Characterizing Polymer Modified Asphalt Performance with PG Plus Tests

2020 OAPC Asphalt Symposium

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June 16, 2020

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CPATT
CENTRE FOR PAVEMENT AND TRANSPORTATION TECHNOLOGY

UNIVERSITY OF WATERLOO

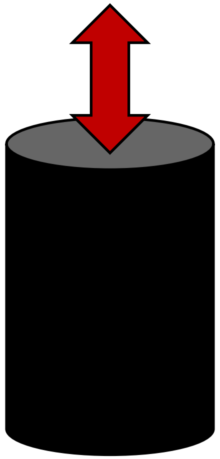
Physical Properties of PMA

Stiffness

- Increases
- Improves rutting resistance
- Can improve fatigue cracking resistance

Response to Loading

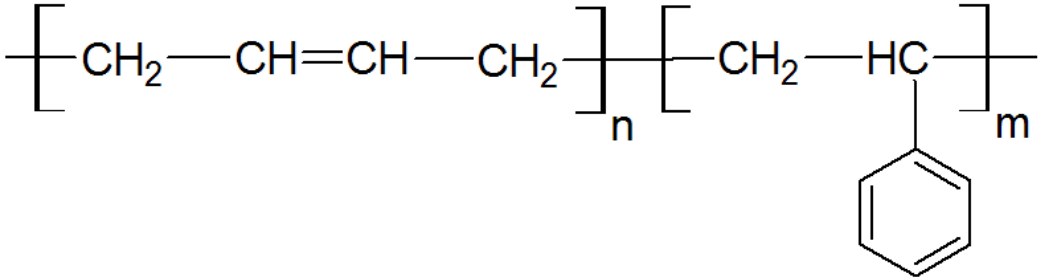
- More elastomeric
- No longer purely ductile/brittle
- Improves cracking resistance



Coil- speedwaymotors.com
Pavement Distresses- pavementinteractive.com

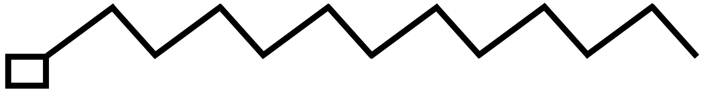
Styrene-Butadiene-Styrene

Butadiene Styrene

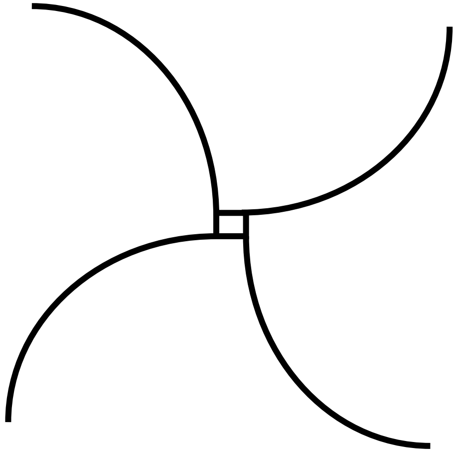


- Thermoplastic- Rubber
- Good solubility in asphalt (Hildebrand parameters are similar)
- Glass Transition Temperature (Tg) of -90˚C

Linear



Radial



SBS Structure- polymerdatabase.com

PMA Compatibility

- Good compatibility causes swelling of SBS chains (increase in volume fraction)
- Good compatibility causes increase in stiffness and elastomeric properties

Asphalt Cement Chemistry

- Different crude sources result in asphalt with different chemistries
- Increase in aromatic fraction can improve compatibility

SBS Microstructure

- Molecular weight can effect dispersion in asphalt
- Styrene content can effect level of swelling

Cross-linking Agents

- Generally improve SBS stability
- Can improve quality of polymer network

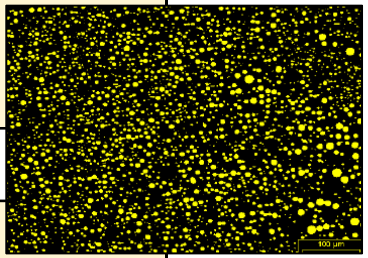
Increasing Compatibility

Images- Planche, Elwardany, Adams, Rovani, Boysen, “Compatibility in Asphalt – A moving Target with Sources, Modifications and Aging”, TRB Annual Meeting, January 13, 2020

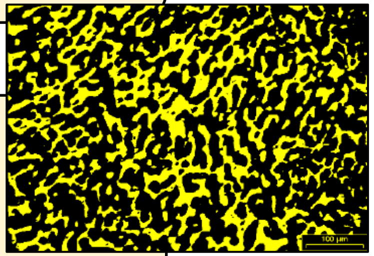
How much SBS do we need?

Performance increases as concentration increases

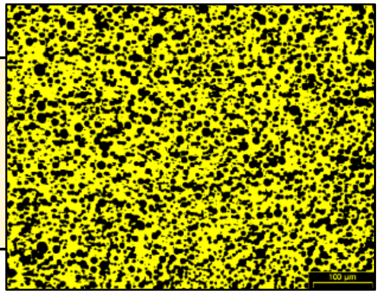
0 – 2%
- Small increase in stiffness
- Not enough to improve elastomeric properties



2 – 4%
- Asphalt continuous phase
- Noticeable improvement to elastomeric properties



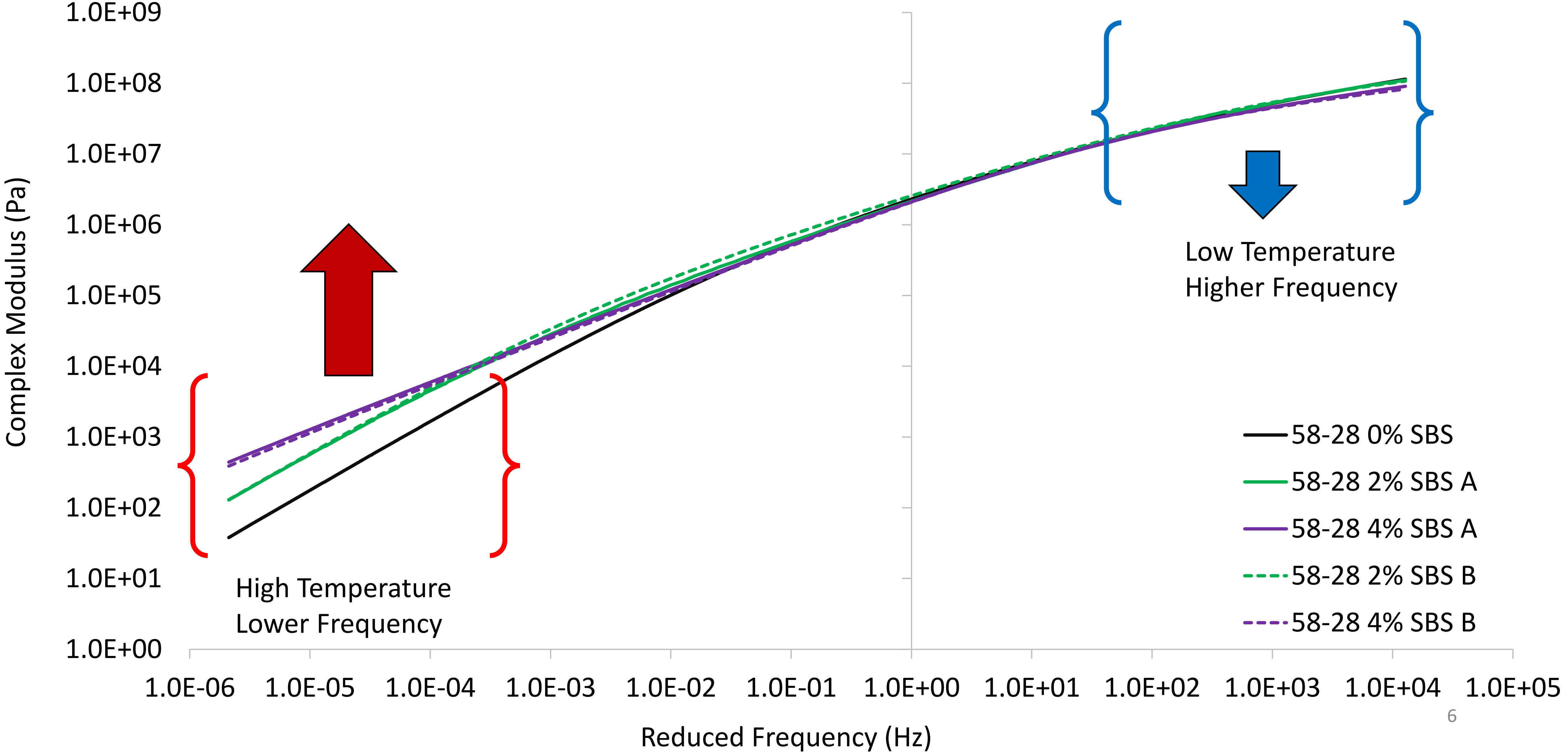
4 – 6%
- Co-continuous phases
- Possibility of instability?



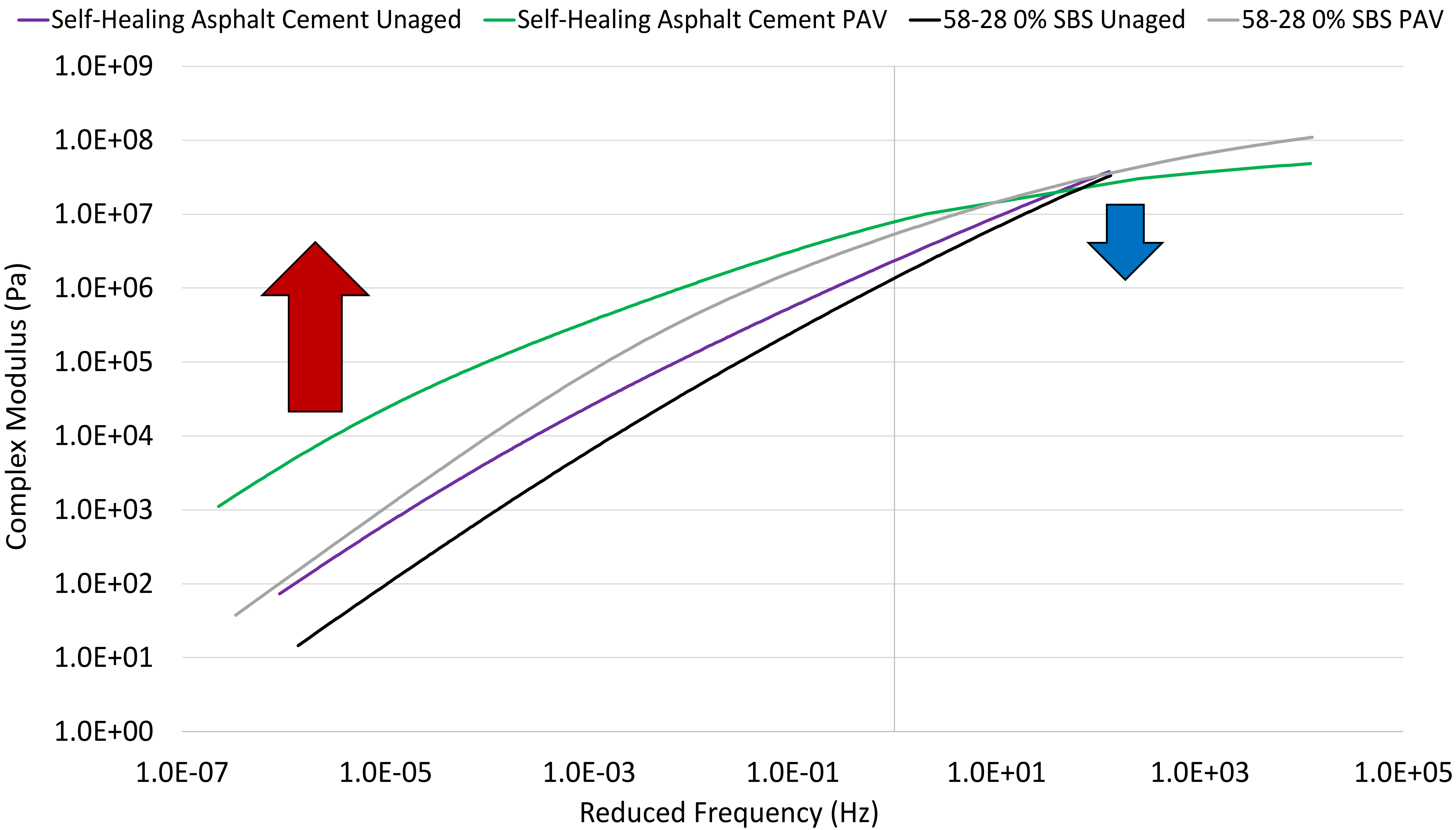
6 – 8%
- Polymer continuous phase
- Great performance but expensive

