Design Consideration of Asphalt Mixtures Containing RAS: Impact of Recycling Agents

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Asphalt Binder
Expert Task Group
Baton Rouge, Louisiana
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Presentation Outline

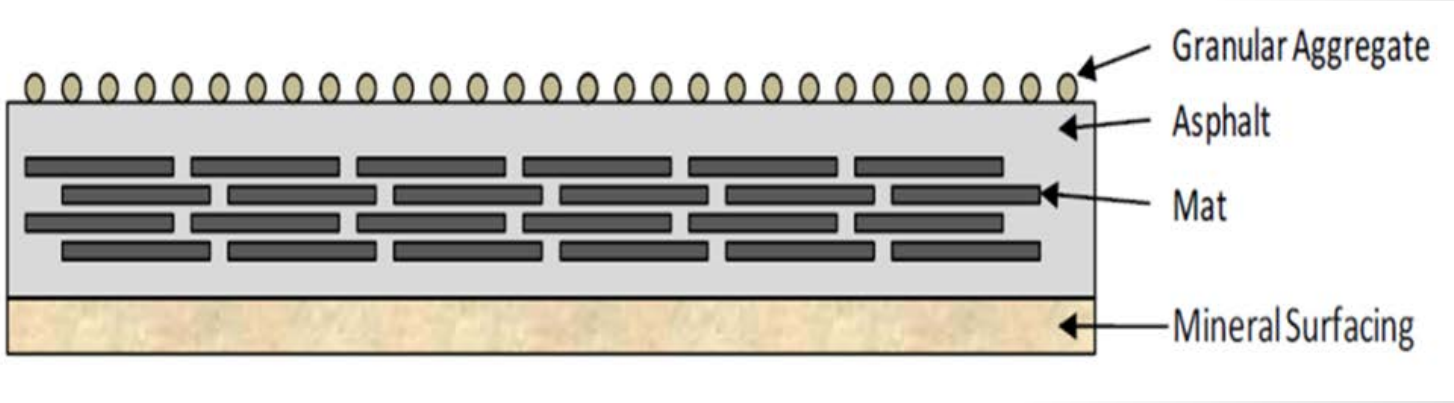
- Background
- Objective/Scope
- Methodology
  - Mix experiment
  - Binder Experiment
- Results
- Summary/Conclusions

Sustainability in Flexible Pavement

- Conventional materials
  - Asphalt Treated Mixtures
- Recycled materials
  - RAP, CRM, RAS
- Industrial waste extender
  - Sulfur
- Plant-based
  - Bio-binder
  - Bio-rejuvenator
- Pavement construction practice
  - Warm Mix Asphalt
- Air-pollution reduction
  - photocatalytic pavements

Recycles Asphalt Shingles

- **Asphalt binder**
  - Post Consumer: 25 – 30%
  - Manufacture waste: 18 – 22%
- **Mineral matter**
  - 40 to 60%
  - granules and fillers
- **Fibers**
  - 8 to 12%



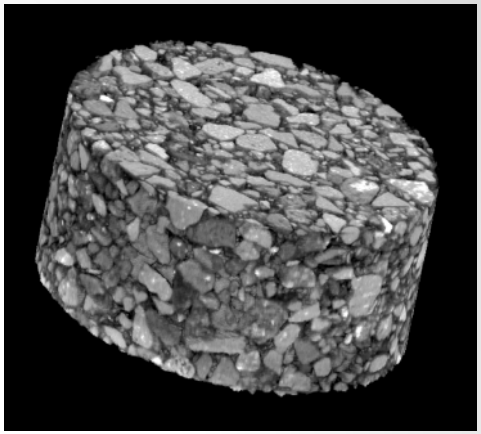
Recycles Asphalt Shingles

- Supply (US)
  - 10M: Post Consumer
  - 01M: Manufactures Waste
- Benefits
  - Sustainability
  - Partial aggregate and binder replacement
  - Prevent landfilling of valuable resource
  - Improved rut resistance
- Concerns
  - Consistency of asphalt content
  - Availability vs Credit of the asphalt binder
  - Quantity vs Quality of the asphalt binder
  - Performance
    - Intermediate and low temperature

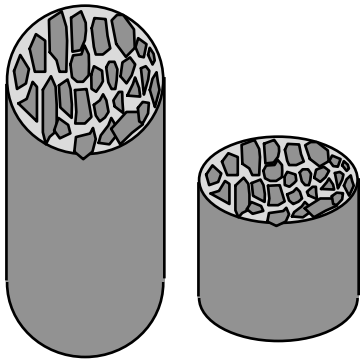
http://www.disastersafety.org/hail/shingle-roofs/attachment/asphalt-shingles/

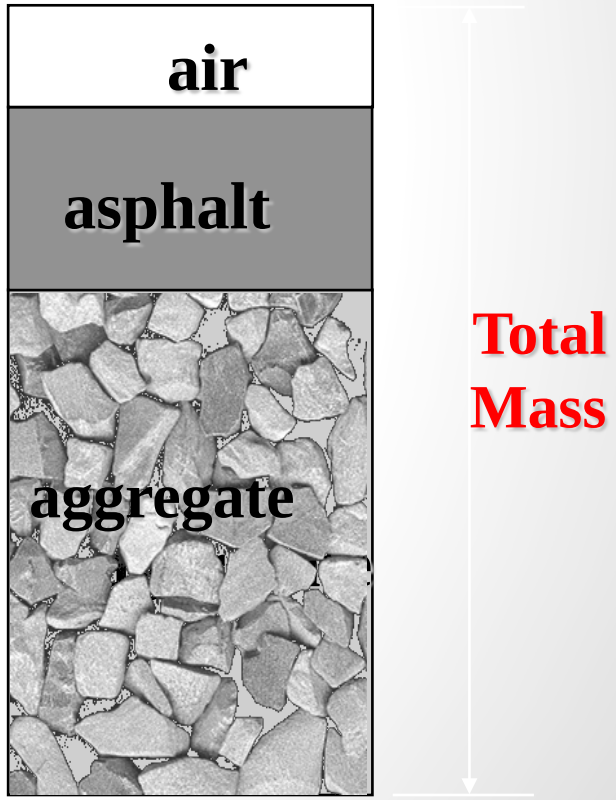
http://www.solidwasteagency.org/#/business/drop-off/shingle/

Typical Asphalt Mixture Design



- **Volumetrics**
  - Voids in the Total Mix, VTM
  - Voids in the Mineral Aggregate, VMA
  - Voids Filled with Asphalt, VFA
- **Densification**
  - Stages during lab compaction process





Use of RAS in HMA/WMA?

- **AASHTO MP 15-09 → AASHTO MP 23-14**
  - ***Use of RAS as an Additive in Hot Mix Asphalt (Asphalt)***
- **Provides Standard definitions for RAS**
- **Process RAS**
  - **100% passing 12.5-mm sieve**
  - **Allows blending of RAS with fine aggregate**
    - **Prevent agglomeration**
  - **Addresses deleterious materials**

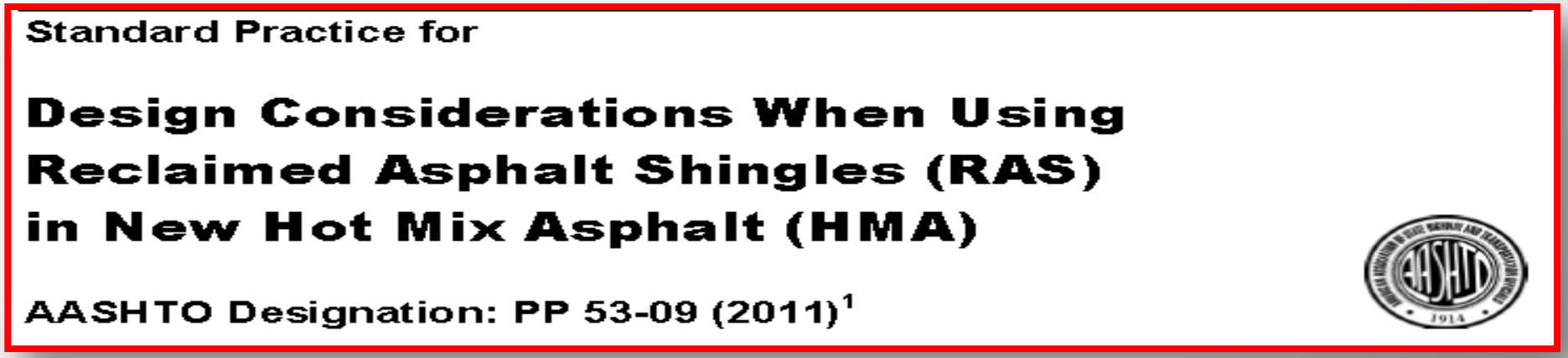
Standard Specification for

Use of Reclaimed Asphalt Shingles as an Additive in Hot Mix Asphalt (HMA)

AASHTO Designation: MP 15-09 (2011)[1]

How to incorporate RAS in HMA/WMA?

- **AASHTO PP53** → **AASHTO PP 78-14**
  - ***Standard Practice for Design Considerations When Using RAS in Asphalt Mixtures***
- **Provides guidance on design considerations**
  - **RAS size can affect the fraction of RAS binder that contribute to the final blended binder**
  - **fibers in RAS may require additional**
  - **virgin asphalt binder**
- **RAS asphalt availability factor is 0.70 - 1.0**


Standard Practice for

Design Considerations When Using Reclaimed Asphalt Shingles (RAS) in New Hot Mix Asphalt (HMA)

AASHTO Designation: PP 53-09 (2011)[1]

Our Experiment

- Design mixture with no shingles
  - Calculate OAC
    - VMA, VTM
- Add shingles
  - Calculate OAC
  - VMA and VTM similar to mix with no shingles
  - Binder credit
- Add shingles + Recycling Agents
  - Calculate OAC
  - VMA and VTM similar to mix with no shingles
  - Binder credit

Objective / Scope – Mixture Experiment

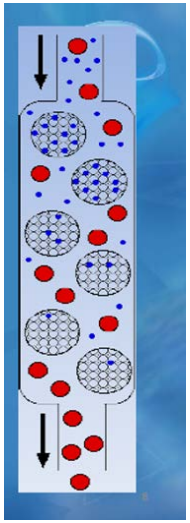
- Evaluate the intermediate and low temperatures laboratory performance
  - conventional asphalt mixtures
  - mixtures containing RAS
  - Effect of recycling agents (RAs)

- Three 12.5mm Mixtures - NRA
  - Mix 1: 70CO
    - RAS = 0%
    - PG 70-22M
  - Mix 2: 70PG5M-B
    - RAS = 5%
    - Type: manufacturer waste shingles (MWS)
    - PG 70-22M
  - Mix 3: 70PG5P-B
    - RAS = 5%
    - Type: post-consumer waste shingles (PCWS)
    - PG 70-22M

- Three 12.5mm Mixtures - RAs
  - Mix 4: 52PG5P-*RA 1*-B
    - RAS = 5% PCWS
    - RA 1: PG 52-28
  - Mix 5: 70PG5P-*RA 2*-B
    - RAS = 5% PCWS
    - RA 2 = 5%
  - Mix 6: 70PG5P-*RA 3*-B
    - RAS = 5% PCWS
    - RA 3 = 12%

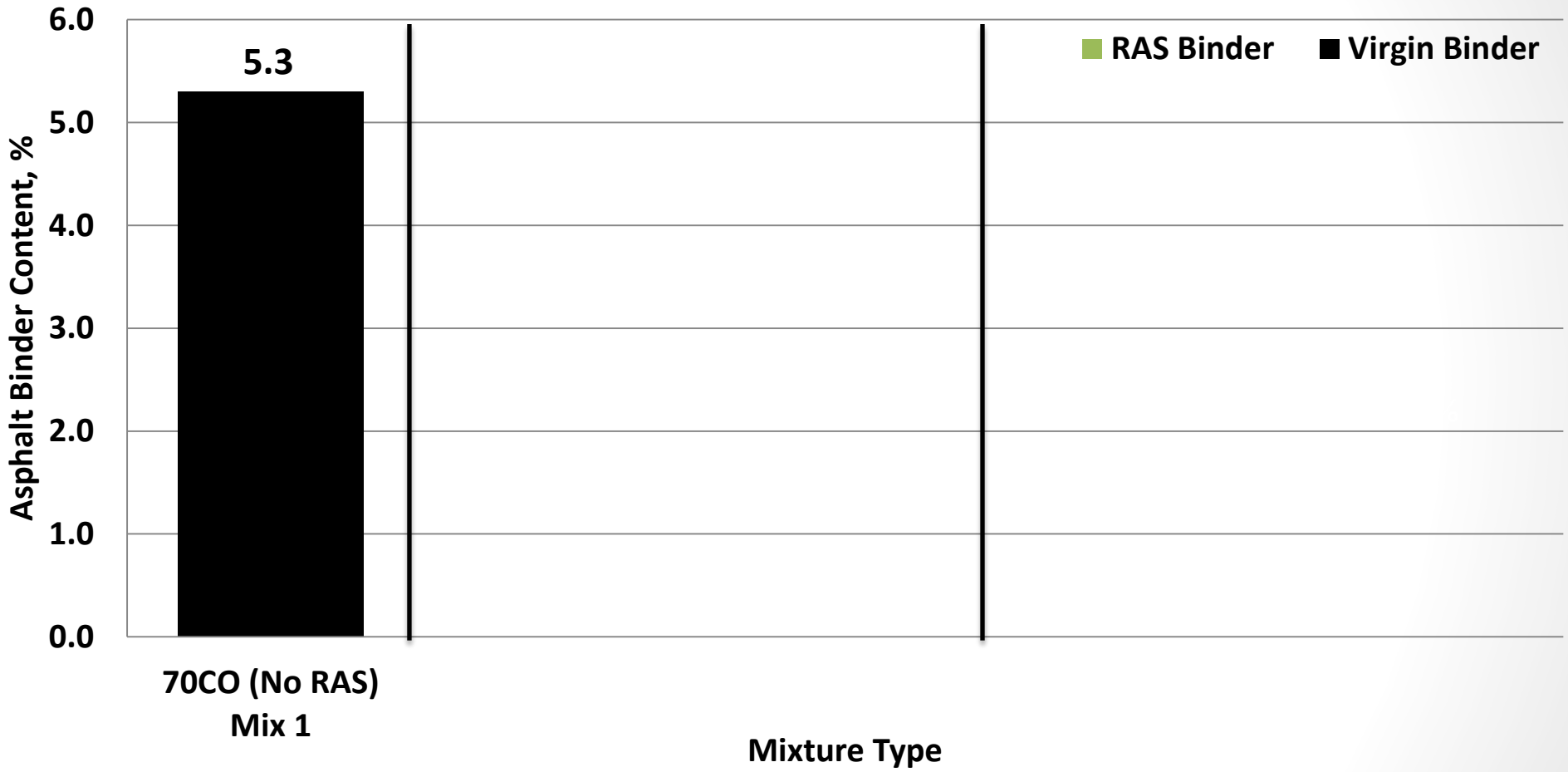
Objective / Scope – Binder Experiment

- Correlate the molecular structure of asphalt binders to fracture property of asphalt mixtures
  - Asphalt mixtures: Conventional
  - Asphalt mixtures: RAS with and without RAs
- Gel Permeation Chromatography (GPC)
- Fourier Transform Infrared Spectroscopy (FTIR)



