Mix Design and Laboratory Performance of Asphalt Mixtures with High RAP Content

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Introduction

- **ICT Project R27-37**

Impact of High RAP Content on Pavement Structural Performance

- **Research Team: Imad L. Al-Qadi, Sam Carpenter, Bill Pine, and Qazi Aurangzeb**
- **TRP Chair: Jim Trepanier (IDOT)**

Research Objectives

- The objective of this study is to design asphaltic mixes with high RAP content that meet volumetric requirements and to evaluate their potential performance:
  - Effect of RAP content using lab testing: dynamic modulus, flow, low temperature fracture, and fatigue
  - Examine the effect of single- and double-bumped asphalt binder on the aforementioned properties
- Evaluate the durability of mixtures w/ high RAP using Wheel Track, TSR, and visual stripping rating

Mix Designs and Testing

- **Candidate Mixtures**
  - **Control Mixtures:**
    - District-1
    - District-5
  - **RAP Content:**
    - 30%
    - 40%
    - 50%
  - **Binder grade:**
    - PG 64-22 (Base)
    - PG 58-22
    - PG 58-28
- **Laboratory Tests**
  - **Moisture Susceptibility**
  - **Dynamic Modulus**
  - **Flow Number**
  - **Fatigue**
  - **Fracture**
  - **Rutting**

RAP Preparation Process

RAP dried at 50°C for 36-48 hrs

RAP *Fractionated* at various sizes (the same sizes used to separate virgin aggregate)

Retained aggregates on each sieve were reported, *"apparent gradation"*

RAP is sandwiched between the virgin aggregates before heating to mixing temperature

RAP Processing

Apparent vs. Extracted RAP Gradation

Fraction	Passing (%)			
	Apparent Gradation		Extracted Gradation	
	+3/8” RAP	-3/8” RAP	+3/8” RAP	-3/8” RAP
3/4 ”	96.6	100	99.3	100
1/2 ”	79.1	100	90.8	100
3/8 ”	57.1	98.5	78.6	99.3
No. 4	19.7	65.2	39.0	71.7
No. 8	10.0	35.8	26.5	48.6
No. 16	-	-	19.1	32.6
No. 30	3.9	7.2	14.8	24.2
No. 50	-	-	10.7	17.2
No. 100	-	-	7.7	12.7
No. 200	-	-	6.0	10.1

Mix Aggregate Gradation: Verification

	D1-30% RAP			D1-50% RAP		
Sieve (mm)	DMF[1] (%)	Extraction (%)	Diff (%)	DMF[1] (%)	Extraction (%)	Diff (%)
1”	100.0	100.0	0.0	100.0	100.0	0.0
3/4 ”	96.1	95.8	-0.3	96.4	96.2	-0.2
1/2 ”	75.6	76.0	0.4	78.0	78.0	0.0
3/8 ”	63.3	63.5	0.2	65.0	64.8	-0.2
No. 4	38.3	38.8	0.5	37.5	37.3	-0.2
No. 8	23.8	23.7	-0.1	21.9	21.2	-0.7
No. 16	16.7	16.4	-0.3	16.3	15.7	-0.6
No. 30	12.7	12.4	-0.3	13.1	12.6	-0.5
No. 50	9.5	9.4	-0.1	10.1	9.8	-0.3
No. 100	6.9	6.9	0.0	7.2	7.2	0.0
No. 200	5.4	5.5	0.1	5.8	5.8	0.0

[1] Design Mix Formula

Mix Aggregate Gradation: Verification

	D5-30% RAP			D5-50% RAP		
Sieve (mm)	DMF[1] (%)	Extraction (%)	Diff (%)	DMF[1] (%)	Extraction (%)	Diff (%)
1”	100.0	100.0	0.0	100.0	100.0	0.0
3/4 ”	93.7	94.7	-1.0	95.2	95.6	-0.4
1/2 ”	77.6	77.8	-0.2	81.2	81.8	-0.6
3/8 ”	68.3	68.8	-0.5	71.4	71.6	-0.2
No. 4	39.5	39.5	0.0	39.9	40.3	-0.4
No. 8	22.4	22.4	0.0	23.3	23.3	0.0
No. 16	14.6	15.1	-0.5	15.6	15.7	-0.1
No. 30	10.6	10.6	0.0	11.7	11.9	-0.2
No. 50	7.9	7.9	0.0	8.6	8.7	0.0
No. 100	6.3	6.4	-0.1	6.6	6.8	-0.2
No. 200	5.3	5.5	-0.2	5.4	5.7	-0.2

[1] Design Mix Formula

Mix Designs: District 1

19mm NMAS Binder Mix - N_{design} = 90 Gyrations

Mix Type	CM11 (%)	CM16 (%)	FM20 (%)	FM 22 (%)	+3/8 RAP (%)	-3/8 RAP (%)	MF01 (Mineral Filler) (%)	Blend (%)
Control	43.2	27.10	28.5	-	-	-	1.2	100
30% RAP	37.7	12.5	8.5	10.5	15.0	15.0	0.8	100
40% RAP	31.0	13.3	4.0	11.0	25.0	15.0	0.7	100
50% RAP	25.5	14.0	0	10.0	35.0	15.0	0.5	100

Mix Designs: District 5

19mm NMAS Binder Mix - N_{design} = 90 Gyrations

Mix Type	CM11 (%)	CM16 (%)	FM20 (%)	FM 22 (%)	+3/8 RAP (%)	-3/8 RAP (%)	MF01 (Mineral Filler) (%)	Blend (%)
Control	38.5	37.9	21.6	-	-	-	2.0	100
30% RAP	34.5	15.5	9.0	10.0	15.0	15.0	1.0	100
40% RAP	31.2	12.5	6.5	9.0	25.0	15.0	0.8	100
50% RAP	25.6	9.5	4.8	9.6	35.0	15.0	0.5	100

Mixture Volumetrics

District 1

RAP (%)	Total AC (%)	Binder Replaced (%)	Air Void (%)	VMA (%)	VFA (%)
0	4.9	0	4.0	13.7	70.8
30	4.9	27.6	4.0	13.6	70.6
40	5.1	34.6	4.0	13.7	70.8
50	5.0	43.7	4.0	13.7	70.8

Mixture Volumetrics

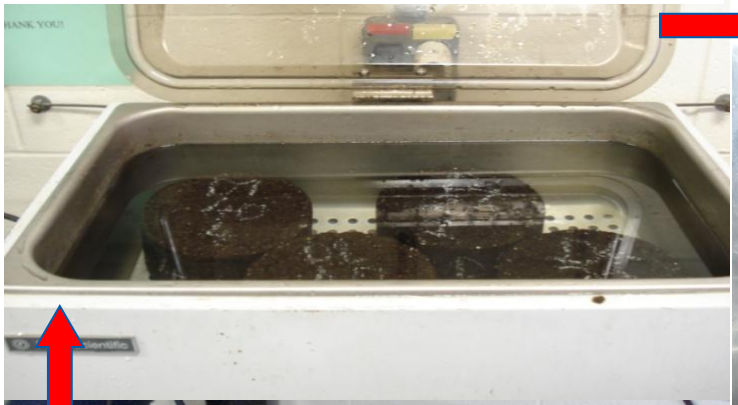
District 5

RAP (%)	Total AC (%)	Binder Replaced (%)	Air Void (%)	VMA (%)	VFA (%)
0	5.2	0	4.0	13.8	71.0
30	5.2	26.1	4.0	13.8	71.0
40	5.2	33.4	4.0	13.6	70.8
50	5.2	40.8	4.0	13.5	70.4