Images- Planche, Elwardany, Adams, Rovani, Boysen, "Compatibility in Asphalt – A moving Target with Sources, Modifications and Aging", TRB Annual Meeting, January 13, 2020

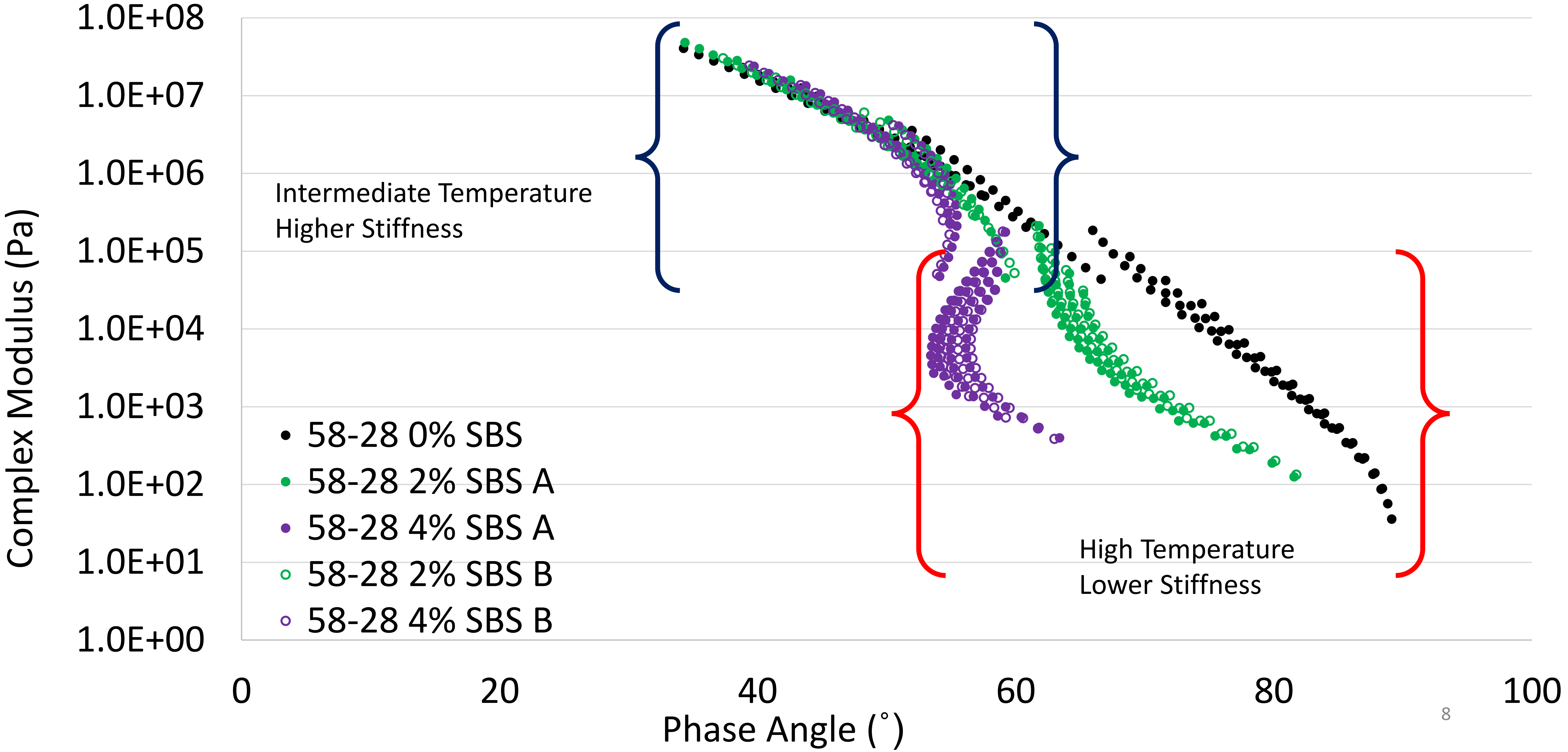
PMA Master Curve



Aging Master Curve



PMA Black Space Diagram



Experimental Design

5 Asphalt Cements:

- PG 58-28
- PG 64-28
- PG 52-34
- PG 58-28B
- PG 52-34B

2 SBS Sources:

- SBS A
- SBS B

Concentrations:

0, 1, 2, 3 and 4%

RTFO

Large Strain Amplitude Rutting Test:

- MSCR

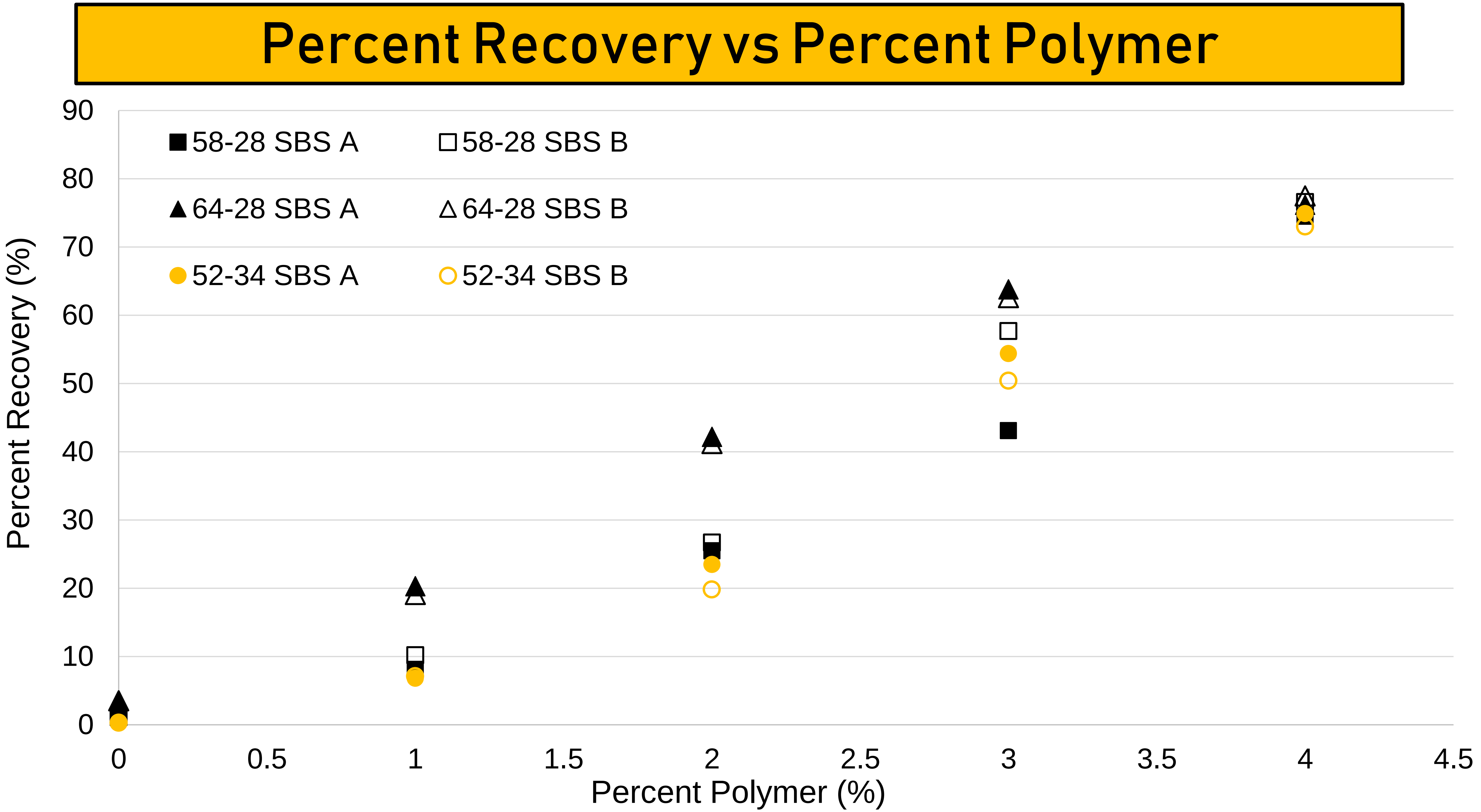
20 Hour PAV

Low Strain Amplitude Cracking Tests:

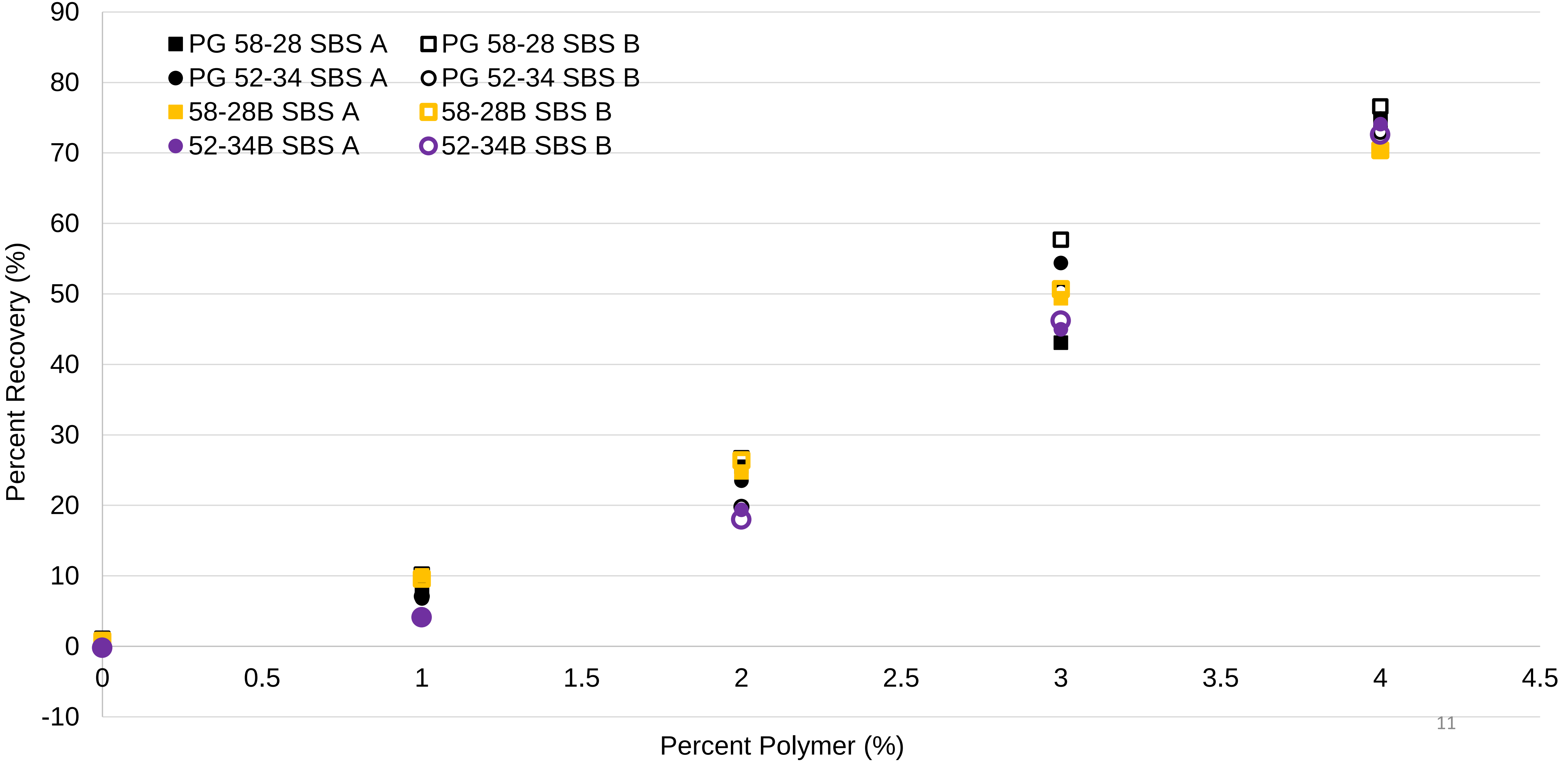
- DENT
- ΔT_c / ExBBR
- Glover-Rowe Parameter
- Cross-Over Temperature

