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Impacts of Lubricating Oils on Rheology and Chemical Compatibility of Asphalt Binders

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Outline

1. Introduction
   - Background
   - Performance Grading of Asphalt Binders
   - Binder Modification
2. Objective and Hypothesis
3. Materials and Methods
4. Results
5. Concluding Remarks

Common Targets for Bitumen Specifications-Performance Based Grading

- Constructability

- Performance
  - PG Grading

Rutting

Fatigue Cracking

Thermal Cracking

- Durability

Required PG Grades In Estonia

PG 58-28

PG 58-34

PG 58-40

Bitumen Sources in Estonia

Estonia Bitumen Sources

Binder Code	Description	Crude Oil	PG
A	Pen 70-100	Venezuela	64-22
B	Pen 70-100	Russia	58-22
C	Pen 70-100	Russia	58-22
D	Pen 70-100	Russia	58-28
E	Pen 70-100	Russia	**70-28**
F	Pen 160-220	Venezuela	52-28
G	Pen 160-220	Russia	52-28
H	Shale Oil	Estonia	**52-4**

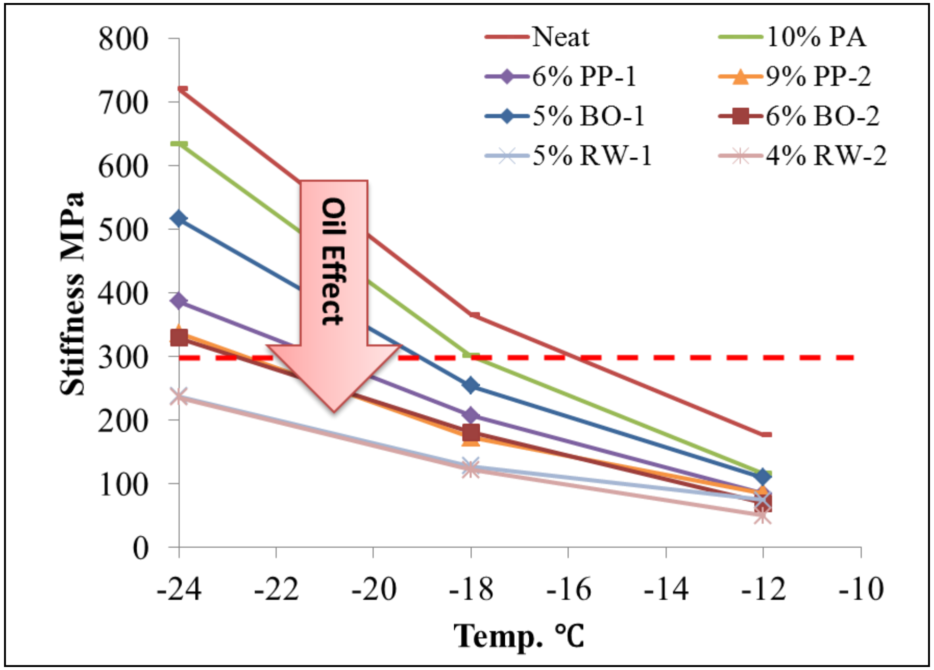
Available vs. Required PG Grades

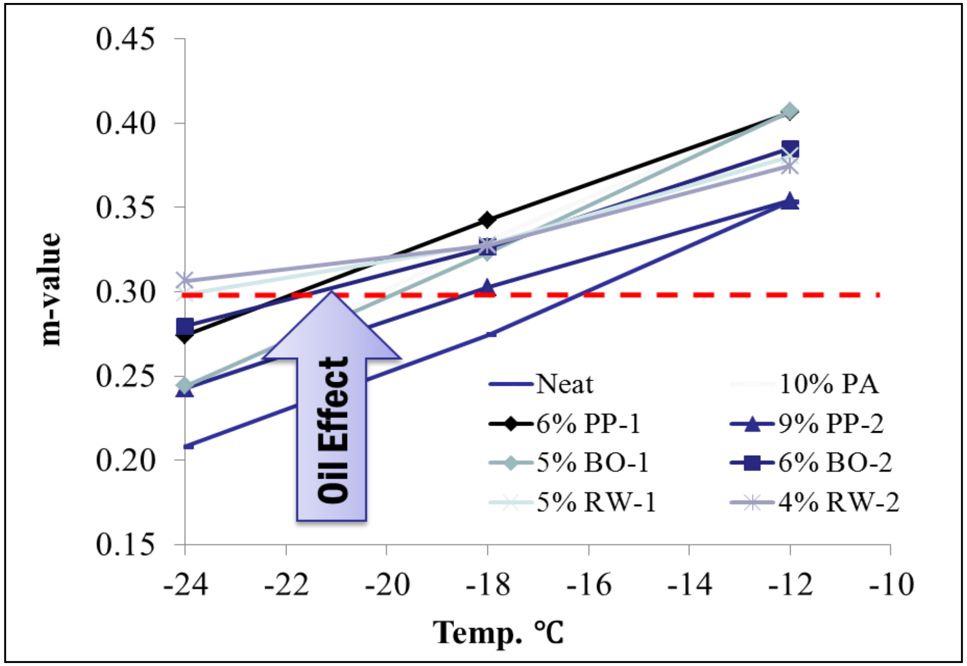
●	Available PG
○	Needed, Unavailable PG

		High Service Temperature			
		52	58	64	70
Low Service temperature	-22	●	●	●	
	-28		●		●
	-34		○		
	-40		○		

Need Oils to modify Low Temperature Grade

Modification Alternatives to improve Low Temperature PG grade





Different Types of oil:

- Petroleum-based Oils
- Plant–based Oils
- Refined Waste Oils

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Hypothesis & Objectives

- **Hypothesis:**
  - Modification of existing Supply of bitumens in Etsonia can be done to meet the climate and traffic conditions effectively.
- **Objectives:**
  - Determine the PG grades of Estonian binders.
  - Compare available grades to the required for existing climatic conditions.
  - Investigate additives needed to produce required grades.

Modification Used: Oils + (when needed) Polymers

Base Binder	Modification	Modified Binder Code	PG
A	5% Oil-A	M-A	58-28
B	10% Oil-B + 2% Plastomer	M-B	58-34
C	8% Oil-B + 3% Elastomer	M-C	58-34
D	8% Oil-B + 2% Plastomer	M-D	58-34
E	11% Oil-A	M-E-1	58-34
E	8% Oil-B	M-E-2	58-40
F	8% Oil-B + 4% Plastomer	M-F	58-34
G	8% Oil-B + 5% Elastomer	M-G	58-34

- **Oil A**: Bio Oil
- **Oil B**: Refined Waste Oil

- **Elastomer**: SBS-x linked
- **Plastomer**: Functionalized Polyethylene (Titan 7686)

Selection of the **dosage of oil modifier** was to reach the **required low temperature** PG