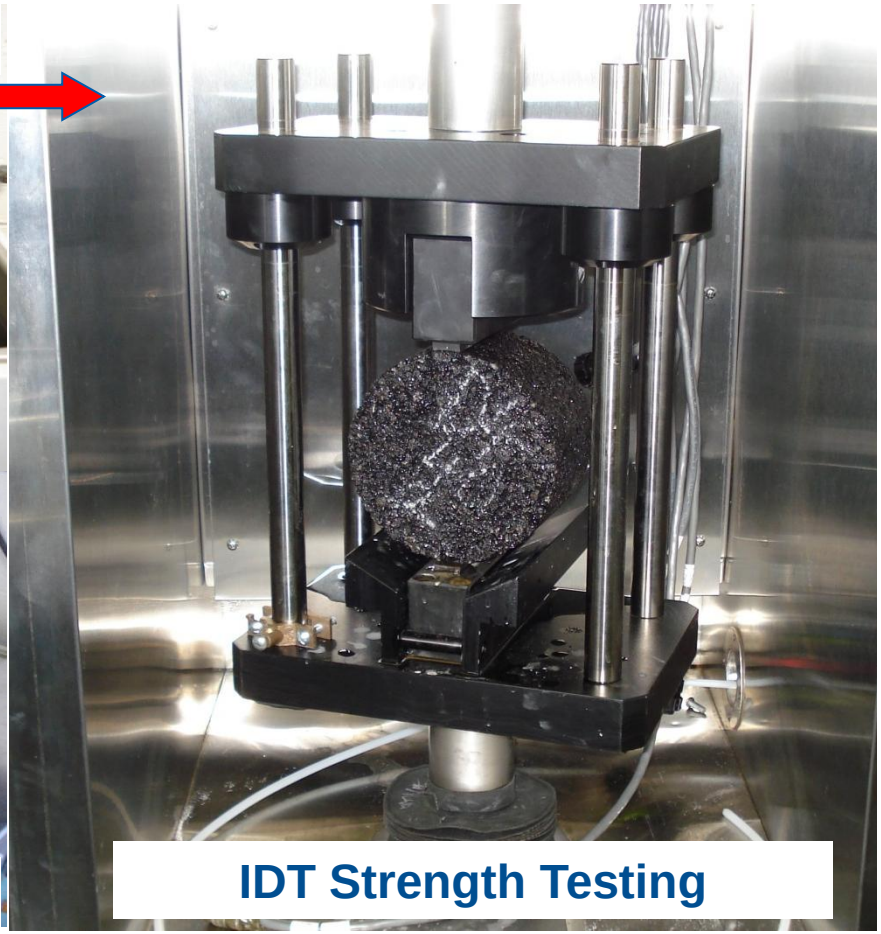
District 1 – Test Results

Moisture Susceptibility Test

Conditioning @ 25°C for 2 hrs



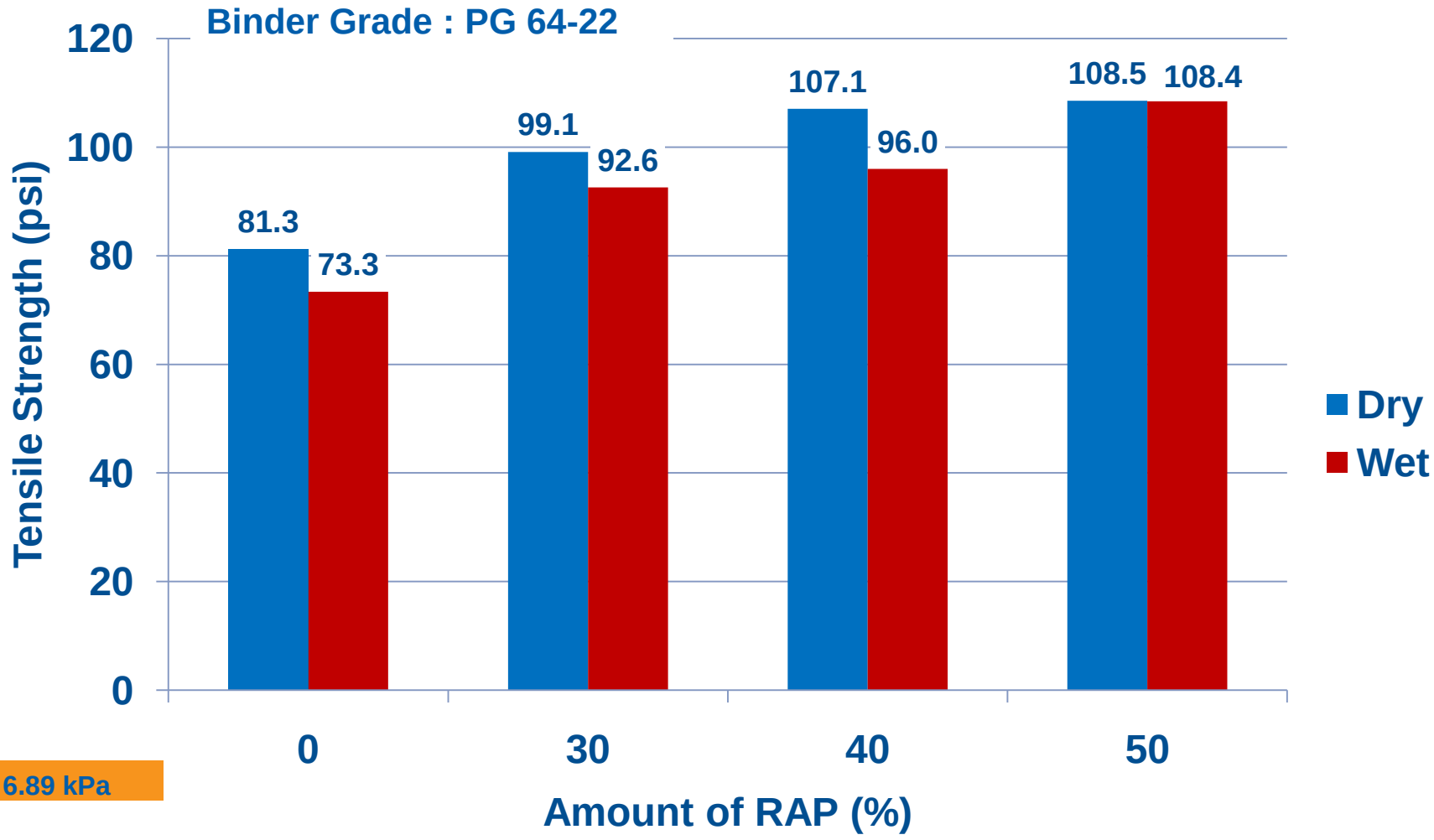
Conditioning @ 60°C for 24 hrs



IDT Strength Testing

Moisture Susceptibility Test

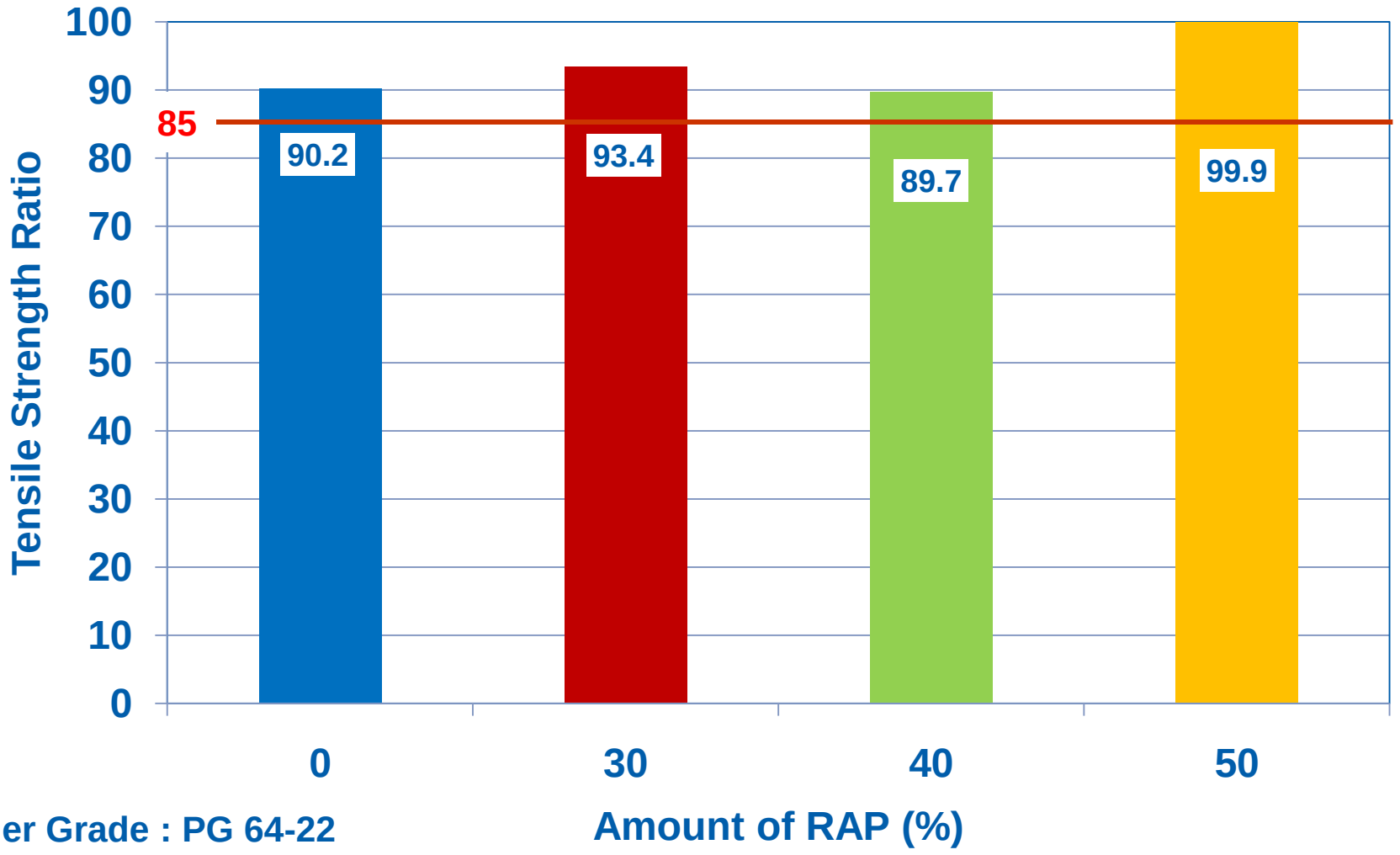
Tensile Strength



1 psi = 6.89 kPa

Moisture Susceptibility Test

Tensile Strength Ratios (TSR)



Binder Grade : PG 64-22

Experimental Design

Complex Modulus

Temperature (°C)	RAP (%)				Total
	0	30	40	50	
-10	3	9	9	9	30
4	3	9	9	9	30
21	3	9	9	9	30
38	3	9	9	9	30
54	3	9	9	9	30
Total	15	45	45	45	150

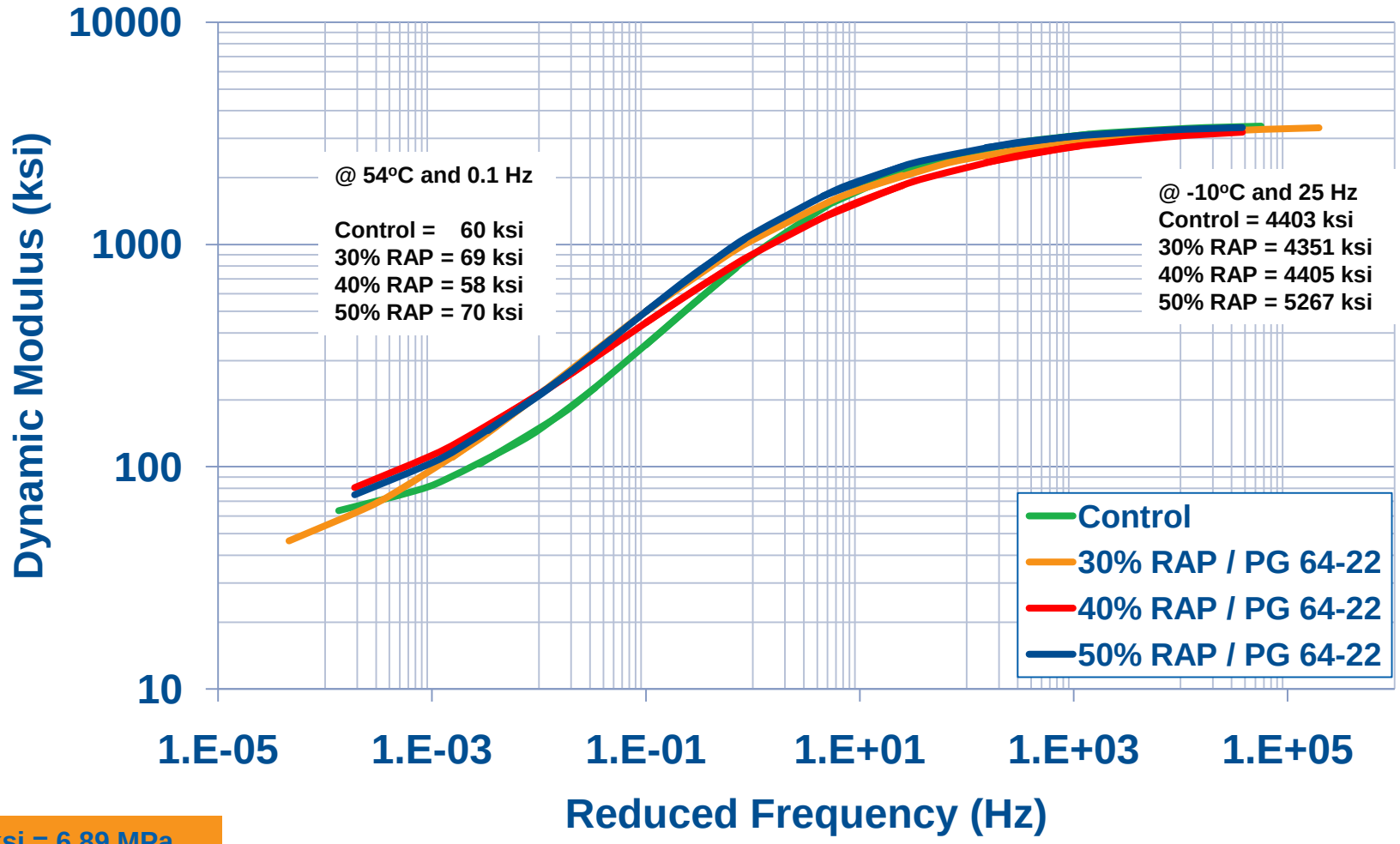
- Same three samples are tested at all temperatures @ 0.1, 1, 5, 10, 25Hz
- Three test sets (no bump, single, double)
- Threshold is 50μstrain