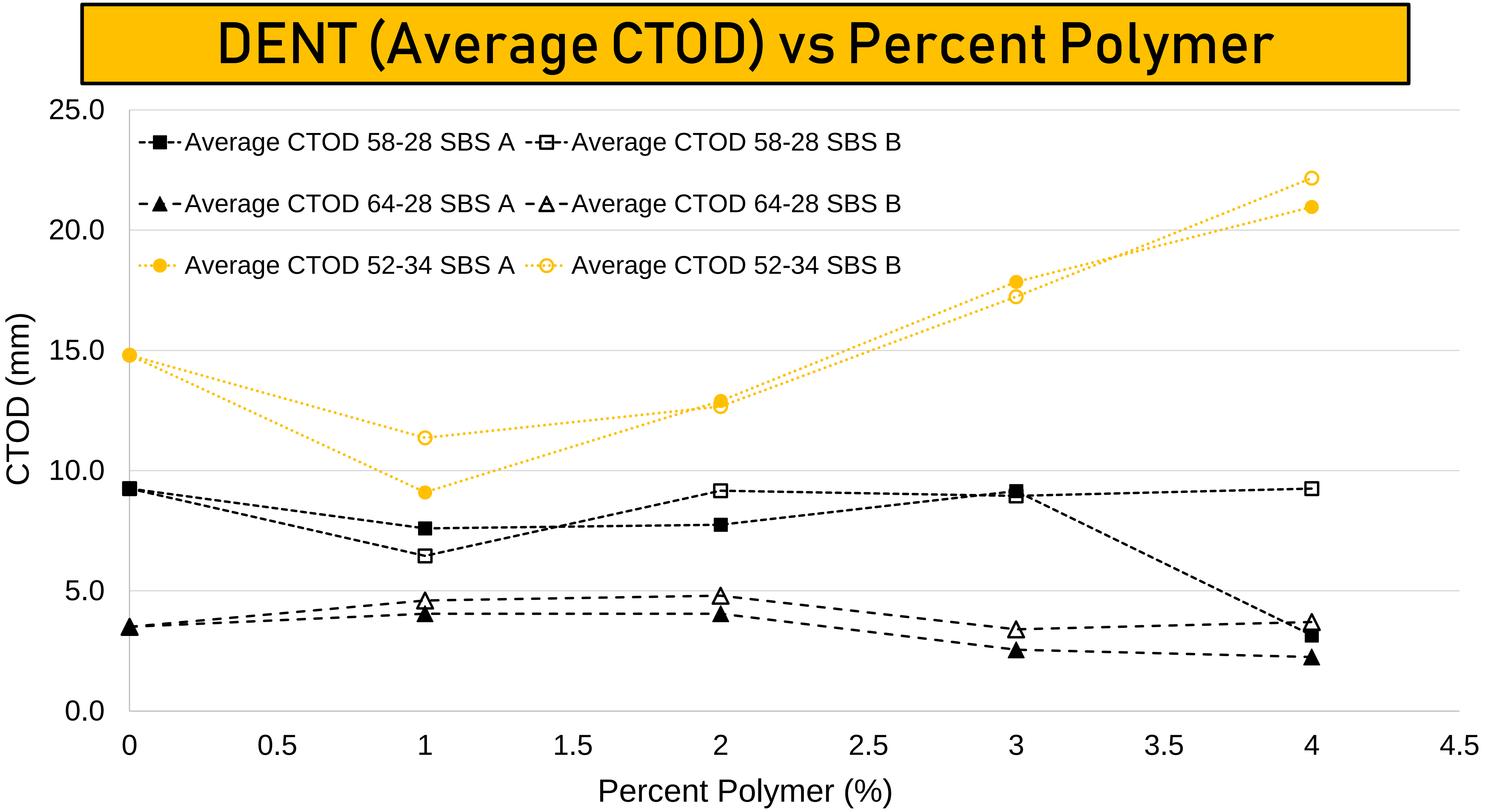
Large Strain Amplitude Cracking Tests:

- Linear Amplitude Sweep (LAS)
- Asphalt Binder Cracking Device (ABCD)

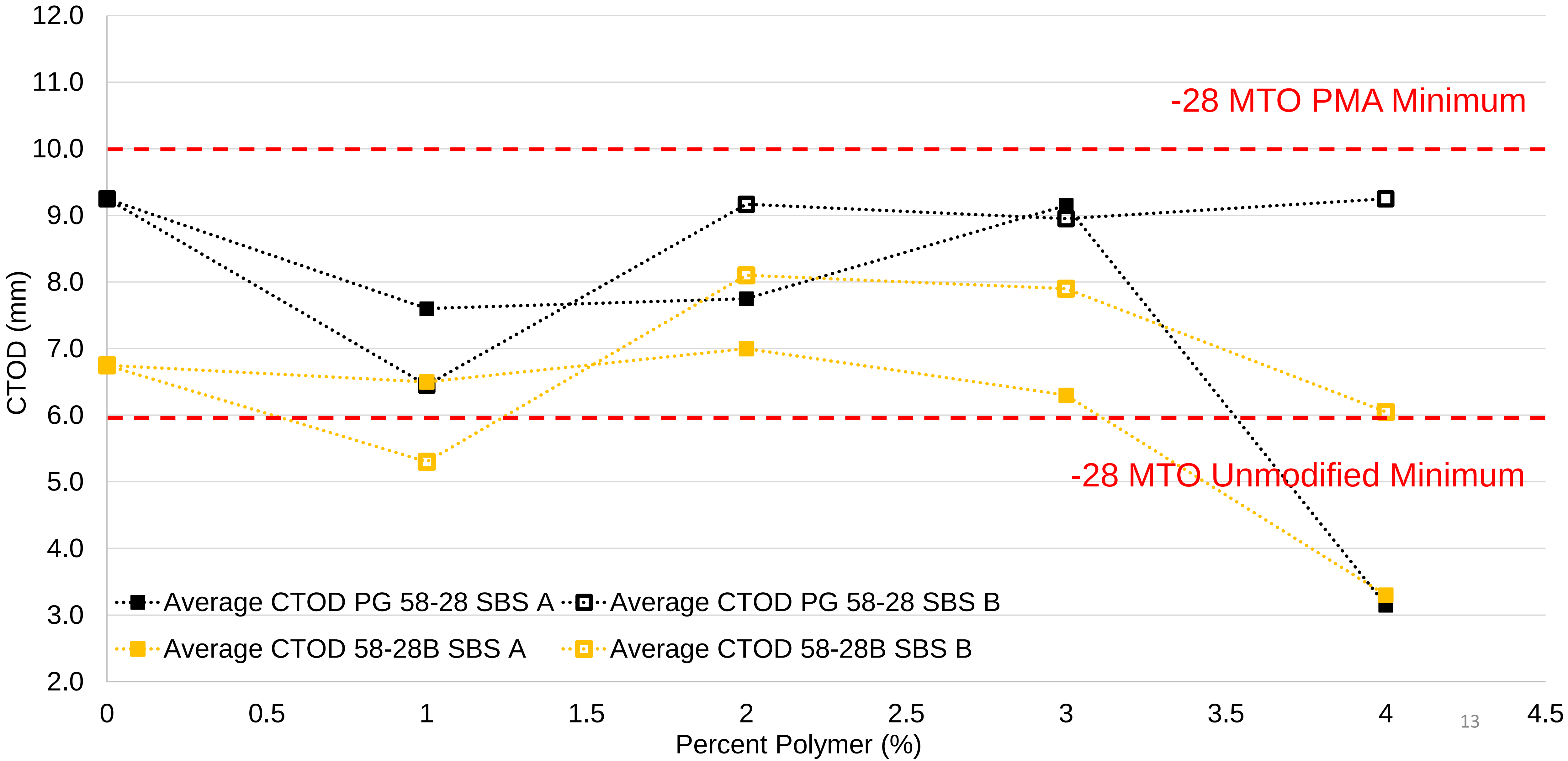

Percent Recovery vs Percent Polymer
58-28 SBS A
58-28 SBS B
64-28 SBS A
64-28 SBS B
52-34 SBS A
52-34 SBS B
Percent Recovery (%)
Percent Polymer (%)
0
10
20
30
40
50
60
70
80
90
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5

Percent Recovery vs Percent Polymer

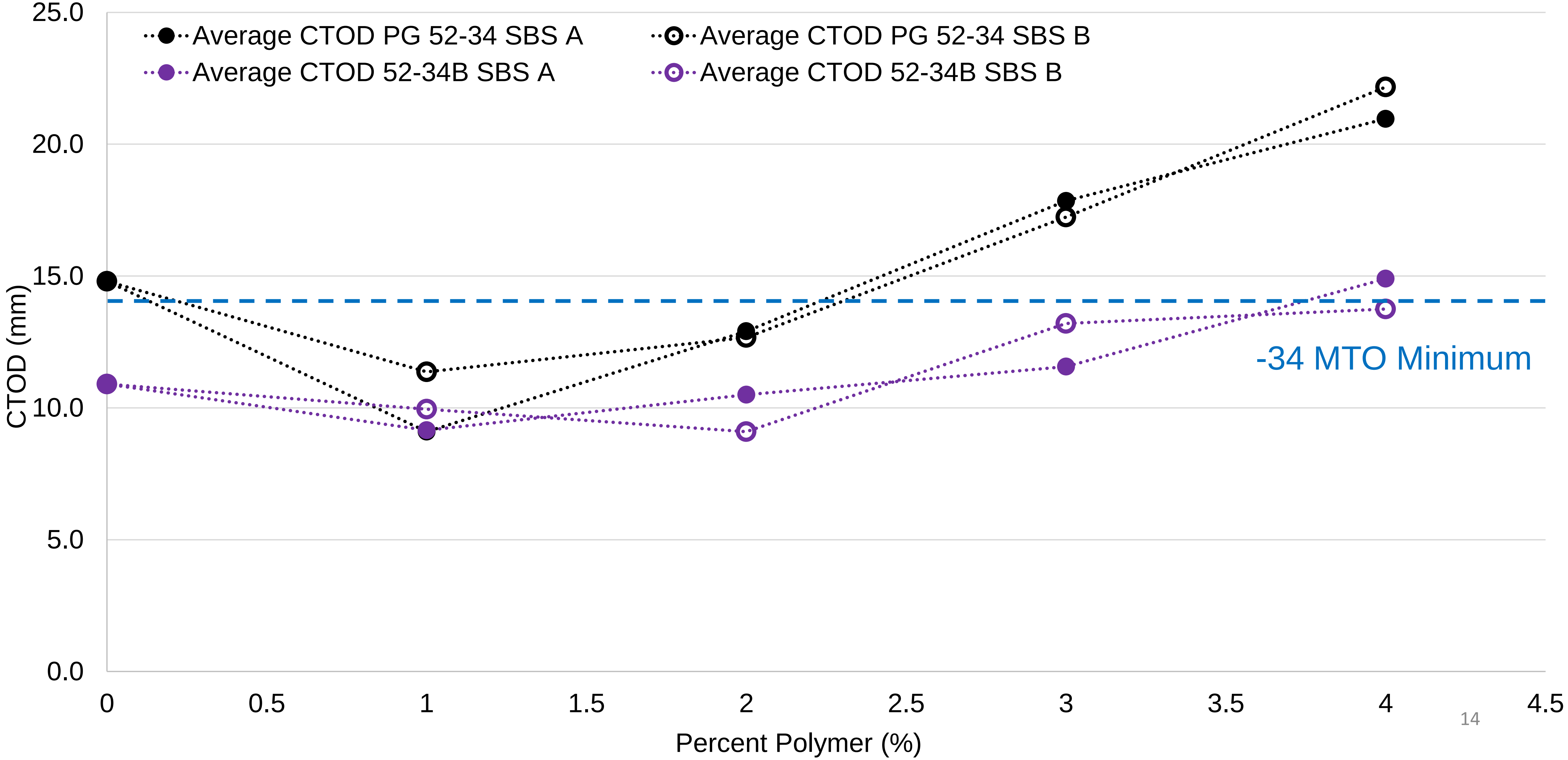



DENT (Average CTOD) vs Percent Polymer
Average CTOD 58-28 SBS A
Average CTOD 58-28 SBS B
Average CTOD 64-28 SBS A
Average CTOD 64-28 SBS B
Average CTOD 52-34 SBS A
Average CTOD 52-34 SBS B
CTOD (mm)
25.0
20.0
15.0
10.0
5.0
0.0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Percent Polymer (%)