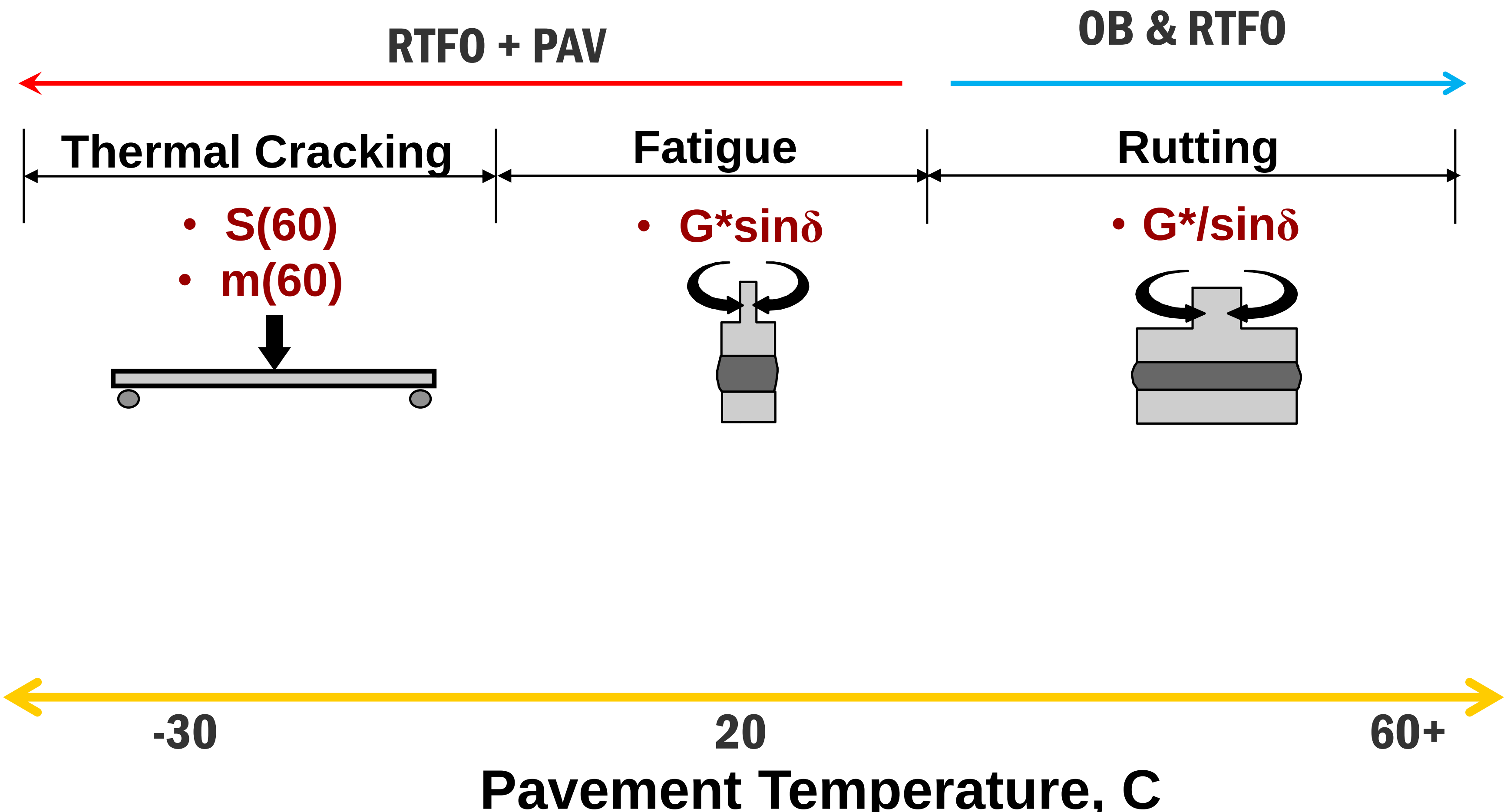
Test Methods

Test Methods Selected for Binder Evaluation

	Engineering Property of the Binder	Conventional PG Tests	Advanced Binder Tests
1	**Rutting** resistance	DSR HT PG	---
2	**Fatigue** Cracking Resistance	DSR IT PG	Linear Amplitude Sweep (LAS)
3	**Thermal** Cracking Resistance	Bending Beam Rheometer (BBR)	Single Edge Notched Beam (SENB)
4	**Chemical** Content Spectrum	---	Gel Permeation Chromatography (GPC)

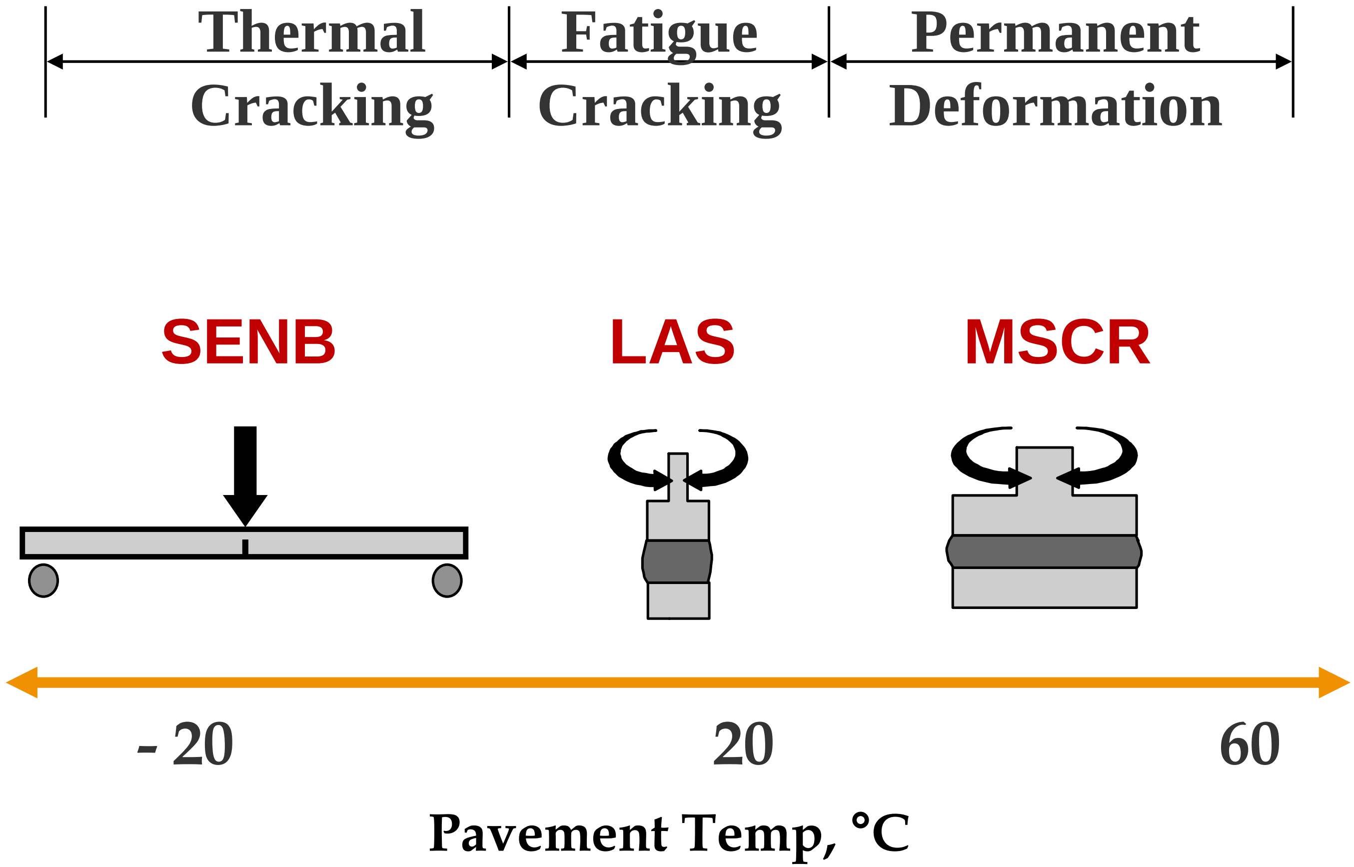
Current State of Practice

PG , and PG+ Specifications



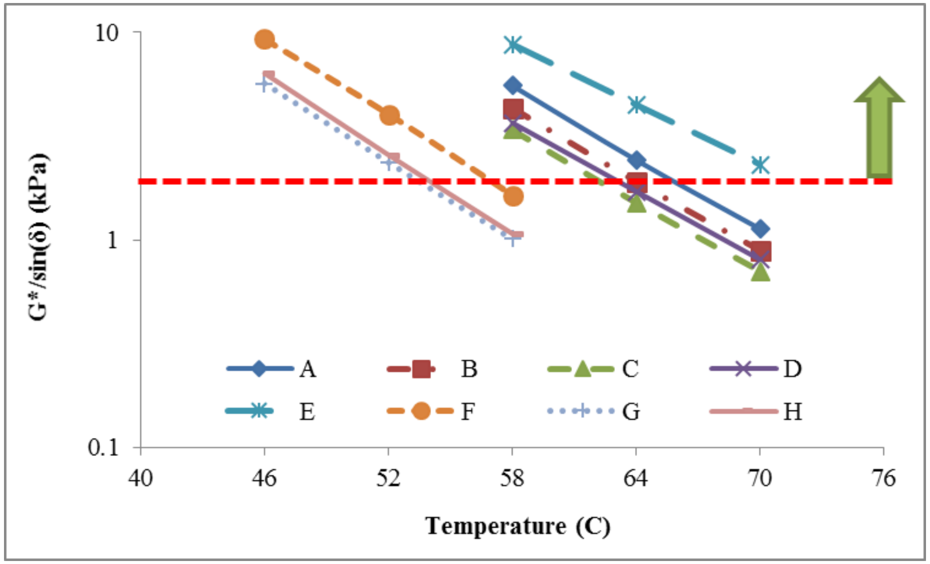
New Methods for Modified Binder Evaluation

