U.S. Department of Transportation
Federal Highway Administration

Evaluation of RAP Binder Blending Part II - 2010

Audrey Copeland – FHWA
Raj Dongré - DLSI
John D'Angelo – D'Angelo Consulting

RAP ETG
October 27, 2010
Oklahoma City, OK

Acknowledgements

- **Matthew Corrigan- FHWA**
- Satish Belagutti
- David Heidler
- Darnell Jackson
- John D’Angelo Jr.
- Brad Wilhoit

Current Guidelines

- AASHTO M 323 *Standard Specification for Superpave™ Volumetric Mix Design*

Recommended Virgin Asphalt Binder Grade	**Percent (%) RAP**
No change in binder selection	< 15
Select virgin binder grade one grade softer than normal	15 – 25
Follow recommendations from blending charts	> 25

- Based on significant blending between virgin and RAP binder
- Based on limited aging data & climate variability
- Did not consider processing (i.e. fractionation) or plant production effects
- Softer binder grade requirements

Recent Research Findings

- Blending implications
  - *Field Evaluation of a High Reclaimed Asphalt Pavement/Warm Mix Asphalt Project in Florida: A Case Study*, To be published in **Transportation Research Record**, TRB, 2010.
  - "Recycled Asphalt Pavement Research Update and Evaluation of RAP Binder Blending." Presented at the Petersen Asphalt Research Conference, July 2009.
- Binder grade changes
  - *Investigation of Low and High Temperature Properties of Plant-Produced RAP Mixtures - Phase II*, draft final report submitted to FHWA, North Central Superpave Center, 2010.

Where are we heading?

Implications for Practice

- Verify that complete or close to complete blending is not necessary for performance
- Alleviate recommendations for binder changes based on complete blending
- Replace extraction & recovery with performance testing
- Provide guidance for optimizing binder content in RAP mixes and determining RAP amount limits to mitigate fatigue and durability issues

Recent Blending Studies

- Determining blending based on mix properties
  - Bonaquist – WMA and HMA
  - FHWA – WMA and HMA
- Blending based on mix time and temperature
  - Grzybowski – Virgin Aggregate with RAP Aggregate

RAP + Virgin Binder Blending BONAQUIST APPROACH

- Determine volumetric properties
- **Measure** mix dynamic modulus, **E*** (AMPT)
- Extract and recover binder (assumes total blending)
- Perform DSR tests to obtain binder modulus master curve
- **Estimate E*** based on effective shear modulus, G*, using Hirsch model
- Compare estimated E* to measured E*
  - Overlap or close values indicates good mixing

Take-away

- Blending is not always happening & may be a concern with RAP & WMA, however the method for evaluating mix blending has merit.
- RAP may have less impact than assumed.

Developing Problem Statement

- Grzybowski *visually* showed that mixing time and temperature affects the extent of RAP and virgin binder blending.
- First, we *quantified* what we observed.
- Now, let's hypothesize that our measurements verify that complete blending is not occurring at typical production temperatures and mixing times.
  - Does it matter?
  - In other words – Can the physical properties of mix that we desire be achieved without significant blending?

Objectives

- Quantify blending between RAP and virgin binder in RAP modified mixtures.
- Demonstrate the composite effect of layers of RAP and virgin binder on the modulus of RAP-modified mixtures.
- Evaluate the behavior of RAP and virgin binder behavior on asphalt content and stiffness.
- Propose new asphalt mixture evaluation method for RAP use.

Approach

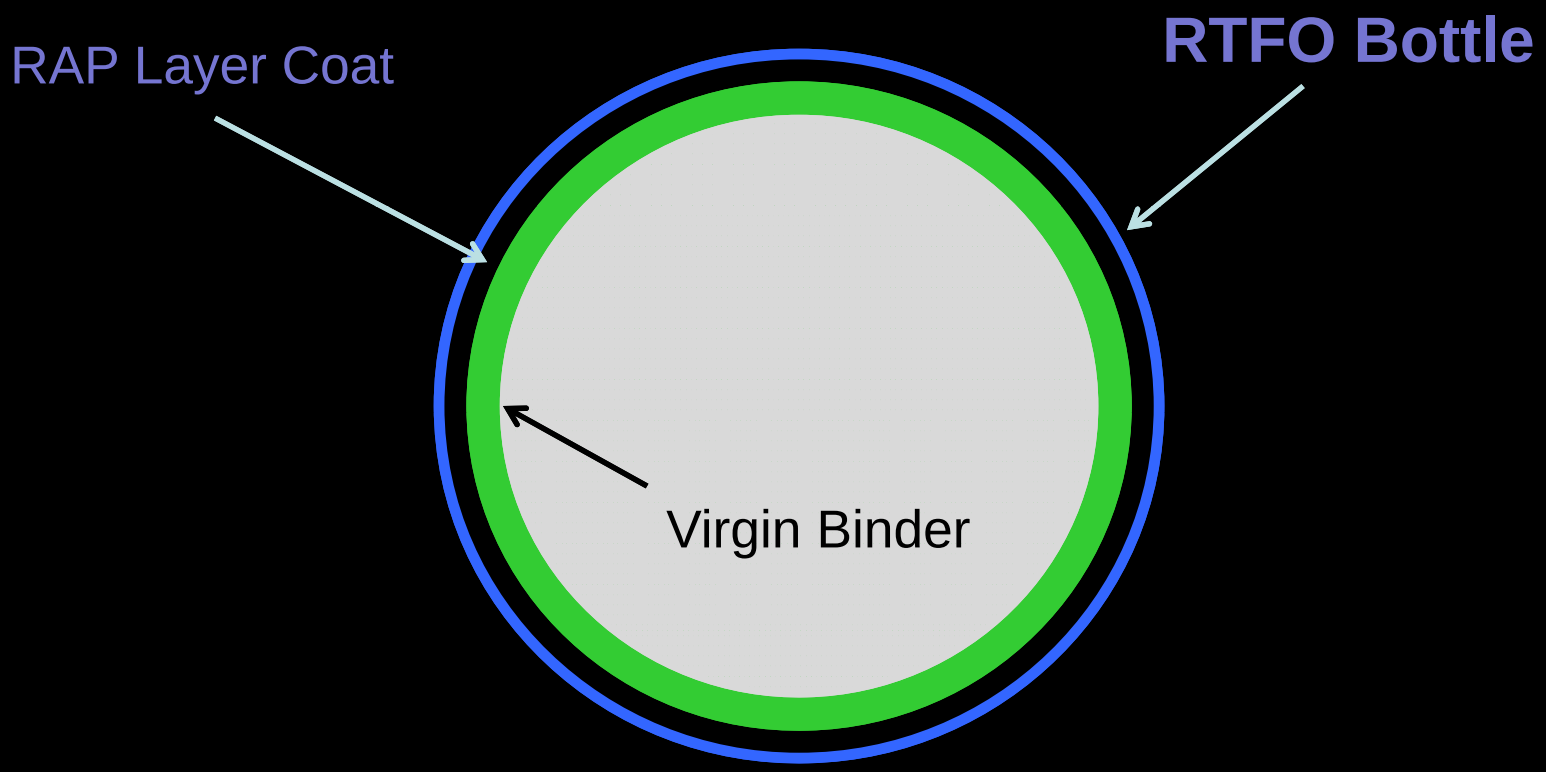
- Study I – Quantifying Blending between RAP & Virgin Binder (presented to RAP ETG in December 2009)
- Study II – Hot Mix Validation Study
- Implications – Evaluating RAP Use based on Mix Properties

FHWA Exploratory Experiment

(Presented in 2009)

- Part I: Quantifying that mix time and temp have an effect on blending
  - Laboratory Simulation of RAP Binder and Virgin Binder Blending in RTFO
    - Followed by testing in the DSR
- Part II: Does blending matter for mix properties?
  - Laboratory Simulation of RAP Binder and Virgin Binder Blending in Hot-Mix
    - E* and Flow Number from AMPT Device
    - Comparison with Plant Produced Hot-Mix

RTFO Experiment



What did we learn?