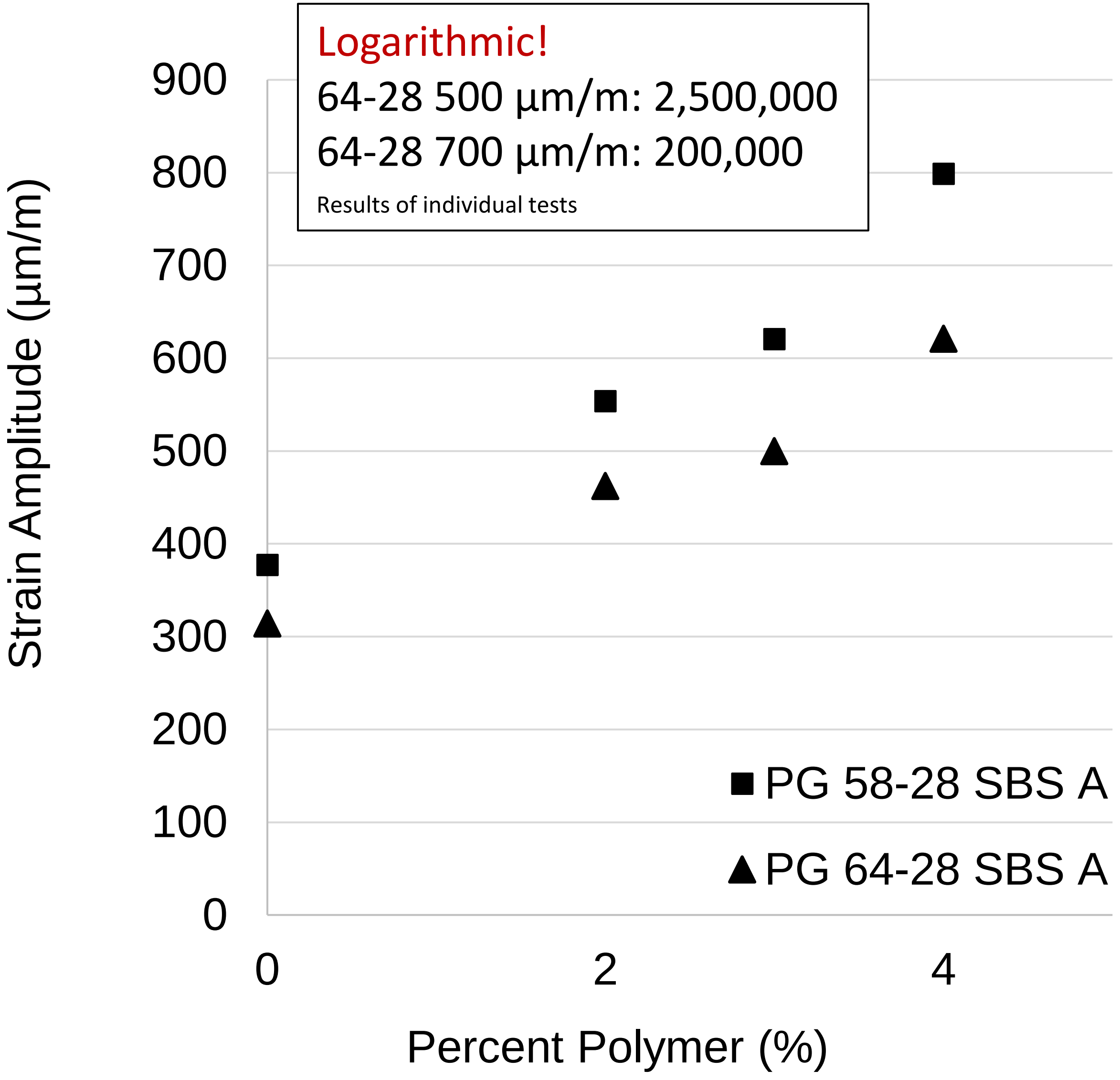
58-28 DENT (CTOD) vs Percent Polymer

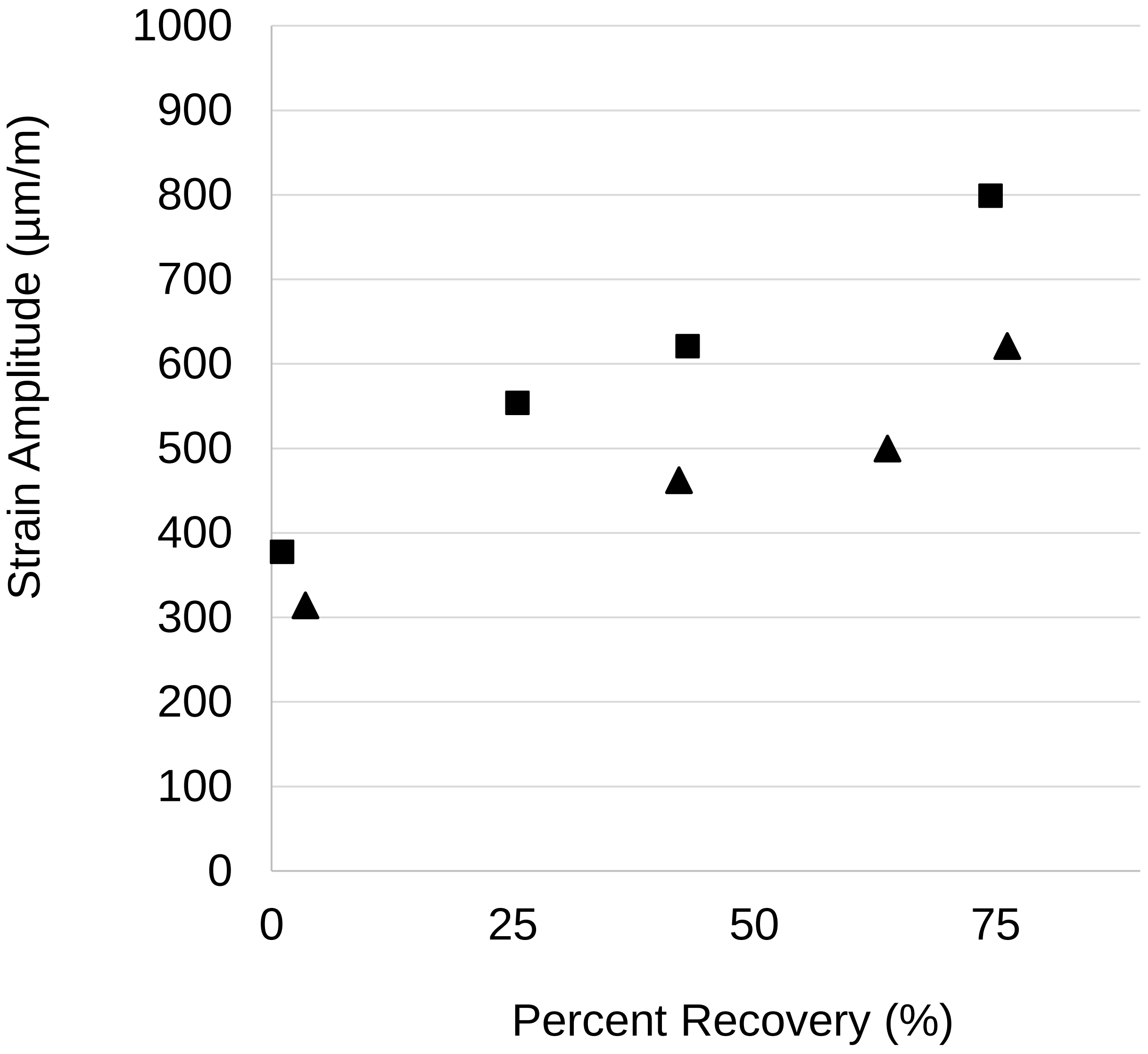


52-34 DENT (CTOD) vs Percent Polymer

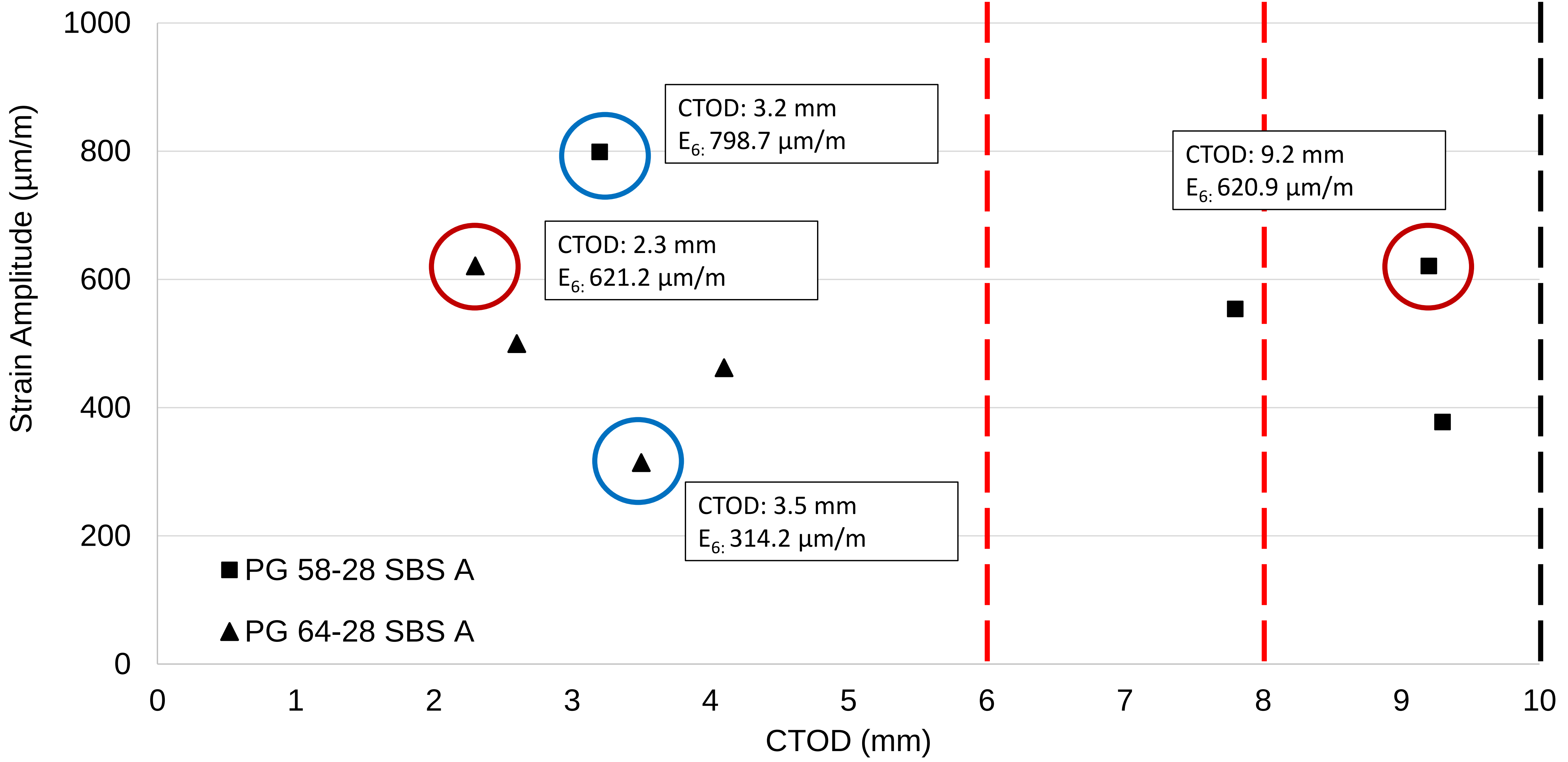


Fatigue Indicator (ε_6) vs Percent Polymer and Recovery



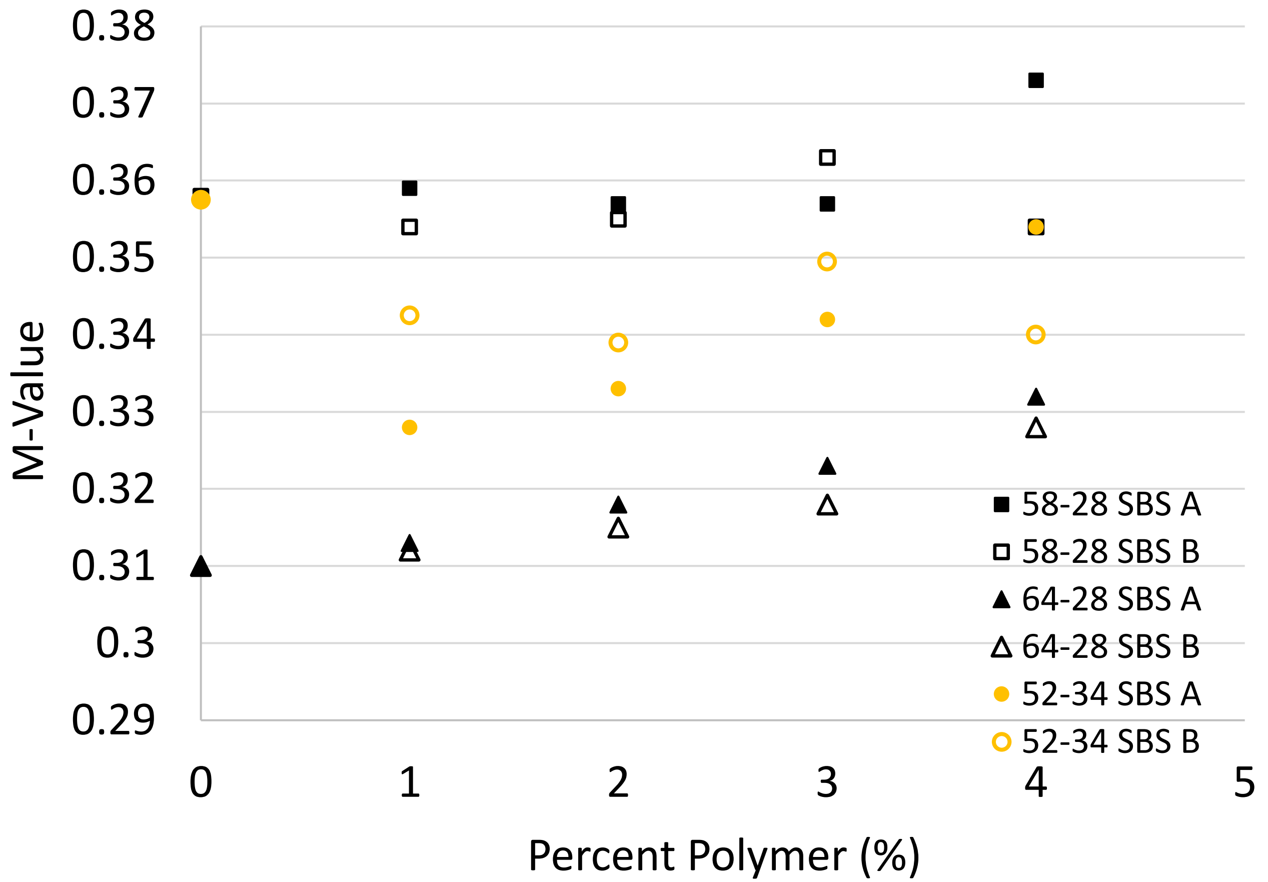


Fatigue Indicator (ε_6) vs DENT (CTOD)



