Advances in Asphalt Materials through the Use of Sustainable Materials

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Technologies

- Bio derived polymers, block co-polymers
  - Butadiene replacement
  - Styrene replacement
- Ground tire Rubber
- Bioasphalt
- Fluxes
- Rejuvenators

Why alternative sustainable asphalt materials?

- Address reduction in market share of paving industry.
  - Price competitive on initial cost
  - Increase benefit-cost ratio
- Must be environmentally neutral or better
  - Life-cycle assessment
  - Energy
  - Greenhouse Gases

Our work is interdisciplinary

- Civil Engineering
- Chemical Engineering
- Mechanical Engineering
- Agricultural Engineering
- Chemistry
- Plant Science

Do we understand our asphalt?

- Historical, today and what will be tomorrow?
- Are we using the correct tools to understand asphalt?
  - Mechanical/rheological
  - Chemical

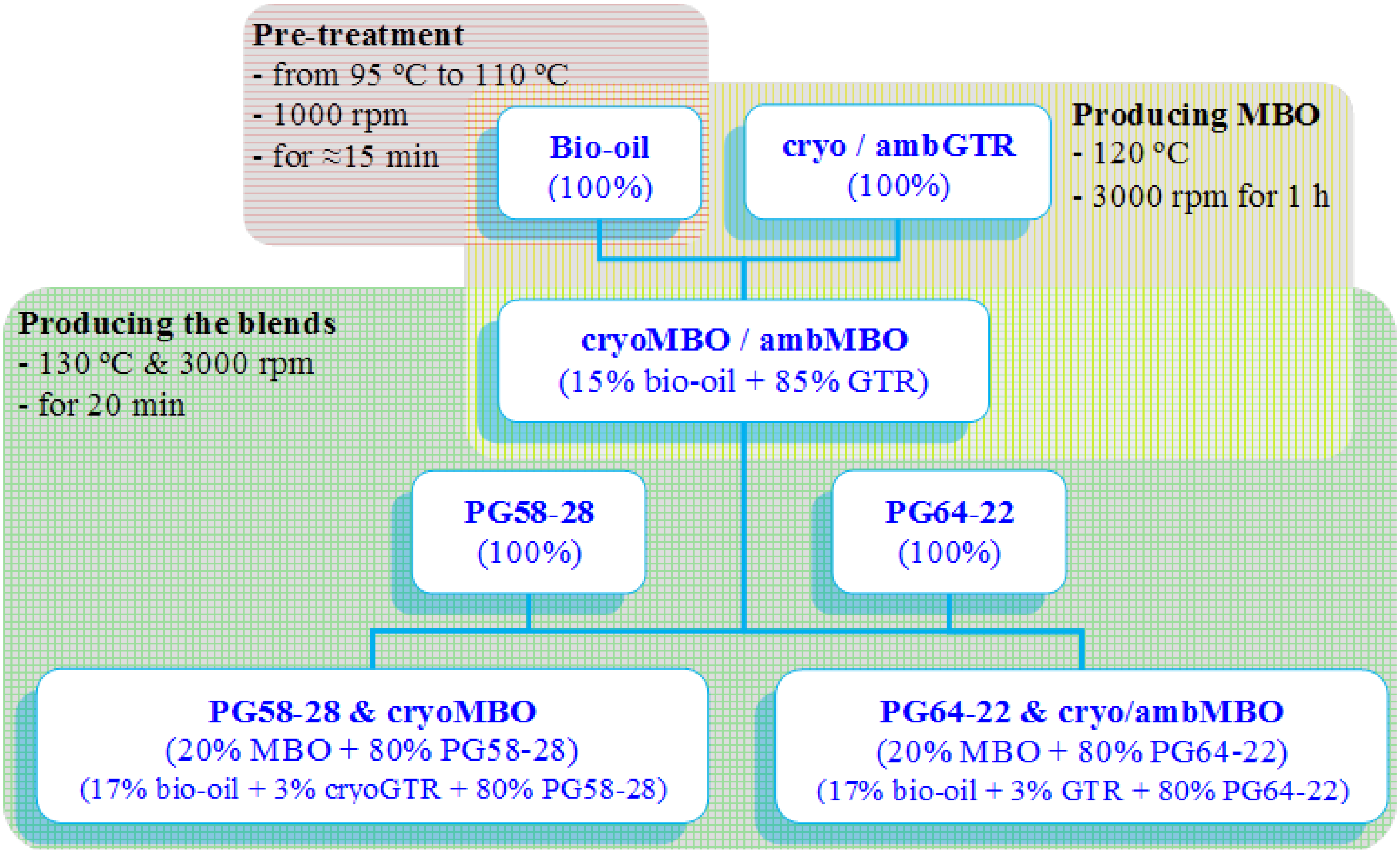
What are these terms?