Air Void	7.0% ±0.5(SGC)

TRANSPORTATION

E* Master Curve

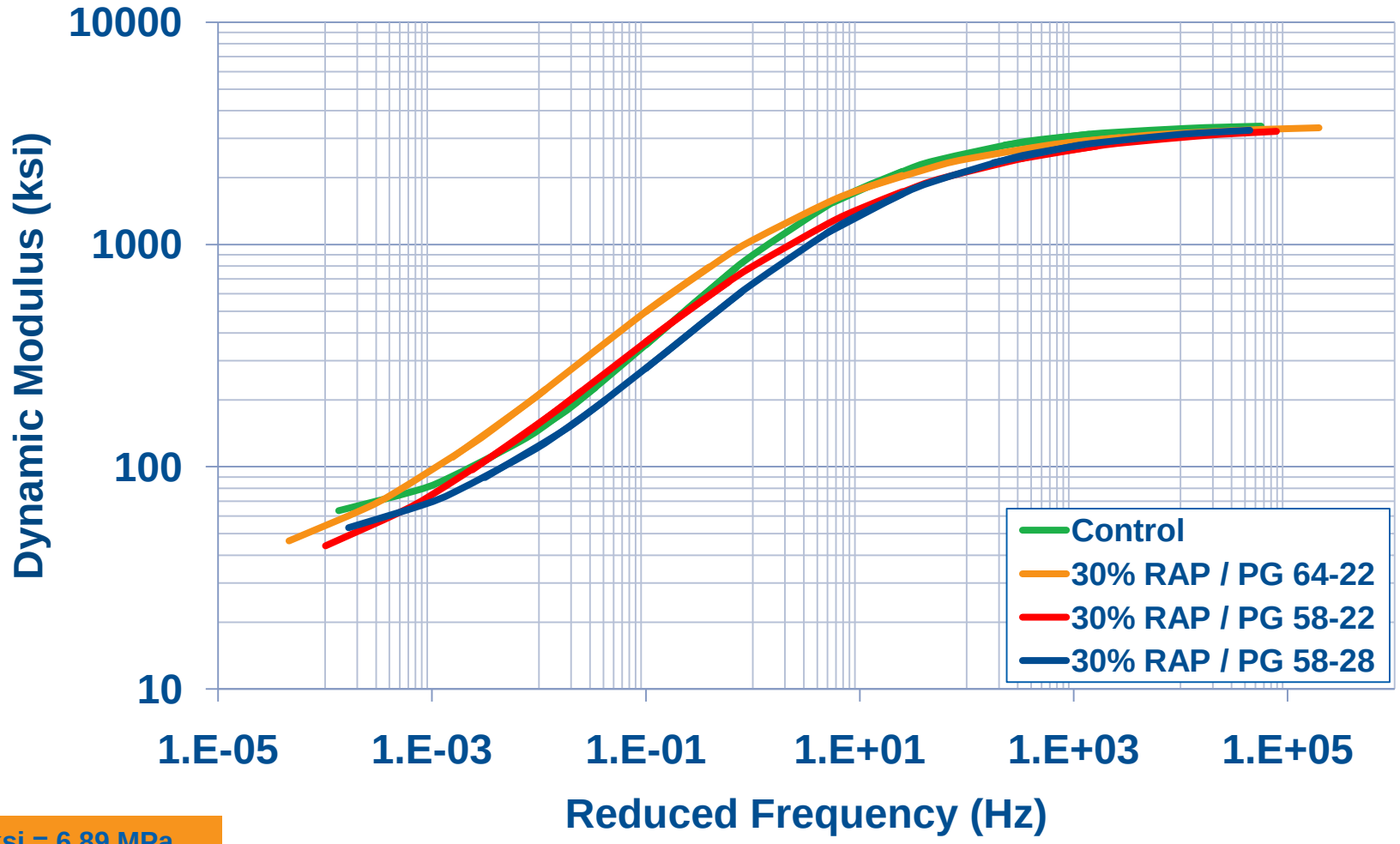
Effect of RAP Content



1 ksi = 6.89 MPa

E* Master Curve

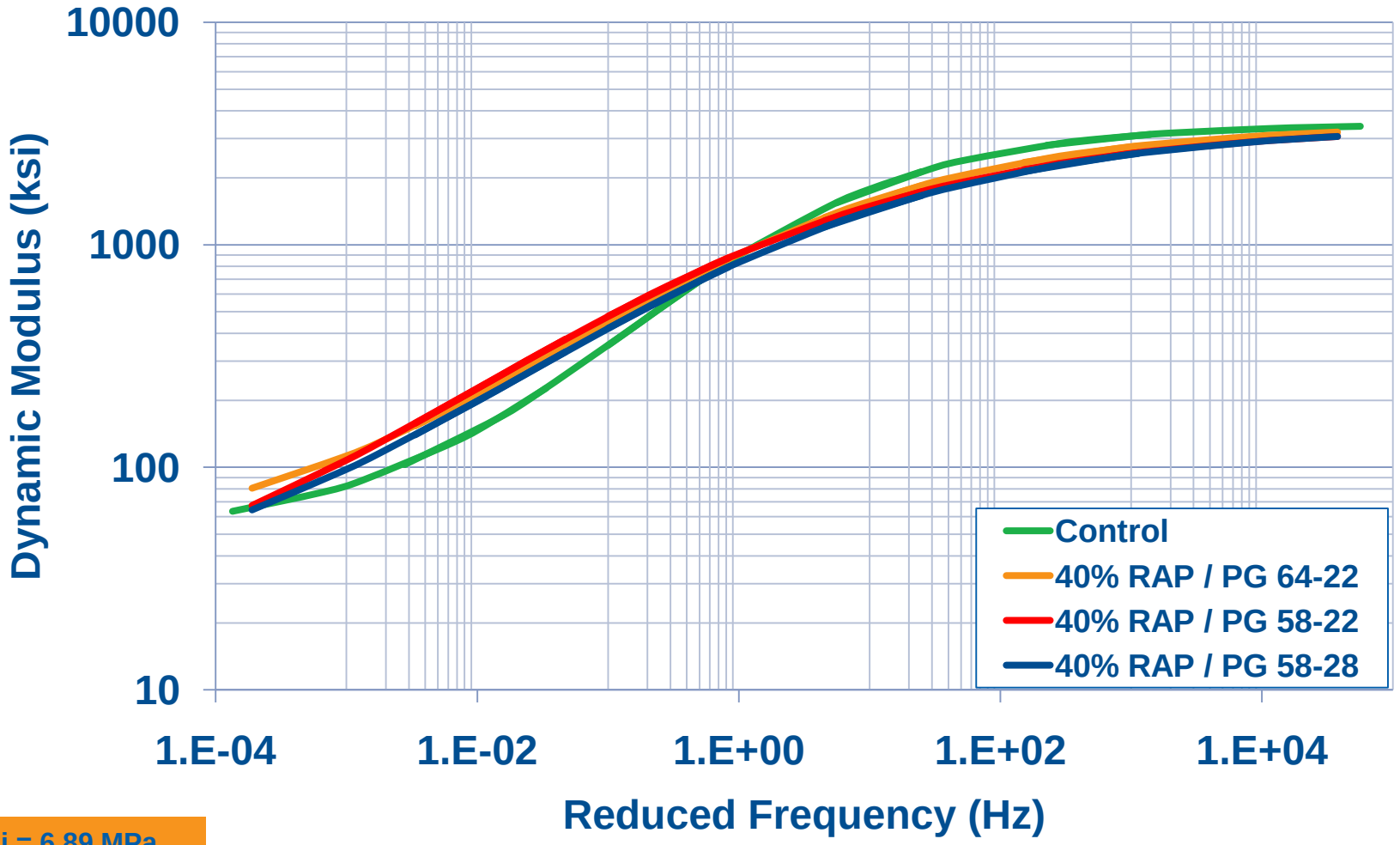
Effect of Binder Grade Bumping for 30% RAP