Bending Beam Rheometer

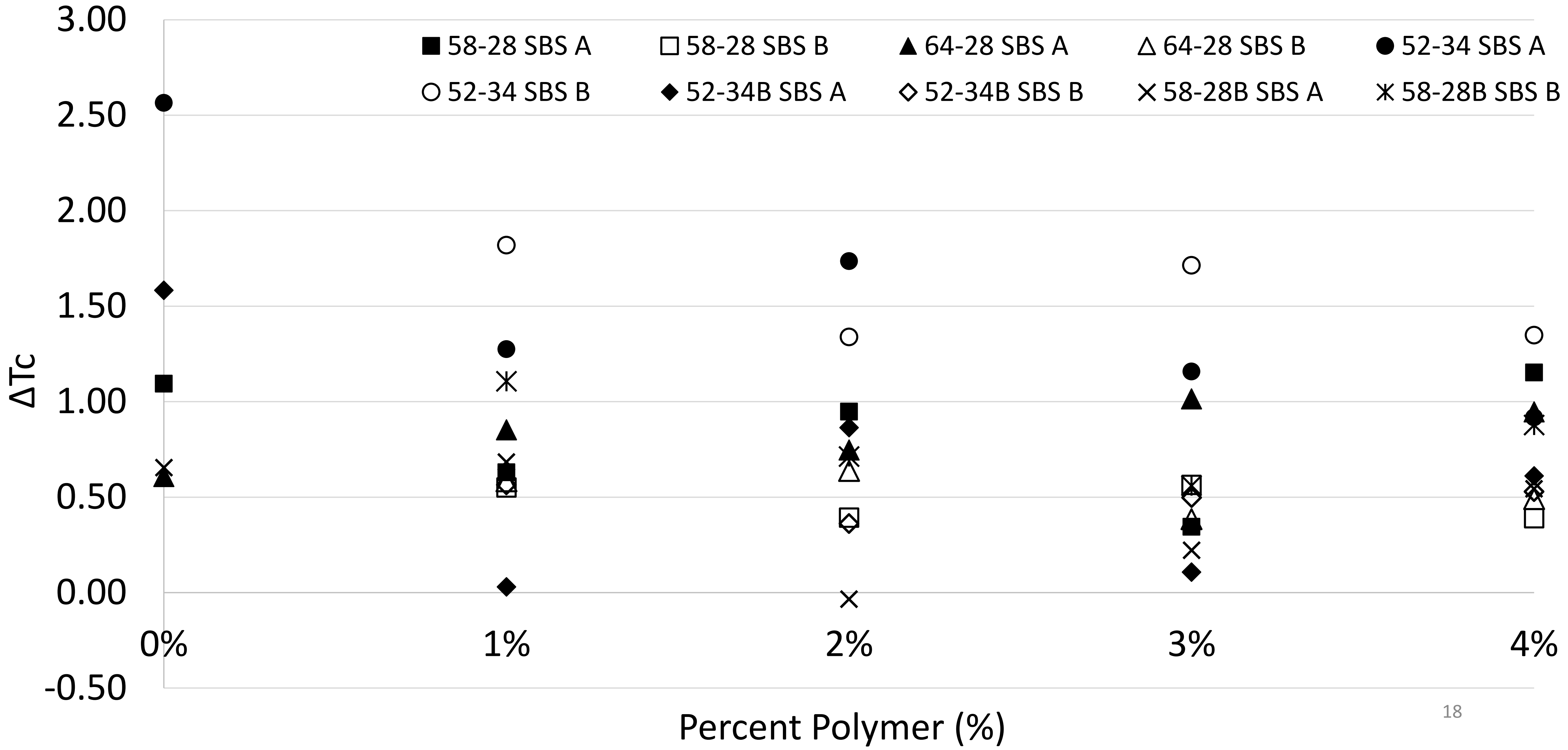
- Used to determine Low Temperature Grade, ΔT_c, Low Temperature Limiting Grade and Grade Loss
- Does not characterize SBS modified asphalt very well
- Extended conditioning times does not change shortcomings with measurement



$$\Delta T_c = T_{c,S} - T_{c,m}$$

$T_{c,S}$ – Stiffness Critical Temperature
$T_{c,m}$ – m-Value Critical Temperature

ΔTc vs Percent Polymer



Dynamic Shear Rheometer

- Measures phase angle, modulus (stiffness) with constant shear strain and single frequency
  - High temperature grade does not predict rutting resistance well
  - Intermediate temperature grade does not predict cracking resistance well

Glover-Rowe Parameter

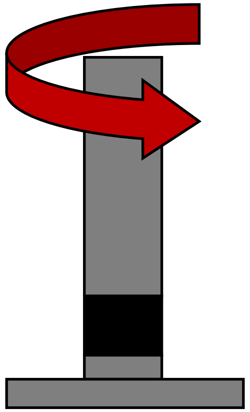
- Taken from master curve data at reference temperature of 15˚C and frequency of 0.005 rad/s
- Damage zone calculated using:

$$G^* \ (\cos\delta)^2/\sin\delta = 180 \text{ kPa}$$

$$G^* \ (\cos\delta)^2/\sin\delta = 600 \text{ kPa} \ \text{ or } 450 \text{ kPa}$$

Cross-Over Temperature

- Temperature at which the phase angle of PAV aged material reaches 45°
- Phase Angle:
  - 0˚ = purely elastic
  - 45˚ = transition between more viscous and more elastic behaviour
  - 90˚ = purely viscous



Black Space Diagrams- Close Ups!