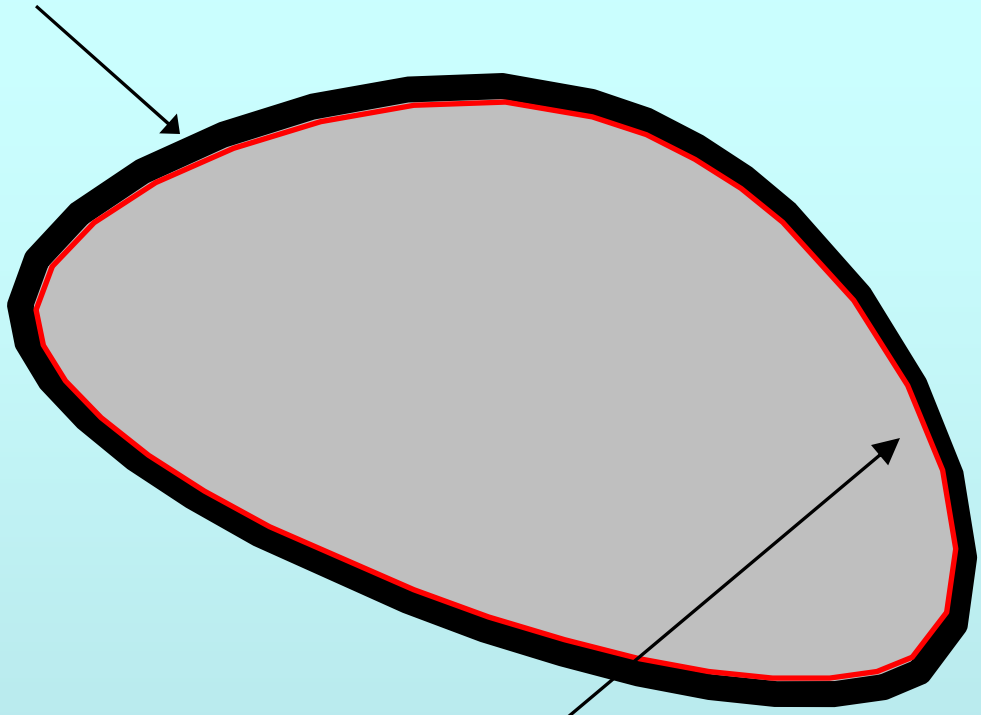
FHWA 2009 exploratory study

- RAP binder and Virgin Binder Blending
  - Not 100% blended with reasonable time and temperature
  - Blending may not be necessary to produce properties similar to blended binder because of composite effect
- Hot-Mix blending
  - Standard lab mixing, mixing separately, and plant produced mixes gave similar properties

Objectives – 2010 Validation Study

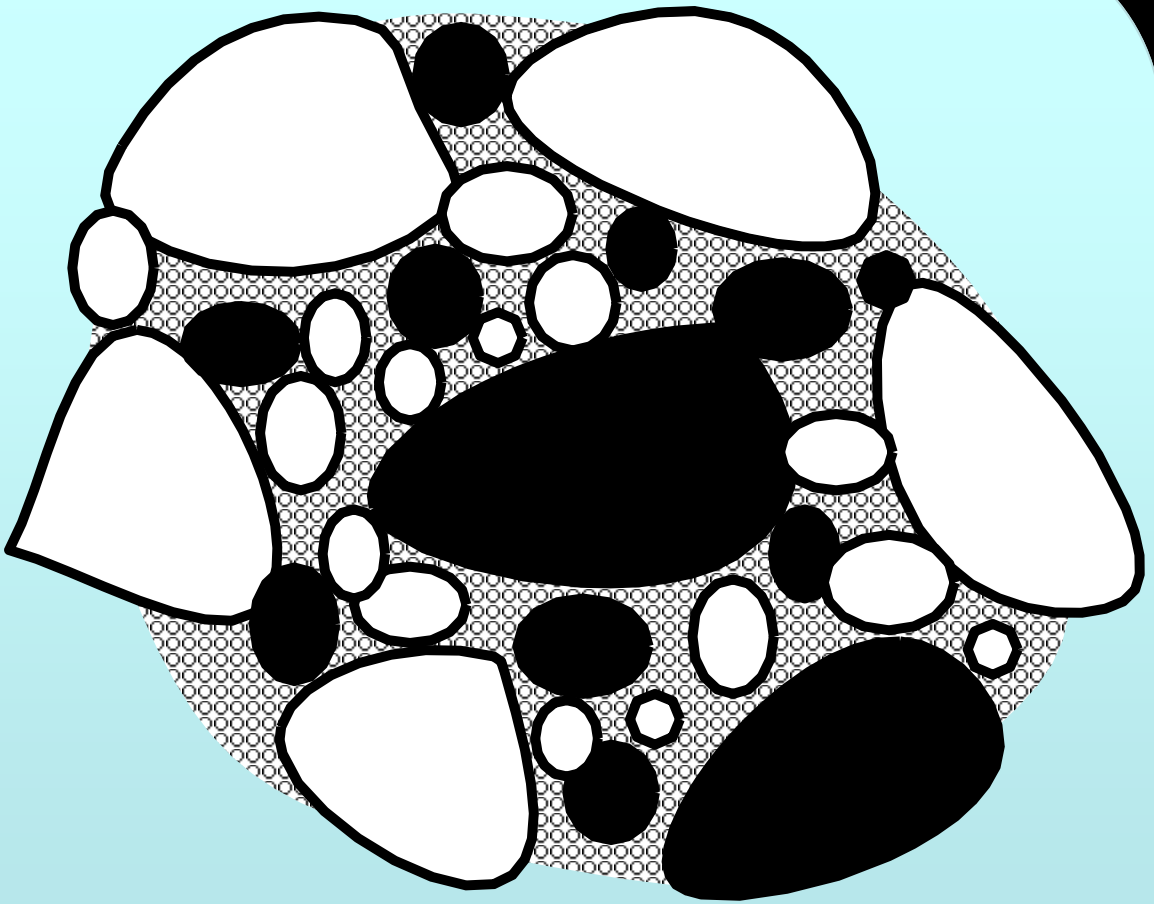
- Further verification of the binder and mix exploratory study
  - Include other RAP and virgin combinations
  - Evaluate different size RAPs
- Demonstrate the Extent of RAP and Virgin Binder Blending in RAP Modified Hot-Mix

Binder Properties on the Aggregate



RAP in an Asphalt Mix

In RAP mix, binder will blend with new binder, however, only the softer components of the RAP binder mix and the highly polar viscosity building materials stay attached to the RAP aggregate surface.



2010 Validation Experiment

- Use Maryland RAP for blending
- Sieve both MD RAP and ALF Virgin Aggregate.
  - Small size will be considered anything retained on #4 sieve.
  - Large size will be considered anything retained on 3/8 sieve.
- Determine binder content and properties of both large and small RAP sizes.

2010 Validation Experiment

- Sieve both MD RAP and ALF Virgin Aggregate.
  - Small size will be considered anything retained on #4 sieve.
  - Large size will be considered anything retained on 3/8 sieve.
- Determine binder content of both large and small RAP.

2010 Validation Experiment…

- Create artificial RAP made using ALF aggregate
  - Small size will be considered anything retained on #4 sieve.
  - Large size will be considered anything retained on 3/8 sieve.
  - Both are to be made at 5.3% binder content.
  - Oven Age at 100 degrees Celsius for 5 days.
  - Determine binder content of both sizes.

2010 Validation Experiment…

- Mixing
  - All percentages are based on binder content of final mix at 4%.
  - Nustar PG 64-22 to be used.
  - Used a heat gun to maintain temperature of mix throughout mixing.
  - Mix times are to be both 5 minutes and 10 minutes.

2010 Validation Experiment…

- Mixing……
  - Small size MD and Artificial RAP
    - 25% binder small sized RAP variable large sized virgin ALF Aggregate.
    - 40% binder small sized RAP variable large sized virgin ALF Aggregate.
  - Large sized MD and Artificial RAP
    - 25% binder large sized Rap variable small sized virgin ALF Aggregate.
    - 40% binder large sized RAP variable small sized virgin ALF Aggregate.

2010 Validation Experiment

- Testing Plan on Extracted Binders
  - Binder Content
  - PG Grading
  - MSCR at 64^{o}C

2010 Validation Experiment

- Testing Plan on Extracted Binders
  - Binder Content
  - PG Grading
  - MSCR at 64^{o}C

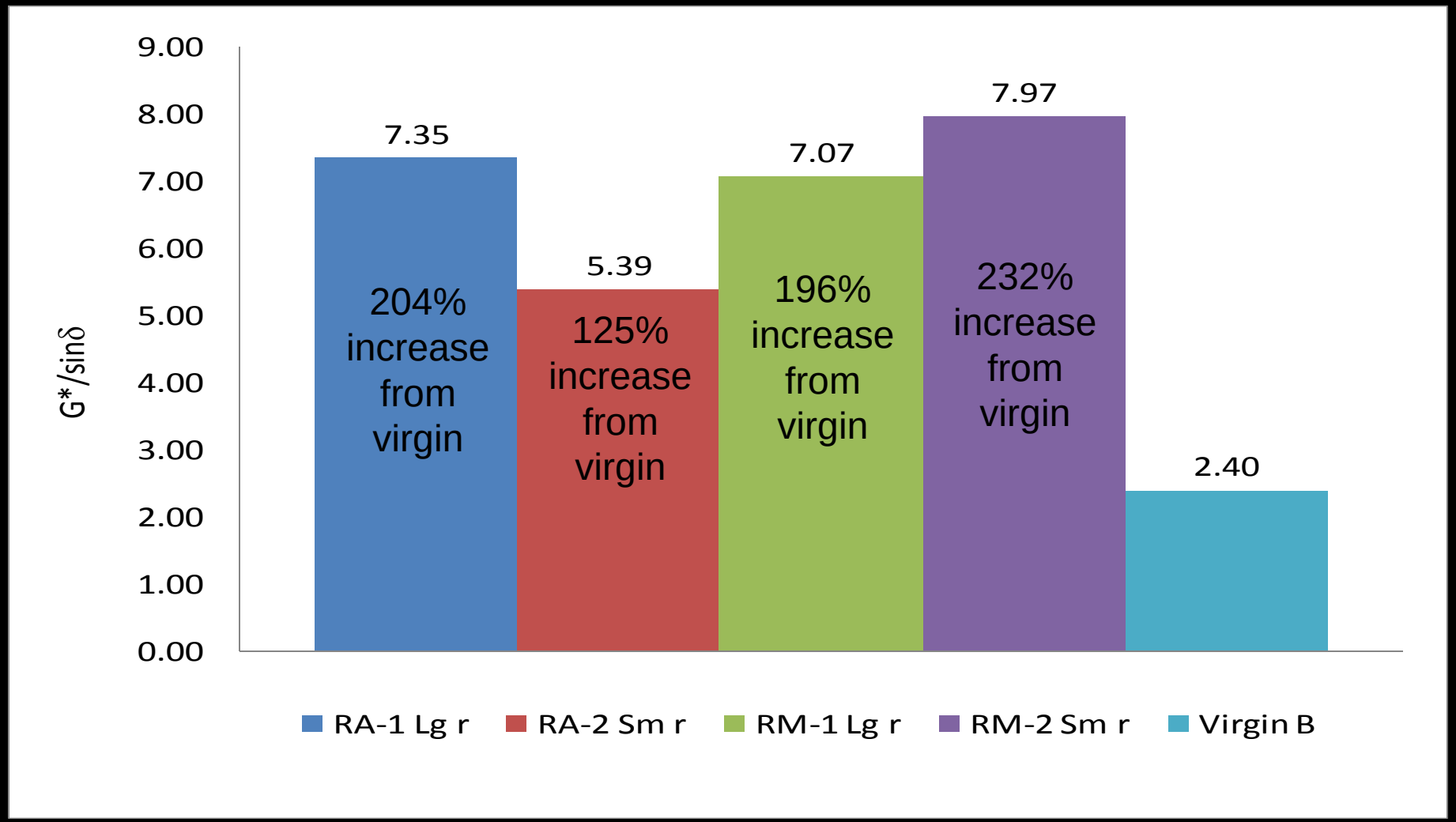
Small Size (#4) MD RAP

RAP Type		Small MD RAP					
Mix Composition %	#4 - RAP	100	N/A	25		40	
	#4 - Virgin	N/A	N/A	N/A		N/A	
	#3/8 - RAP	N/A	100	N/A		N/A	
	#3/8 - Virgin	N/A	N/A	75		60	
Aggregate Size	Separated	N/A	N/A	#4	#3/8	#4	#3/8
Binder Content	Pb %	3.29	2.42	5.63	2.78	4.80	2.92
G*/sind - 70°C	Extracted	7.07	7.97	2.17	2.16	3.44	2.93
G*/sind - 70°C	Virgin - NuStar	2.40	2.40	2.40	2.40	2.40	2.40
PG Grade	Extracted	79.60-30.40	80.39-30.00	69.89-30.13	69.83-30.53	73.78-31.05	72.37-31.30
PG Grade	Virgin - NuStar	70.00-22.10	70.00-22.10	70.00-22.10	70.00-22.10	70.00-22.10	70.00-22.10
	MSCR @64C	0.33	0.25	1.80	1.70	1.11	1.07

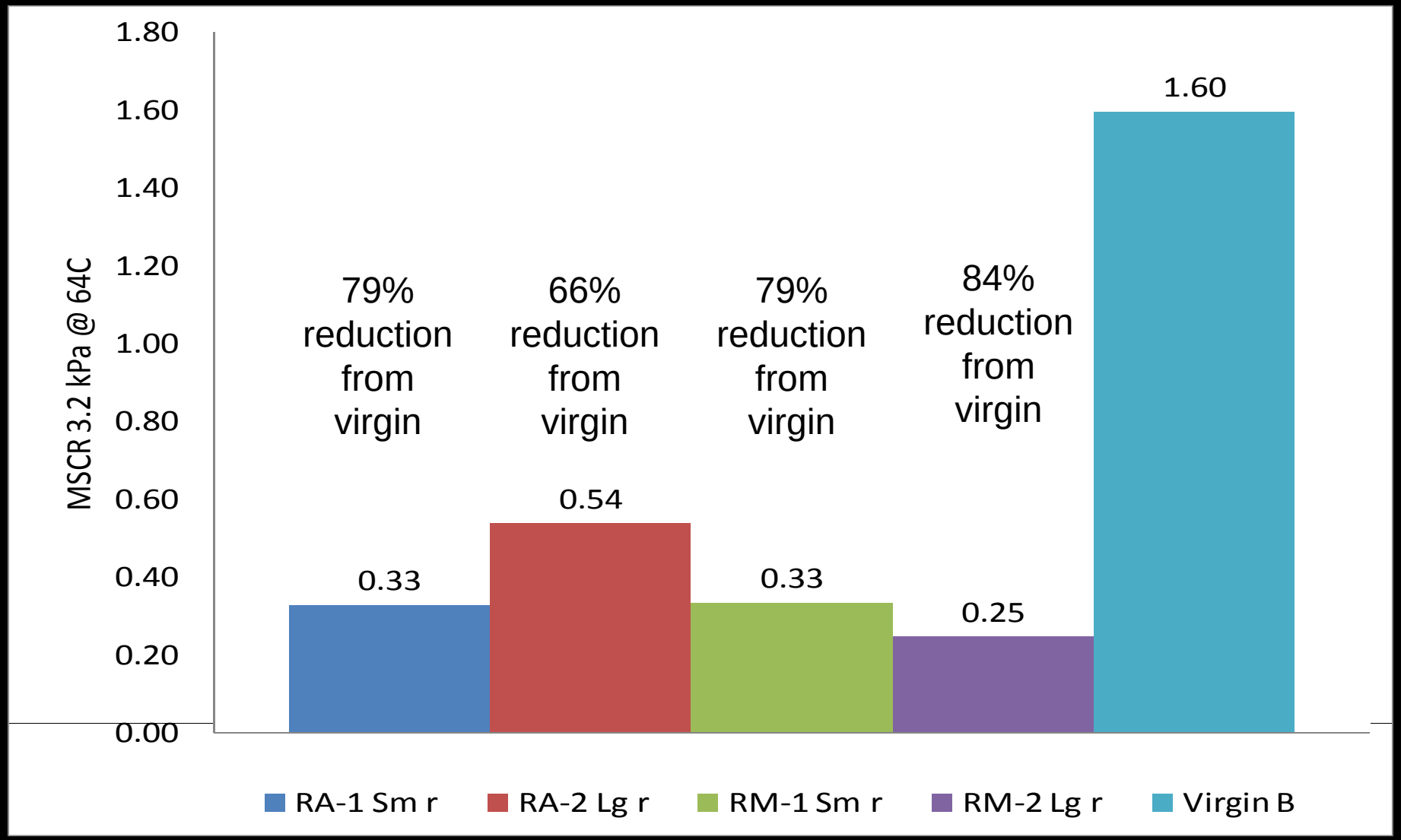
Large Size (#3/8) MD RAP

RAP Type		Large MD RAP					
Mix Composition %	#4 - RAP	100	N/A	N/A		N/A	
	#4 - Virgin	N/A	N/A	75		60	
	#3/8 - RAP	N/A	100	25		40	
	#3/8 - Virgin	N/A	N/A	N/A		N/A	
Aggregate Size	Separated	N/A	N/A	#4	#3/8	#4	#3/8
Binder Content	Pb%	3.29	2.42	4.02	3.02	4.13	3.06
G*/sind - 70°C	Extracted	7.07	7.97	1.96	3.01	2.07	3.47
G*/sind - 70°C	Virgin - NuStar	2.40	2.40	2.40	2.40	2.40	2.40
PG Grade	Extracted	79.60-30.40	80.39-30.00	69.03-31.32	72.61-31.71	69.46-29.77	73.87-30.83
PG Grade	Virgin - NuStar	70.00-22.10	70.00-22.10	70.00-22.10	70.00-22.10	70.00-22.10	70.00-22.10
	MSCR @64C	0.33	0.25	2.13	1.10		

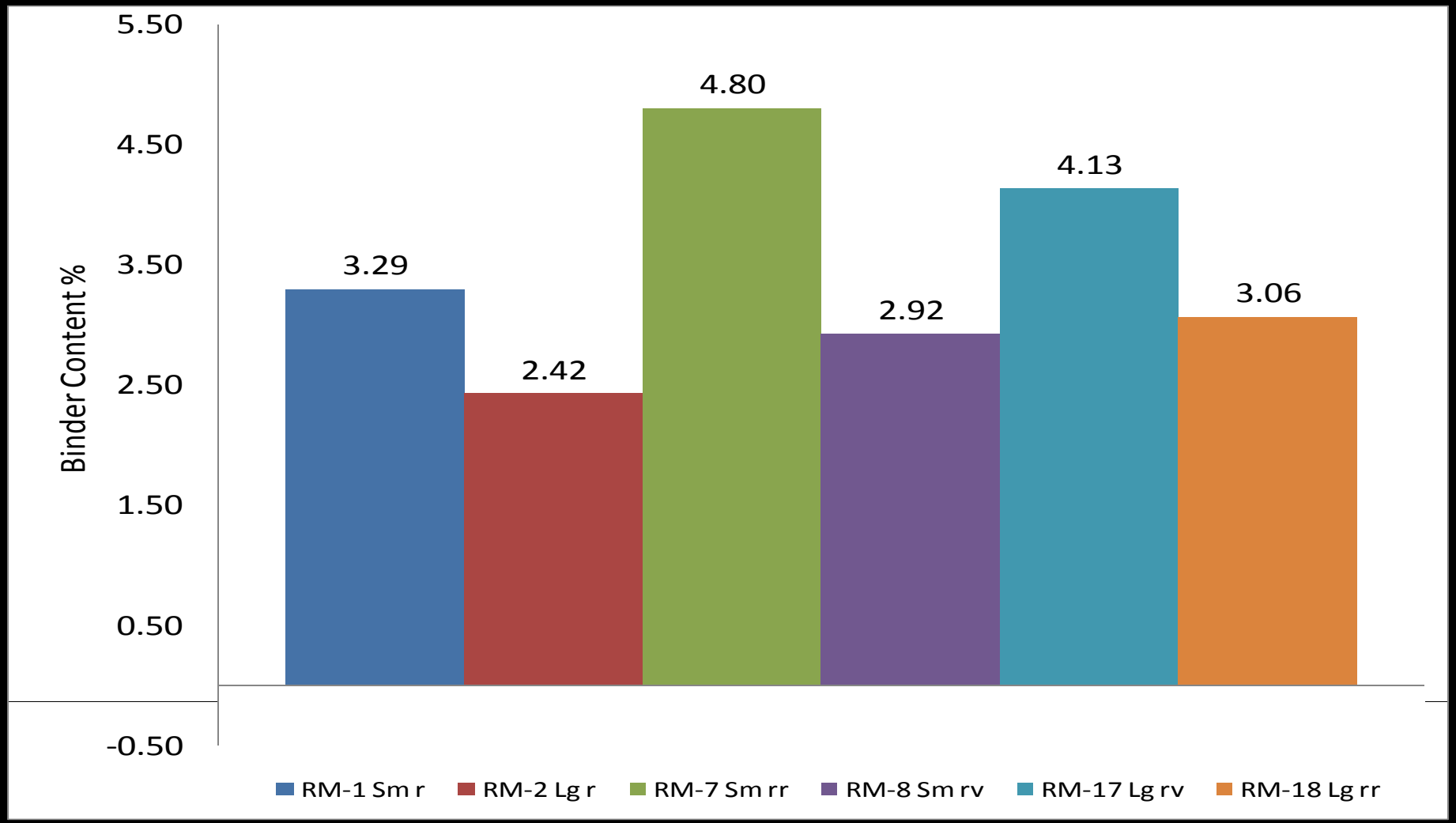
RAP G*/sinδ @ 70C



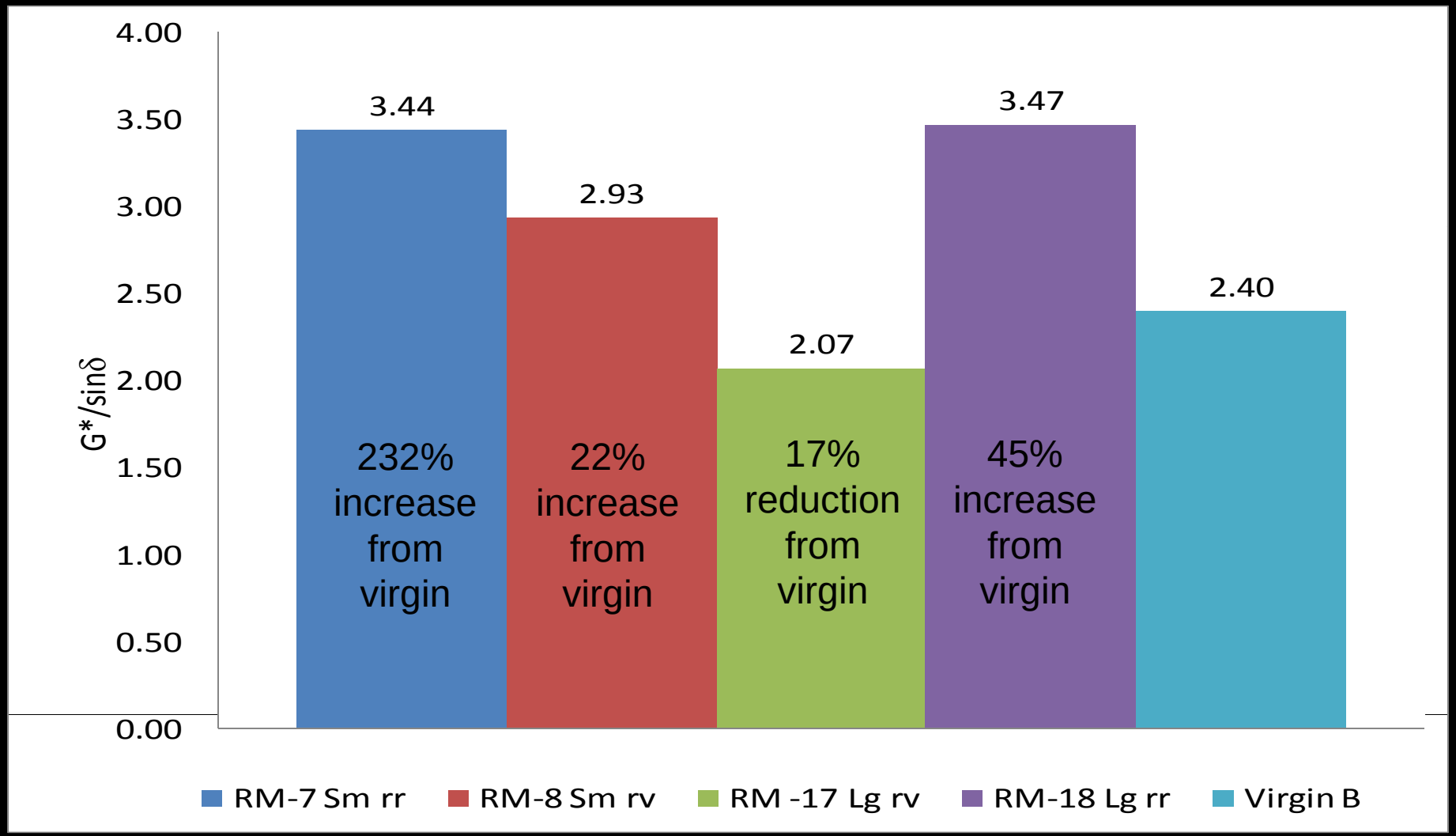
MSCR Jnr @ 64C

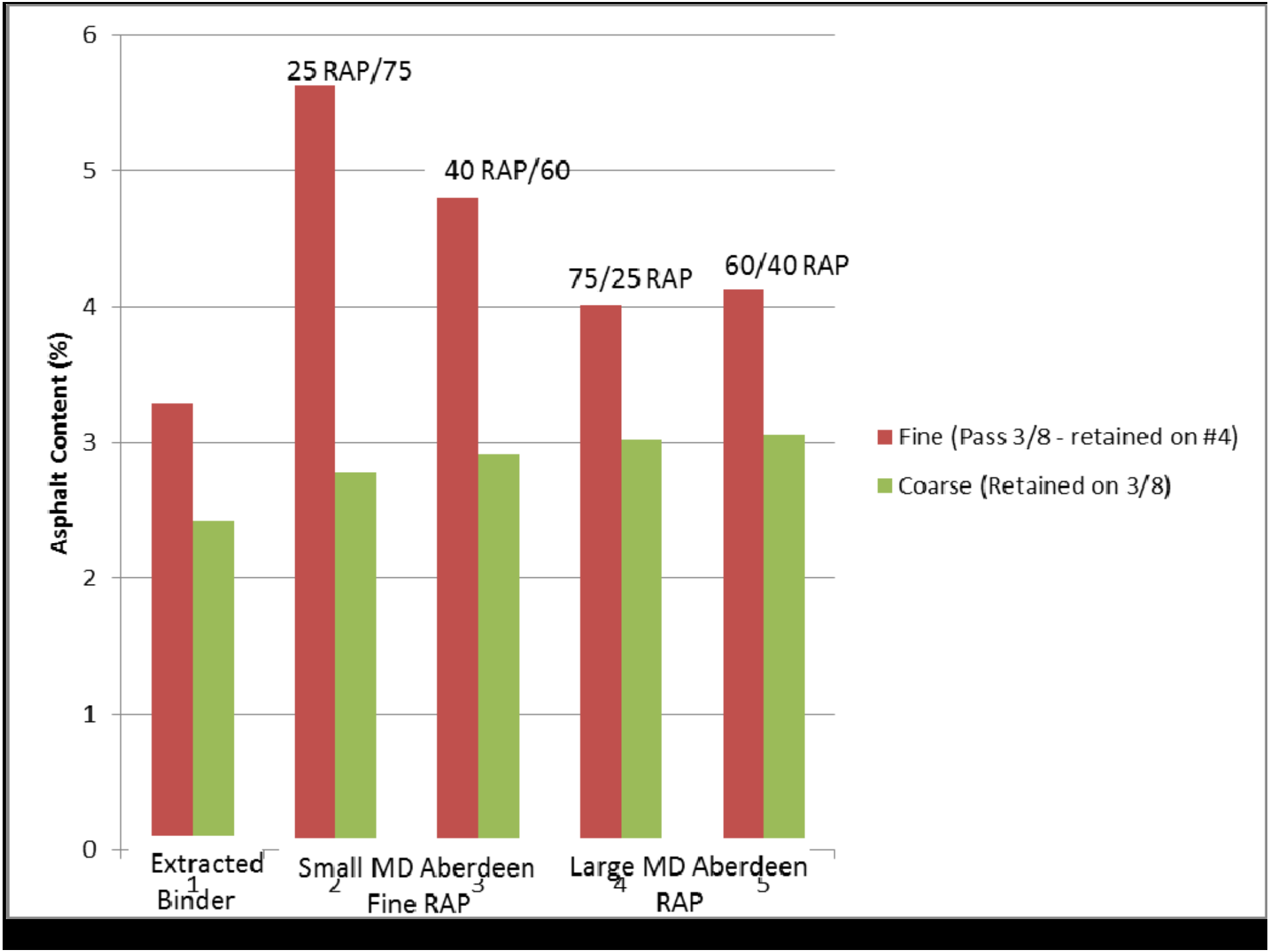

MSCR 3.2 kPa @ 64C
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
79% reduction from virgin
66% reduction from virgin
79% reduction from virgin
84% reduction from virgin
0.33
0.54
0.33
0.25
1.60
RA-1 Sm r
RA-2 Lg r
RM-1 Sm r
RM-2 Lg r
Virgin B

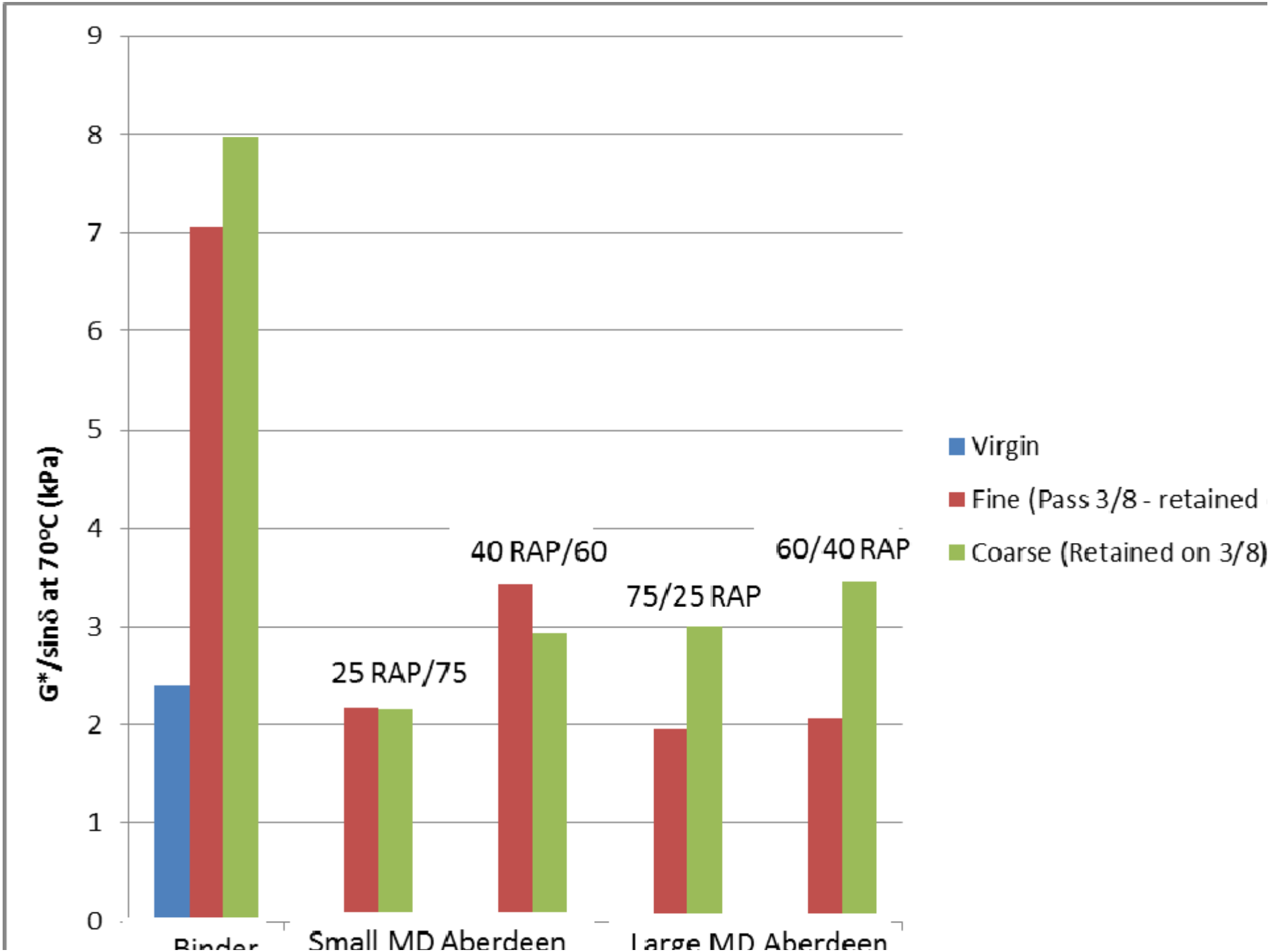
Binder contents of RAP and mix blends @ 40% RAP Blend



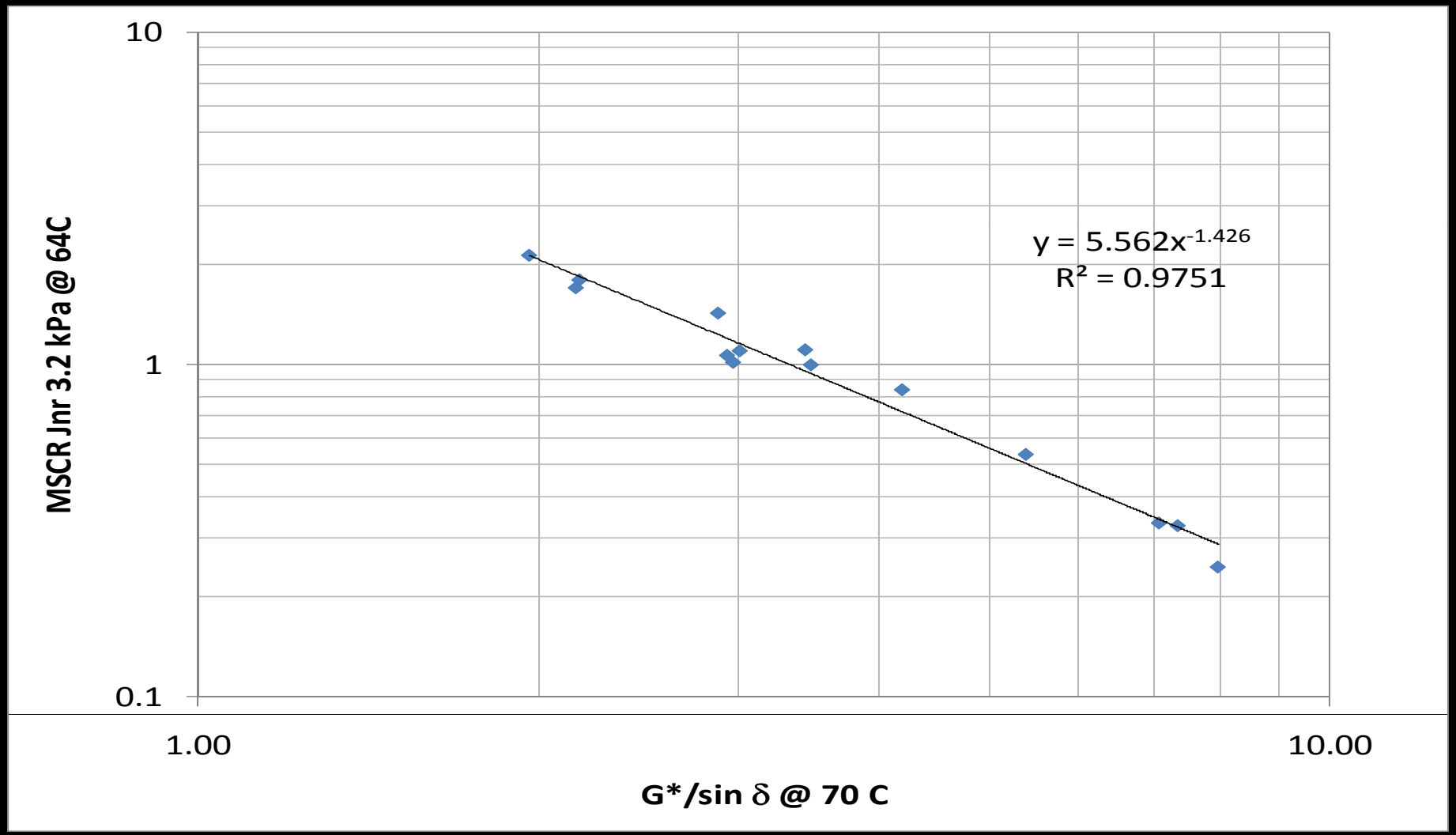
G*/sinδ of RAP and mix blends @ 40% RAP Blend




6
5
4
3
2
1
0
Asphalt Content (%)
25 RAP/75
40 RAP/60
75/25 RAP
60/40 RAP
Extracted Binder
1
Small MD Aberdeen Fine RAP
2
3
Large MD Aberdeen RAP
4
5
Fine (Pass 3/8 - retained on #4)
Coarse (Retained on 3/8)


9
8
7
6
5
4
3
2
1
0
G*/sinδ at 70°C (kPa)
25 RAP/75
40 RAP/60
75/25 RAP
60/40 RAP
Small MD Aberdeen
Large MD Aberdeen
Virgin
Fine (Pass 3/8 - retained
Coarse (Retained on 3/8)

Correlation of Jnr to G*/sinδ for recovered neat binders



Small Size (#4) Artificial RAP

RAP Type		Small Artificial RAP					
Mix Composition %	#4 - RAP	100	N/A	25		40	
	#4 - Virgin	N/A	N/A	N/A		N/A	
	#3/8 - RAP	N/A	100	N/A		N/A	
	#3/8 - Virgin	N/A	N/A	75		60	
Aggregate Size	Separated	N/A	N/A	#4	#3/8	#4	#3/8
Binder Content		4.9	4.4	3.0	1.6	3.1	1.8
G*/sind - 70°C	Extracted	7.35	5.39	4.19	2.88	3.48	2.97
G*/sind - 70°C	Virgin - NuStar	2.40	2.40	2.40	2.40	2.40	2.40
PG Grade	Extracted	80.50-30.39	77.37-30.04	75.42-29.17	72.25-30.36	73.82-29.69	72.55-30.64
PG Grade	Virgin - NuStar	70.00-22.10	70.00-22.10	70.00-22.10	70.00-22.10	70.00-22.10	70.00-22.10
	MSCR @ 64C	0.33	0.54	0.84	1.43	1.00	1.02

Findings – 2010 Study

- Confirms 2009 binder blending findings
  - RAP and Virgin Binders do not completely Blend in a RAP Modified Hot-Mix
  - RAP aggregate has film thickness that is significantly greater than the virgin aggregate
    - Based on binder content data
  - The interface layer between binder and aggregate maybe the key to modeling hot-mix asphalt

Future Work

- Create artificial RAP with + 3/8 material and -8 materials. This will include sand sizes.
- Produce new mixes with virgin course and sand RAP and course RAP and sand virgin.
- Measure, Pb, G*, MSCR, Chemical Fractions.

So What?

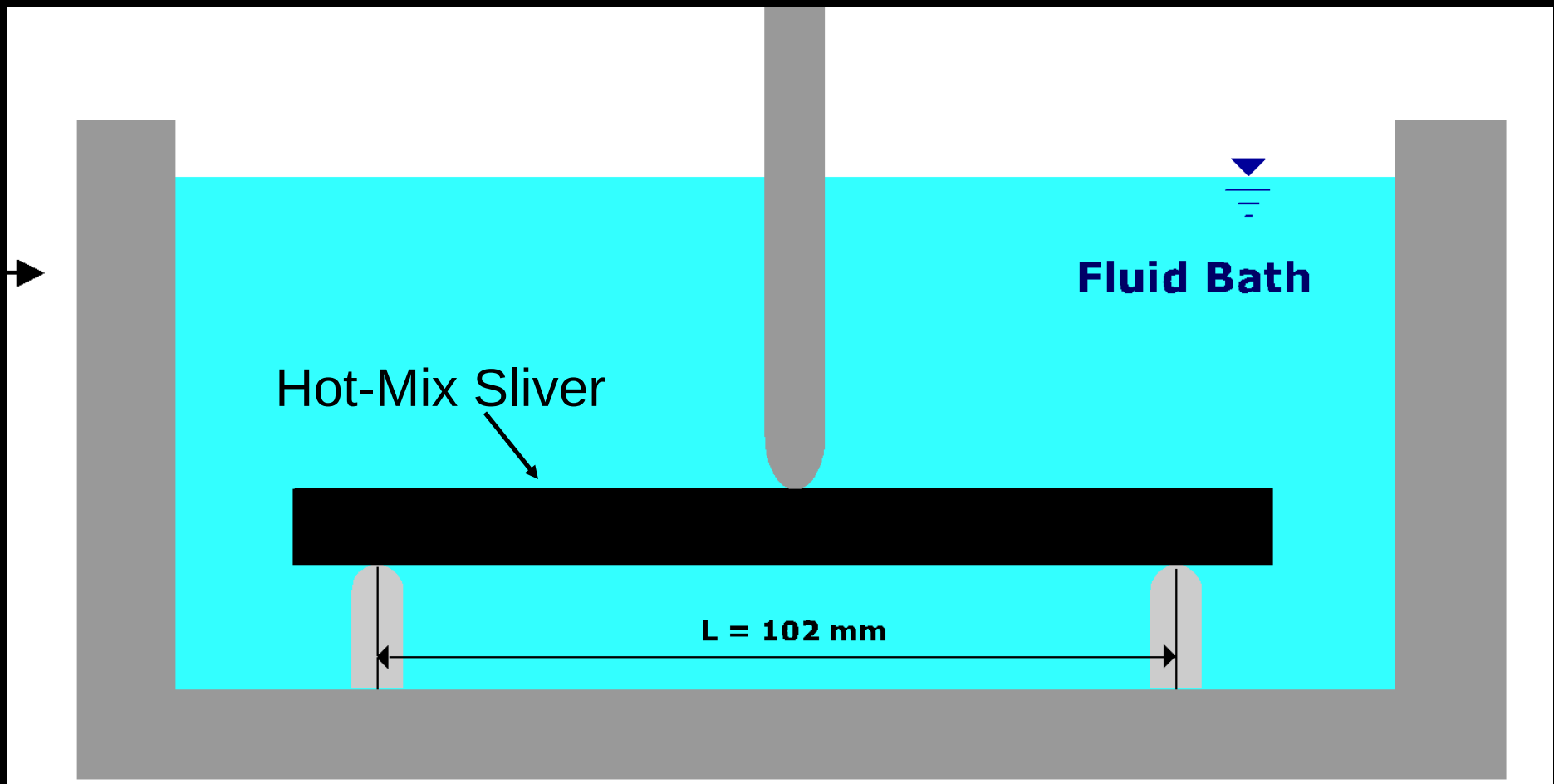
- Implications
  - Blend charts – are they right?
  - Grade softening for high RAP mixes?
- The real issue may be proper homogenous mixing of RAP and Virgin aggregate
  - Plant operation and parameters control that
  - Bonaquist procedure needed but the binder extraction meaningless!

So What Do We Do?

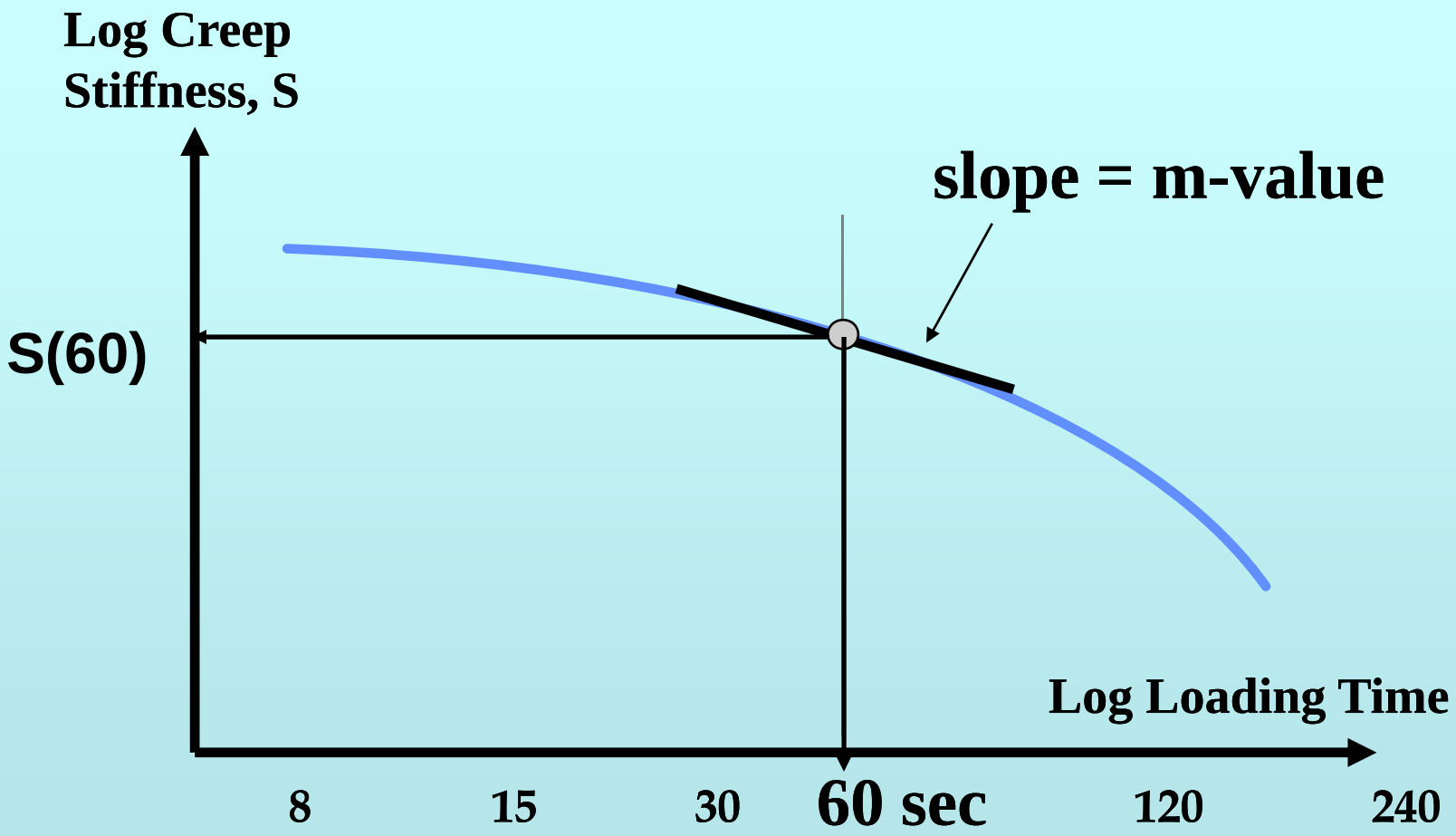
- Need to test the RAP modified Hot-Mix
  - Extracted binder is misleading
  - Current practice is time consuming and meaningless
- Consider a test that can be used as a mix-design as well as QC tool for RAP modified mixes
  - Hot-Mix Sliver test using the BBR
  - Fracture Test

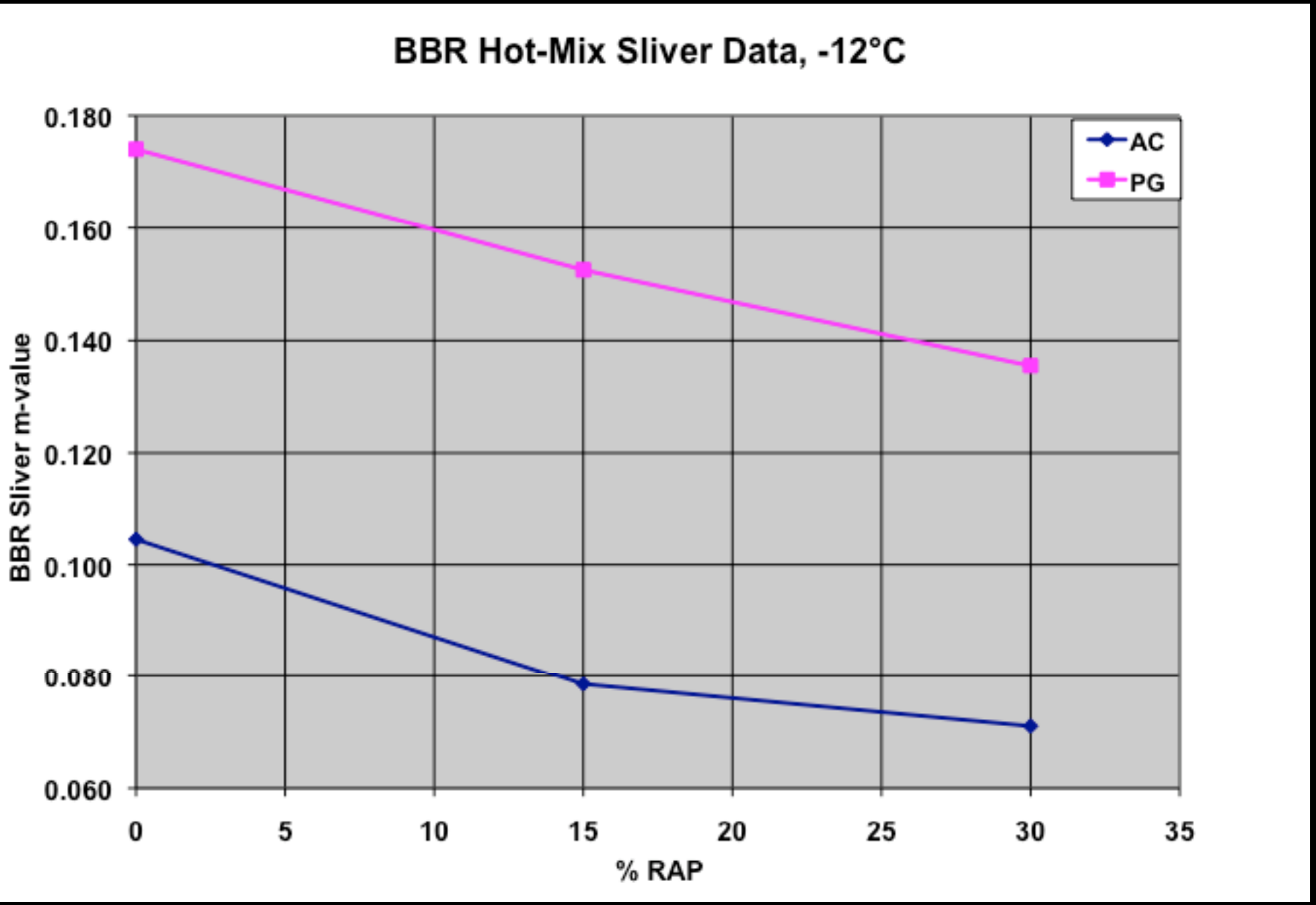
Critical Temperature, ºC	AASHTO M323-07 Appendix X1 Requirements for			PG 64-22 Available Properties
	25 % RAP	30% RAP	35% RAP	
High	> 54.7	> 52.0	> 49.0	66.2
Intermediate	< 24.4	< 24.2	< 24.0	23.1
Low	< -23.8	< -24.3	< -24.8	-24.8

BBR Creep Test



Data Analysis for S(60) & m-value




BBR Hot-Mix Sliver Data, -12°C
BBR Sliver m-value
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0
5
10
15
20
25
30
35
% RAP
AC
PG

Thank You!
Questions?