Design Consideration – OAC=5.3%

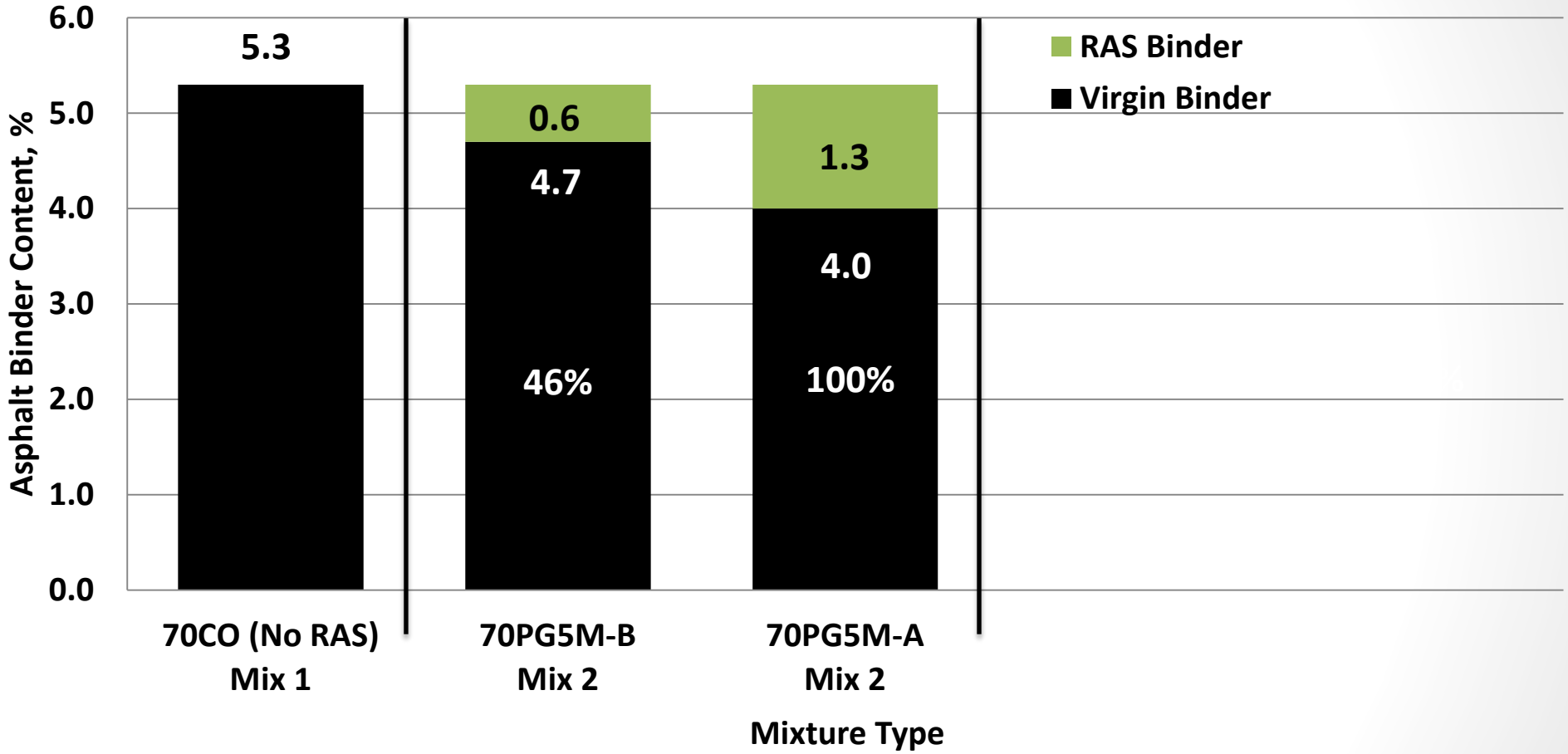
No Recycling Agent



Available RAS Binder = 26 * 5% RAS = 1.3

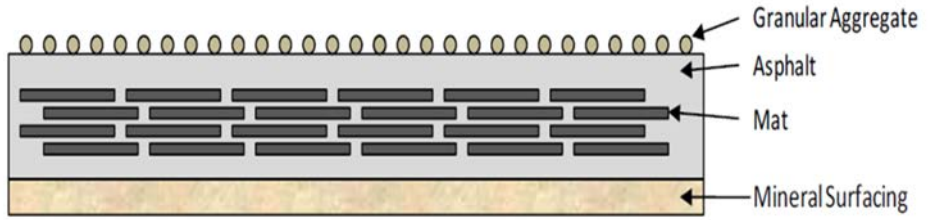
Design Consideration – OAC=5.3%

No Recycling Agent



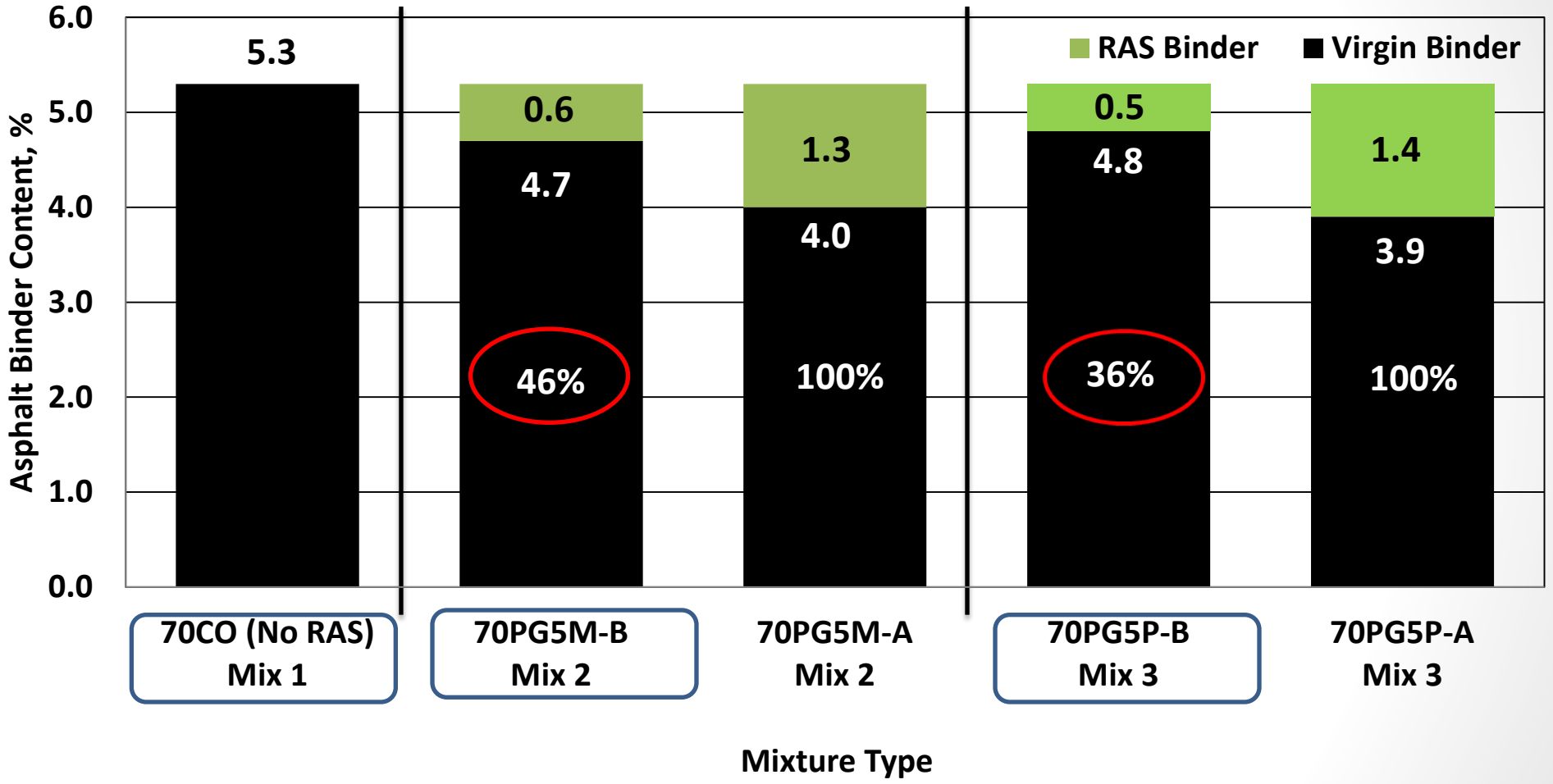
Available MWS RAS Binder = 26 * 0.05 = 1.3

Available Binder Factor = (0.6/1.3)*100 ≈ 46%



Design Consideration – OAC=5.3%

No Recycling Agent Virgin Binder ~ 90%



Available PCWS RAS Binder = 28% * 0.05 = 1.4%

Available Binder Factor = (0.5/1.4)*100 ≈ 36%

Mixture Design Concern

RAS Type	%RAS Total AC Content	%RAS in Mix Design	%RAS AC Binder Available
PCWS	28.6	5.0	1.4

- Recycled binder Ratio (RBR)
  - ✓ Recycled binder content / total binder content
- Design binder content – Mix with No RAS
  - ✓ 5.3% binder
- Scenario 1 (100% availability -- P)
  - ✓ RBR = 1.40 / 5.3 = 0.26
- Scenario 2 (< 100% availability -- P)
  - ✓ RBR = 0.50 / 5.3 = 0.09
- Increase the RBR
  - ✓ Recycling Agents
    - Softening
    - Rejuvenators
- RBR = 0.30 – 0.50
  - ✓ Ensuring structural performance + volumetrics
    - high temperature
    - intermediate temperature
    - low temperature performance
    - moisture damage resistance

Mixture Design Concerns

RAS Type	%RAS Total AC Content	%RAS in Mix Design	%RAS AC Binder Available
PCWS	28.6	5.0	1.4

- **Classes of Recycling Agents**

REJUVENATING AGENTS	SOFTENING AGENTS
Lube Extracts	Lube Stock
Extender Oils (aromatic oils)	Lubricating or Crankcase Oil
Anti-Stripping Agent	Slurry Oil
Naphthenic Oil	Asphalt Flux Oils
Vegetable Derived Oils	Soft Asphalt Binders

- **Purpose of Recycling Agents**
  - **Softening Agents**
    - lower the viscosity of the ***aged binder***
  - **Rejuvenators**
    - help restore physical and chemical properties of ***aged binder***
    - contain a high proportion of maltene constituents

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Naphthenic Oil – RA 3	Asphalt Flux Oils
Vegetable Derived Oils – RA 2	Soft Asphalt Binders -- RA 1

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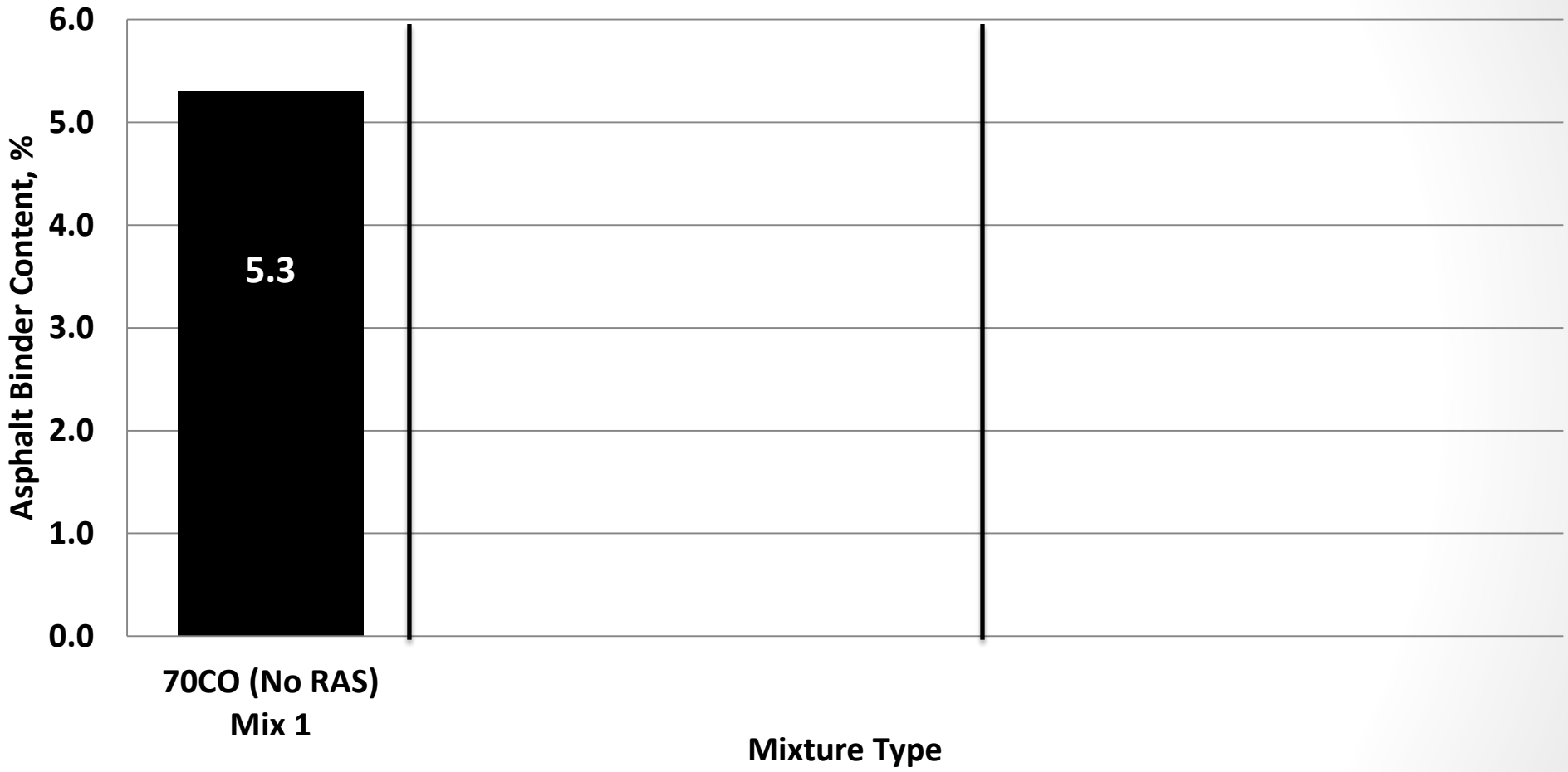
Design Consideration – OAC=5.3%