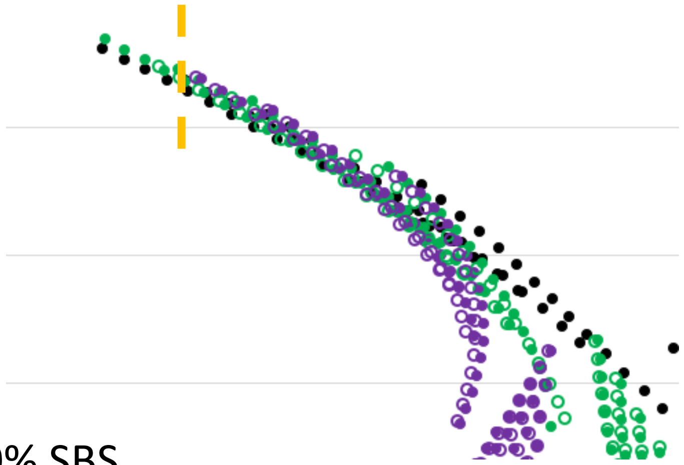
Black: 0% SBS

Green: 2% SBS

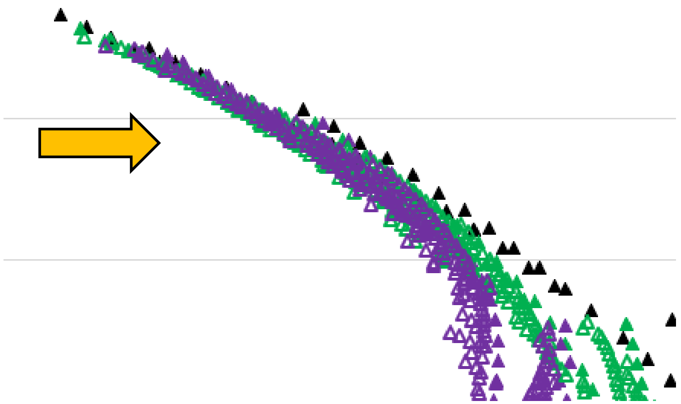
Purple: 4% SBS

Y-Axis: Complex Modulus

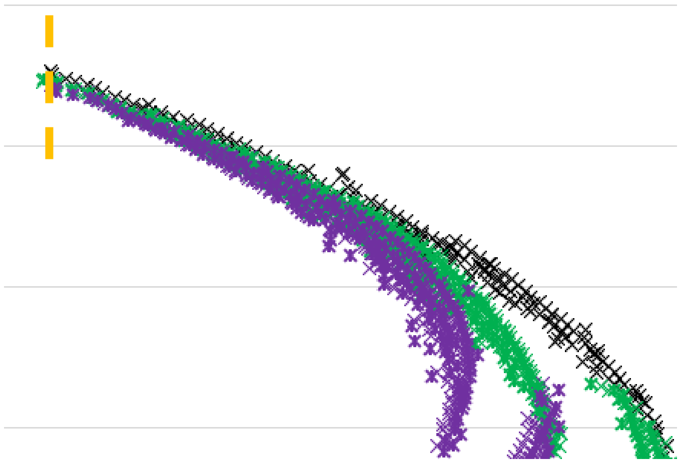
X-Axis: Phase Angle



58-28



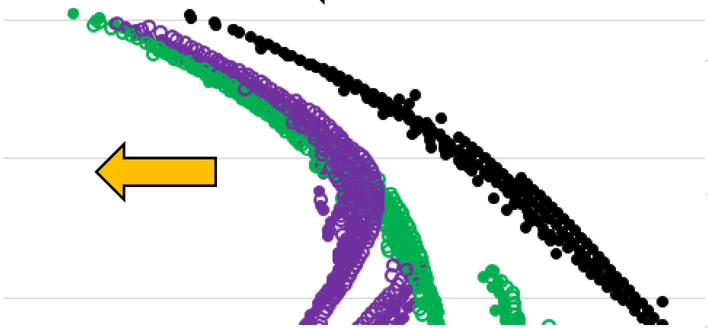
64-28



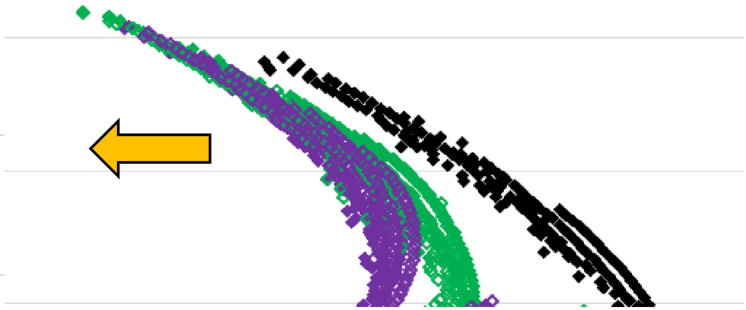
58-28B

Phase Angle Decreases

Phase Angle Increases

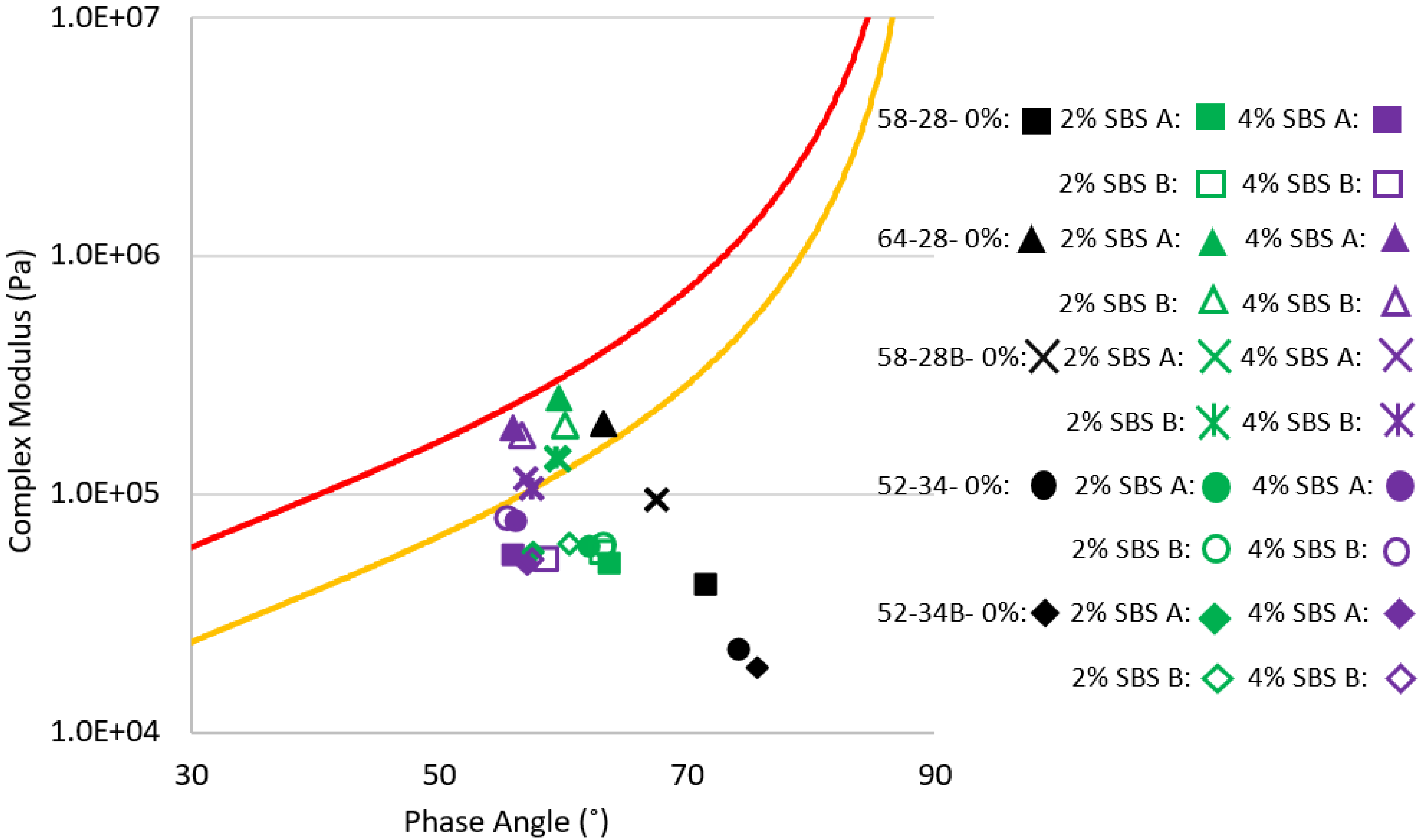


52-34

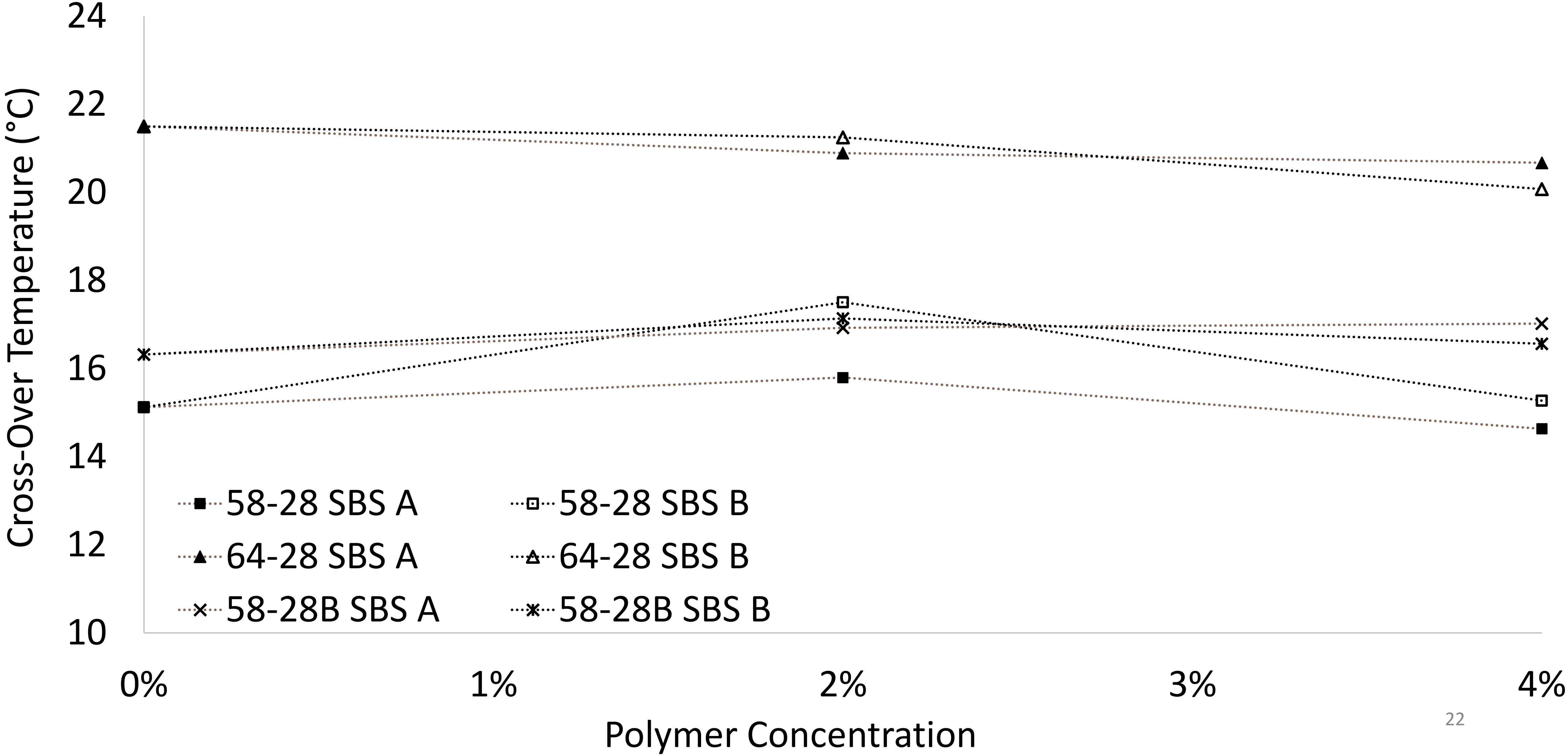


52-34B

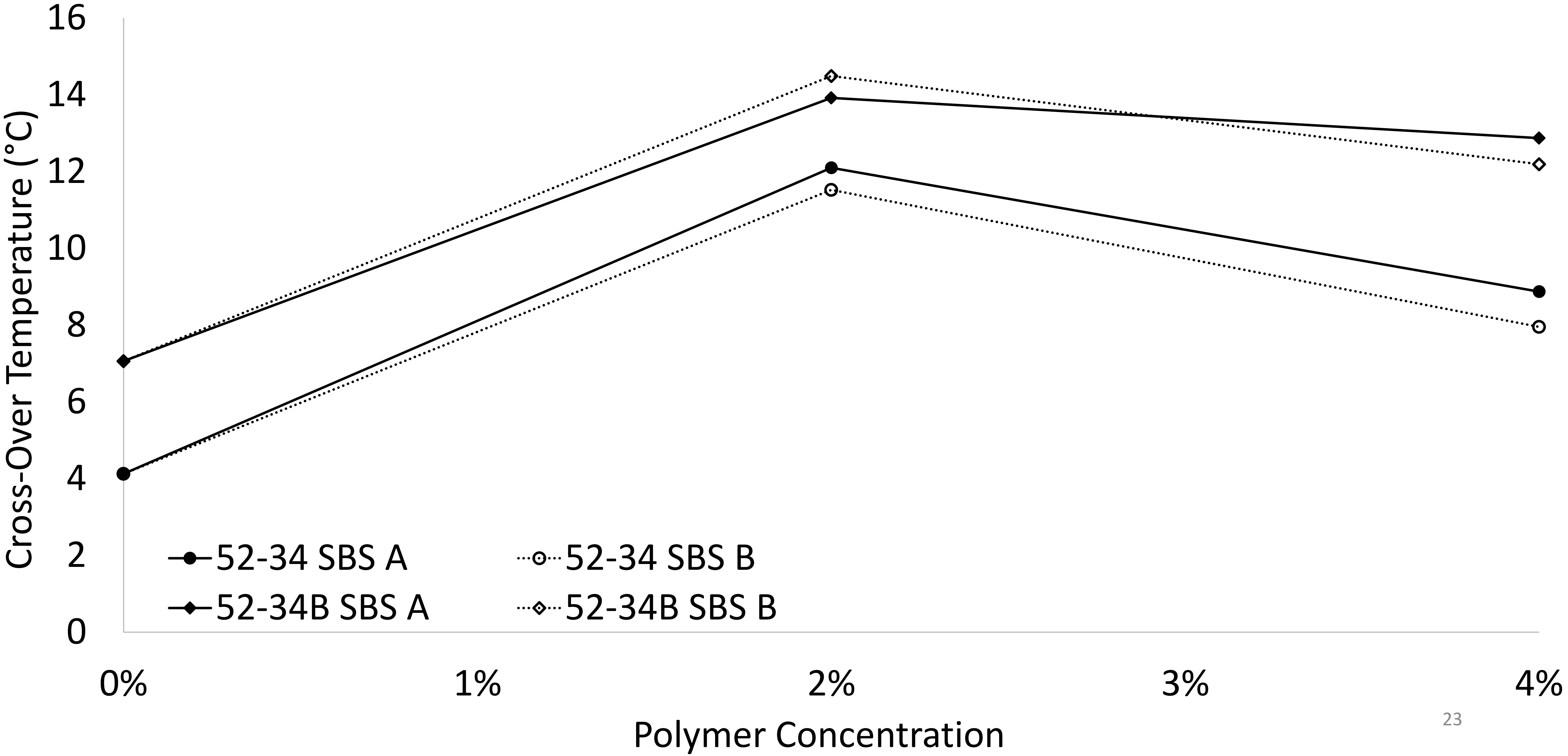
Glover-Rowe Parameter vs Percent Polymer



Cross-Over Temperature vs Percent Polymer



Cross-Over Temperature vs Percent Polymer



Linear Amplitude Sweep

- Part 1: Frequency Sweep- gives initial binder properties
- Part 2: Amplitude Sweep- cyclic loading ramps up from 0.1% to 30% applied strain
    - Binder begins to crack at edge of sample
- AASHTO TP 101
- **Two approaches to data analysis:**

Viscoelastic Continuum Damage Model (VECD)