Damage – Based Characterization

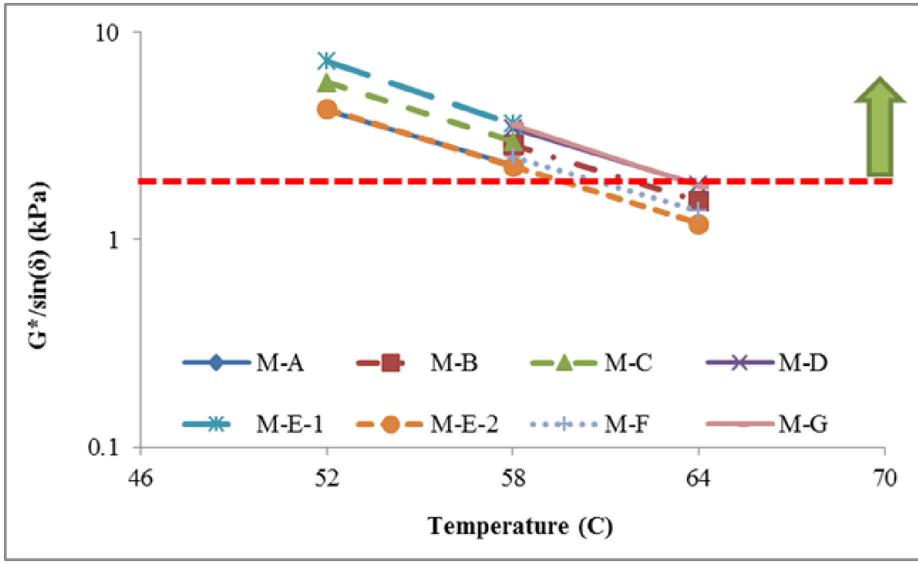


Results
High Temperature True Grade

Unmodified RTFO Aged

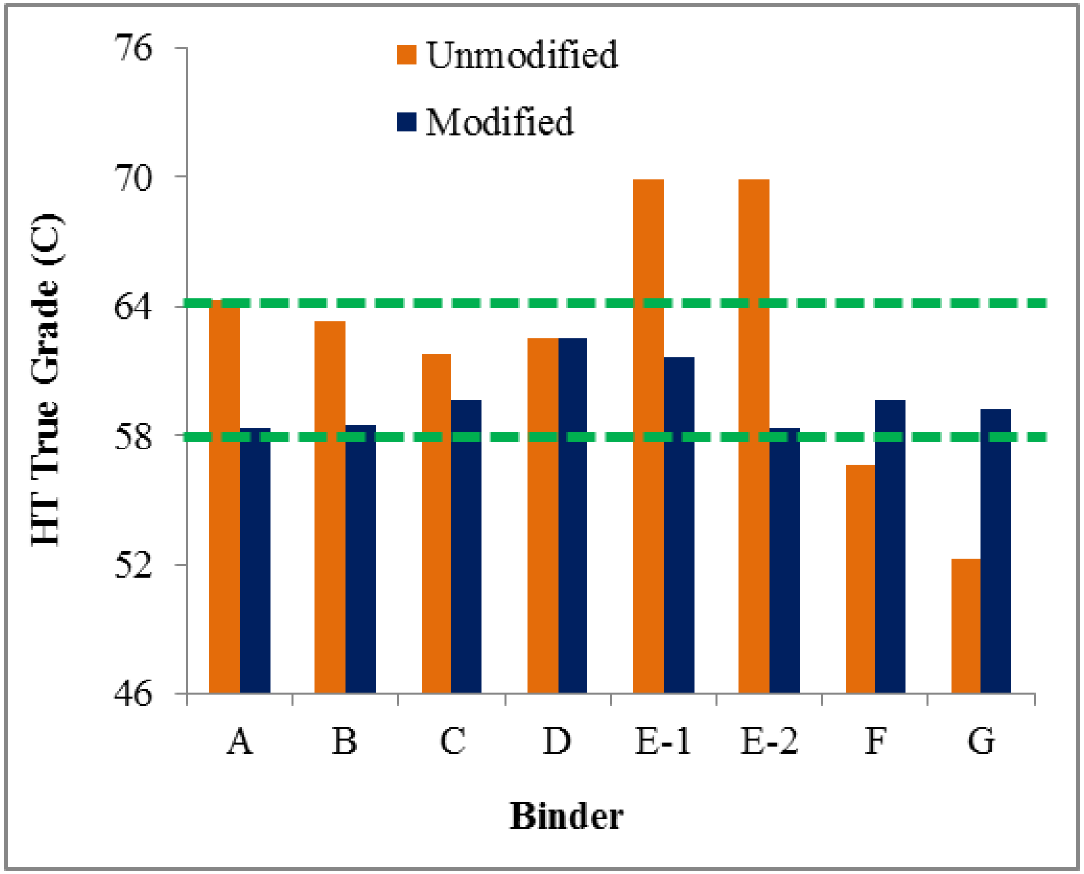


Modified RTFO Aged



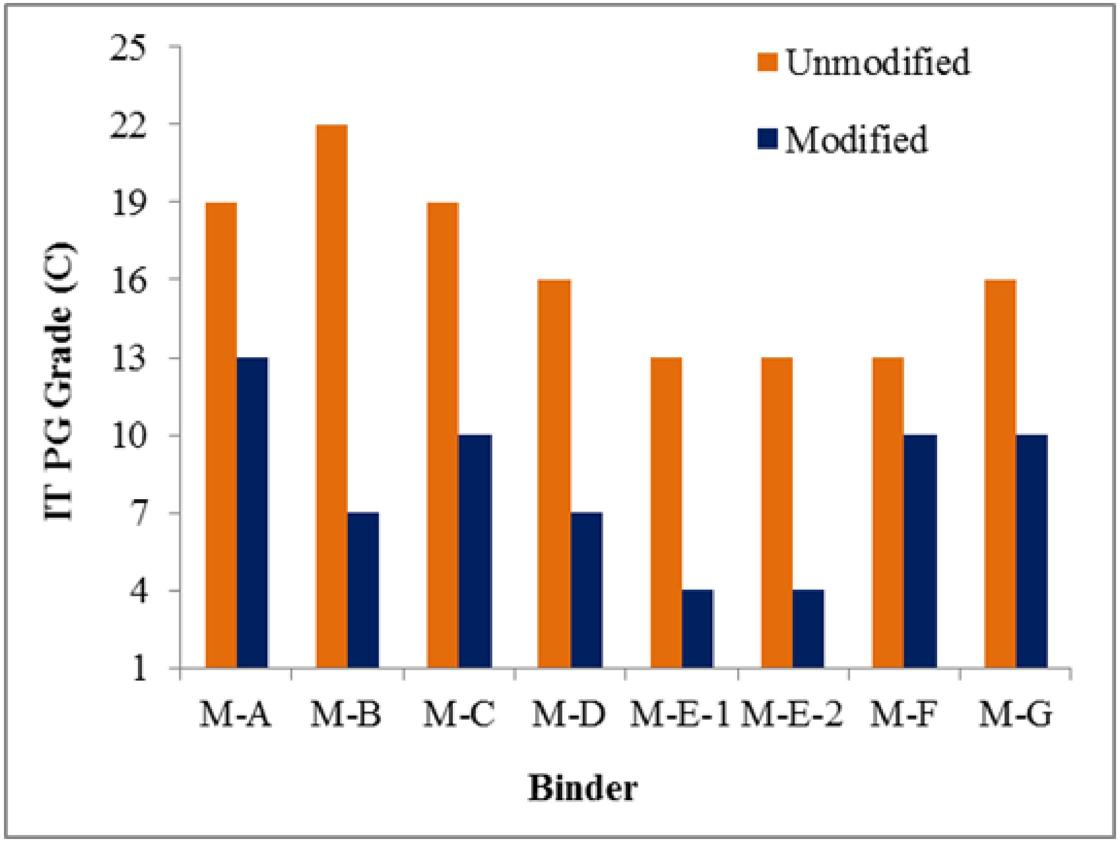
With Oils and Polymers, Grades can be changed

Results
High Temperature Grading- *Continuous Grade*



- binders **with same pen grade (i.e binder A to E)** showed different behavior at high temperatures and **cover a range of three different PG grades**
- adding lubricating oils decrease the high temperature properties of the original binder

Results
Intermediate Temperature Continuous Grade



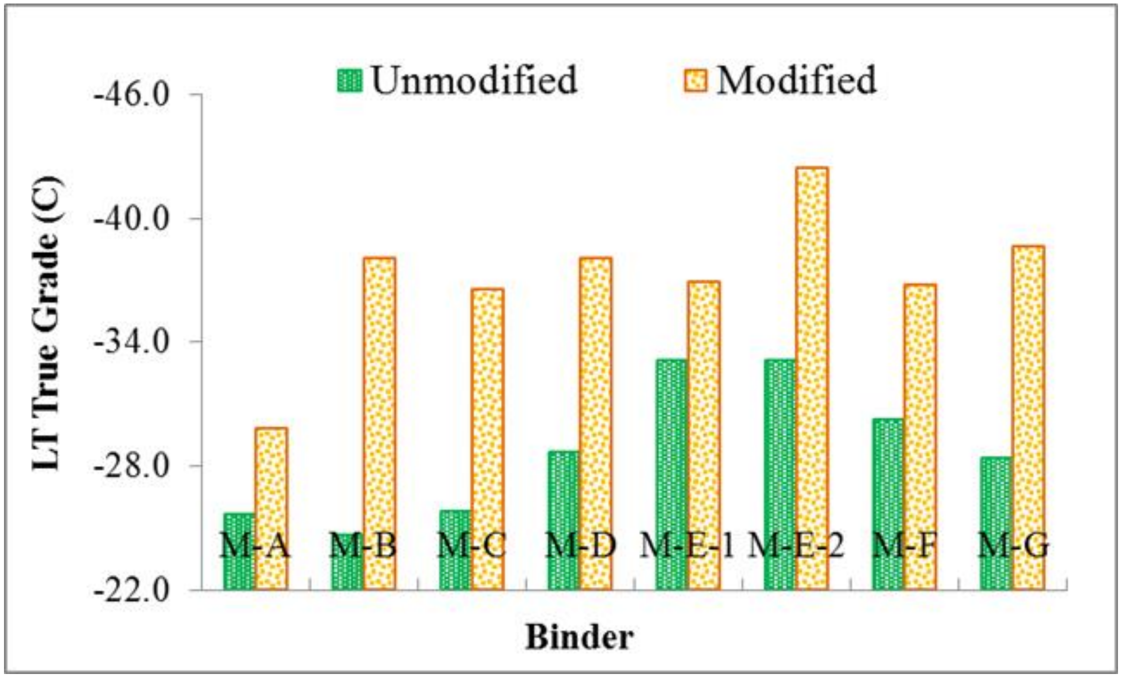
Reduction in the IT grade of binders **by 6 to 15°C** by **binder modification** in comparison with unmodified binders

Superpave Max IT Grade:

- PG 58-28: 19°C
- PG 58-34: 16°C
- PG 58-40: 13°C

Results

Low Temperature Grading-*Continuous Grade*

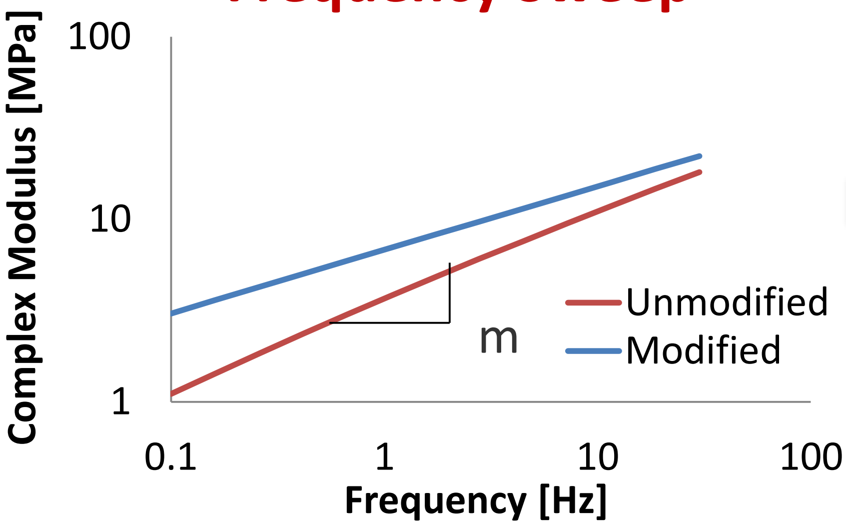


- Considering the high temperature grade of these binders to be kept the same level, **selected modifications** were capable of expanding the performance range of binders by **shifting the lower band up to 10°C**