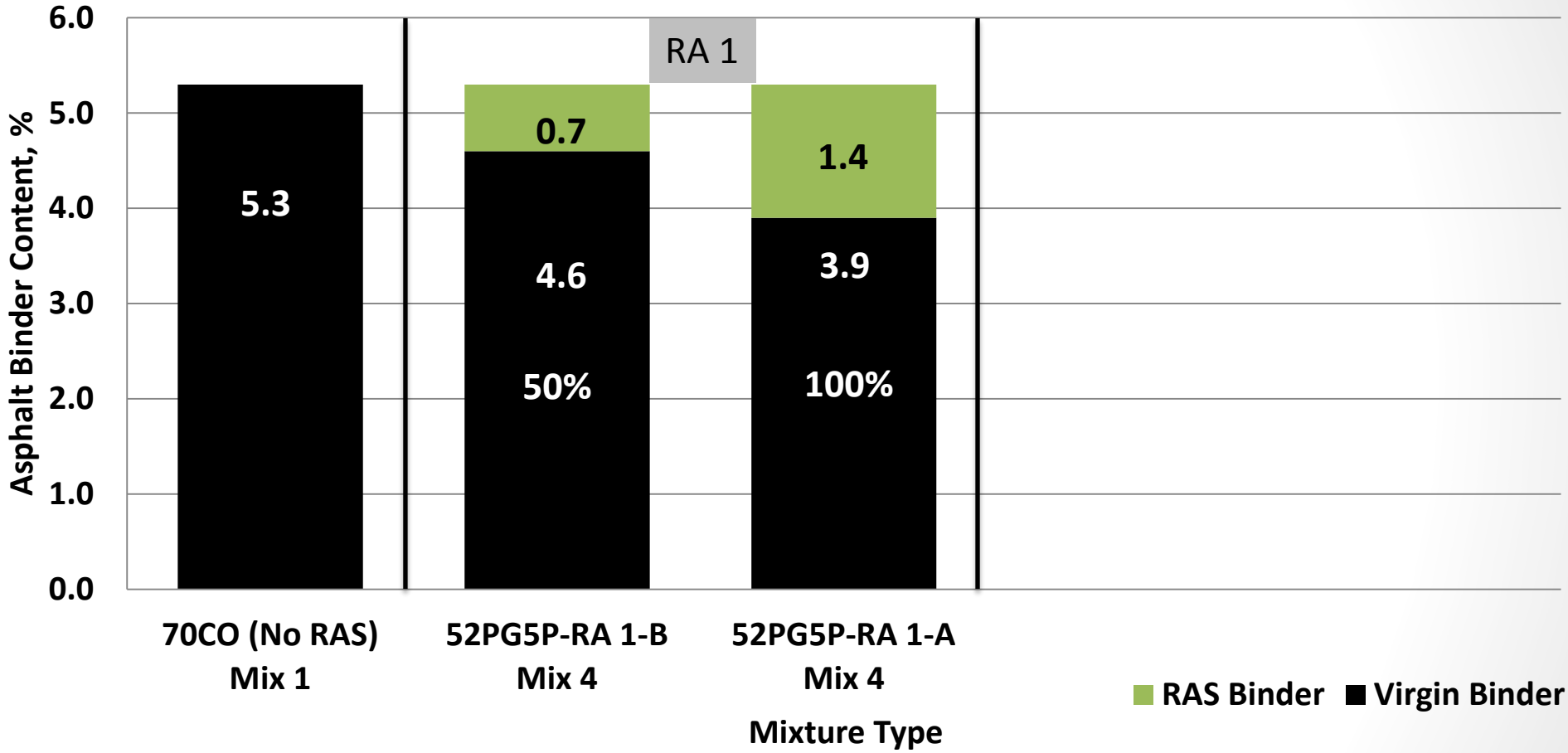
Recycling Agent (RA)



Available RAS Binder = 28 * 5% RAS = 1.4%

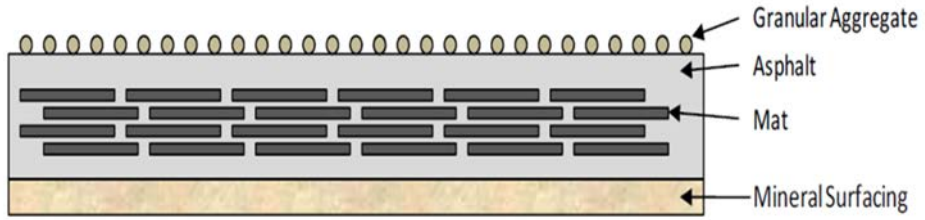
Design Consideration – OAC=5.3%

Recycling Agent



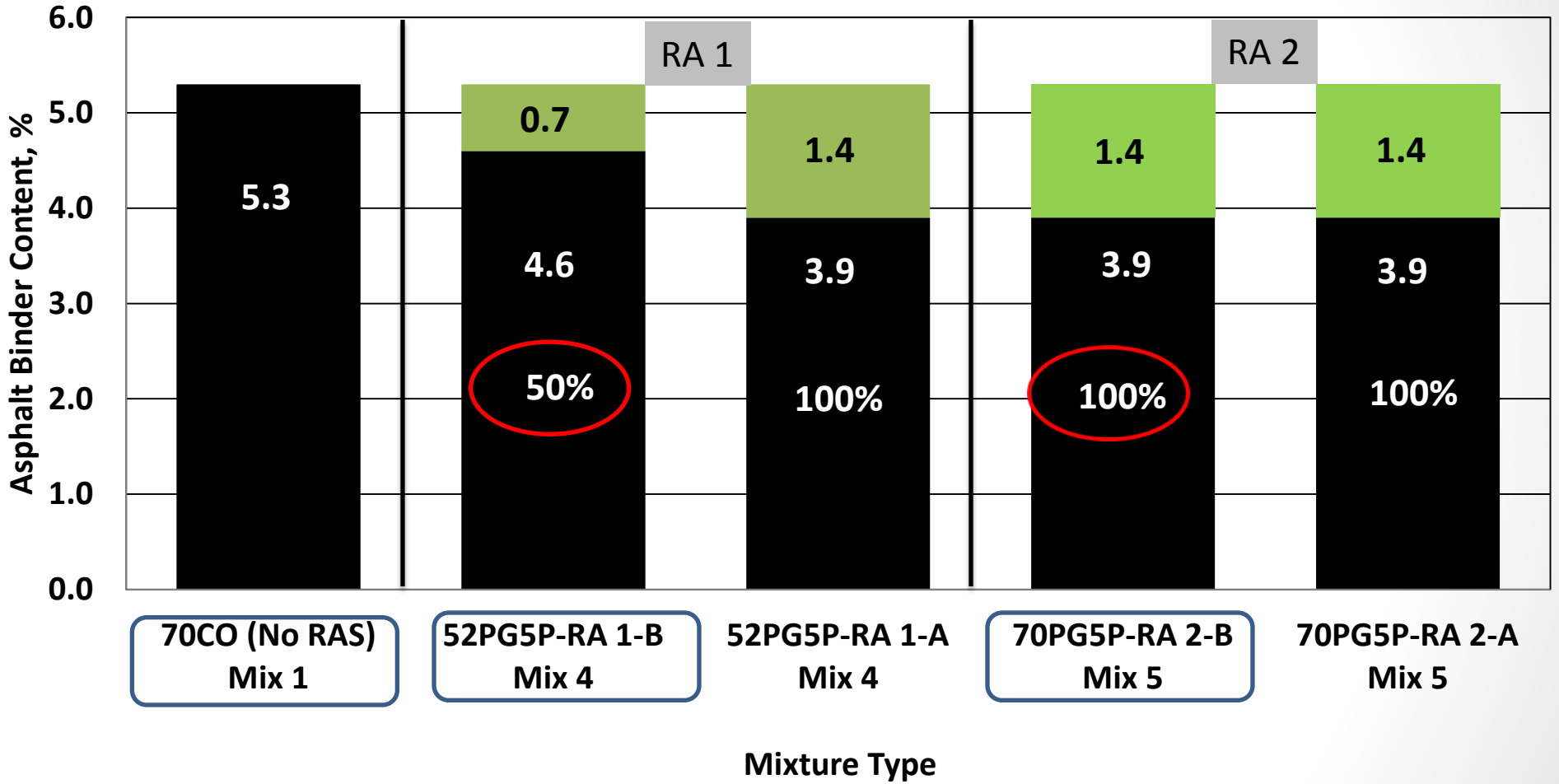
Available PCWS RAS Binder = 28 * 0.05 = 1.4

Available Binder Factor = (1.4/1.4)*100 = 100%



Design Consideration – OAC=5.3%

Recycling Agent (RA)

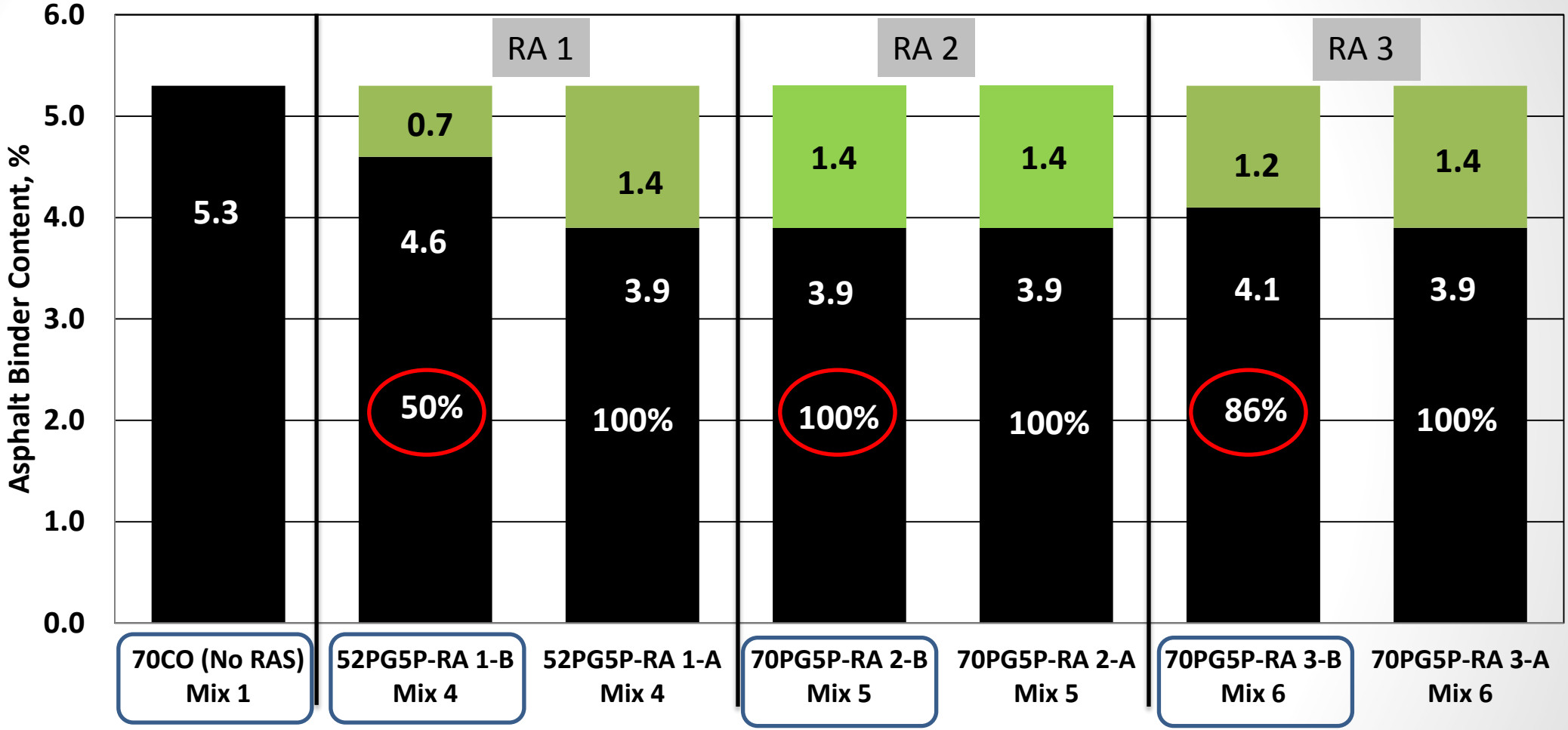


Available PCWS RAS Binder = 28% * 0.05 = 1.4%

Available Binder Factor = (1.2/1.4)*100 ≈ 86%

Design Consideration – OAC=5.3%

Recycling Agent (RA) Virgin Binder: 87%, 74%, 77%



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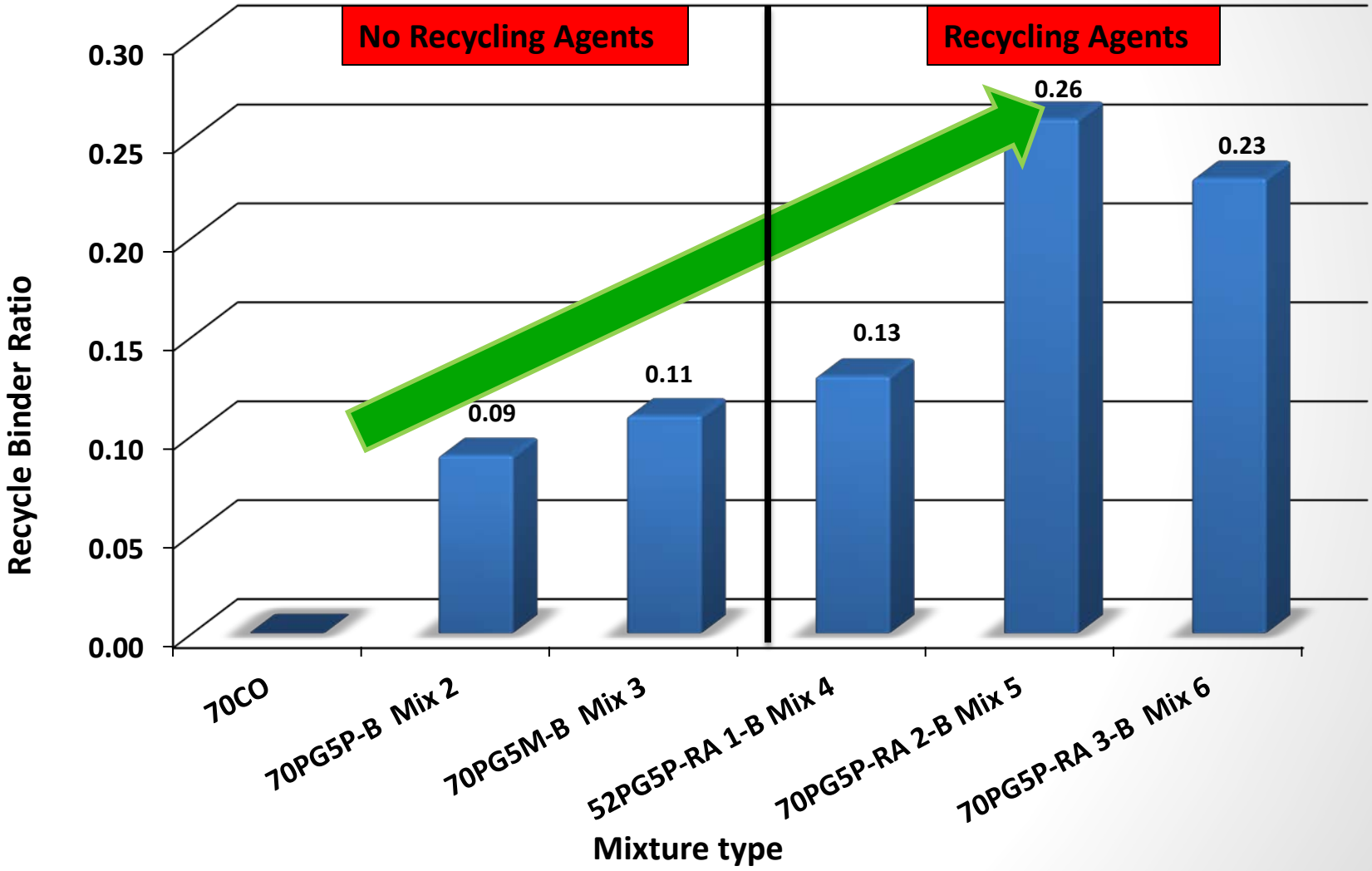
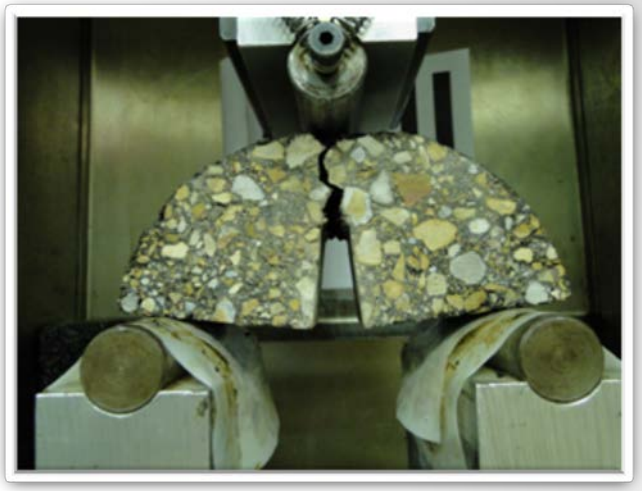
Recycled Binder Ratio



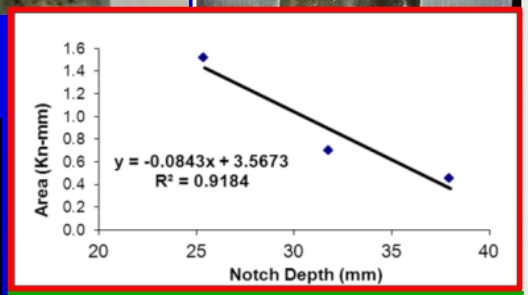
Laboratory Performance Tests Quality vs Quantity

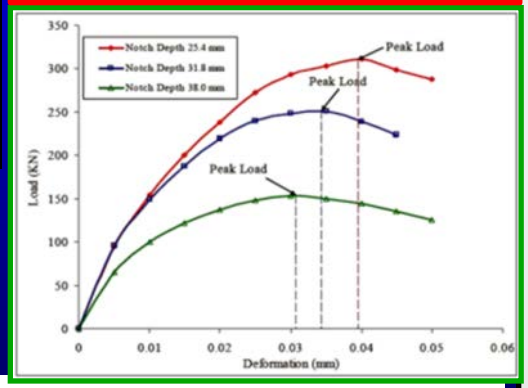
- **Intermediate temperature Performance**
  - semi-circular bending test
- **Low temperature performance**
  - Thermal Stress Restrained Specimen Test
- **Triplicates**
  - VTM: 7 ± 0.5%

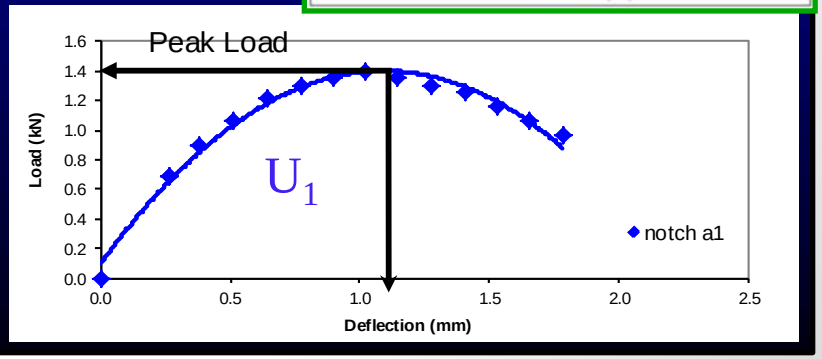


Semi Circular Bend (SCB) Test

- Fracture mechanics
  - used for evaluating fracture resistance in rock mechanics
- Temperature: 25°C
- Half-circular Specimen
  - Laboratory prepared
  - Field core
  - 150mm diameter X 57mm thickness
  - simply-supported and loaded at mid-point
- Notch controls path of crack propagation
  - 25.4-, 31.8-, and 38.0-mm
- Loading type
  - Monotonic
  - 0.5 mm/min
  - To failure
- Aging: 5 days, 85°C
- Record Load and Vertical Deformation
- Compute Critical Strain Energy: Jc

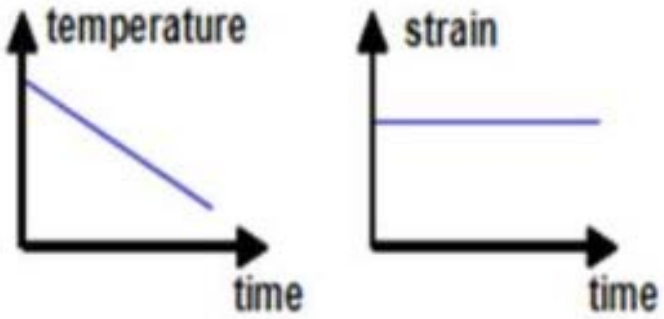


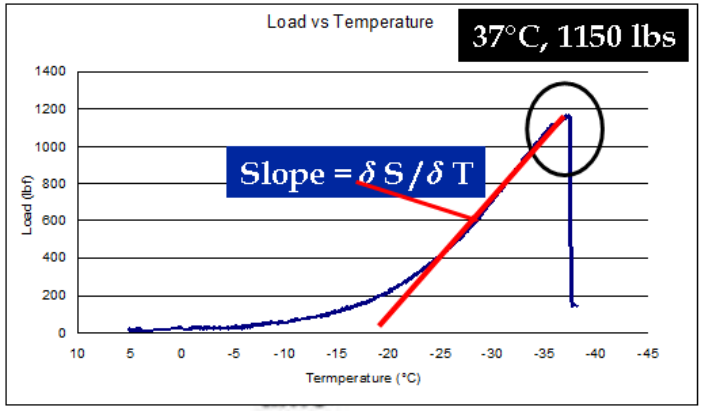




Thermal Stress Restrained Specimen Test

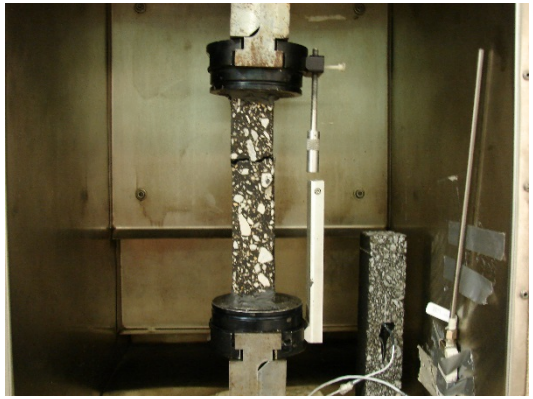
- **AASHTO TP10-93**
- **Apply thermal loading**
  - **-10 ± 1 °C per hour until specimen fracture**
- **Continuously record**
  - **Load, displacement, temperature**
- **Determine the low-temperature cracking susceptibility of asphalt concrete**
  - **Determine temperature and tensile strength at fracture**



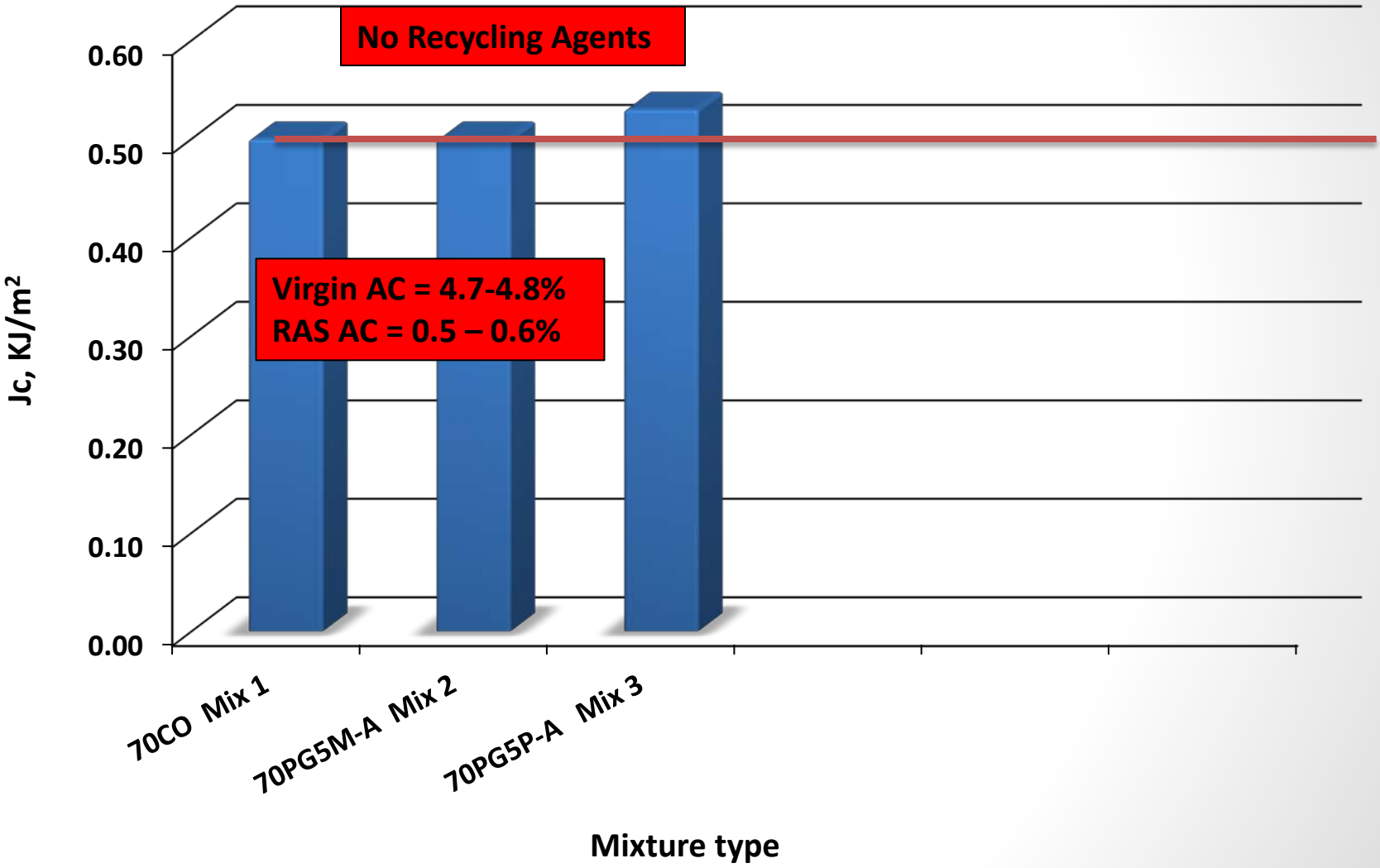


http://www.cooper.co.uk/info/index.asp?page=asphalt_pavement_thermal_testing_system_307

Results



Semi-Circular Bend Test Results, 25°C



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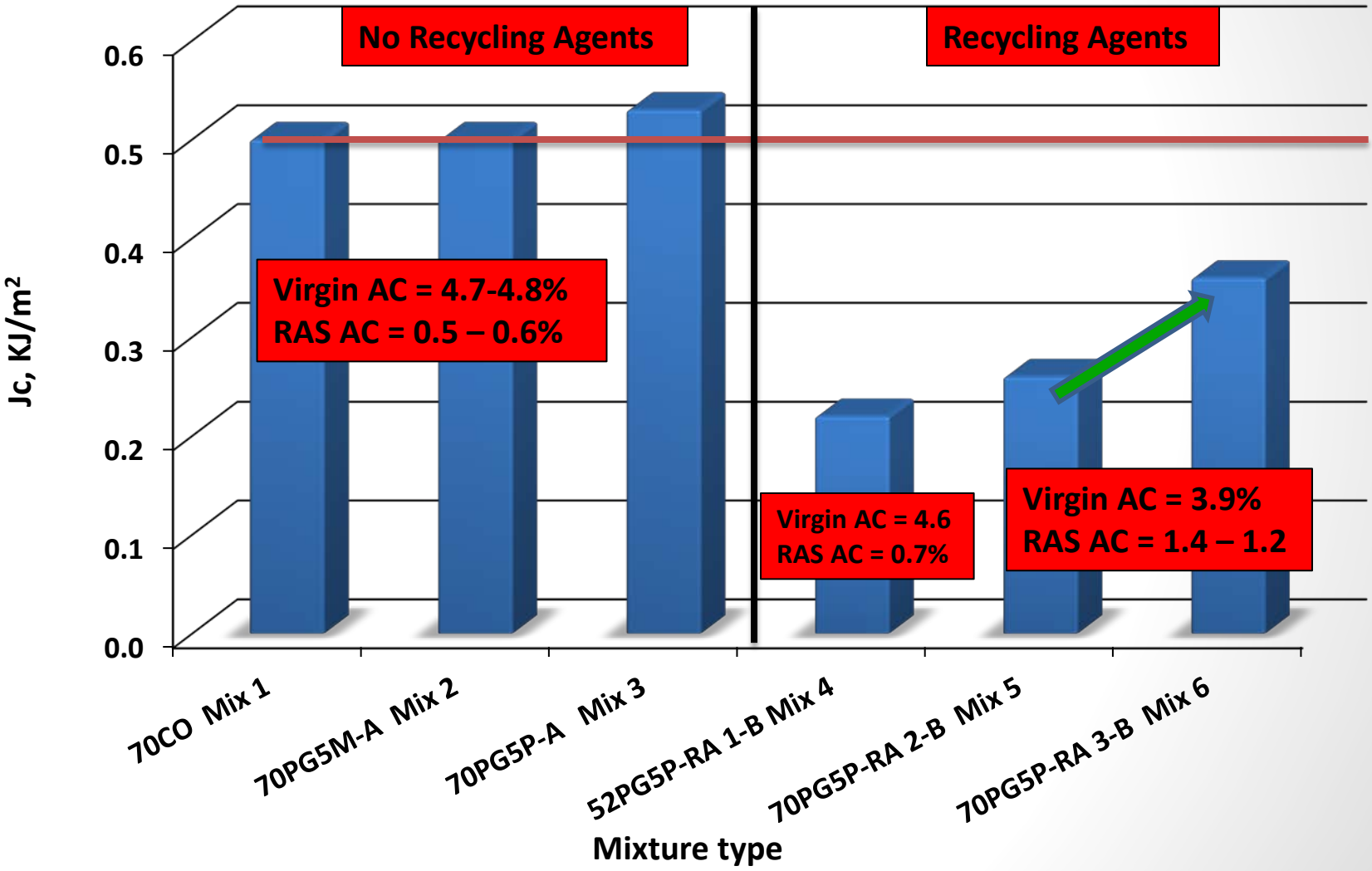

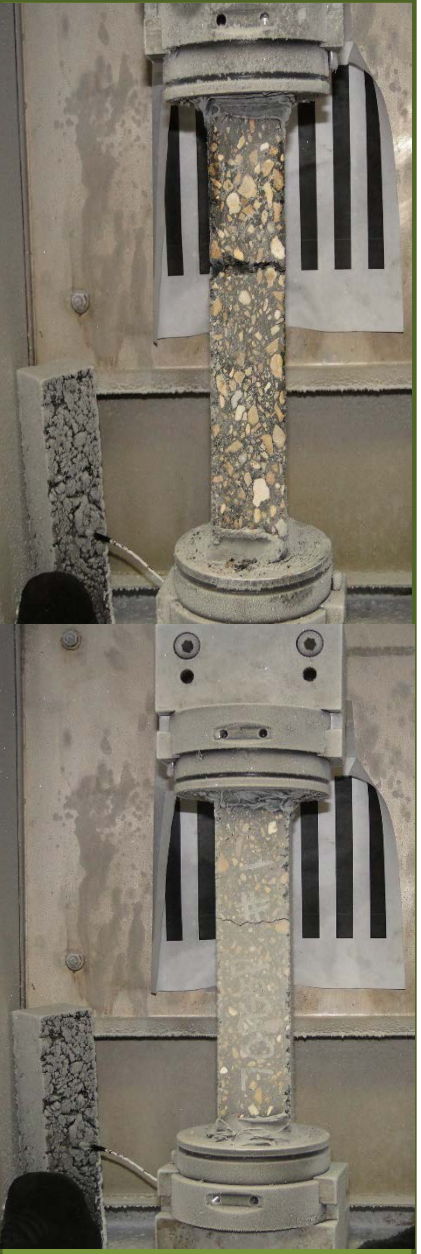

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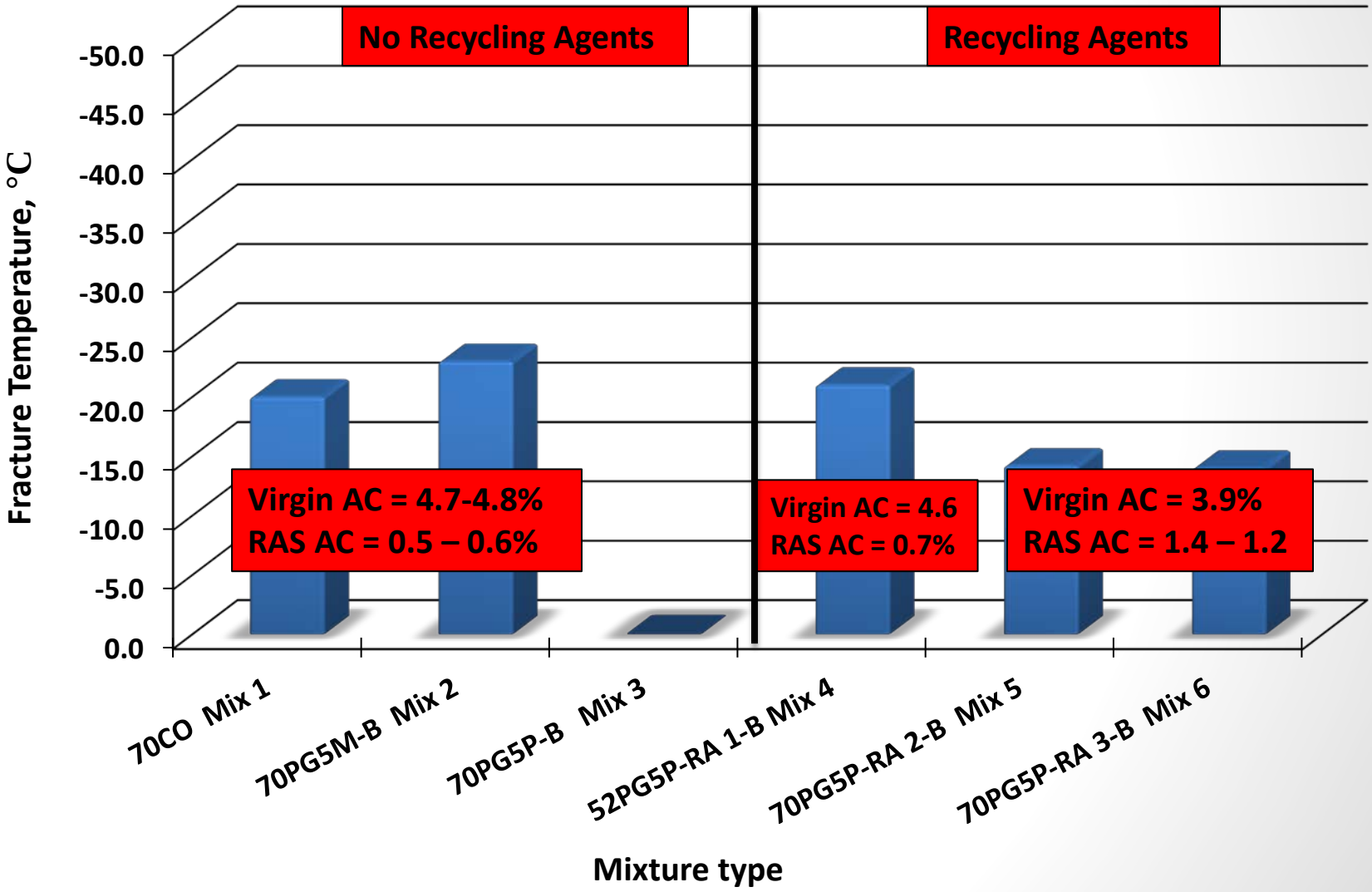
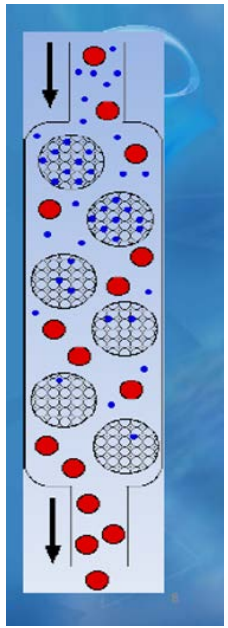


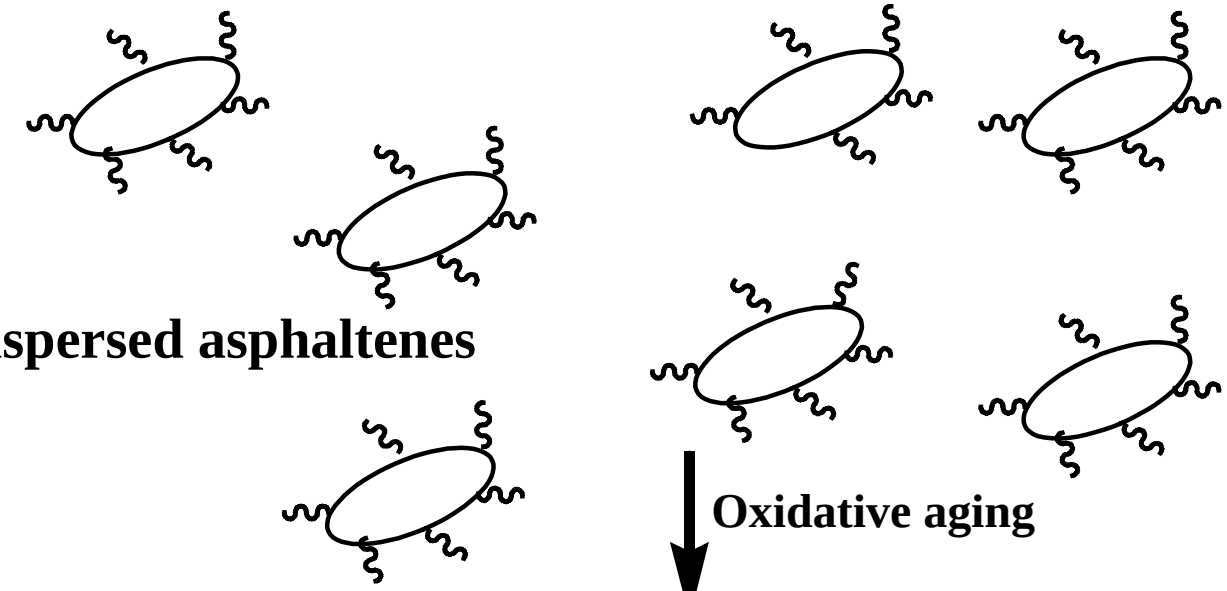
Binder Experiment:

Investigation of the Impact of Recycling Agent

- Concern with mixture performance
  - NRA vs RA
- Chemical analysis
  - Gel Permeation Chromatography, FTIR
- Binder extracted from aged HMA mixtures
  - 5 days, 85°C



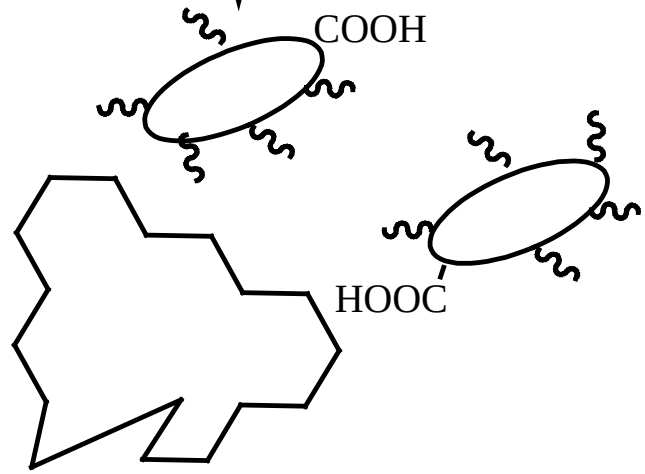
Oxidation of Asphalt Matrix



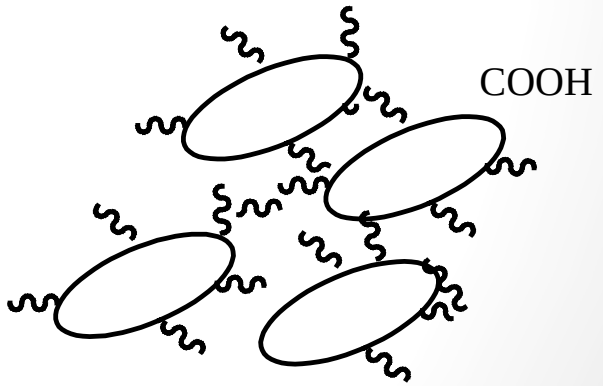
Dispersed asphaltenes

Oxidative aging

Polar groups stabilize aggregation



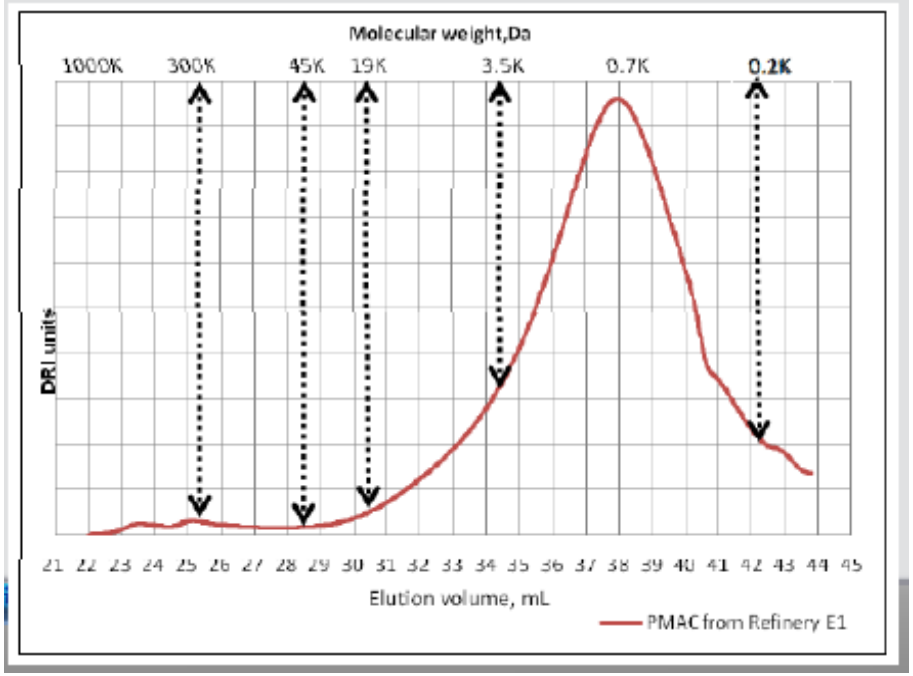
Polar groups may enhance adhesion to binder

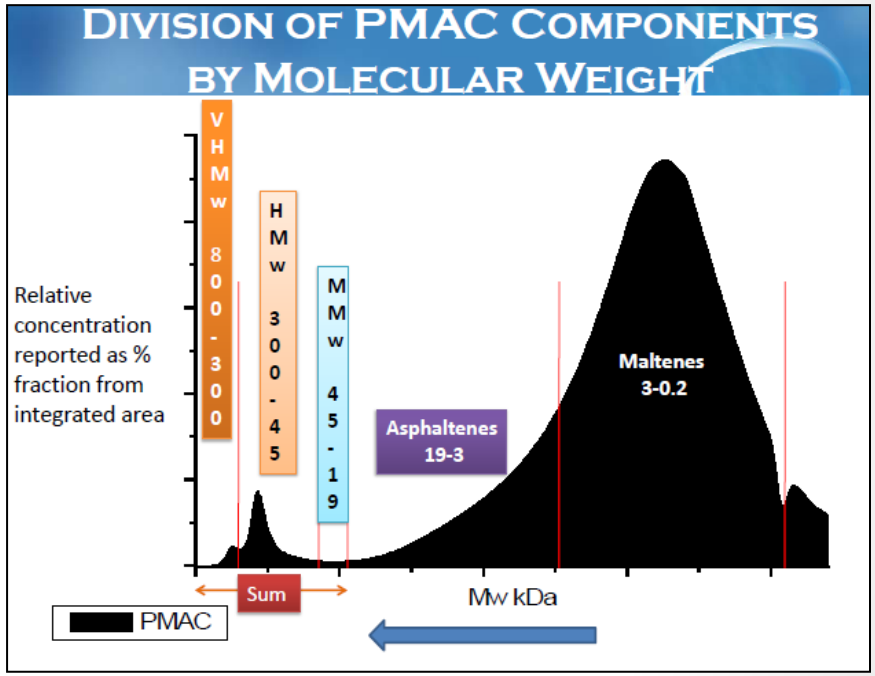


Asphaltene aggregation

Asphalt aggregates reinforce matrix

Typical GPC Chromatogram

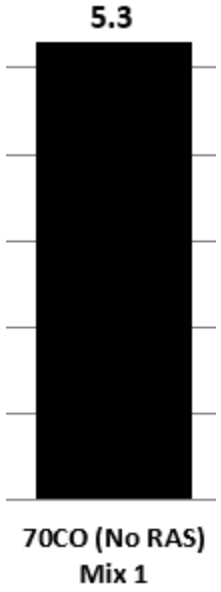




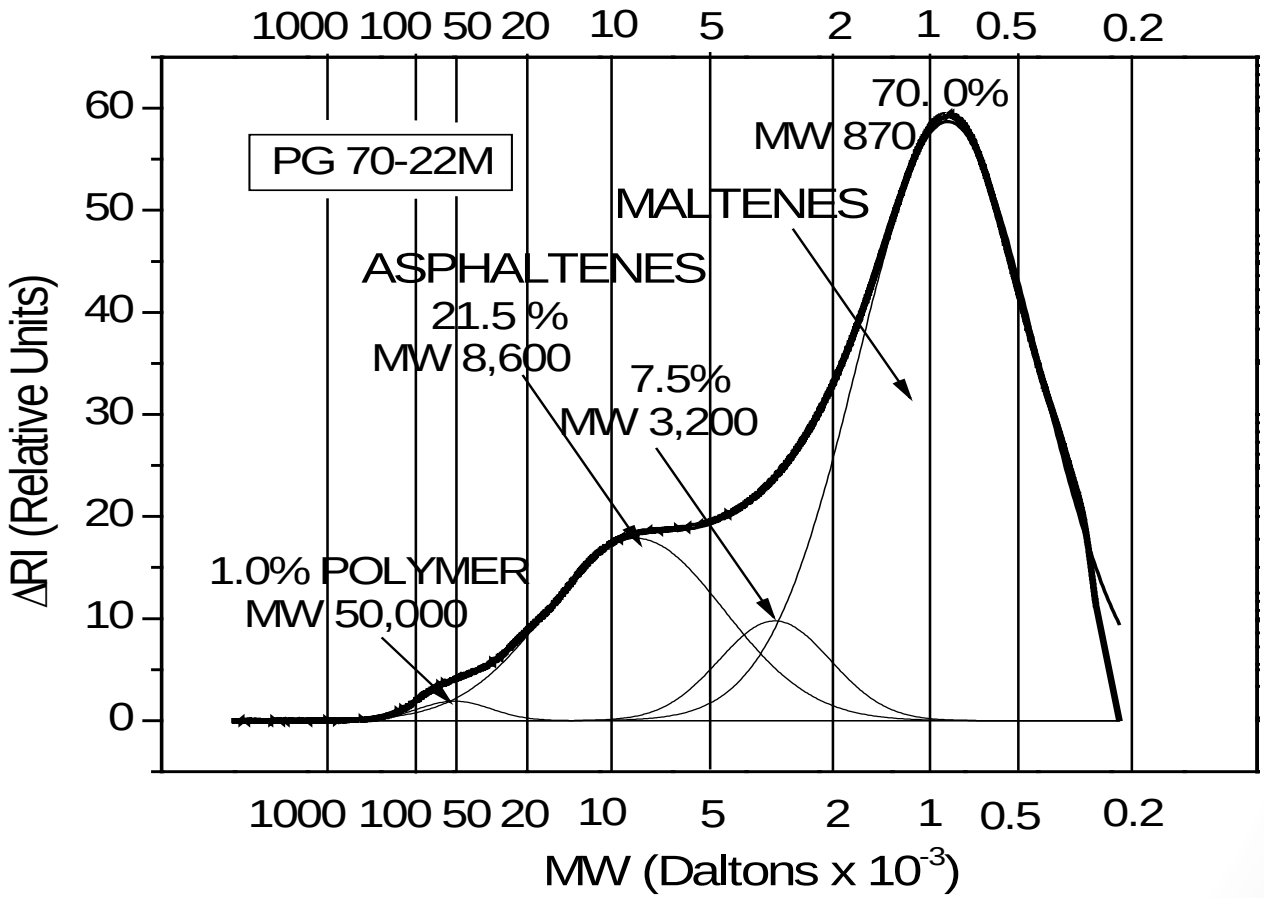
Asphalt Characterization Utilizing Gel Permeation Chromatography (GPC)
William Daly, Ionela Glover, Ioan Negulescu, Christopher Abadie, Louay Mohammad,Rafael Cueto

MW distribution of molecular species of extracted binder:

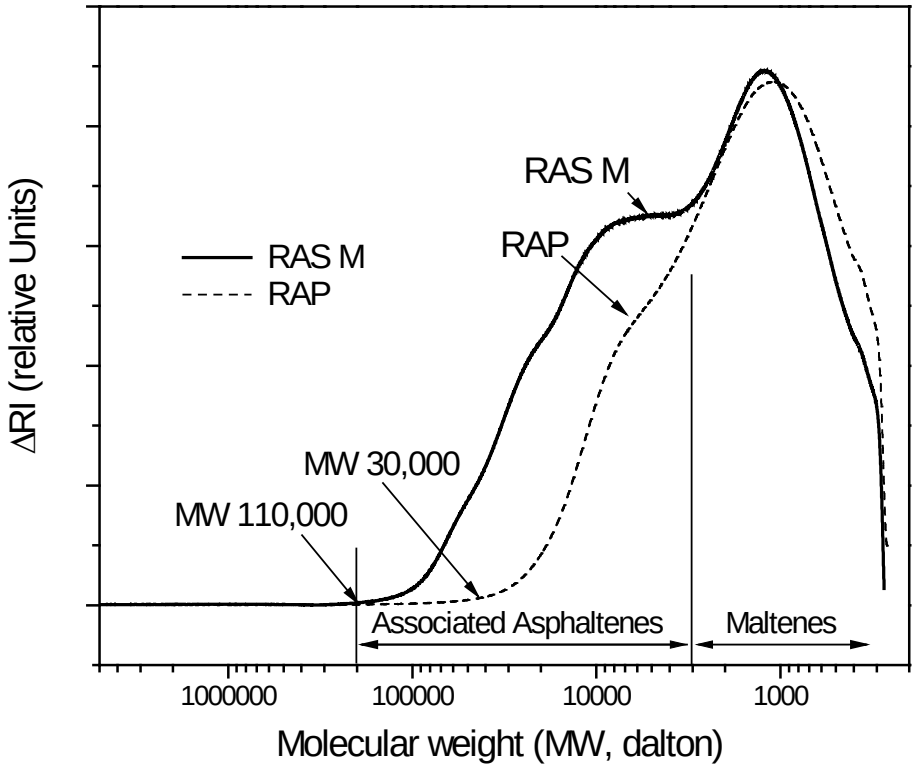
HMA mixture containing 0% RAS and PG70-22M binder



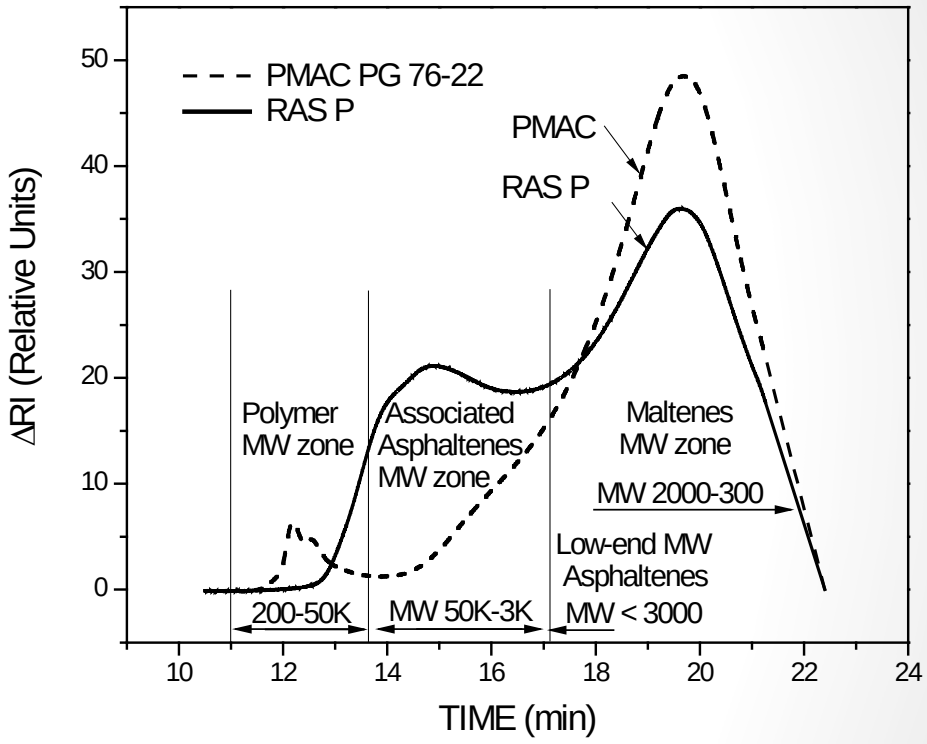
J_c = 0.5 kJ/m^2



Typical MW Distributions of PMAC's Modified with RAS

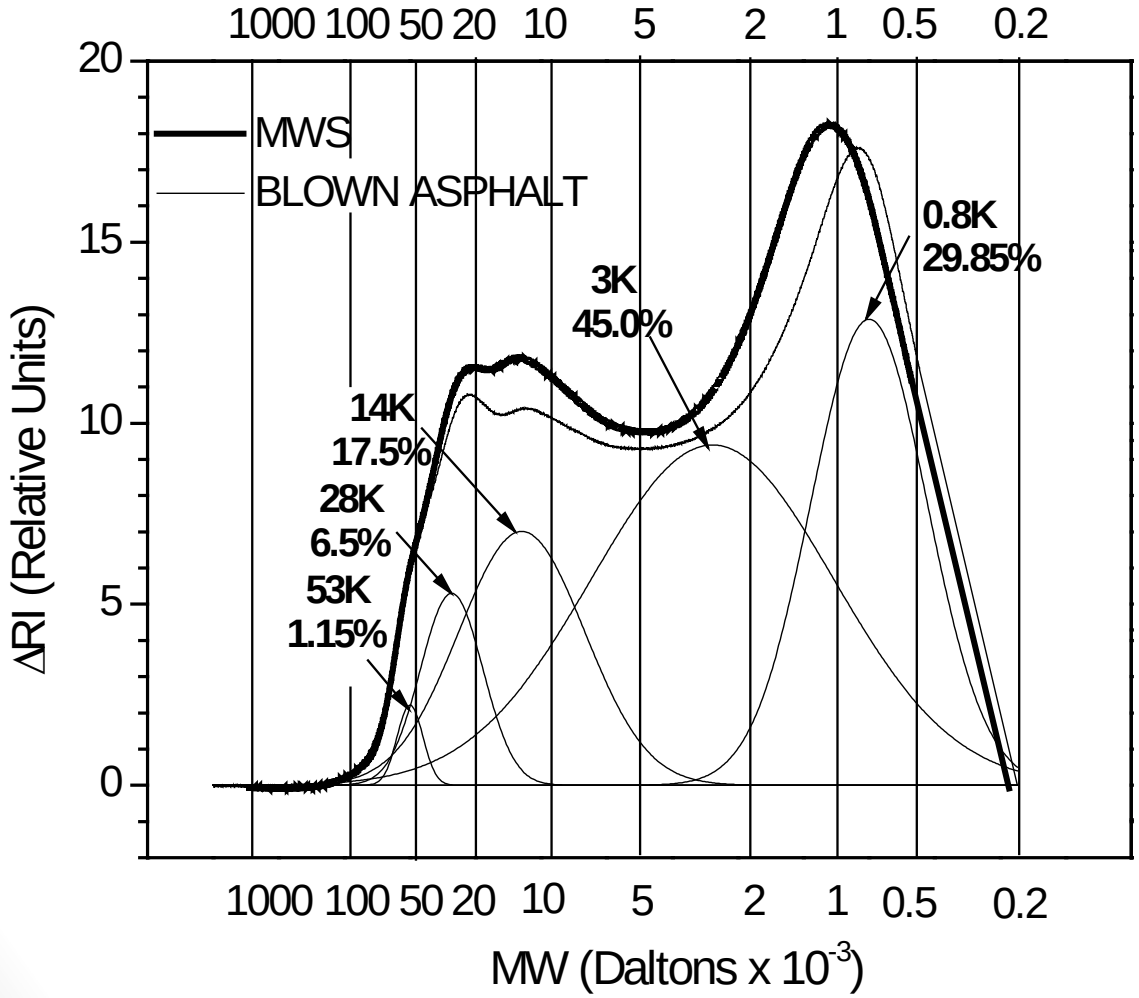


RAS M contributes higher conc. of associated asphaltenes with very high molecular weights than RAP



Associated asphaltenes overlap polymer molecular weights

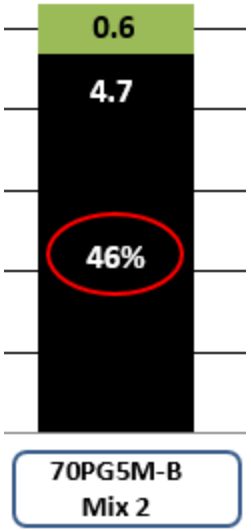
GPC data of Air Blown shingle coating asphalt and MWS (RAS M) extracted binders



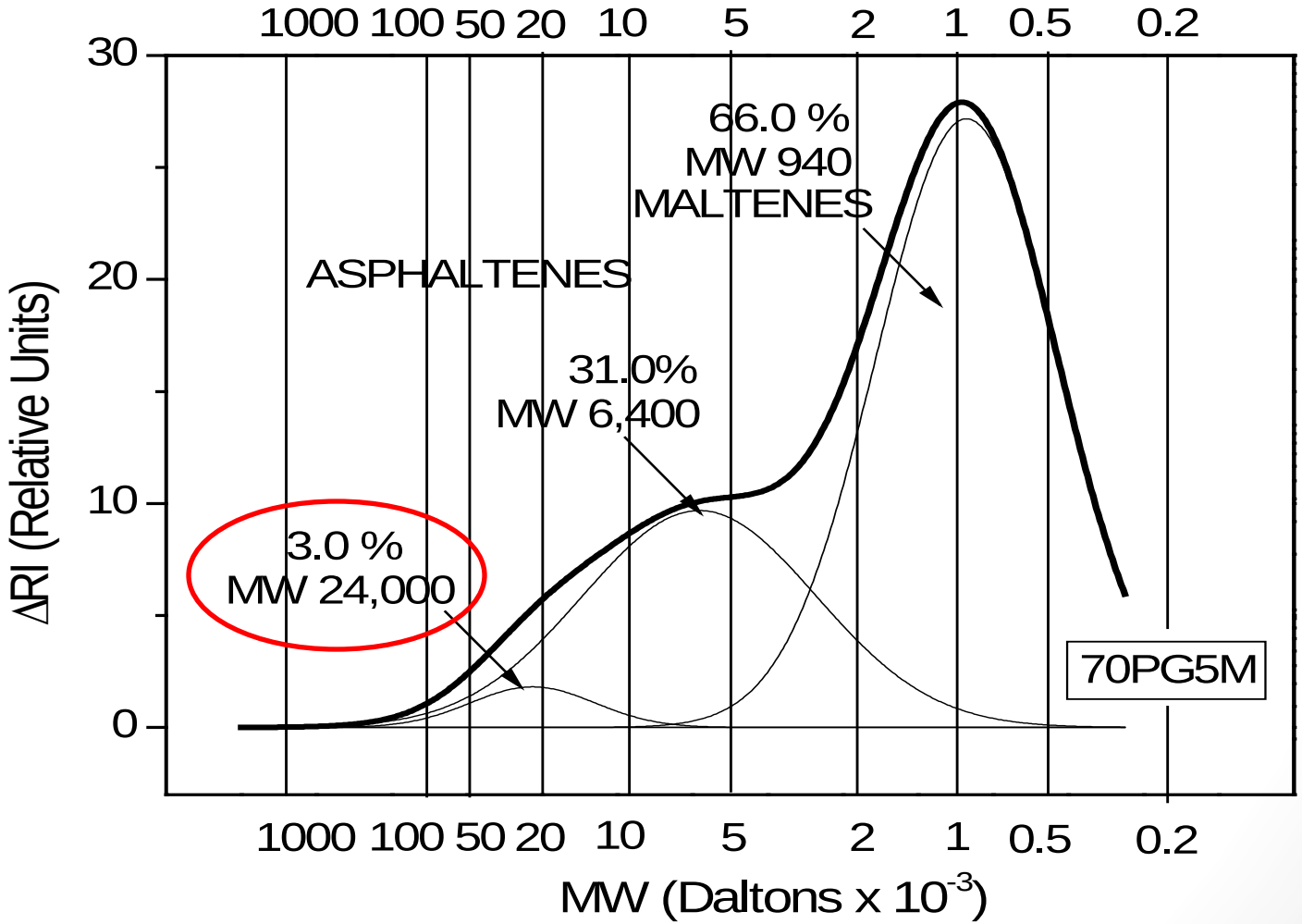
Binder of RAS M is practically identical to blown asphalt

MW distribution of molecular species of extracted binder:

HMA mixture containing 5% RAS-M and PG70-22M binder

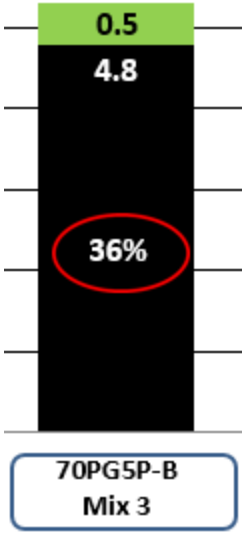


J_c = 0.5 kJ/m^2

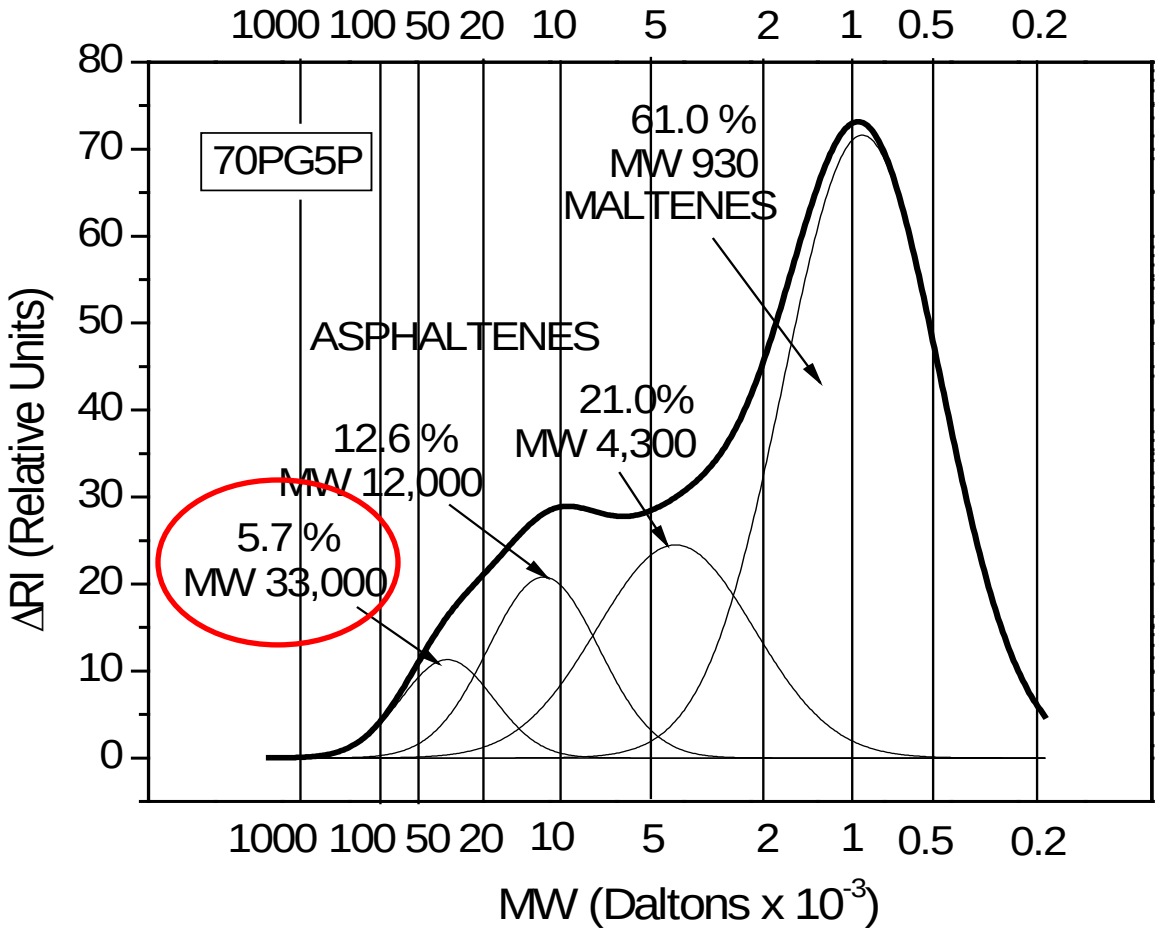


MW distribution of molecular species of extracted binder:

HMA mixture containing 5% RAS-P and PG70-22M binder



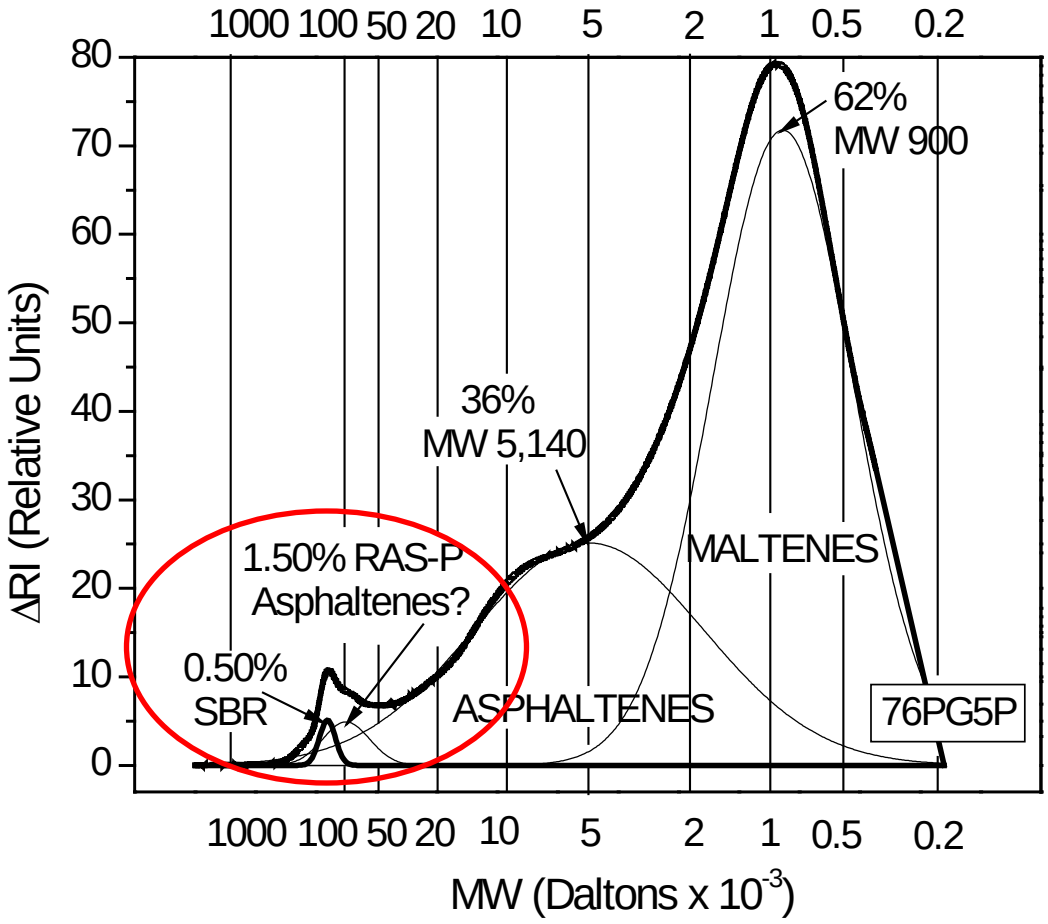
J_c = 0.5 kJ/m^2



MW distribution of molecular species of extracted binder:

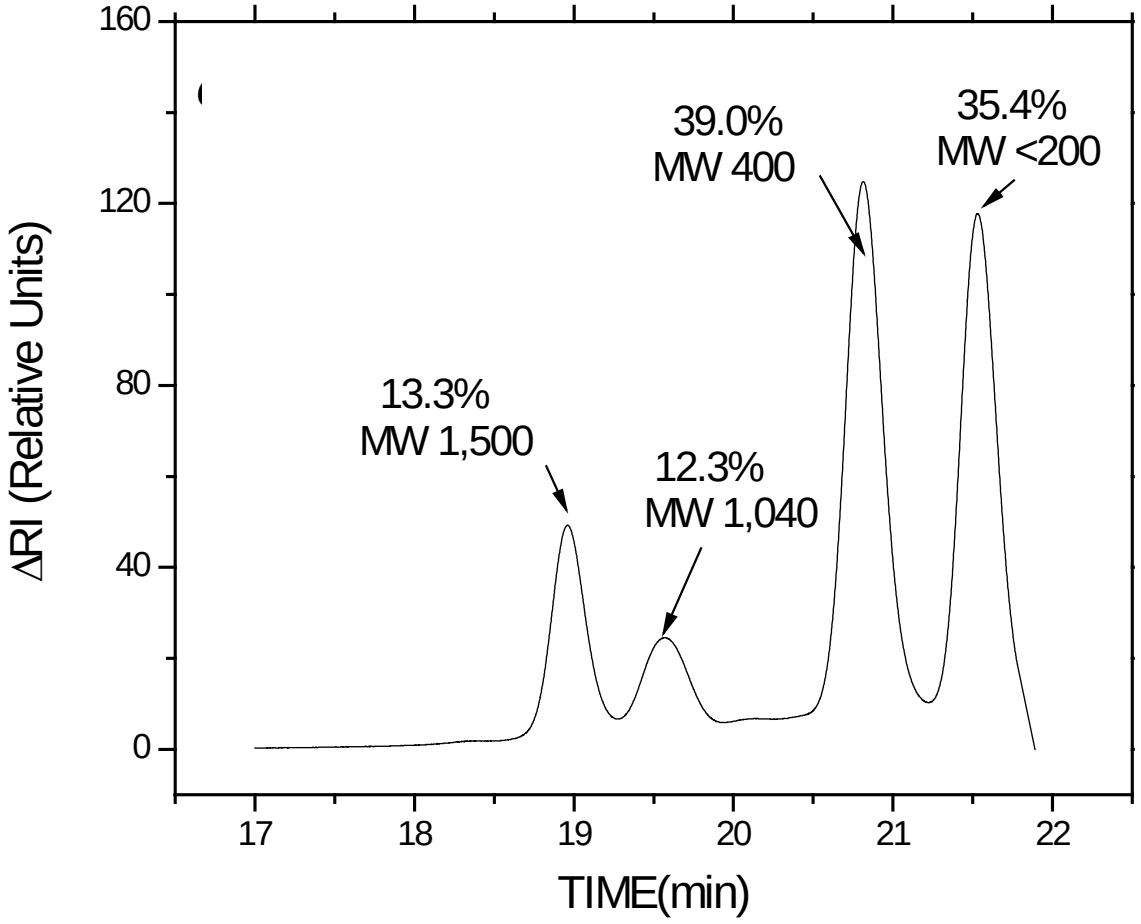
HMA mixture containing 5% RAS-P and PG76-22M binder

J_c = 0.7 kJ/m^2



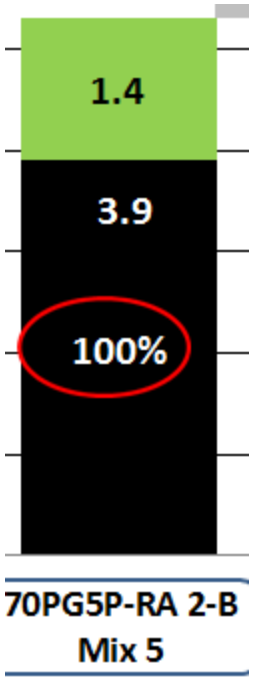
MW distribution of molecular species:

Recycling Agent 2 – RA 2



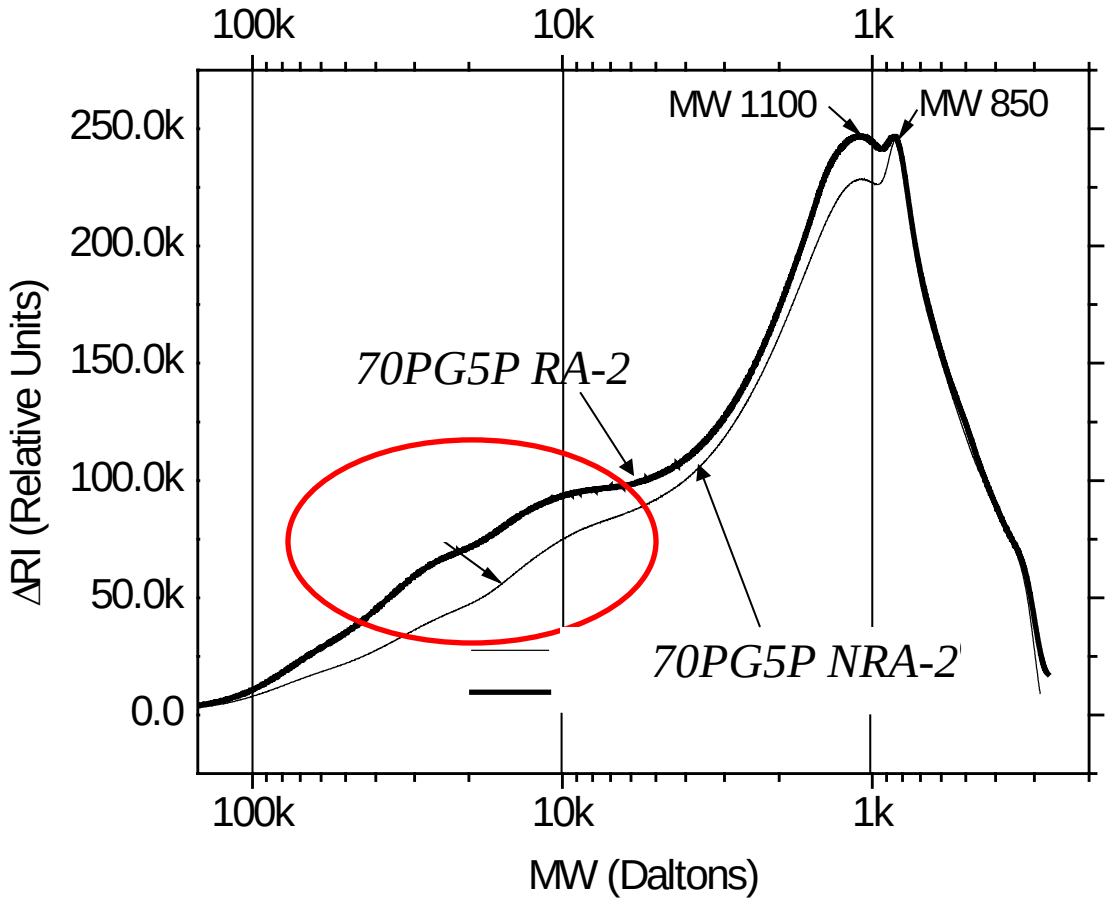
Highest molecular weight component only 1,500 daltons

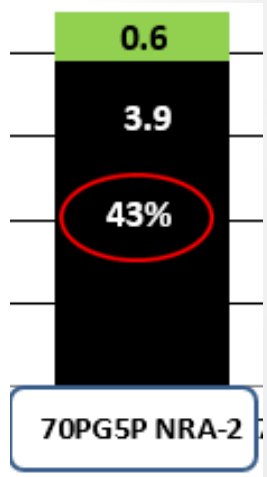
Impact of Recycling Agent 2



J_c = 0.2 kJ/m^2

RAS = 5% PCWS
RA 2 = 5%
PG 70-22M



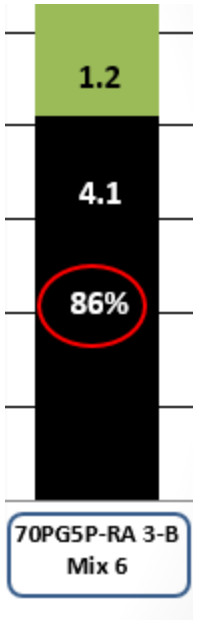


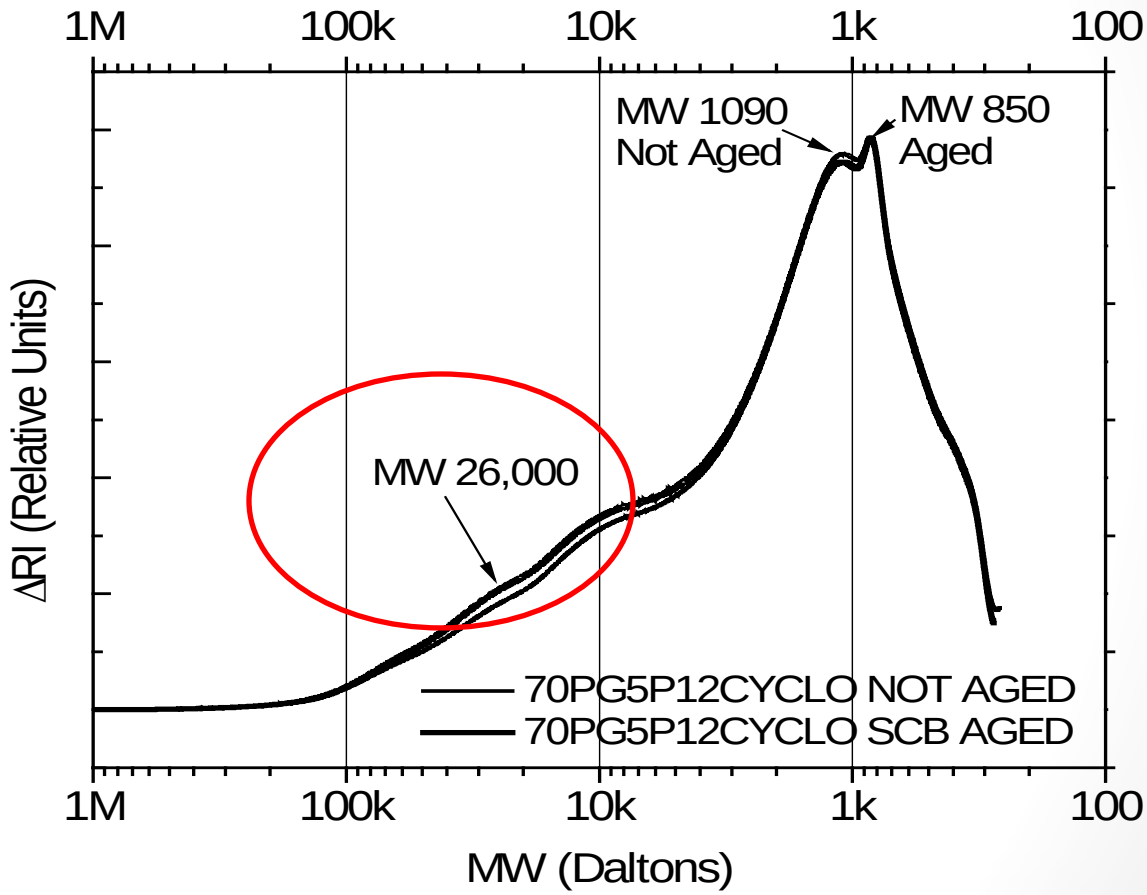
J_c = 0.4 kJ/m^2

RAS = 5% PCWS
No RA
PG 70-22M

Impact of Recycling Agent 3

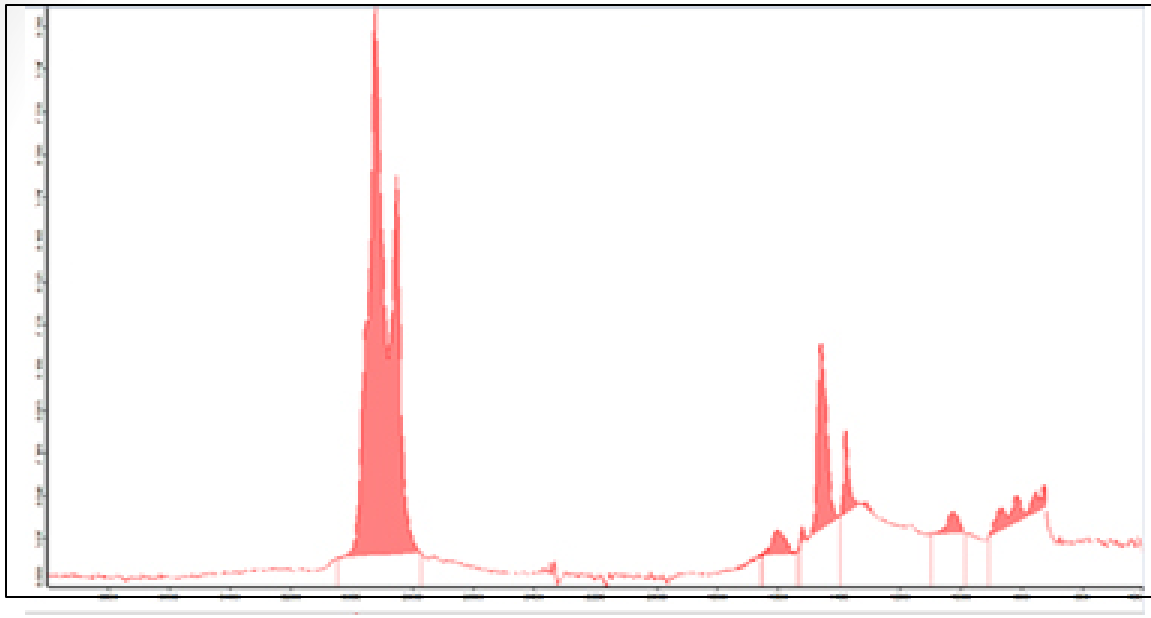
$J_{c\text{-aged}}$ = 0.3 kJ/m^2
$J_{c\text{-unaged}}$ = 0.3 kJ/m^2 } =

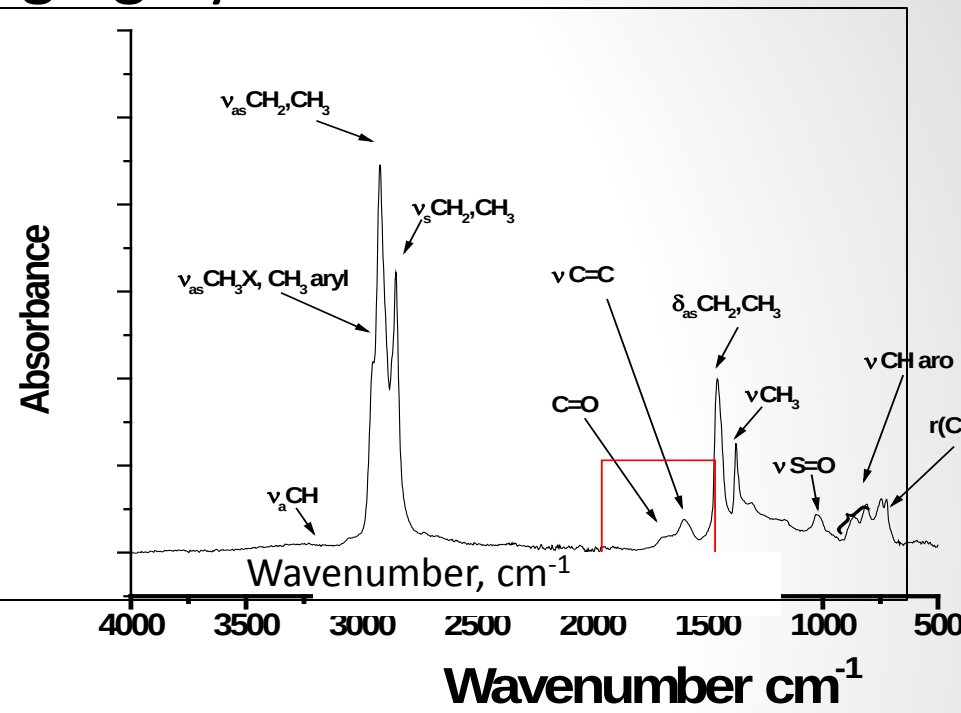




RAS = 5% PCWS
RA 3 = 12%
PG 70-22M

Estimation of Extent of Aging by FTIR





FTIR spectra of the aged samples show a peak around 1700 cm^{-1}, characteristic of C=O species. The carbonyl index was calculated from the band areas measured from valley to valley as shown above*:

$$\text{Carbonyl index} = \frac{\text{Area of the carbonyl centered around 1700 cm}^{-1}}{\Sigma \text{ Area of the spectral bands between 3500 and 500 cm}^{-1}}$$

*J. Lamontagne et al., FUEL, 80(4), 483-48 (2001)

Correlation of VHMW, Carbonyl Index , and Jc

Mixture Type	Total VHMW % Polymer & Highly Associated Asphaltenes >20K	C=O Index $x10^3$	J_c KJ/m^2
70CO	1.0	6.8	0.5
76CO	1.3	10.2	0.6
70PG5P	5.7	21.2	0.5
52PG5P-RA 1-B	5.7	11.7	0.2
70PG5P-RA 2-B	11.5	17.1	0.2
70PG5P-RA 3-B	8.8	13.0	0.3

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Summary / Conclusions

- Laboratory performance evaluation of asphalt mixtures containing RAS
  - Design / Durability
- Design of Asphalt Mixtures
  - Availability of binder from RAS
  - AASHTO PP78 over-estimates the actual shingle asphalt binder availability factor
    - 36% - 46% -- W/O RA
    - 86% - 100% -- RAs
- Volumetric-based design
  - Not sufficient
- Compliment with mechanistic tests
  - Performance related
  - Criteria
- Intermediate Temperature (SCB)
  - No adverse effects Mixes 1 – 3 (NRAs)
  - Lower Jc values Mixes 4 – 6 (RAs)

Summary / Conclusions

- **Effect of Recycling Agents**
  - **Use of soft binder (RA 1) did not improve fracture properties.**
  - **RA 3 performed better than RA 2 at intermediate temp.**
  - **RA 2 enhanced the extraction of the asphaltenes from the RAS.**
  - **Molecular fractionation through GPC of RAS samples confirmed the presence of associated asphaltenes in great concentrations.**
    - **High concentrations of HMW asphaltenes decrease the fracture resistance of the asphalt mixtures**
    - **Presence of SBS additives enhances the compatibility with the HMW asphaltenes.**
  - **C=O is not reliable indicator of intermediate fracture resistance performance.**
  - **Use of RAs evaluated in this study did not reduce the concentration of the highly associated asphaltenes**
    - **Did not improve the cracking resistance**

Thoughts!

- **Is 100% blending of available RAS binder desired?**
- **Consideration of Addition of additives that enhances the compatibility with the HMW asphaltenes**

Photo: Jim Zietz, Office of Public Affairs

THANK YOU