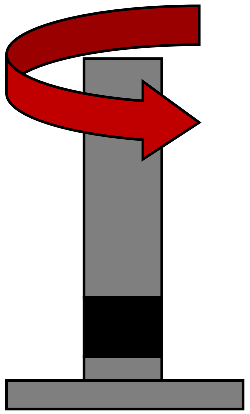
- Number of Cycles to Failure

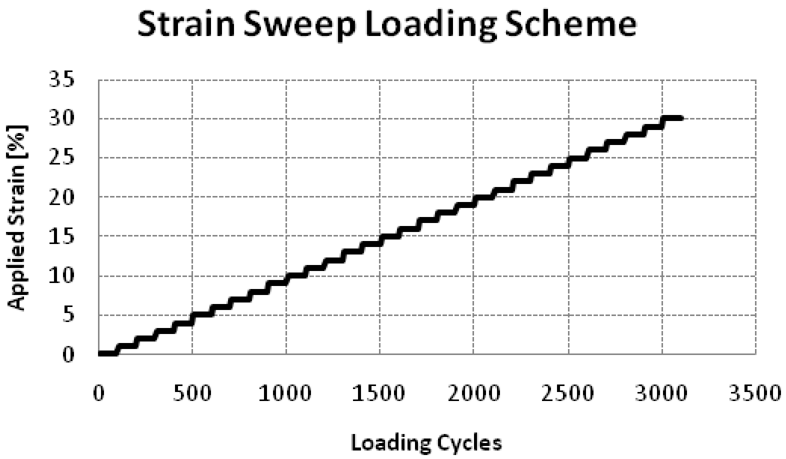
$$N_f = A(\gamma_{max})^B$$

Fracture Mechanics Approach

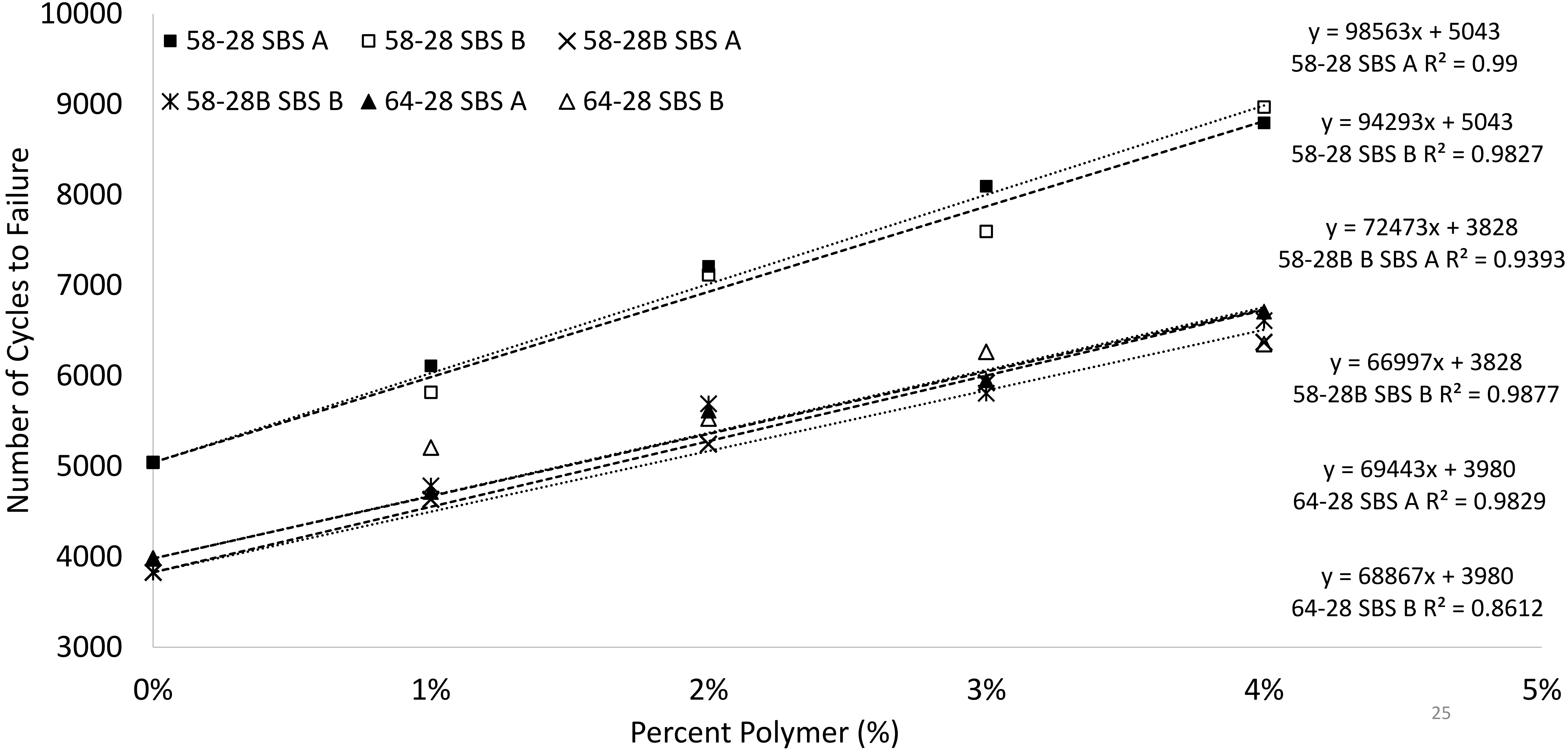
- Fatigue Resistance Energy Index (FREI)

$$FREI = \frac{J_{f-\tau_{max}}}{G_{0.5\tau_{max}}} \cdot \left(\gamma_{0.5\tau_{max}}\right)^2$$

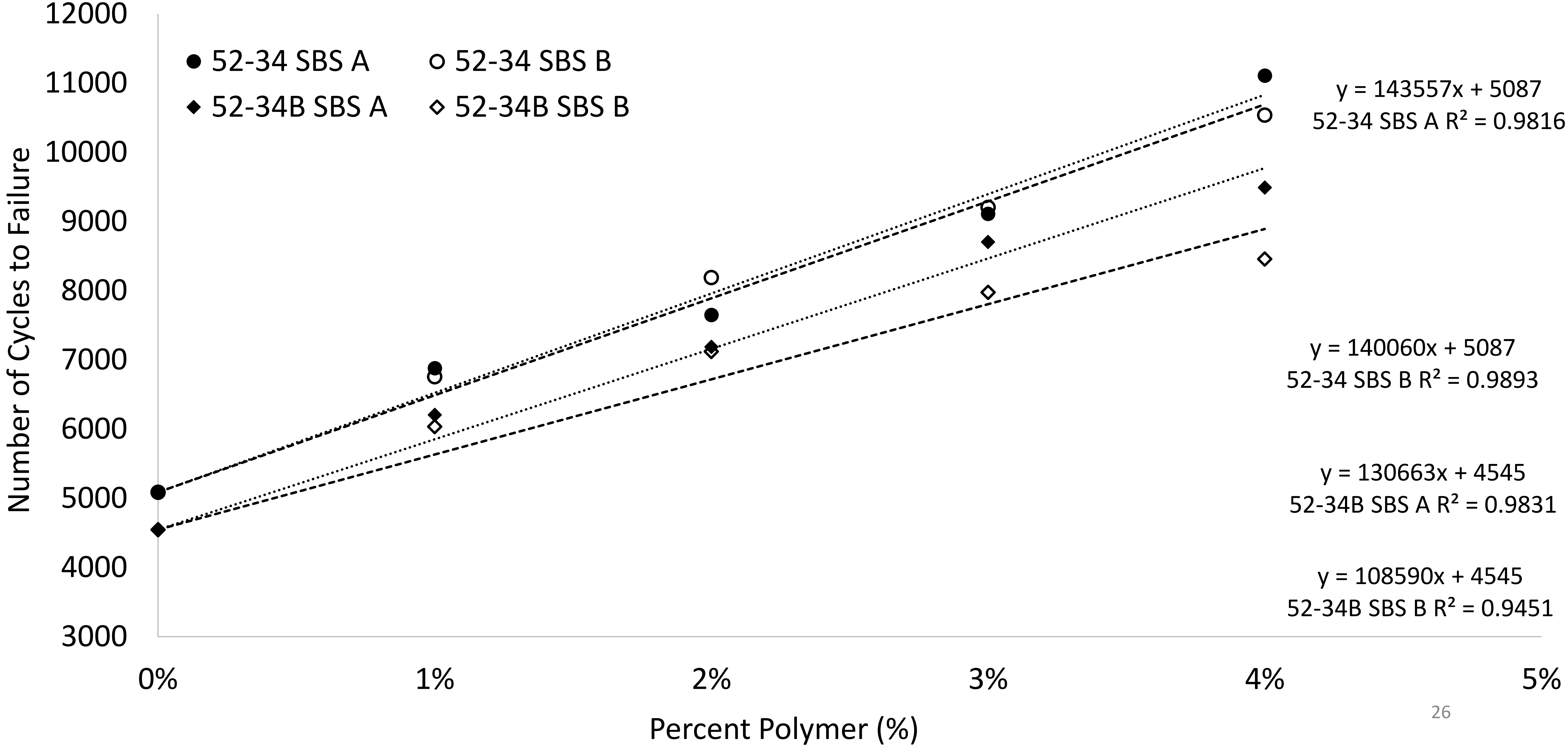




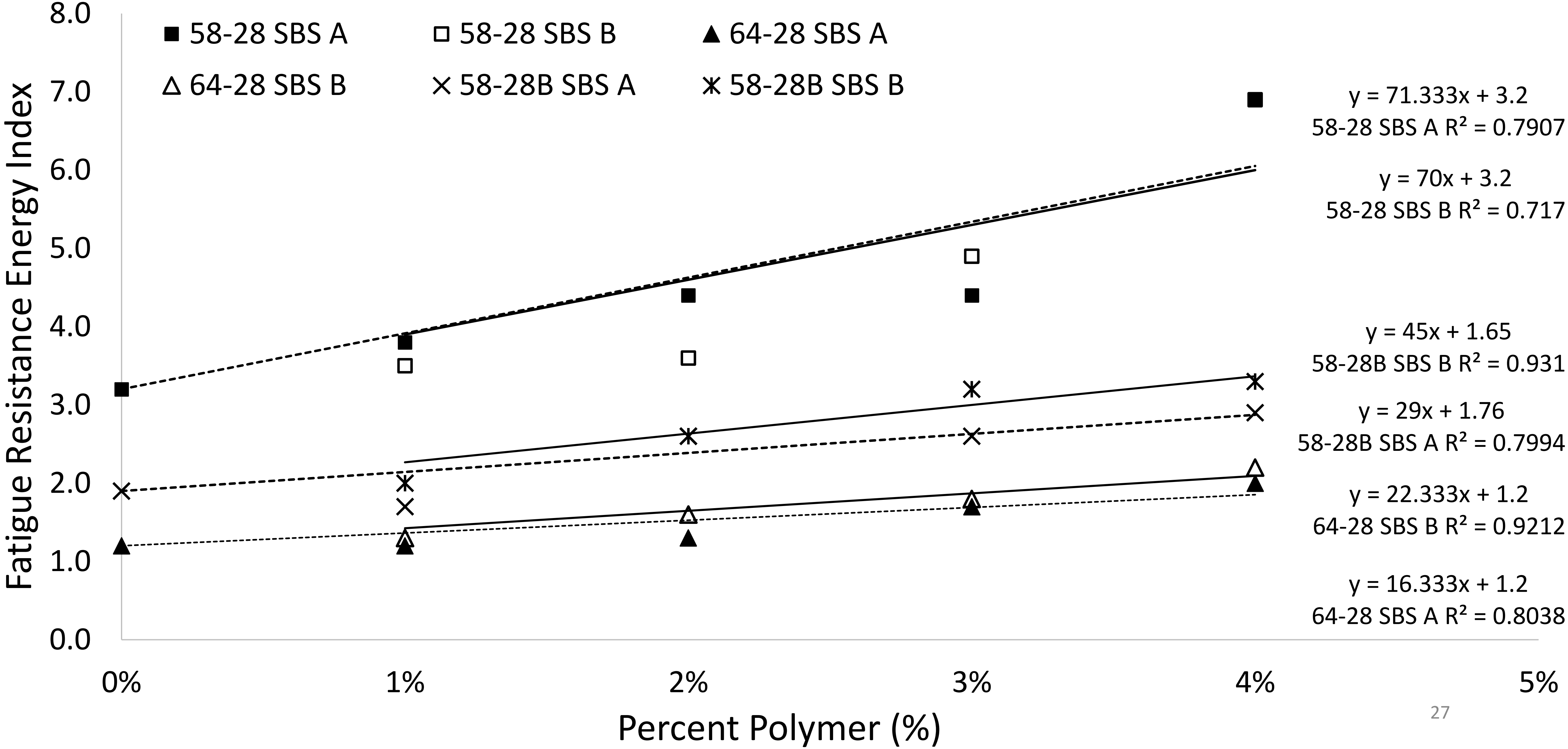
LAS (Number of Cycles to Failure) vs Percent Polymer



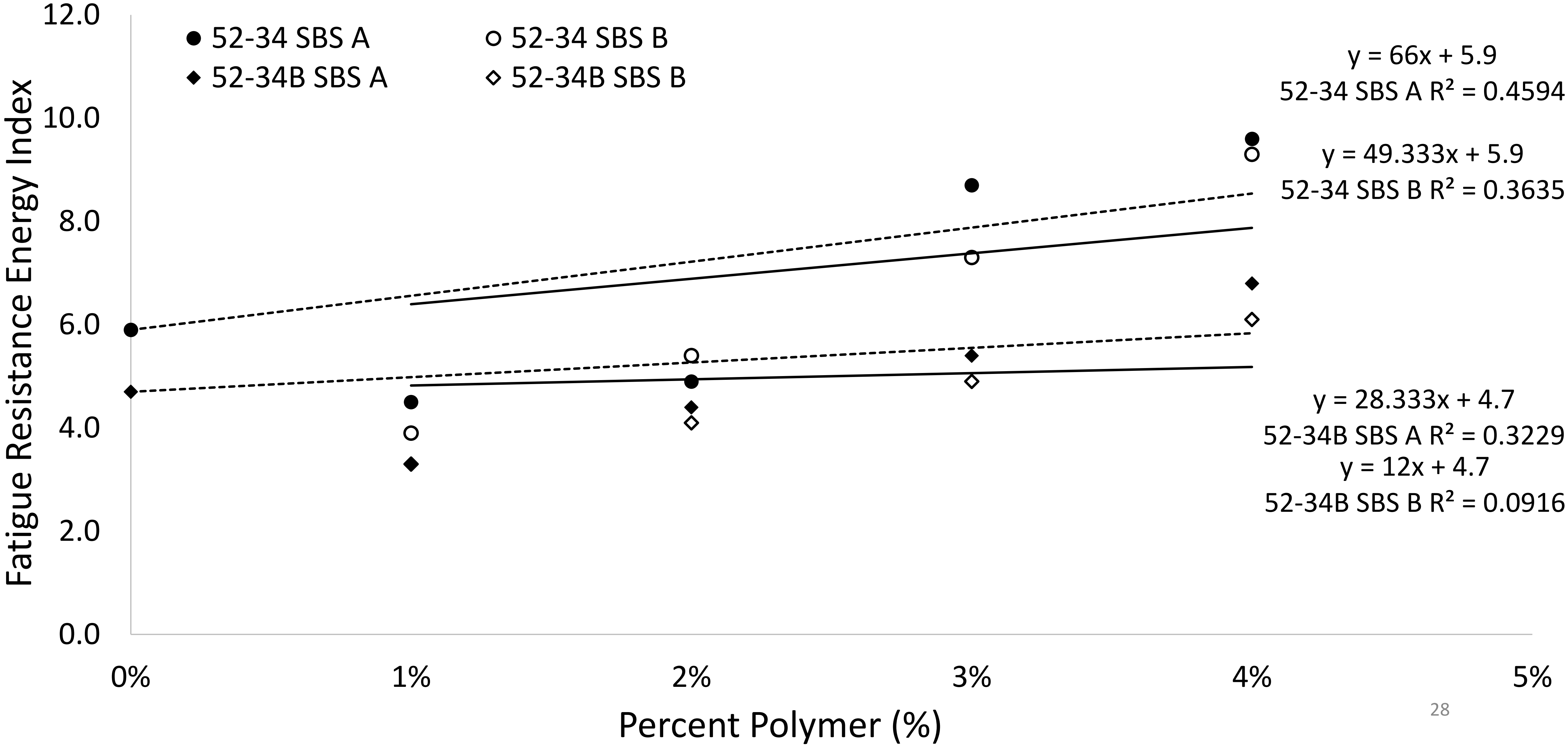
LAS (Number of Cycles to Failure) vs Percent Polymer