Fatigue Life from LAS
Specification based on Binder Nf

Rheology

Frequency Sweep

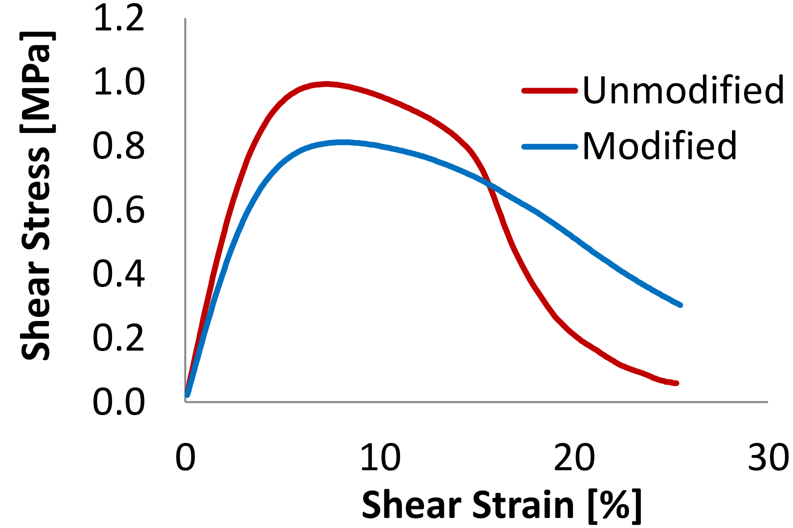


Slope

B

Damage Resistance

Continuous Amplitude Sweep



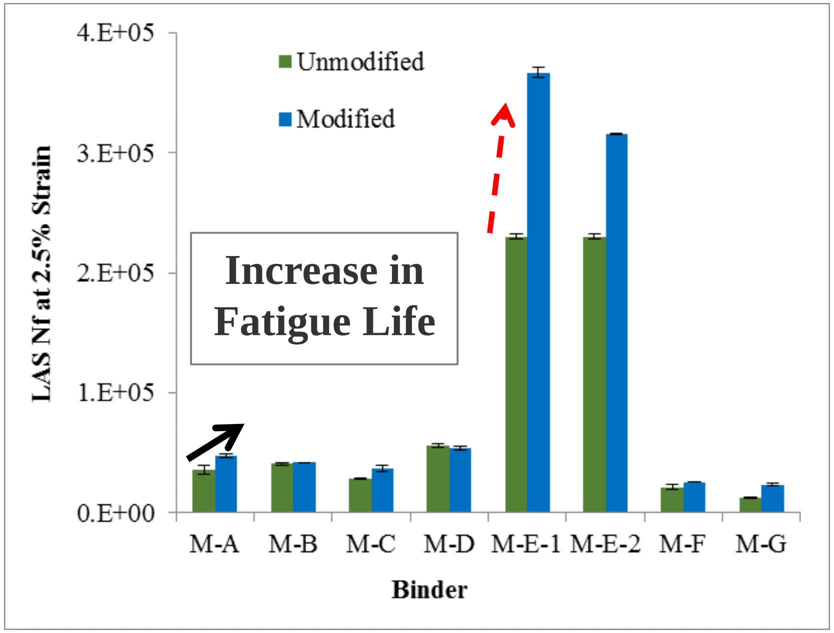
VECD

A

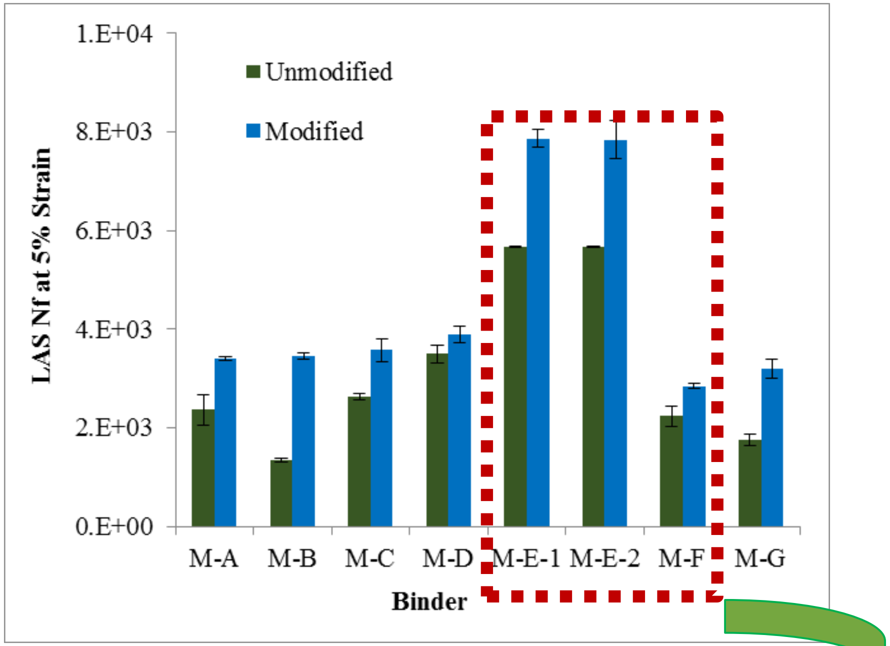
$$N_f = A\,(\gamma_{max})^B$$

Results
Linear Amplitude Sweep (LAS) Test

2.5%Strain Amplitude



5%Strain Amplitude



Lubricating oils improve the fatigue resistance at different strain levels

Same IT PG grade can resist fatigue significantly different

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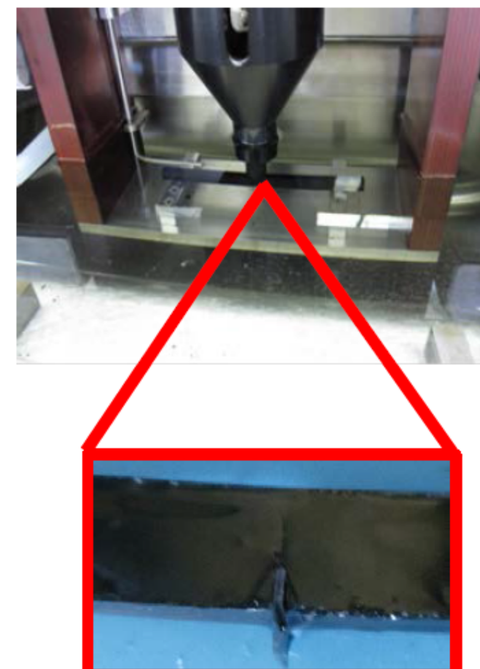
Single Edge Notched Bending (SENB)

Displacement-Controlled Mode

Step Motor

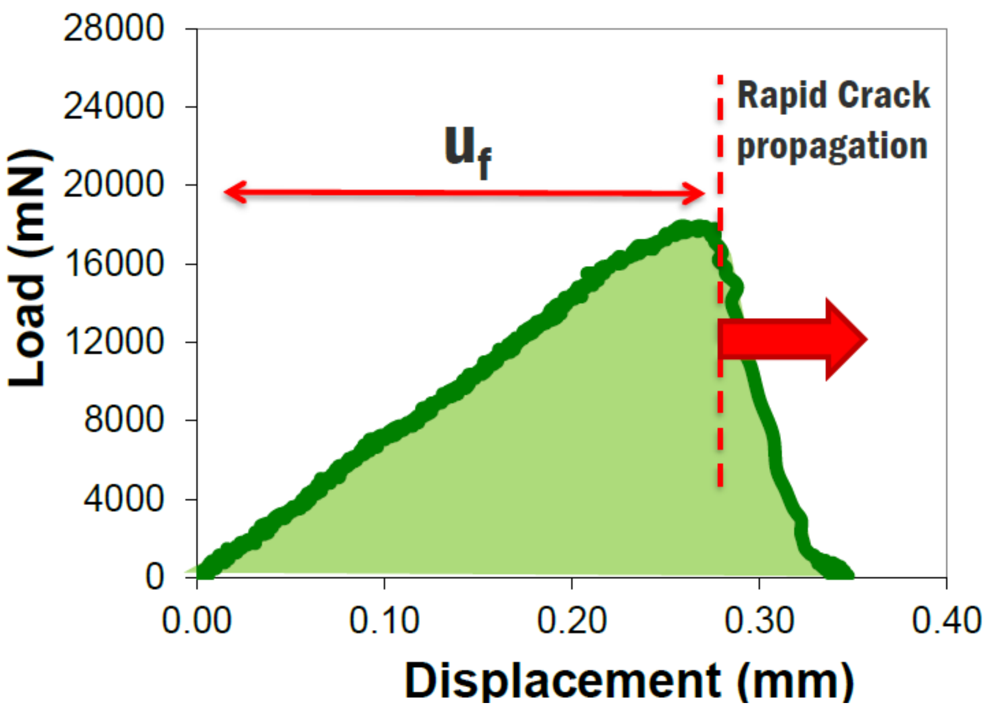
BBR system with a load cell with higher capacity

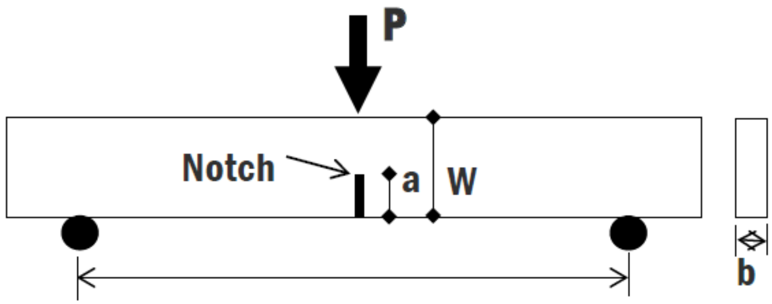


Fracture Properties and Strain Tolerance

Single-Edge Notched Beam (BBR-SENB):

- Failure Energy (G_f)
- Deflection at failure (u_f)





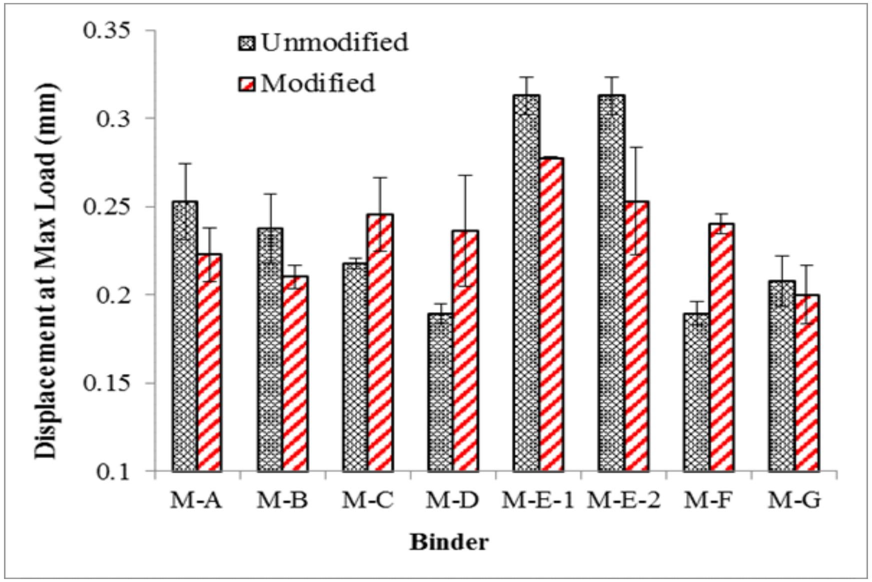
$$G_f = \frac{W_f}{A_{lig}}$$ **Failure Energy**

$$W_f = \int P du$$ **Work**

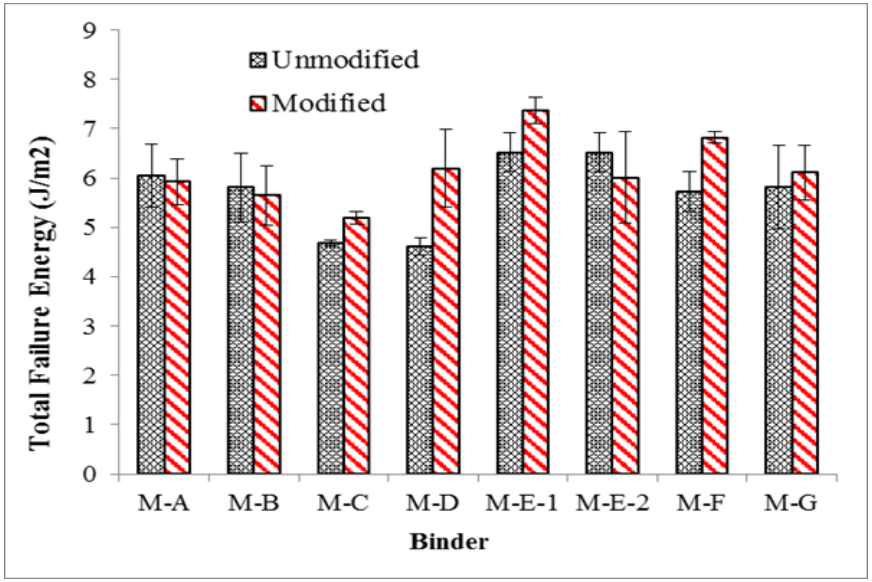
Results

Single Edge Notched Bending (SENB) @ LT Grade

Disp. @ Failure



Failure Energy

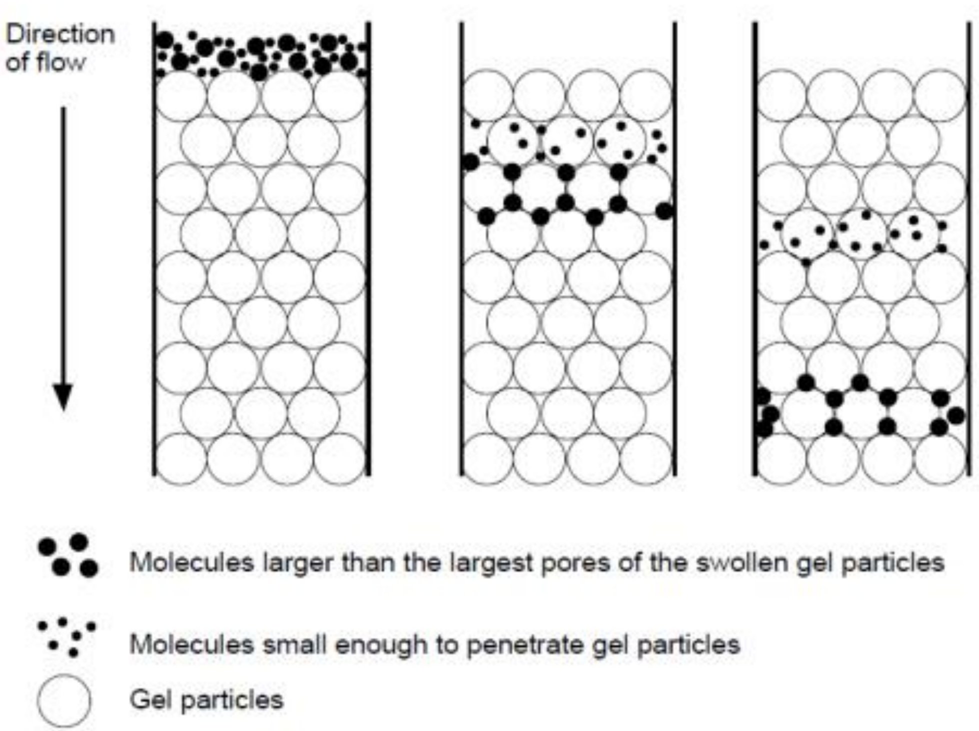


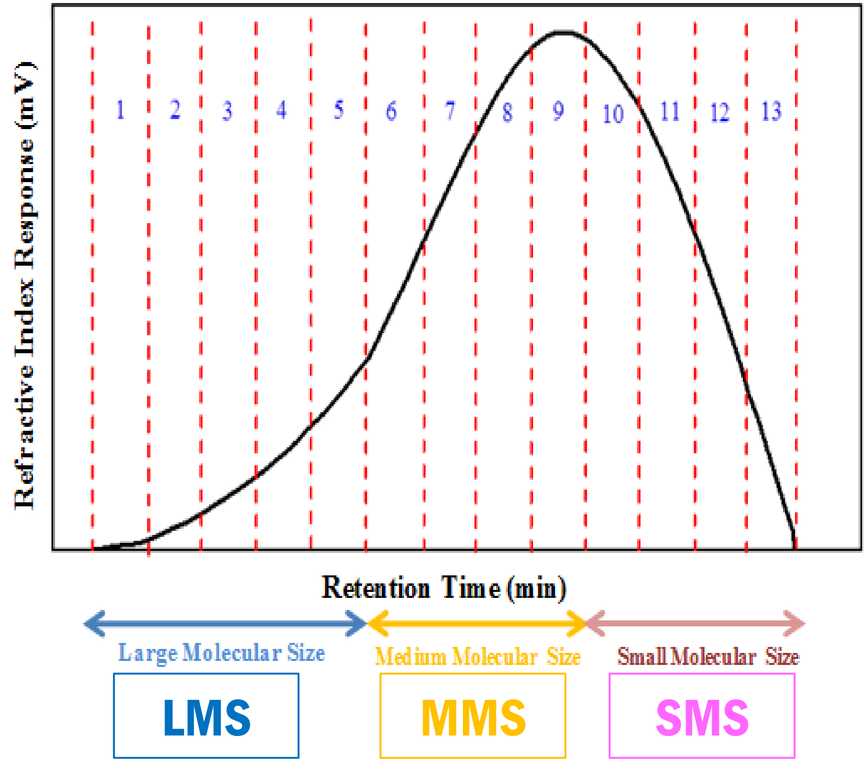
- No significant difference between unmodified and modified binders
- Test is performed at LT grade of the binders and considering that modified binders showed to have one to two lower LT PG grade:

  - Modification improves the thermal cracking properties of the binders by keeping fracture parameters same at lower temperatures

Gel Permeation Chromatograph (GPC)

- **Simple separation technique available that responds to molecular size alone and not to chemical structure.**
  - **Analogous to a type of sieve analysis of sample.**





GPC spectrum divided into 13 equal elution time areas.

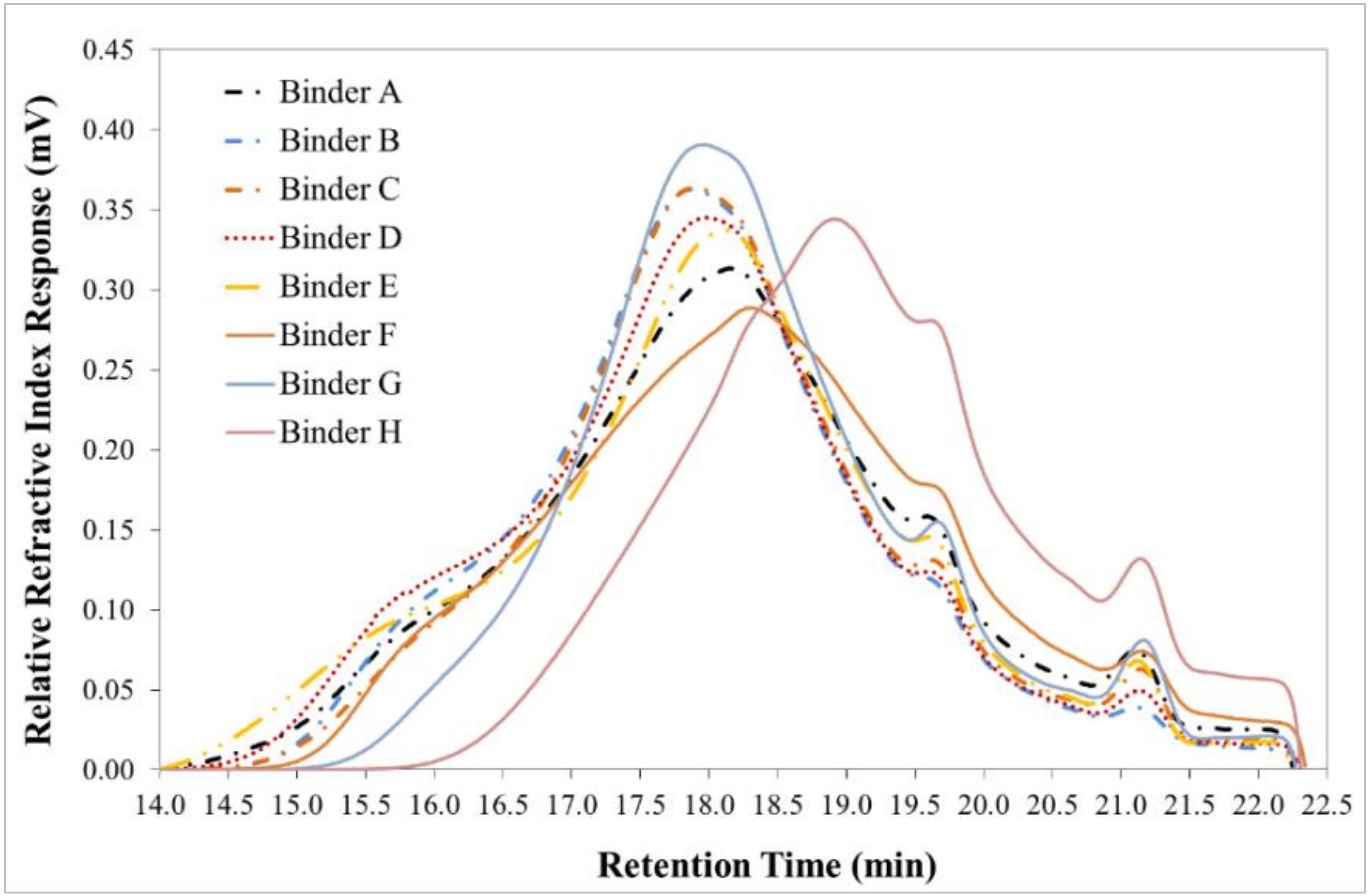
GPC Parameters

- MW: weight-average molecular weight
  - influences the bulk properties and toughness of the material
- Mn: number-average molecular weight
  - influences the thermodynamic properties of the molecule
- Mz: z-average molecular weight
- Mp: peak molecular weight

Results
Evaluation of Chemical Compatibility Using GPC

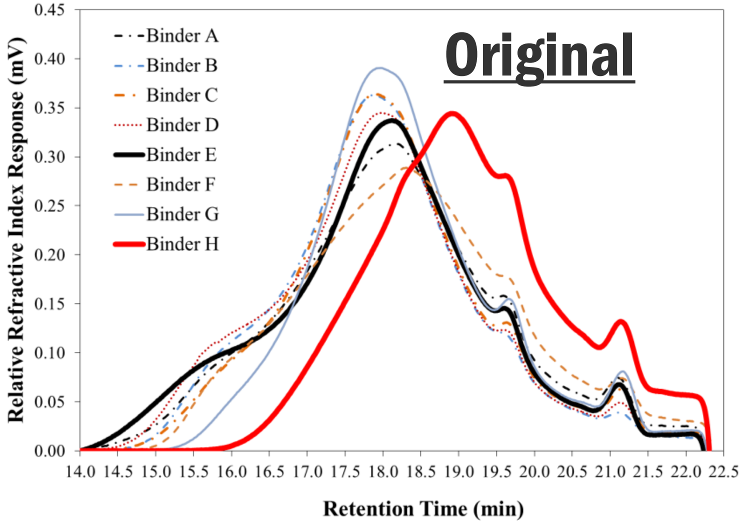
- Some binders showed to have superior laboratory performance at different performance temperatures while the others depicted less desirable characteristics partially or in total
- Binder E showed to have a different trend in comparison with all the other binders
- Chemical composition and molecular distribution of the binders were analyzed using GPC method

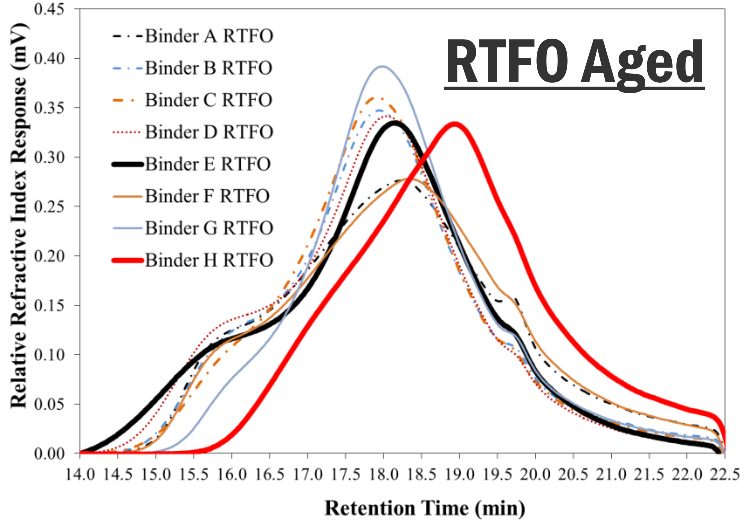
Results
GPC Results

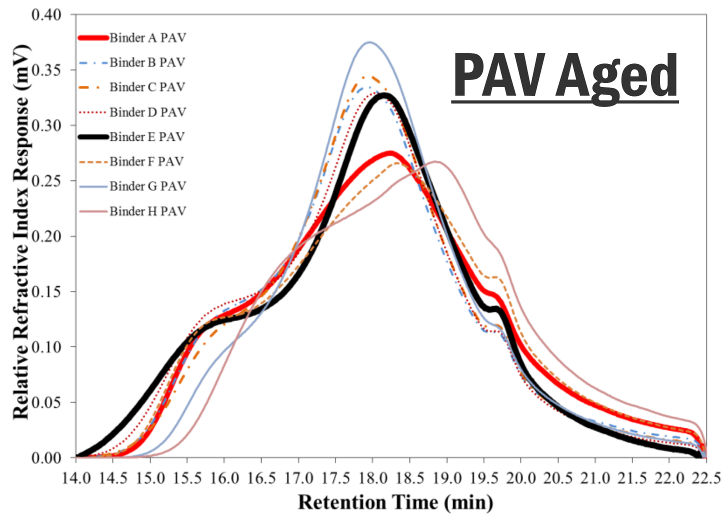


Different patterns of chromatograms and GPC clearly distinct the different molecular size distribution of different binders

Results
GPC Results







Different patterns of chromatograms and GPC clearly distinct the different molecular size distribution of different binders

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Results
GPC Results-1

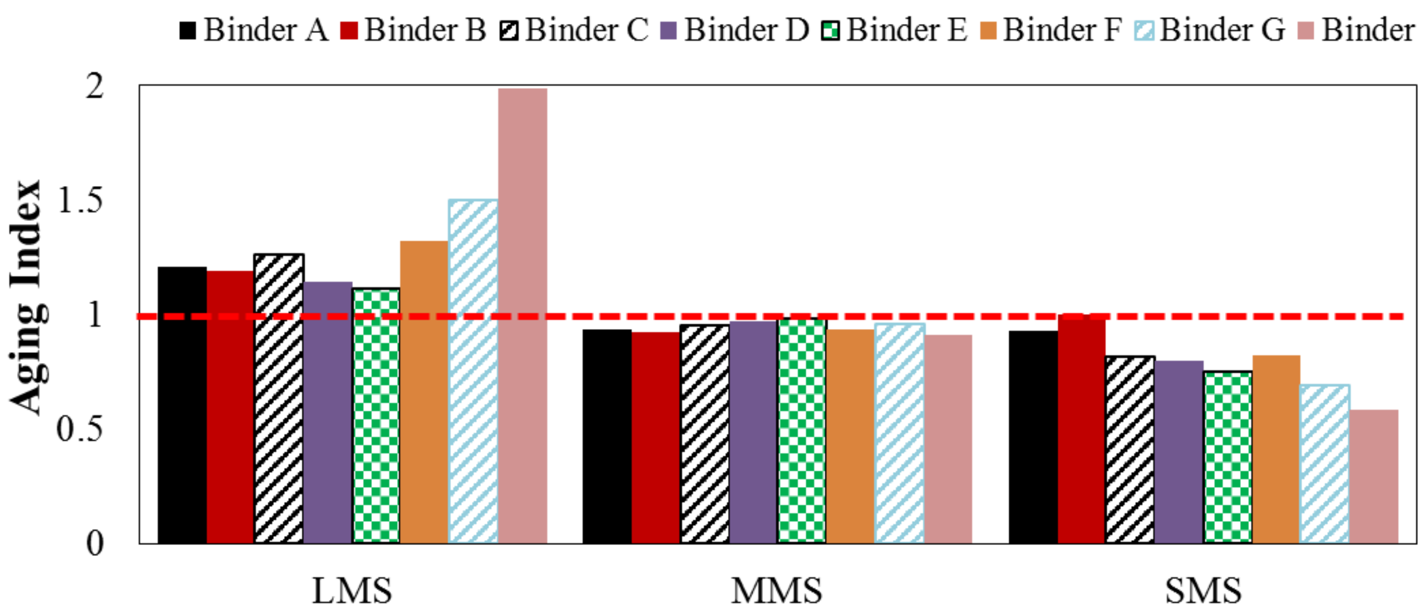
- Three distinct pattern of chromatograms which are correlated to the binder sources
  - Binder from **various crude sources** of Venezuela (binders A and F), Estonia (binder H) and Russia (rest of binders) have **completely different molecular distribution pattern**
- **Binder sources** have a great influence on the binders characteristics

Results
GPC Results-2

- Curves showing the relationship between the GPC detector response and the elution time move toward left along the abscissa after aging
- Corresponds to presence of more large size molecules
- Increasing aging duration results in an increase of LMS percentage regardless of asphalt binder type

Results

GPC Results-Aging Susceptibility



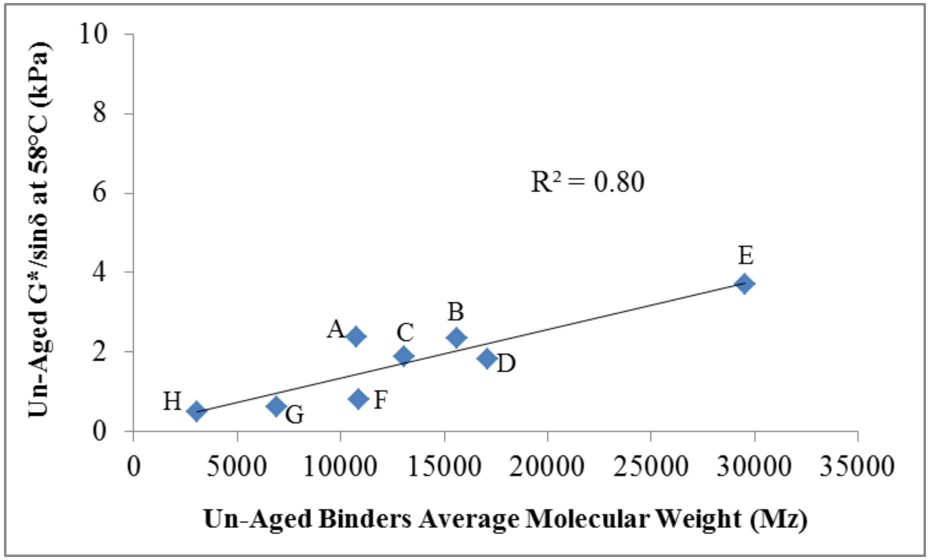
- Ratio between LMS, MMS and SMS after PAV to un-aged condition

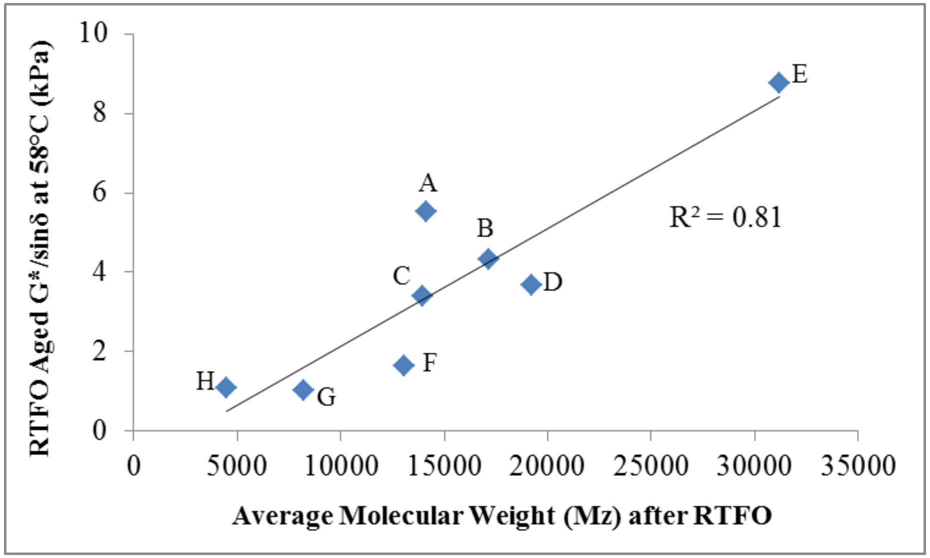
- Binder E shows the least increase in LMS after PAV aging in comparison to the other binders
- Binder E shows to have its MMS unchanged and higher than all the other binders

Less aging susceptibility consistent with superior performance in the rheological testing

Results

Rheological Vs. Chemical Properties-High Temp.



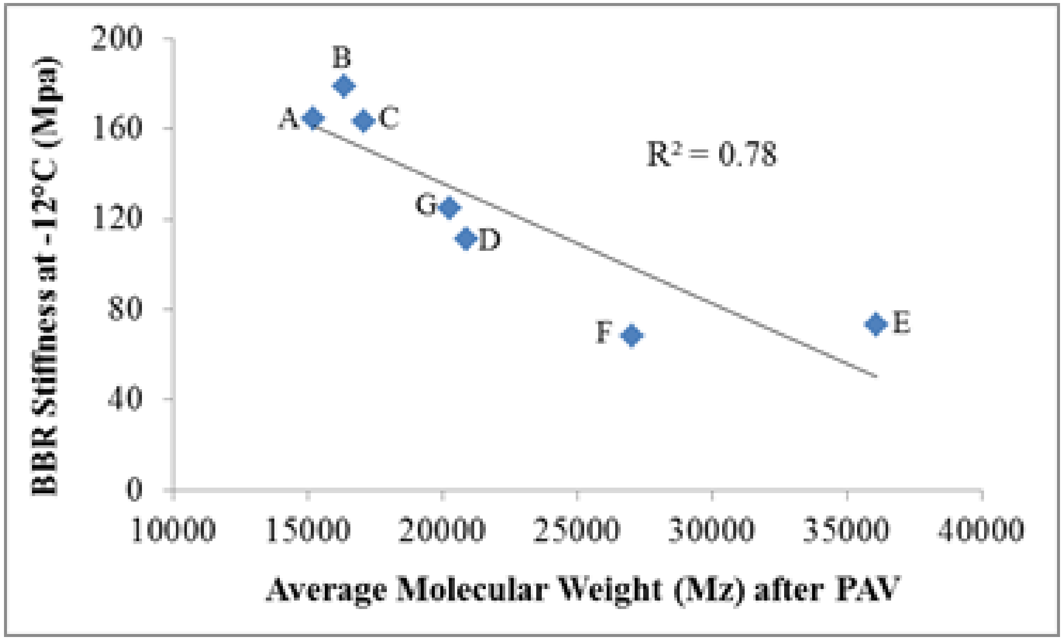


Increase in larger molecules portion of the binder

More asphaltene and higher stiffness at higher temperatures

Results

Rheological Vs. Chemical Properties-Low Temp.



- Relationship between the binder stiffness measured during BBR and the average molecular weight (Mz) in binders
- Decrease Mz corresponds to increments in lighter molecular weight components of the binders

More presence of lighter molecule sizes

Part of maltenes reach their glass transition region at higher temperatures

More brittle behavior

Concluding Remarks

- Estonia will need to use Oil modification to improve performance of pavements
- Oils could result in lower rutting resistance; need polymers to offset this effect
- Fatigue resistance varies significantly based on oils
- Impacts of oils and polymers vary based on oil type and the crude source of binder
- GPC results showed molecule sizes distribution are greatly dependent on binder crude source and the molecular fraction of different binders can be altered significantly by oxidative aging

Thank You!

Questions?

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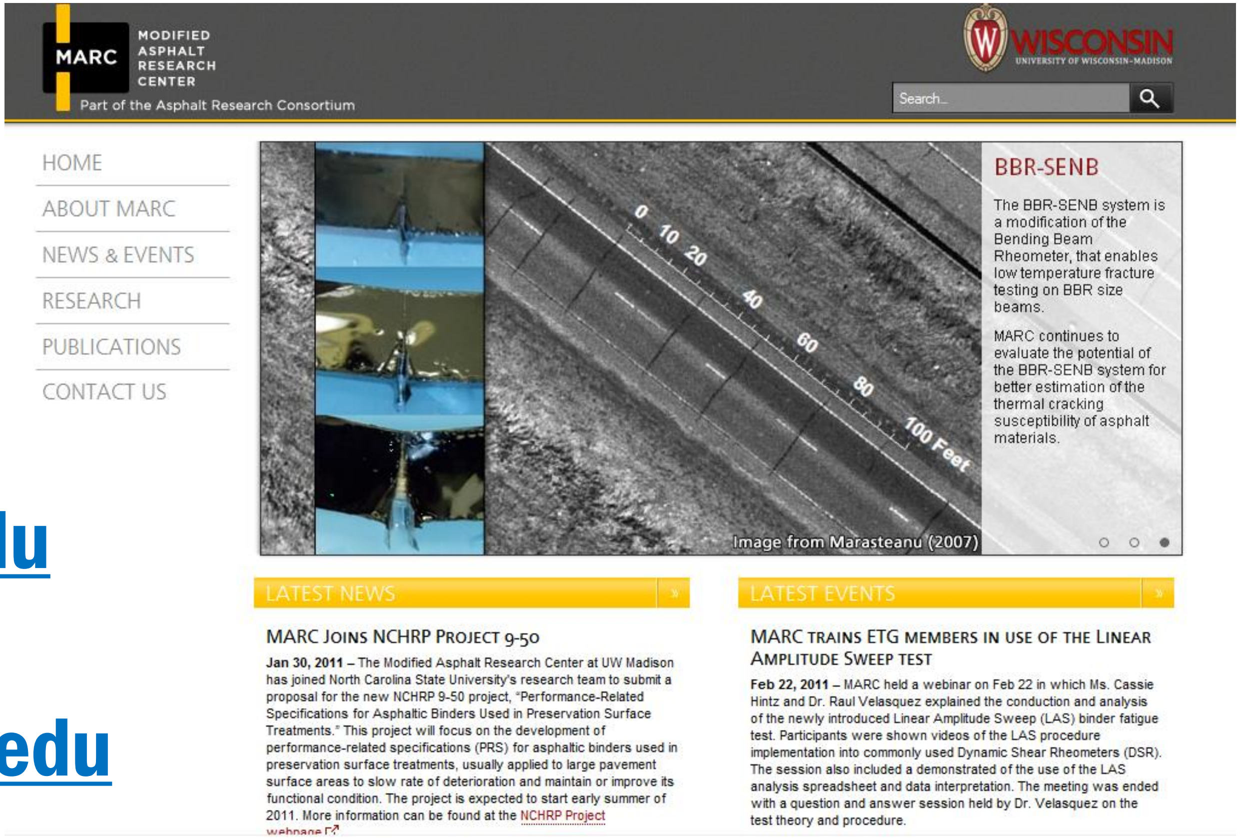
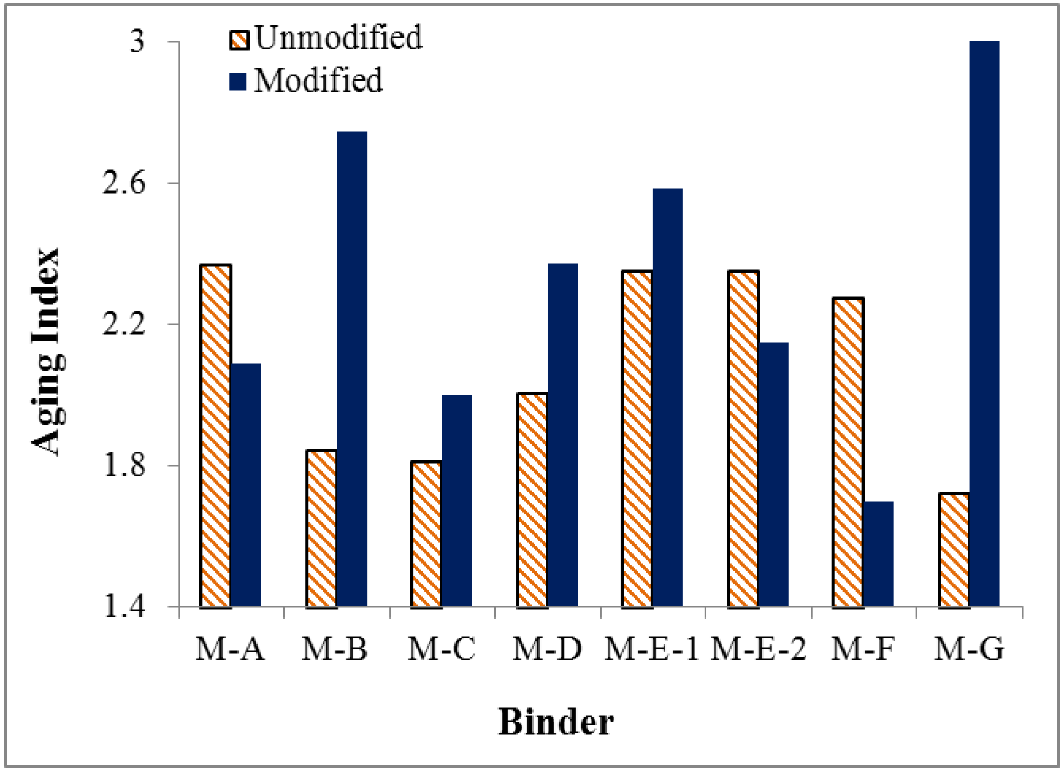


Results

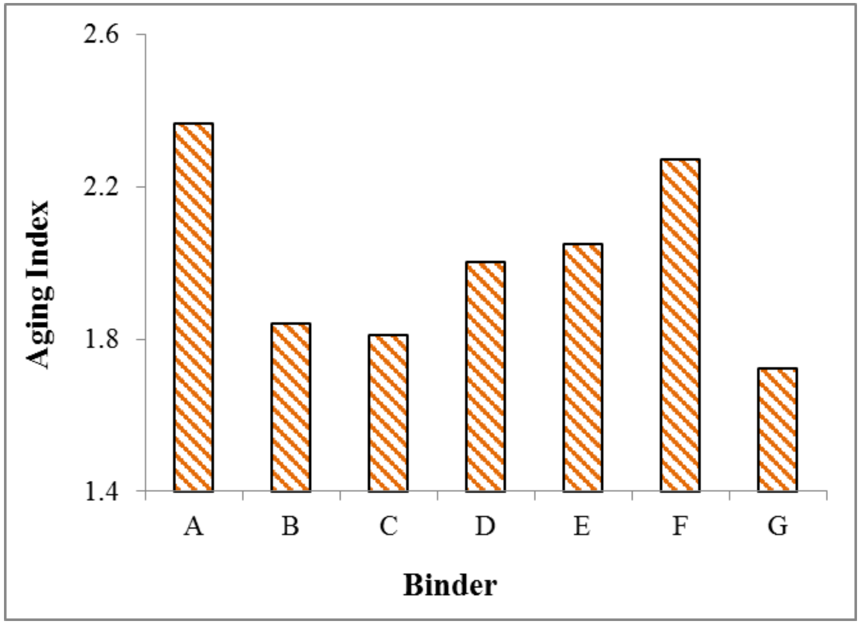
High Temperature Grading-*Aging Susceptibility*

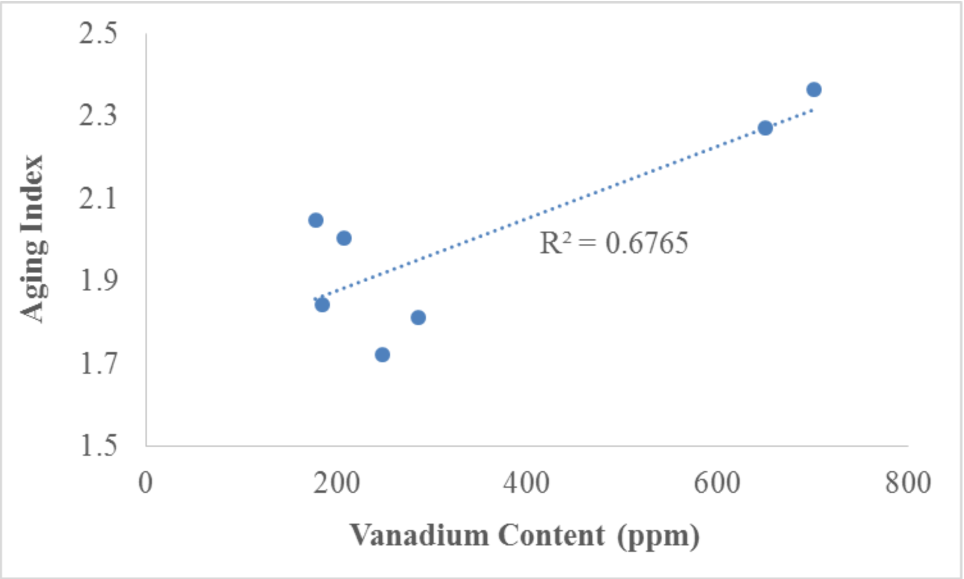


$$A.I. = \frac{\frac{G^*}{sin\delta}RTFO}{\frac{G^*}{sind\delta}OB}$$

- **Aging effect** of different recycling agents are **not the same**
- The difference in aging index for different recycling agents comes from their **different chemical components**
- Values will change if the binder is exposed to long term aging

Results
Aging Vs. Elemental Analysis





$$Aging\ Index = \frac{RTFO\ Aged\ |G*|/sin\delta}{Un-aged\ |G*|/sin\delta}$$

Aging Susceptibility has fair relationship to Vanadium Content