1 ksi = 6.89 MPa

E* Master Curve

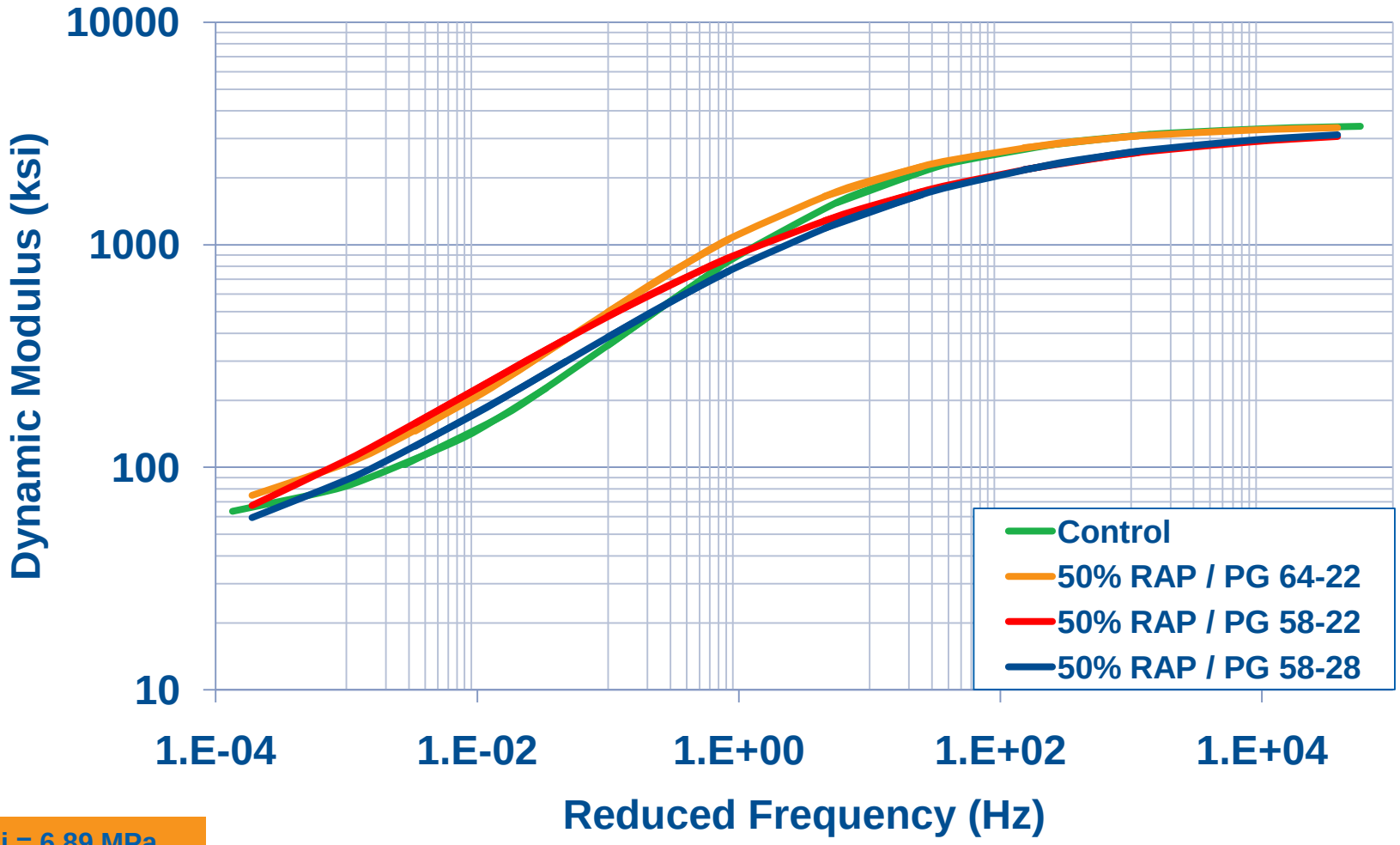
Effect of Binder Grade Bumping for 40% RAP



1 ksi = 6.89 MPa

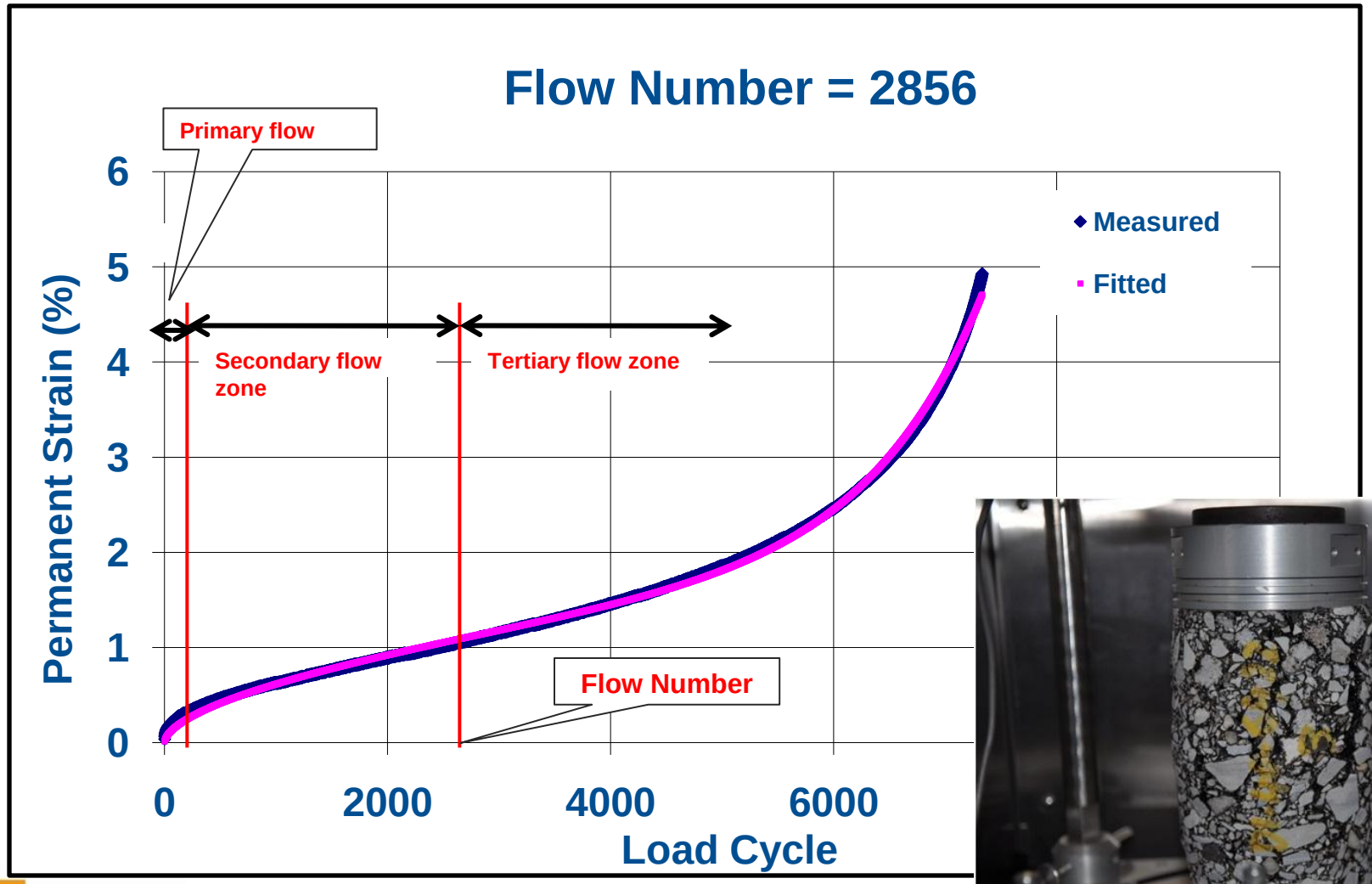
E* Master Curve

Effect of Binder Grade Bumping for 50% RAP



1 ksi = 6.89 MPa

Flow Number Test



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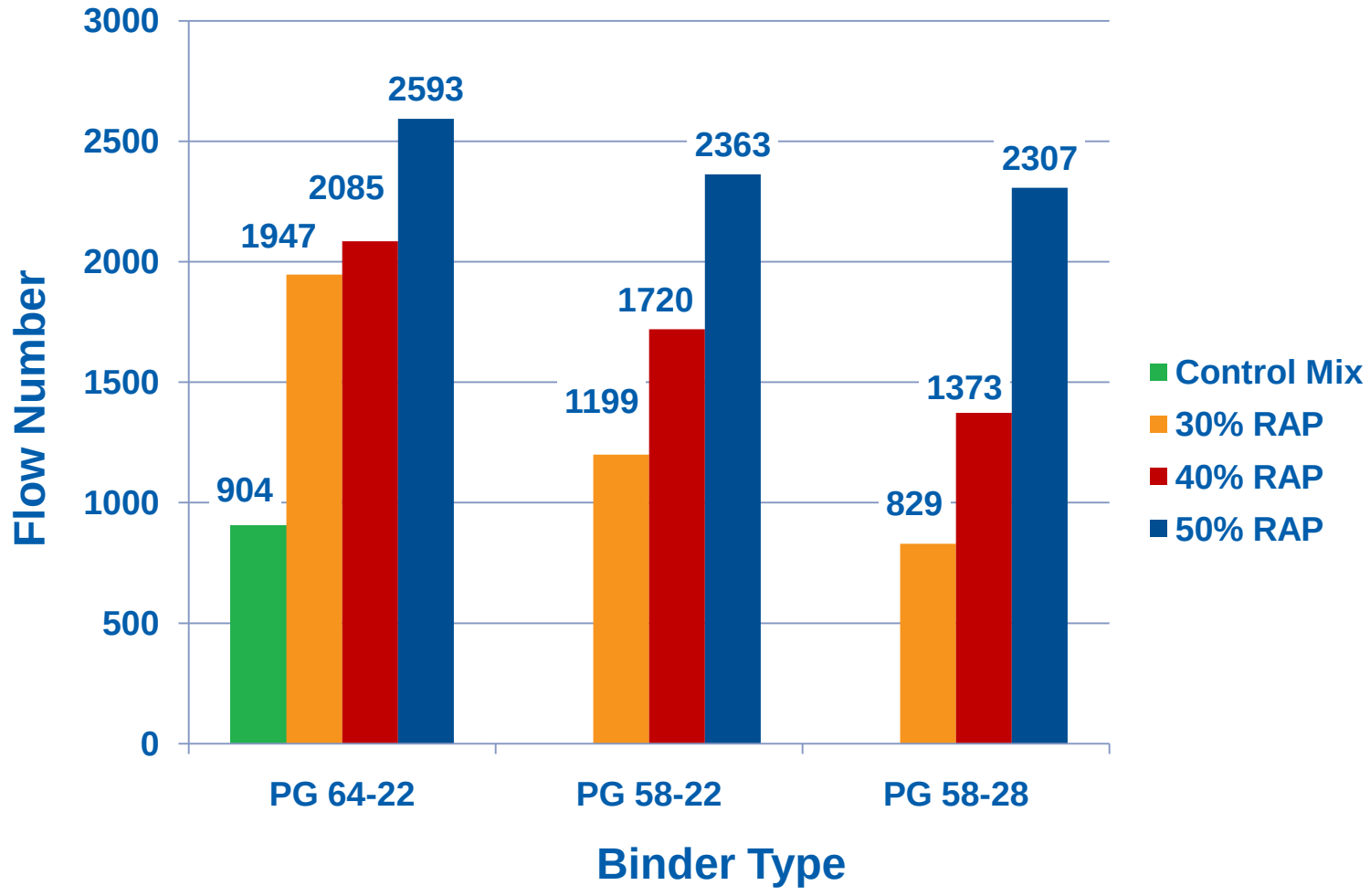
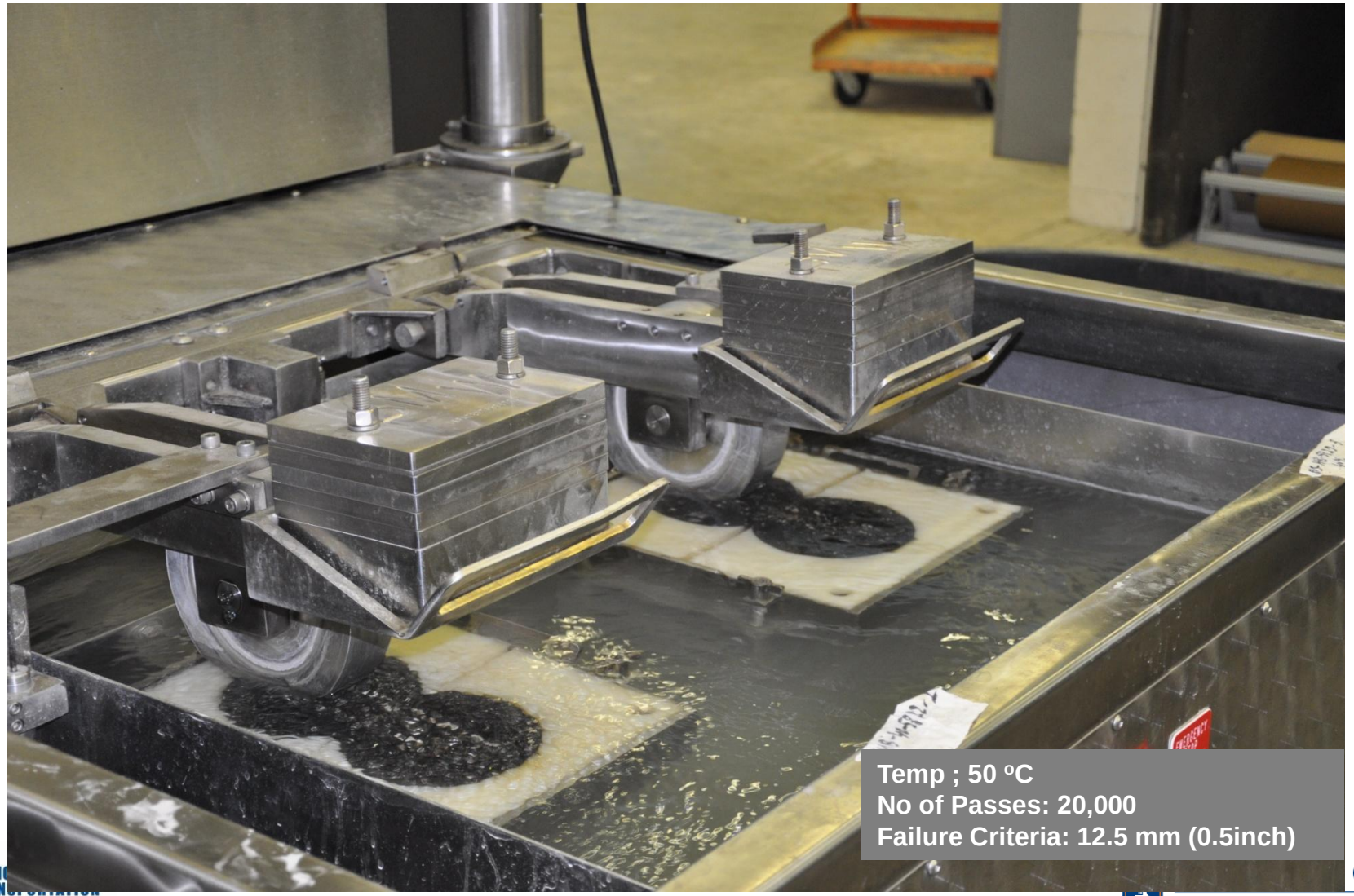
RAP & Binder Effect

Flow Number Test

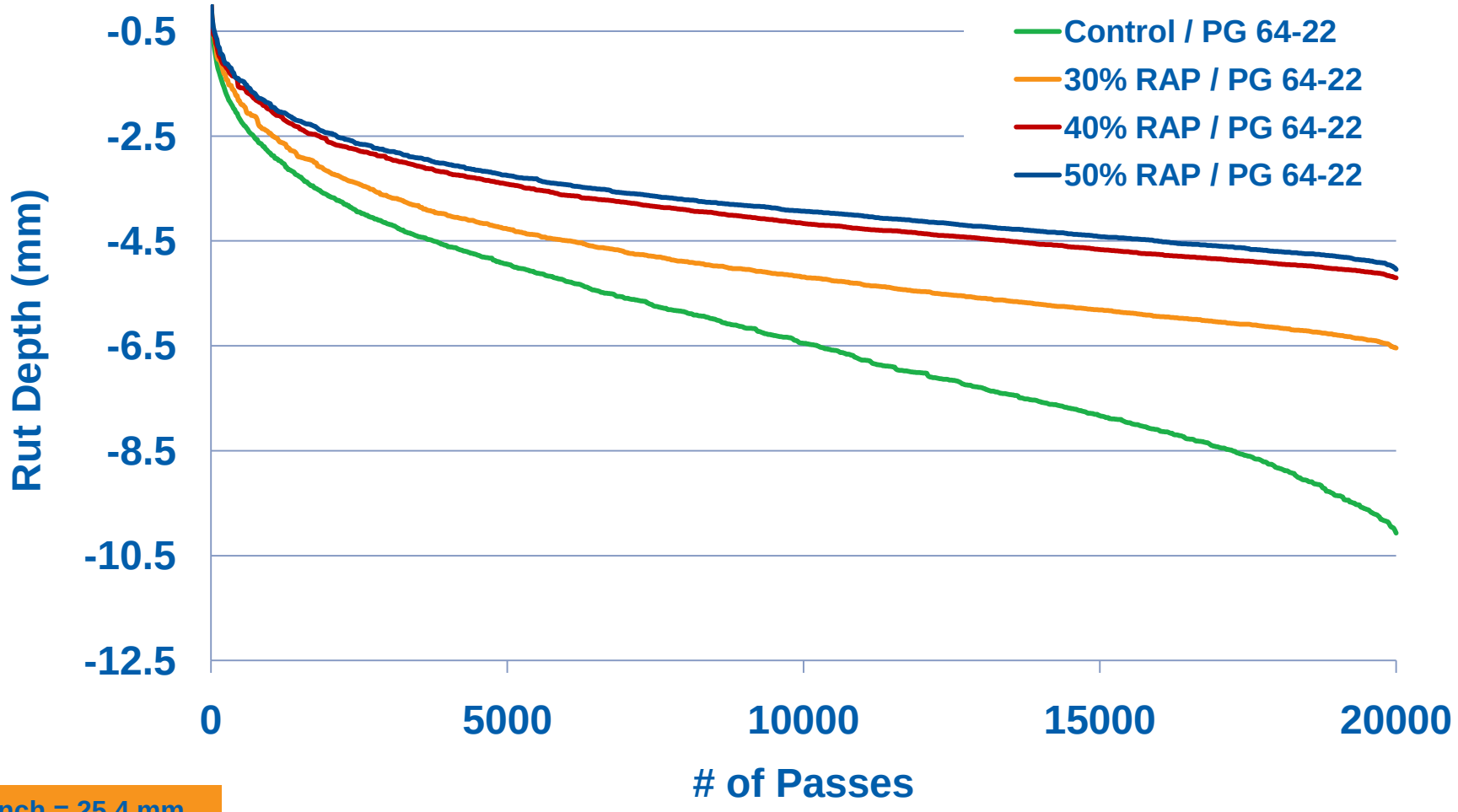


Wheel Tracking Test



Wheel Tracking Test

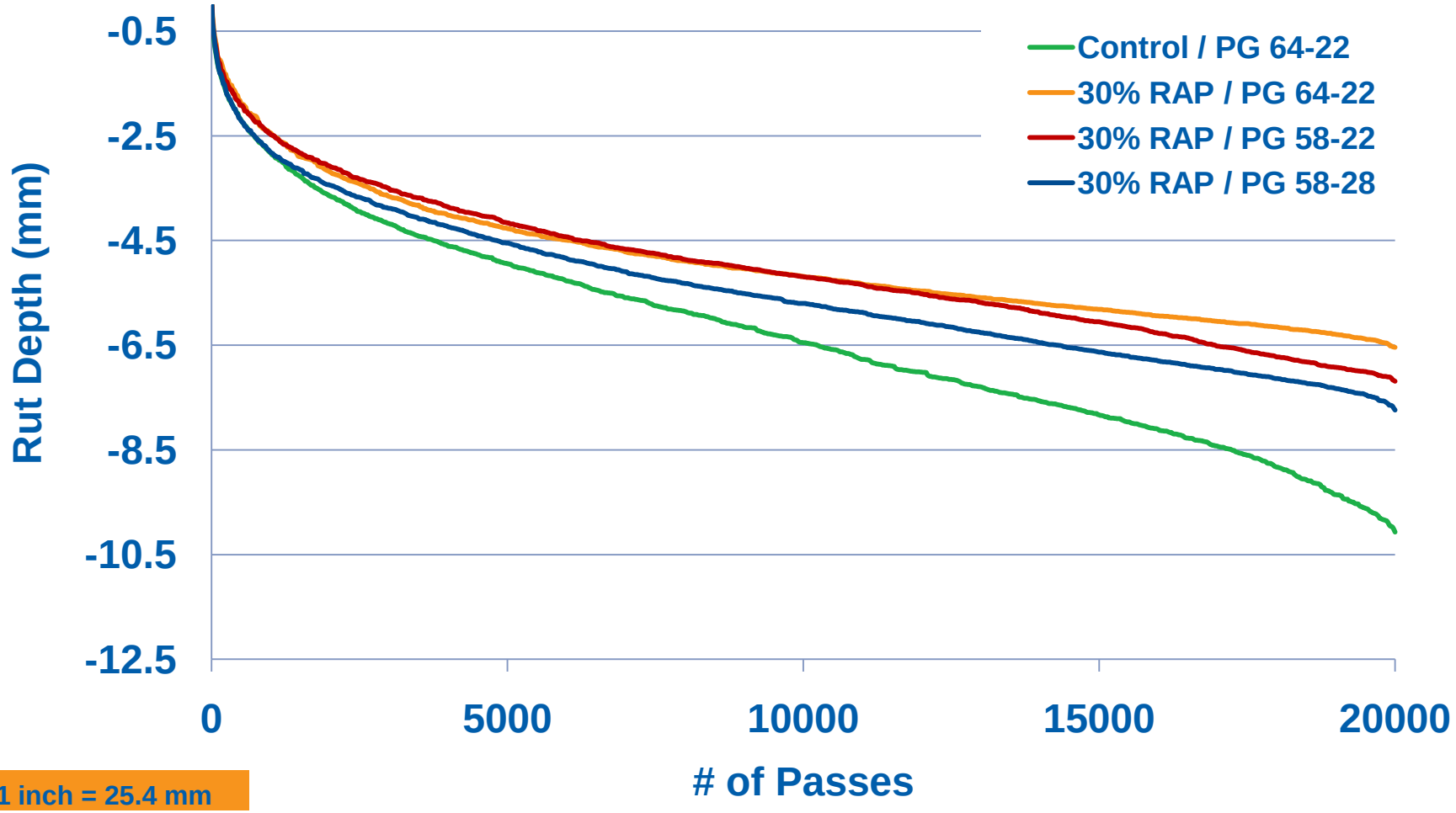
Effect of RAP



1 inch = 25.4 mm

Wheel Tracking Test

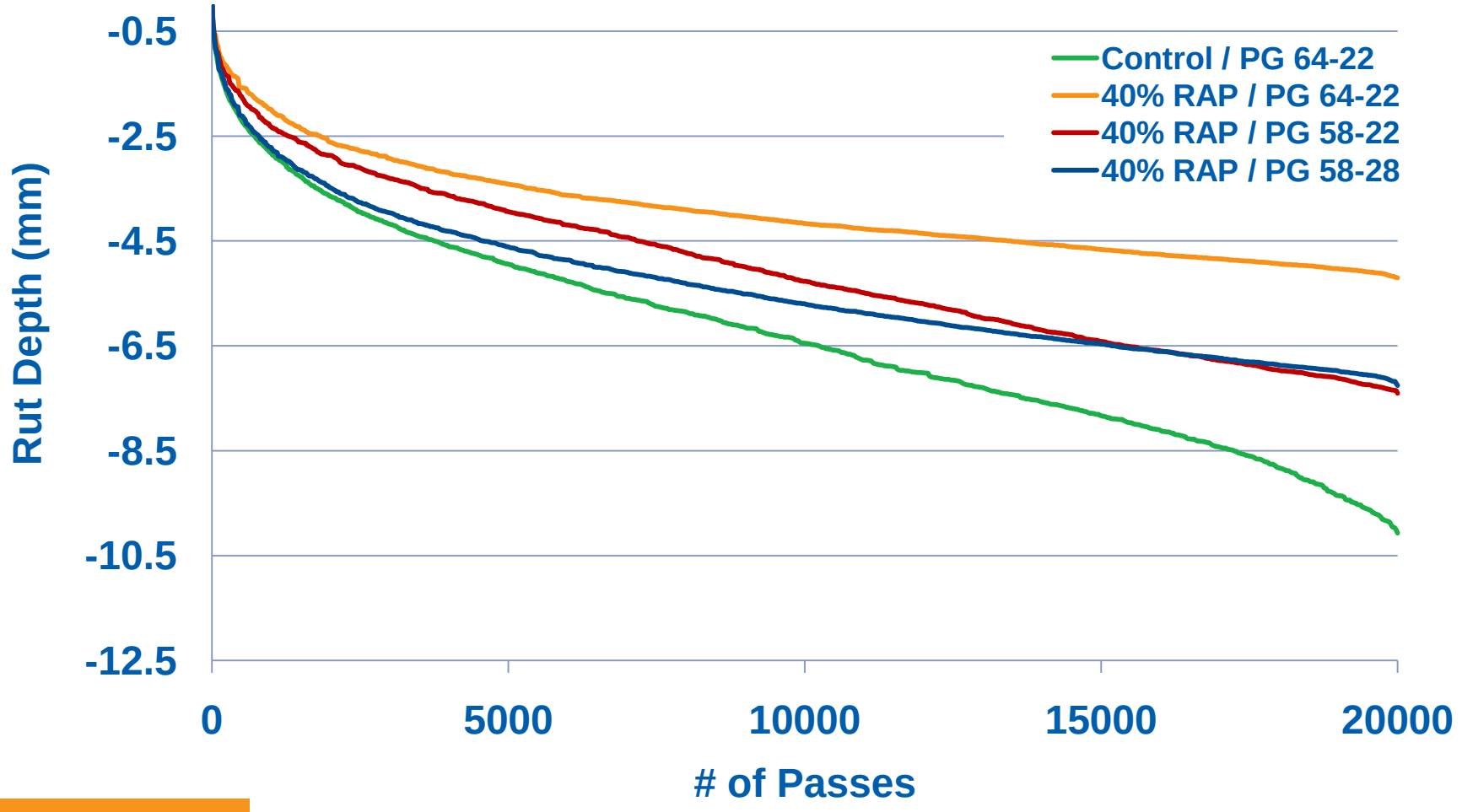
Binder Grade Bumping – 30% RAP



1 inch = 25.4 mm

Wheel Tracking Test

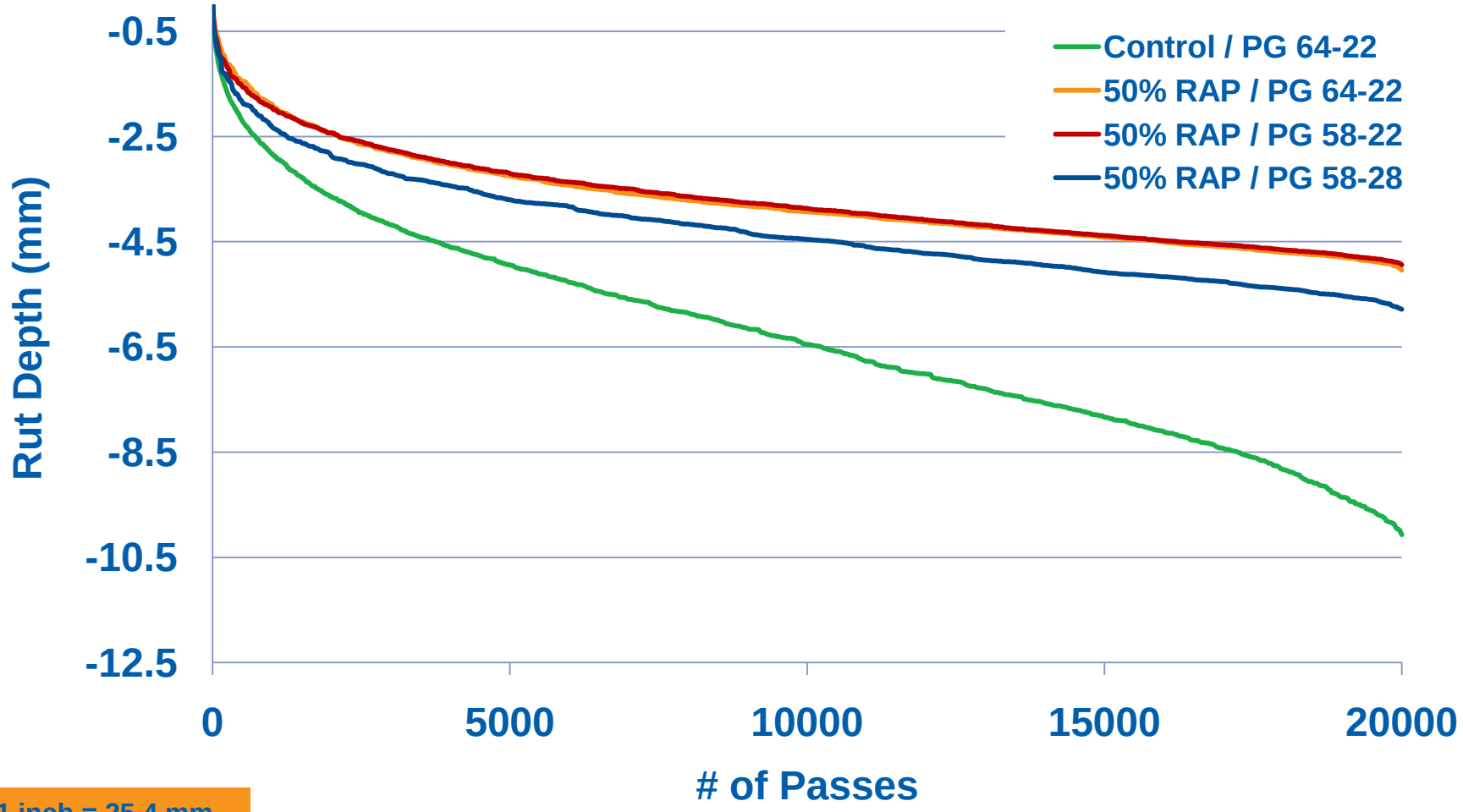
Binder Grade Bumping – 40% RAP



1 inch = 25.4 mm

Wheel Tracking Test

Binder Grade Bumping – 50% RAP



1 inch = 25.4 mm

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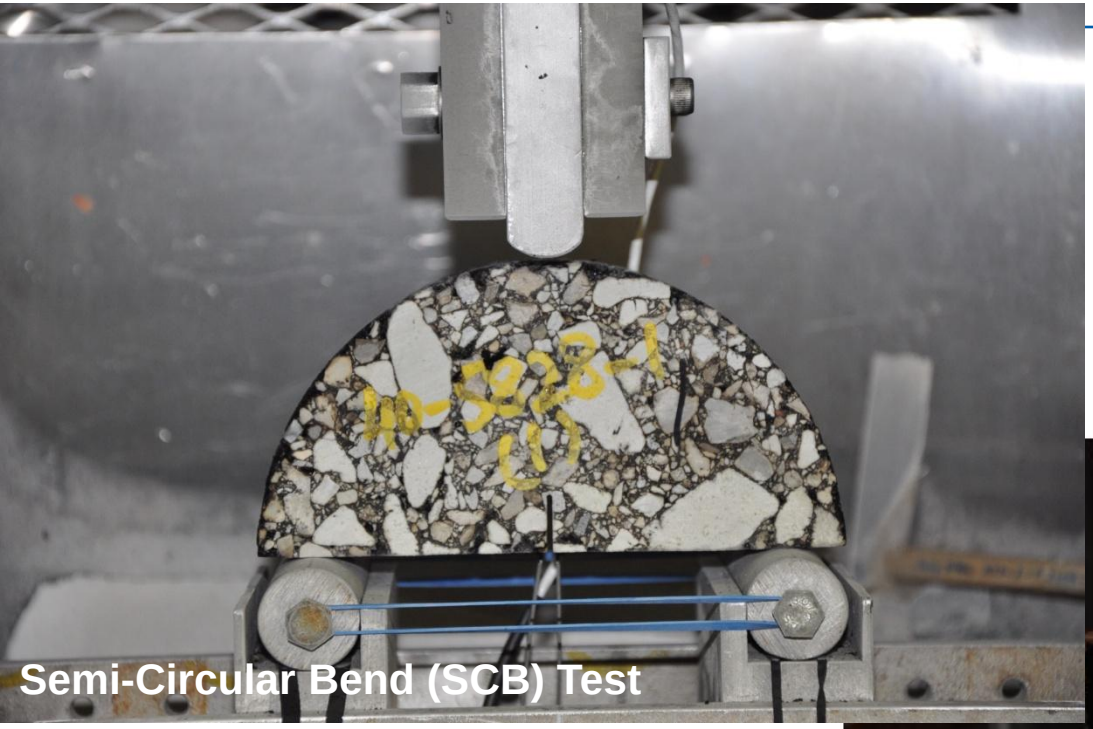
Fracture Test Results

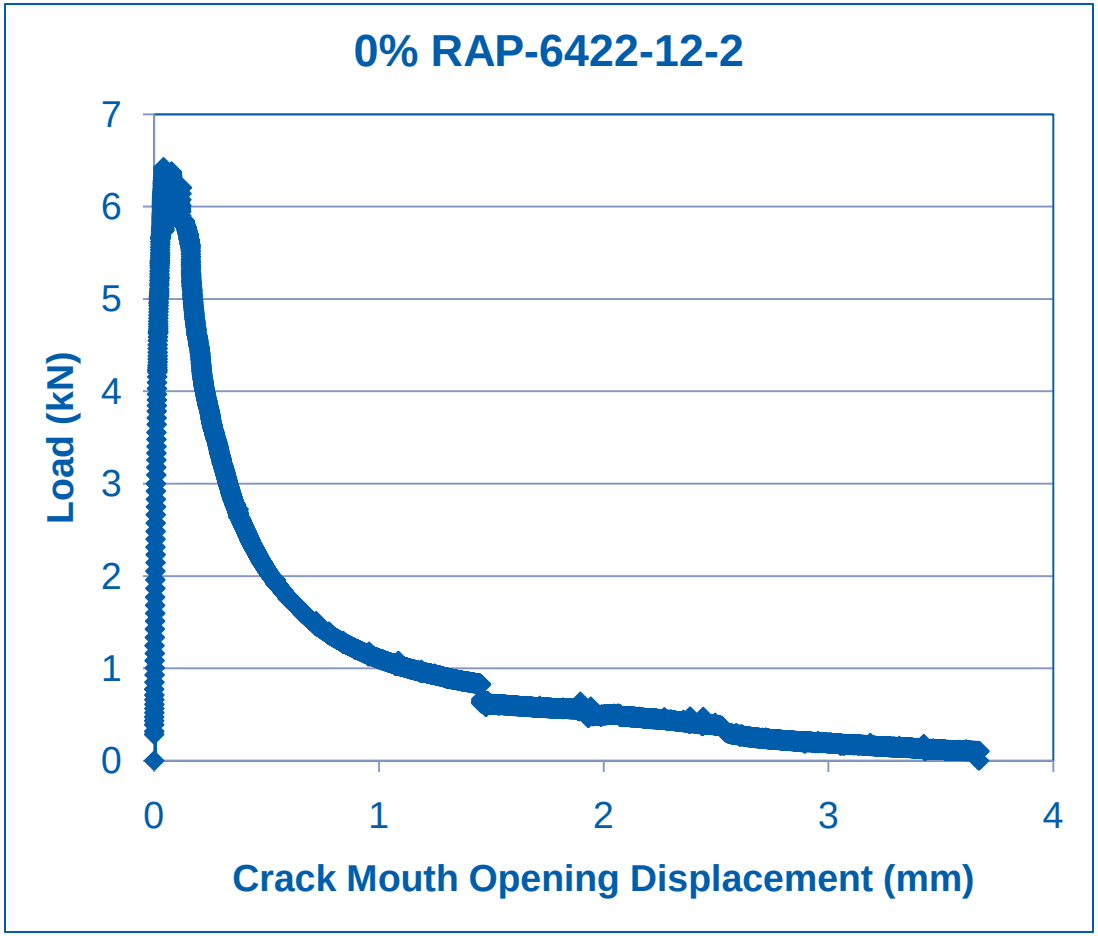


Semi-Circular Bend (SCB) Test

Disc Compact Tension (DCT) Test

Fracture Test Results

Fracture Energy

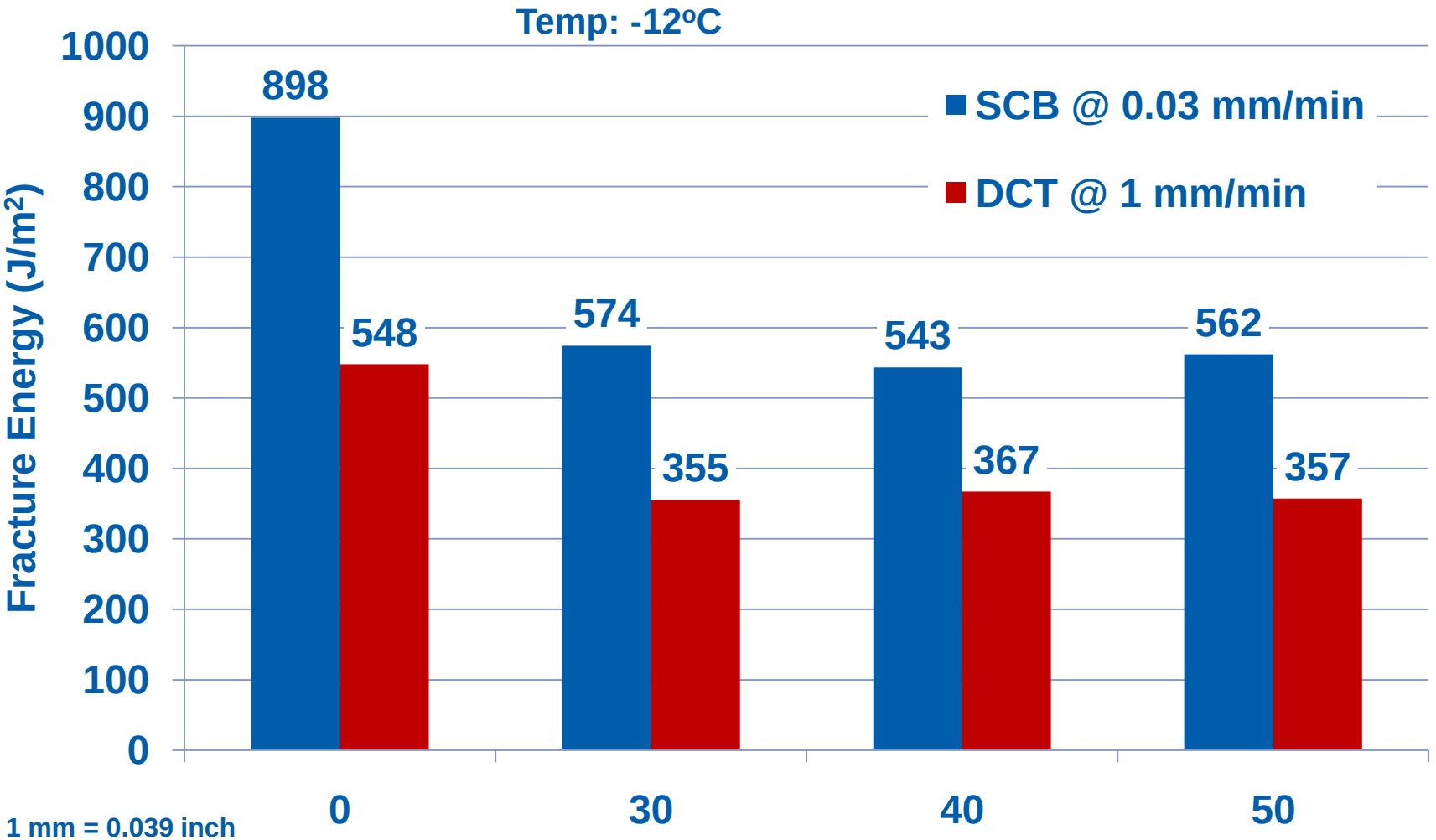


$$G_f = \frac{W_f}{A_{lig}}$$

where:

G_f = fracture energy
W_f = fracture work
A_{lig} = area of a ligament

Fracture Test Results



1 mm = 0.039 inch
0.03 mm = 0.001 inch
1J/m² = 1N-m/m² = 0.00571 lb-in/in²

Fatigue Testing

Beam Fatigue Test

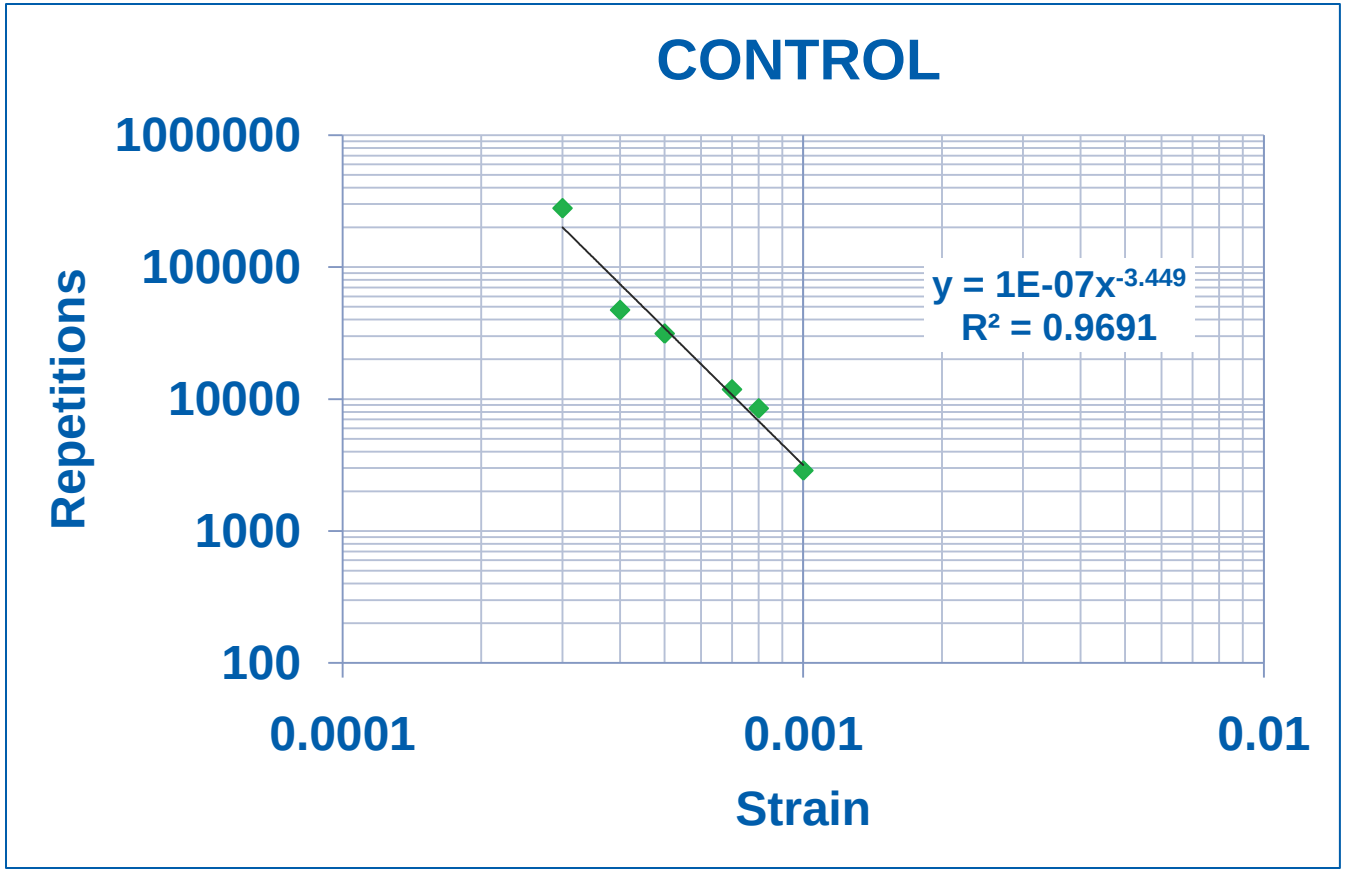
Beams per Mix = 6

Strain levels: 300, 400, 500, 700, 800, 1000 µstrains

Frequency = 10 Hz
Temp ; 20 ºC

Fatigue Testing

Beam Fatigue Test



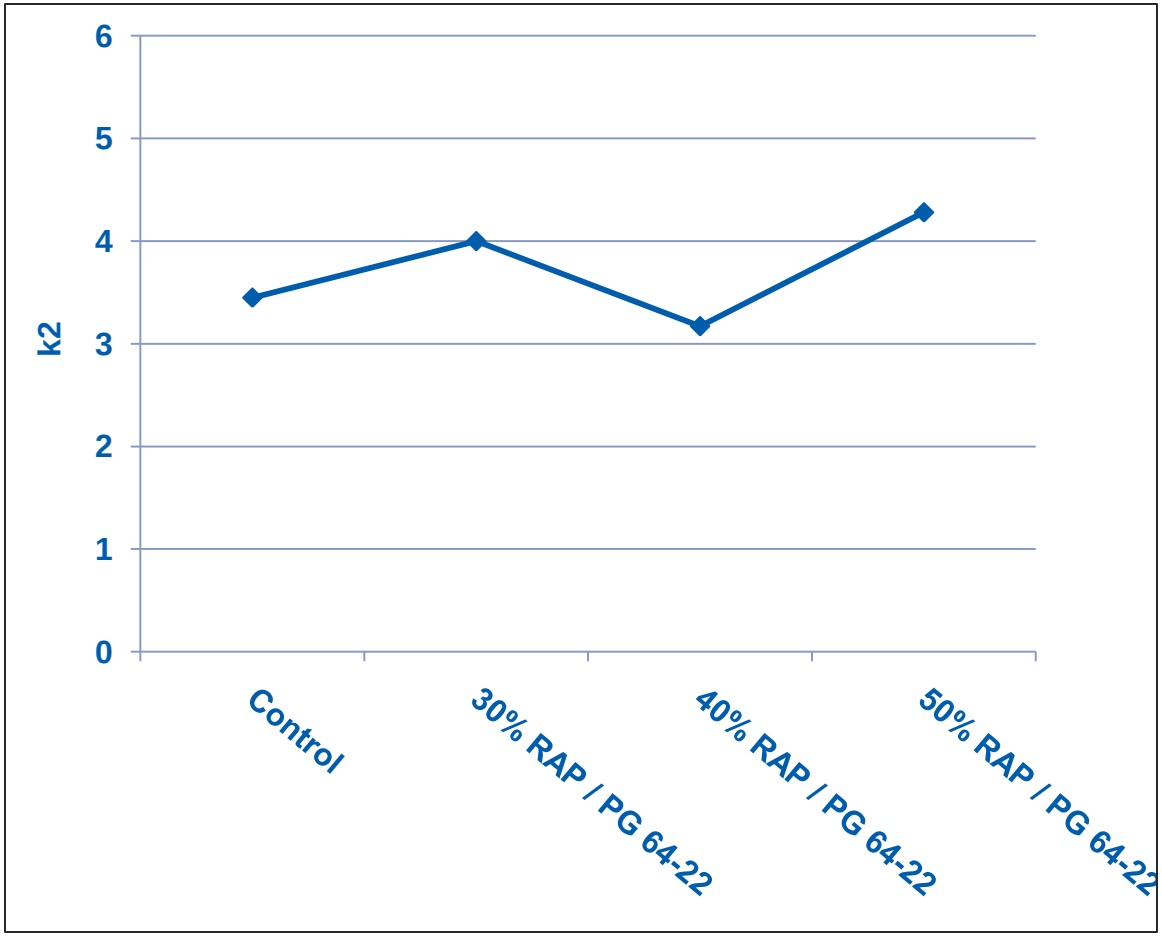
$$N_f = k_1\left(\frac{1}{\varepsilon_{AC}}\right)^{k_2}$$

k1, k2 = factors depend on composition and properties of HMA

Fatigue Testing

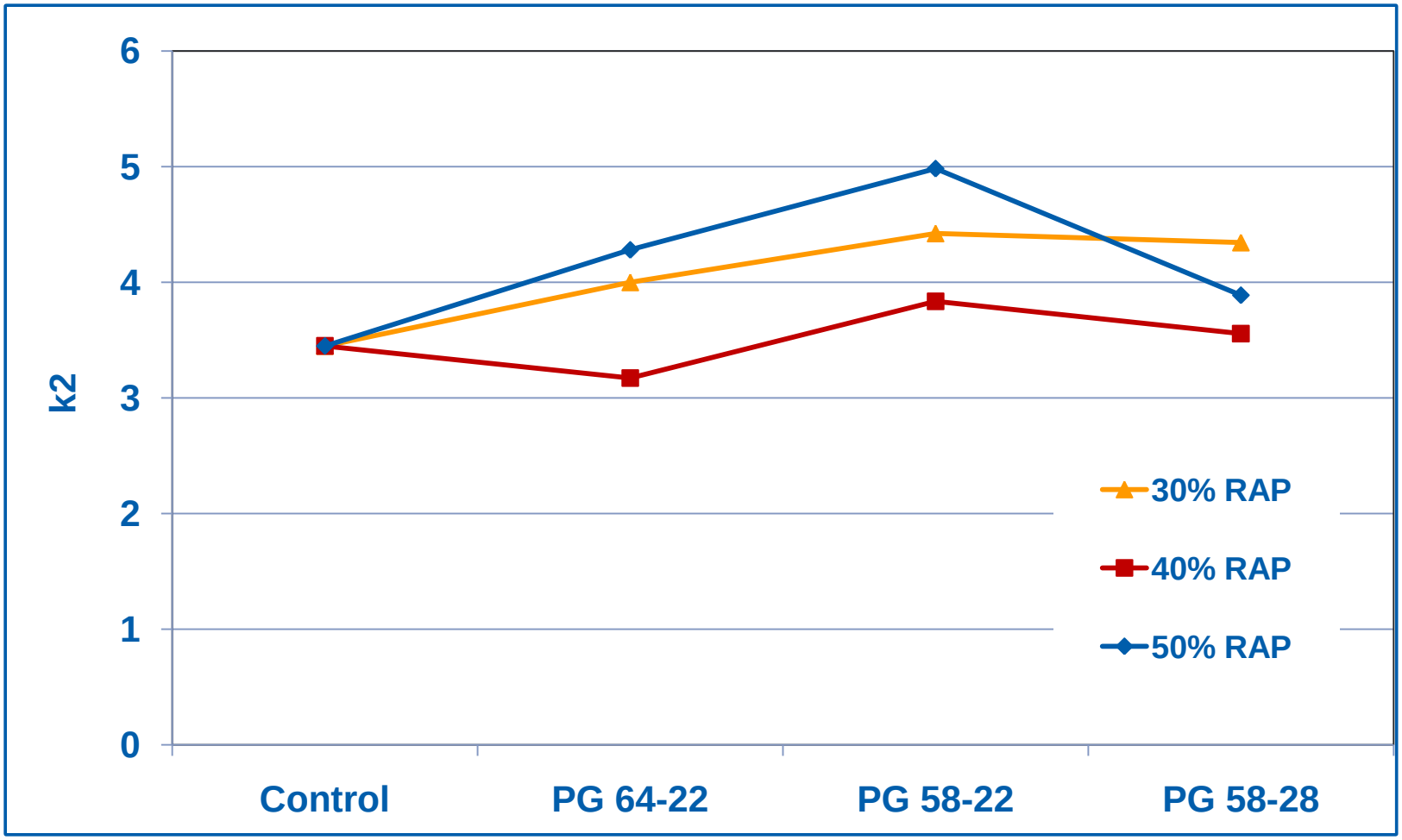
Beam Fatigue Test – RAP Effect

Sample	k2
Control	3.45
30% RAP / PG 64-22	4.00
30% RAP / PG 58-22	4.42
30% RAP / PG 58-28	4.34
40% RAP / PG 64-22	3.17
40% RAP / PG 58-22	3.84
40% RAP / PG 58-28	3.56
50% RAP / PG 64-22	4.28
50% RAP / PG 58-22	4.98
50% RAP / PG 58-28	3.89



Fatigue Testing

Beam Fatigue Test - Binder Effect



Summary

- Achieving acceptable and consistent mixture volumetrics (e.g. VMA) when using high RAP is possible
- TSR values were not jeopardized by addition of RAP
- Dynamic moduli increased with an increase in RAP
- Rutting resistance increased with an increase in RAP (both flow number and wheel tracking)
  - Effect of single and double bumping is pronounced at lower RAP level
  - Bumping effect diminishes with an increase in RAP
- Based on limited testing, fracture energy decreased for all RAP blends relative to the control, but increasing RAP content did not decrease fracture energy
- Fatigue behavior of asphalt mixtures improved with the addition of RAP. Single bumping improved the fatigue behavior whereas double bumping did not

Acknowledgements

- Illinois Department of Transportation (IDOT)
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THANK YOU

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