LAS (FREI) vs Percent Polymer



LAS (FREI) vs Percent Polymer



Asphalt Binder Cracking Device

- ABCD critical temperature based on modulus, phase angle, thermal coefficient of contraction and failure strength of binder
- Proposed to replace Direct Tension Test
- Sample is cooled at constant rate of -10˚C until cracking occurs
- AASHTO TP 92

15g X 3-4 Rings
= 1 additional PAV pan

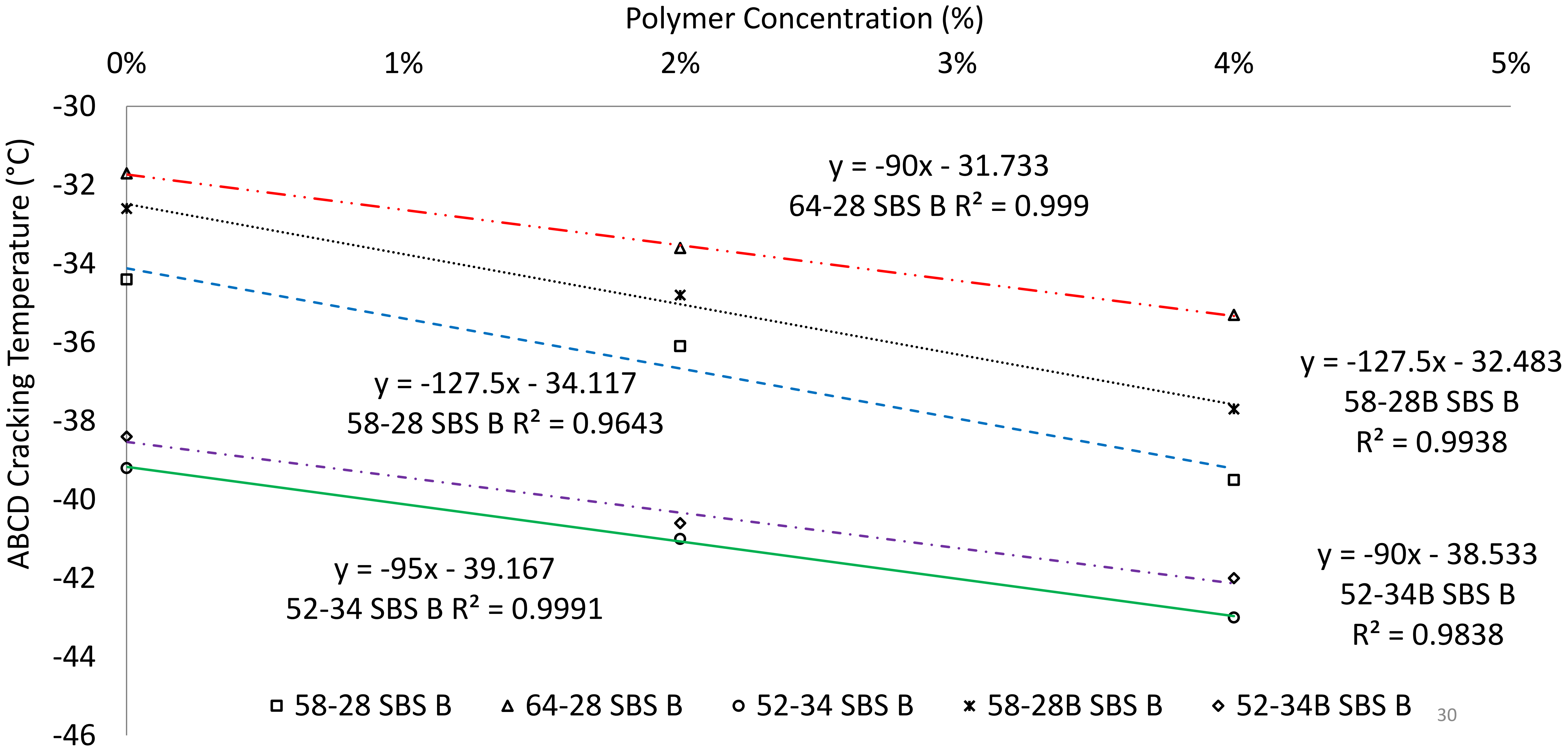
$$\Delta T_f = T_{c,S} - T_{cr}$$

(BBR) (ABCD)

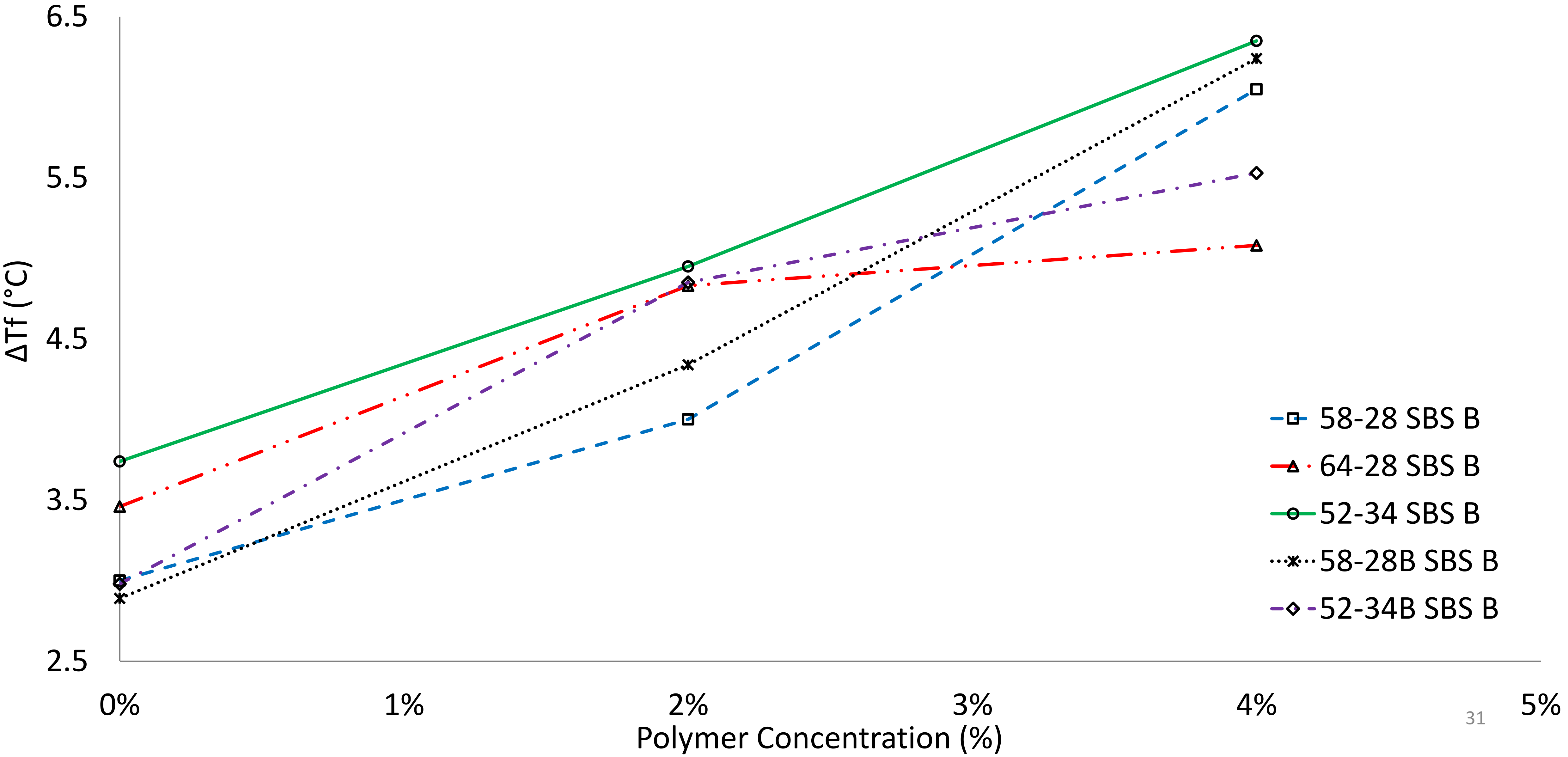
Western Research INSTITUTE

Elwardany, Planche and King, "A Tale of Two Deltas: Toward a Universal "Blind" Framework for Asphalt Durability", TRB Annual Meeting, January 13, 2020

ABCD (T_{cr})vs Percent Polymer



ABCD (ΔT_f)vs Percent Polymer



Unmodified Asphalt Rankings

58-28B ≈ 64-28 58-28 52-34B 52-34

Less ΔT_c Cracking Resistance More

64-28 58-28B 58-28 52-34B 52-34

Less Cross-Over Temperature Cracking Resistance More

58-28B ≈ 64-28 58-28 52-34B 52-34

Less LAS Cracking Resistance More

64-28 58-28B 58-28 52-34B 52-34

Less ABCD Cracking Resistance More

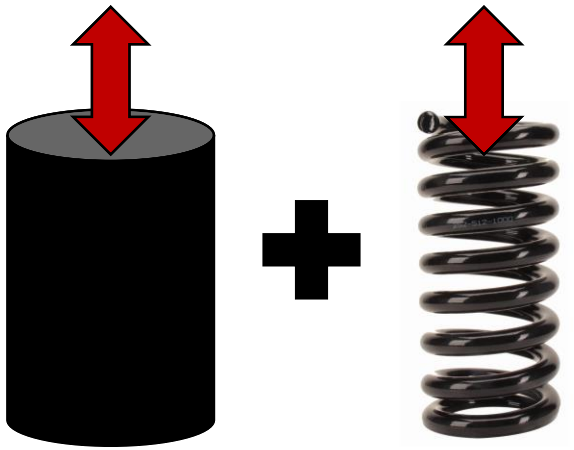
Rankings are relative to each other, not definitive measures of performance

Conclusions

- SBS polymer modified asphalt has a fundamentally different behaviour than unmodified asphalt
  - It is more elastomeric than purely ductile

- Low strain tests and parameters which operate in the linear viscoelastic region seem to be unable to characterize SBS modified asphalt well
  - High temperature grade, low temperature grade, DENT, ΔT_c / Extended BBR, Cross-Over temperature

- Large strain tests produce conditions more comparable to the strains observed in pavements and seem to improve characterization of SBS polymer modified asphalt
  - MSCR, LAS (VECD or fracture mechanics approach) and ABCD



Recommendations

Simpler Binder Characterization

- Single specification across Ontario would be optimal
- AASHTO M 332 would increase simplicity of rutting characterization
- MSCR is suitable for evaluating SBS concentration
- Ash content is suitable for limiting REOB

- More frequent?
  - Increasing simplicity could allow for resources to be reallocated to more frequent testing if desired

+

Mixture Characterization

- Best form of characterization
- Will require multiple years of coordinated work from industry and owners
- Gives understanding of final product performance
- Has been shown to be sensitive to mix and binder properties

Improved Binder Cracking Characterization?

- If necessary, a large strain amplitude cracking test would likely be better suited to characterizing cracking performance for all types of asphalt

Thank You!

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Research Partners: