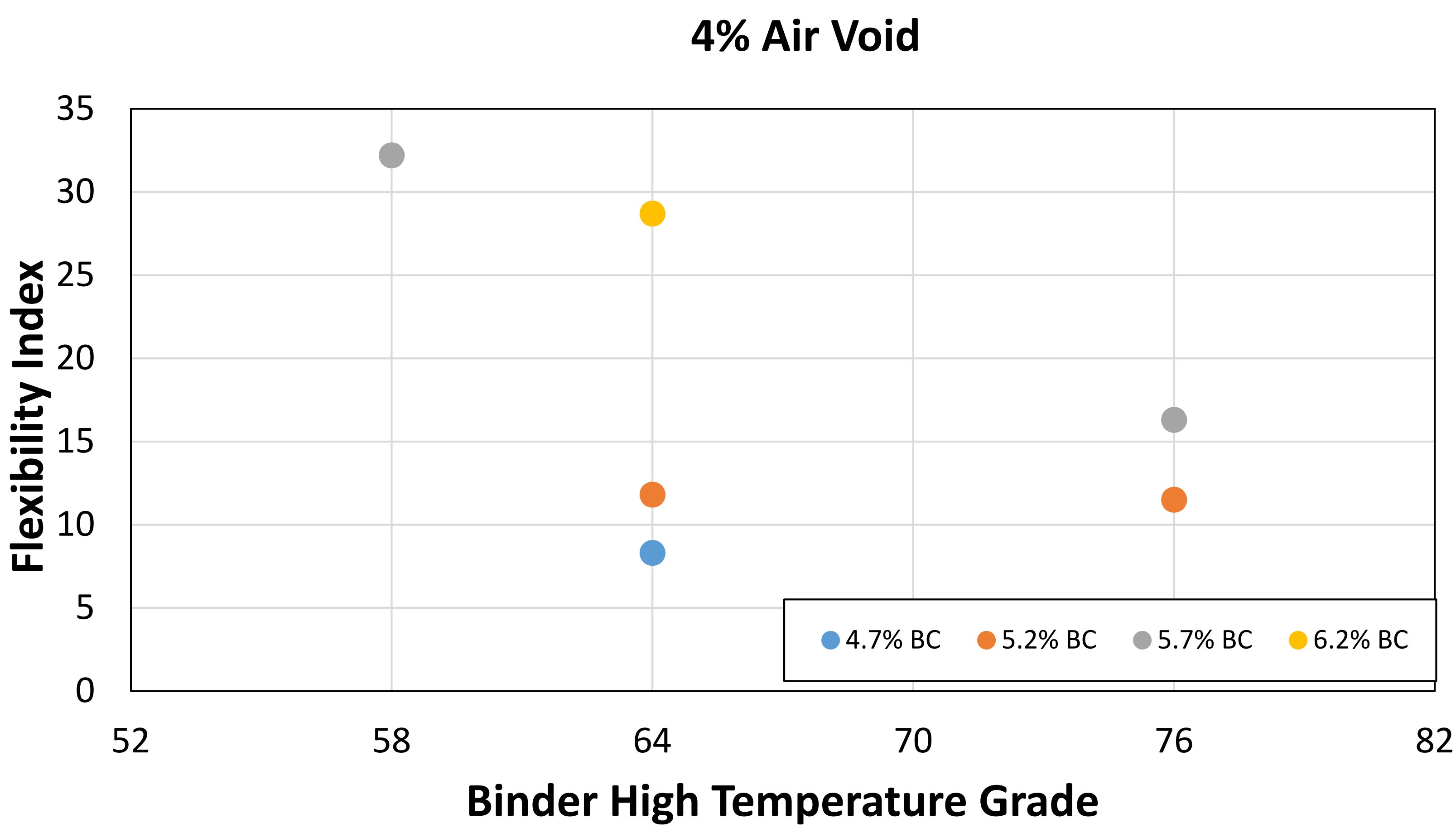

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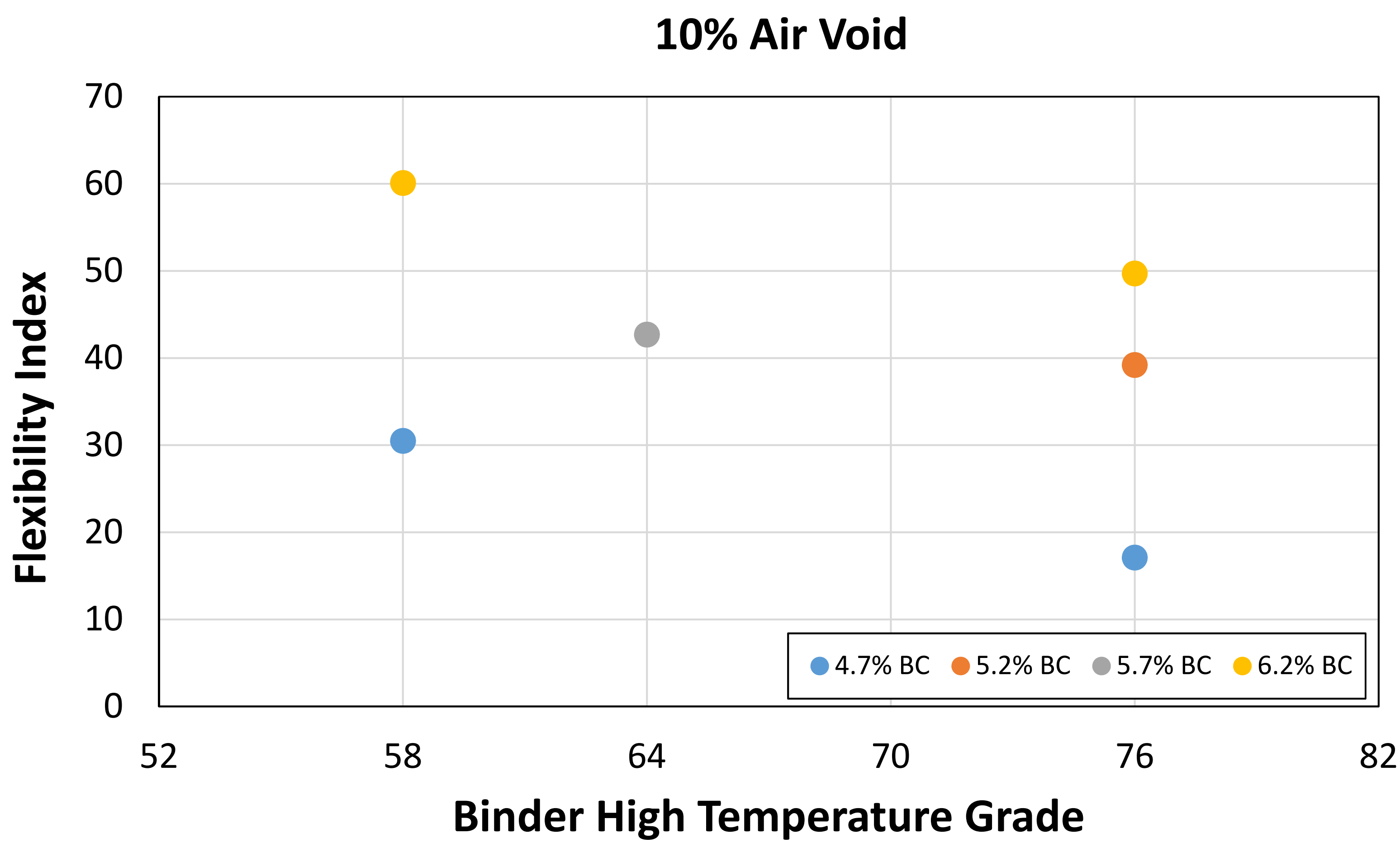
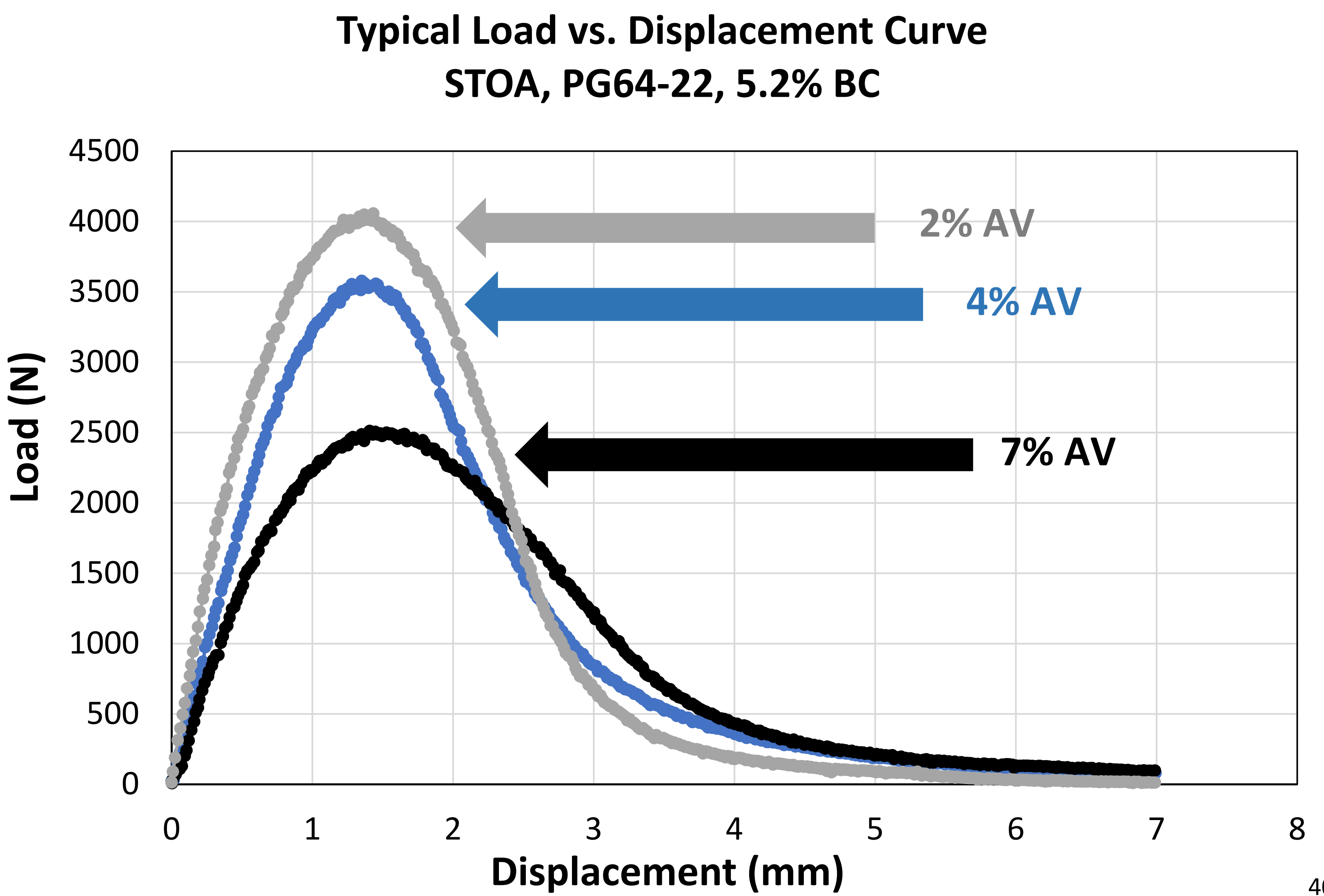
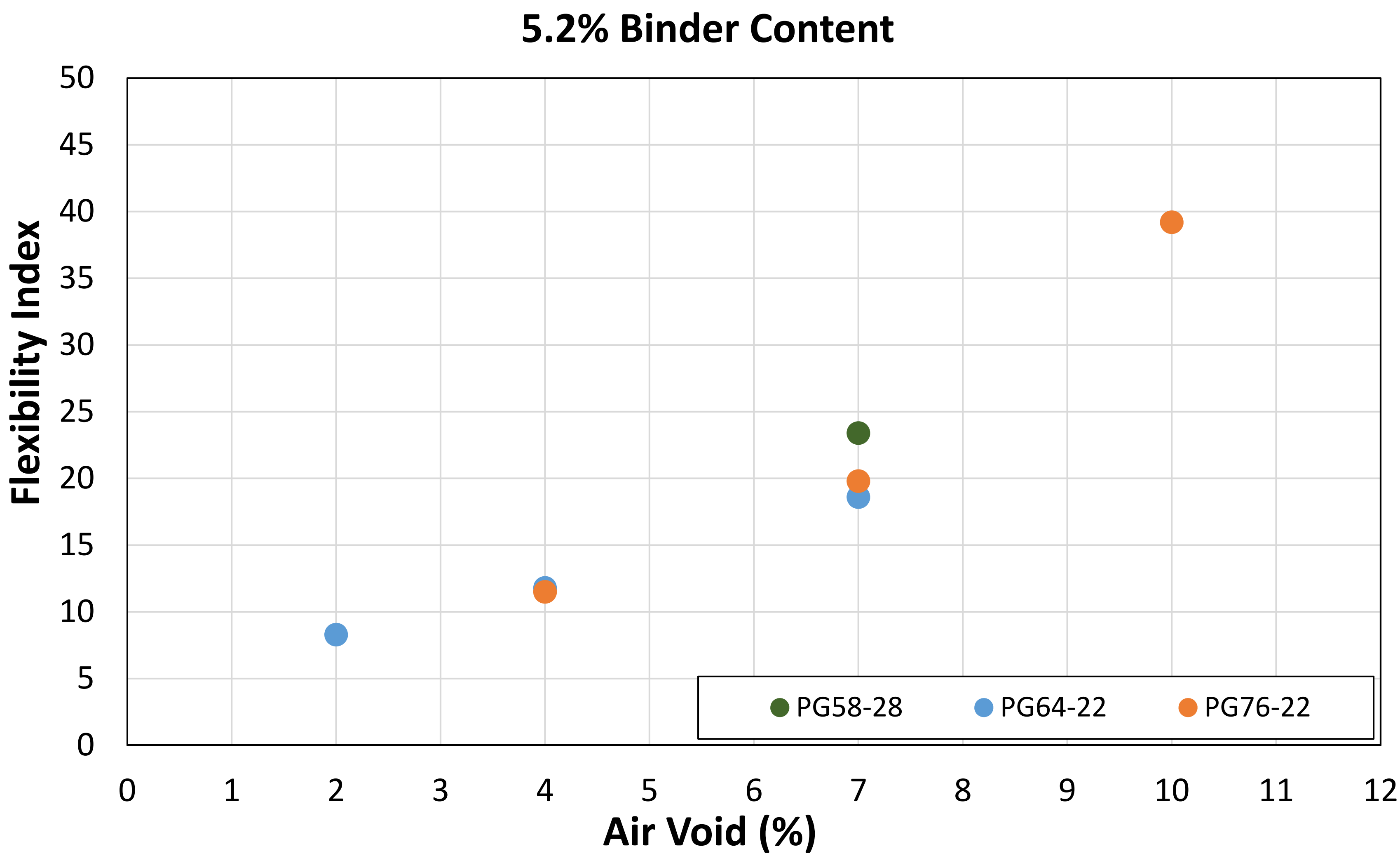


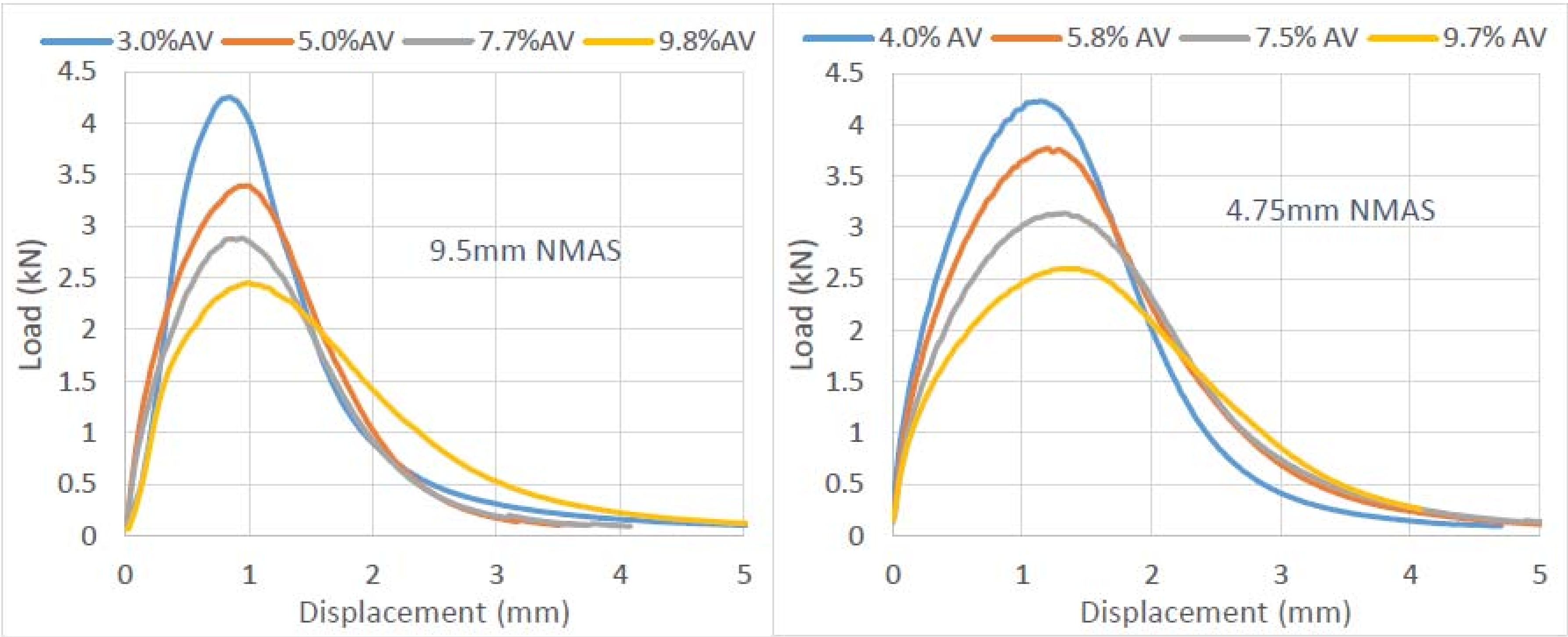
Effect of Air Void



Effect of Air Void

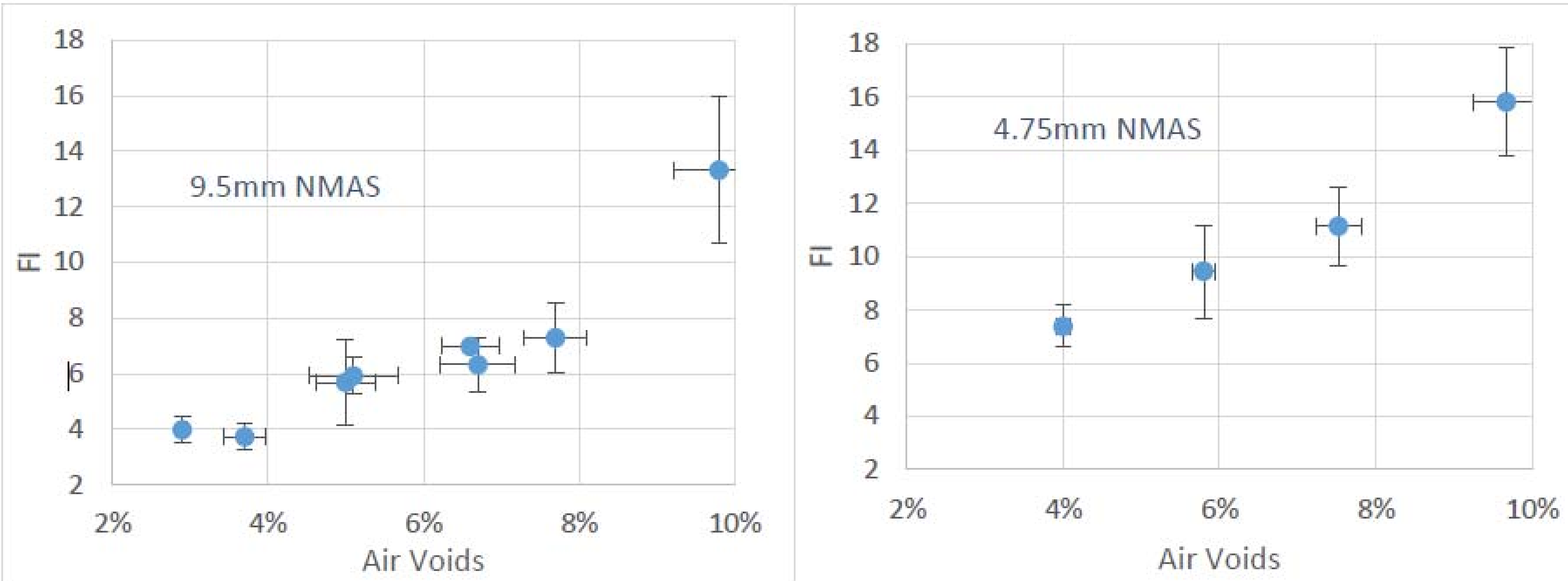


The Effect of Air Void Reported by UIUC



Source: Maxwell 2016

The Effect of Air Void Reported by UIUC



Source: Maxwell 2016

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Where do we go from here?

- Effect of Modifiers
- Effect of RAP/RAS
- Effect of Crumb Rubber
- Plant vs Lab Mixes
- Cataloging PA Mixes
- Correlation with Field Performance

PAPA Proposed Crack Performance Testing

- Virgin vs. 15% RAP mix
- Design Binder vs. +0.5% AC
- Lab mix vs. Production mix
- Short-term vs. long-term aging
- 16 cells in matrix
- Baseline for existing mixes

Thank you!