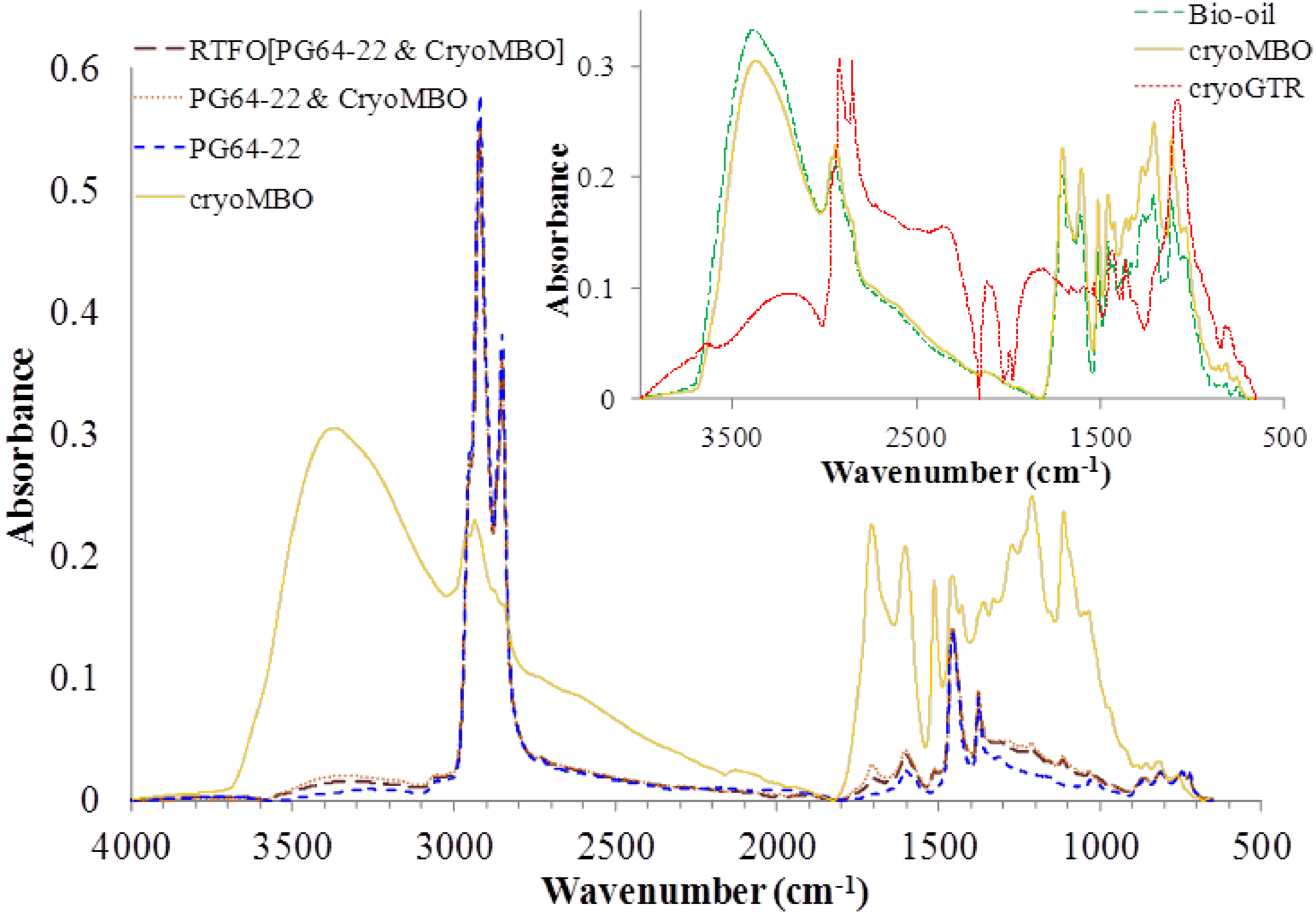
- FTIR
- GPC
- NMR
- SAX

Our approach

- Recognize asphalt binder is a composite material
- Understand the evolution of asphalt from straight run vs. blended asphalts
- Understand today's methods of producing asphalt and how the composition has evolved

Asphalt/Bioasphalt/GTR


Pre-treatment
- from 95 °C to 110 °C
- 1000 rpm
- for ≈15 min
Bio-oil
(100%)
cryo / ambGTR
(100%)
Producing MBO
- 120 °C
- 3000 rpm for 1 h
Producing the blends
- 130 °C & 3000 rpm
- for 20 min
cryoMBO / ambMBO
(15% bio-oil + 85% GTR)
PG58-28
(100%)
PG64-22
(100%)
PG58-28 & cryoMBO
(20% MBO + 80% PG58-28)
(17% bio-oil + 3% cryoGTR + 80% PG58-28)
PG64-22 & cryo/ambMBO
(20% MBO + 80% PG64-22)
(17% bio-oil + 3% GTR + 80% PG64-22)


RTFO[PG64-22 & CryoMBO]
PG64-22 & CryoMBO
PG64-22
cryoMBO
Absorbance
Wavenumber (cm-1)
0
0.1
0.2
0.3
0.4
0.5
0.6
4000
3500
3000
2500
2000
1500
1000
500
Bio-oil
cryoMBO
cryoGTR
Absorbance
Wavenumber (cm-1)
0
0.1
0.2
0.3
3500
2500
1500
500

High Temperature Grades

Materials	High Temperature Continuous Performance Grade (°C)*	
	Un-Aged	RTFO Aged
PG58-28 & cryoMBO	59.3	66.4
PG64-22 & HTBO	60.1	67.4
PG64-22 & cryoMBO	65.5	70.7
PG64-22 & ambMBO	65.2	72.1

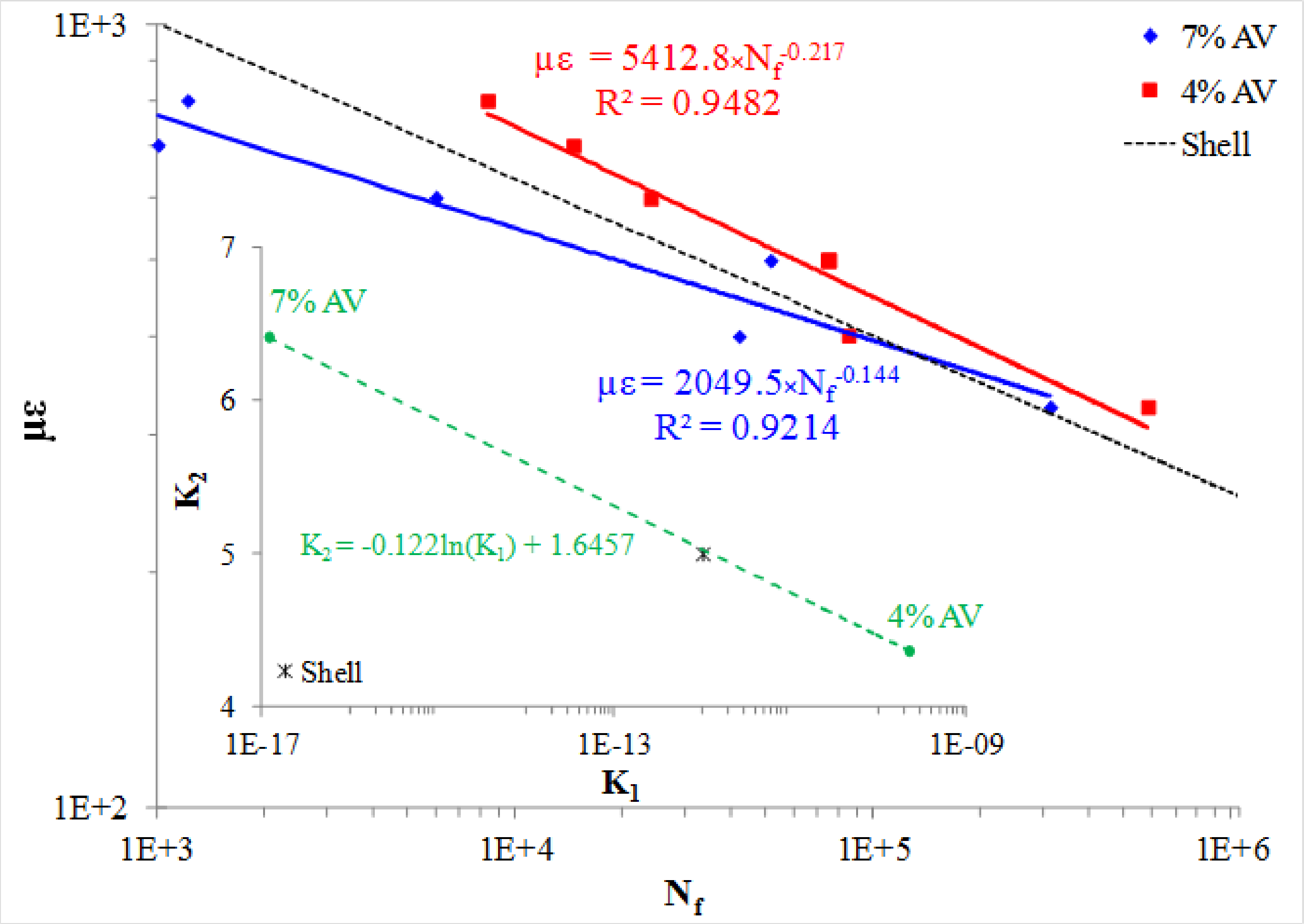
Mixing & Compaction Temperatures

Materials	Mixing Temperature (°C)	Compaction Temperature (°C)
PG58-28 & cryoMBO	160	140
PG64-22 & HTBO	150	140
PG64-22 & cryoMBO	160	150
PG64-22 & ambMBO	170	*

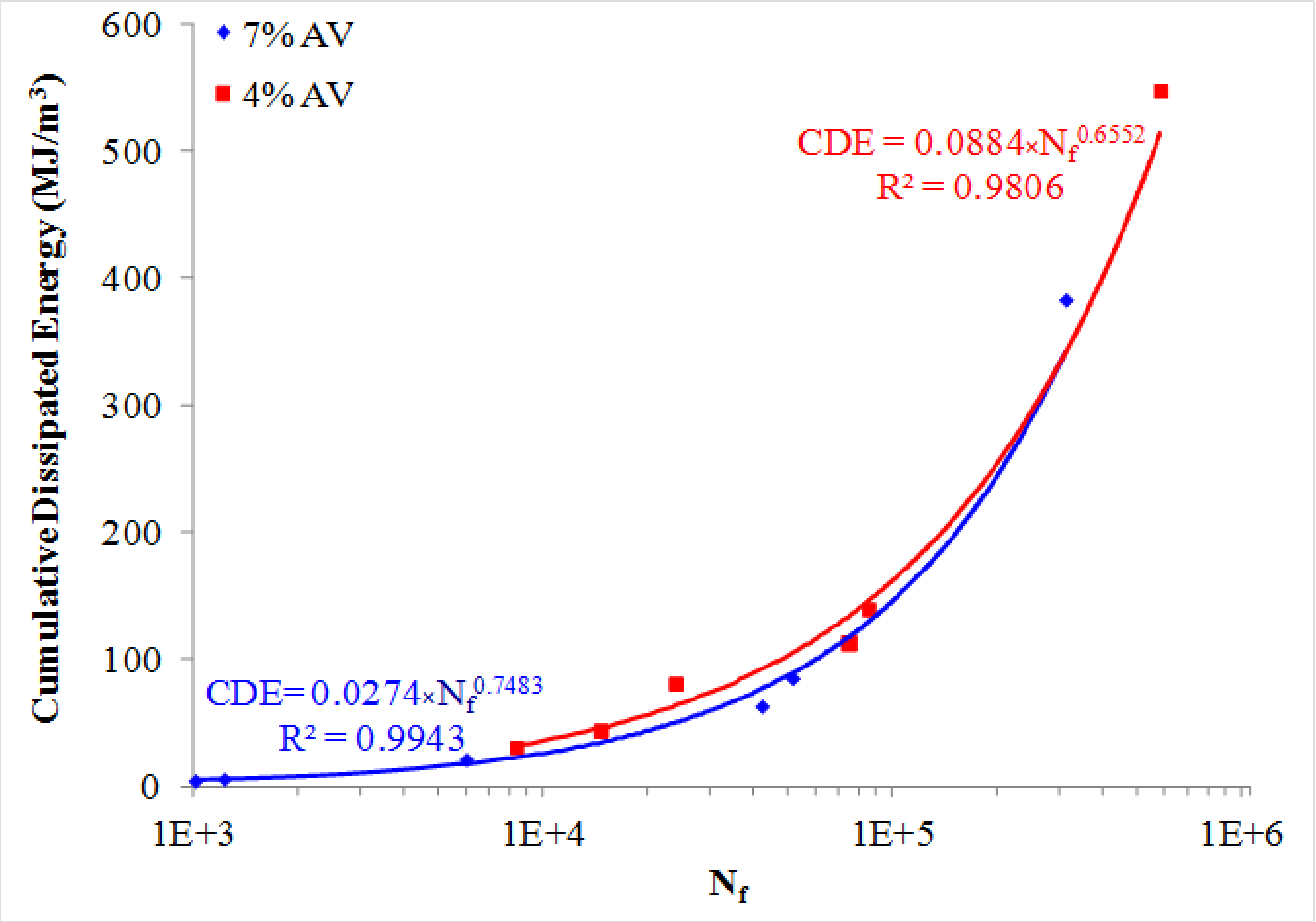
Moisture Susceptibility Testing AASHTO T-283

	Unconditioned Strength (kPa)	Conditioned Strength (kPa)	TSR
Average	1756.4	1461.7	0.84
Standard Deviation	187.1	53.5	0.06
Coefficient of Variation	0.11	0.04	0.07

Fatigue Performance

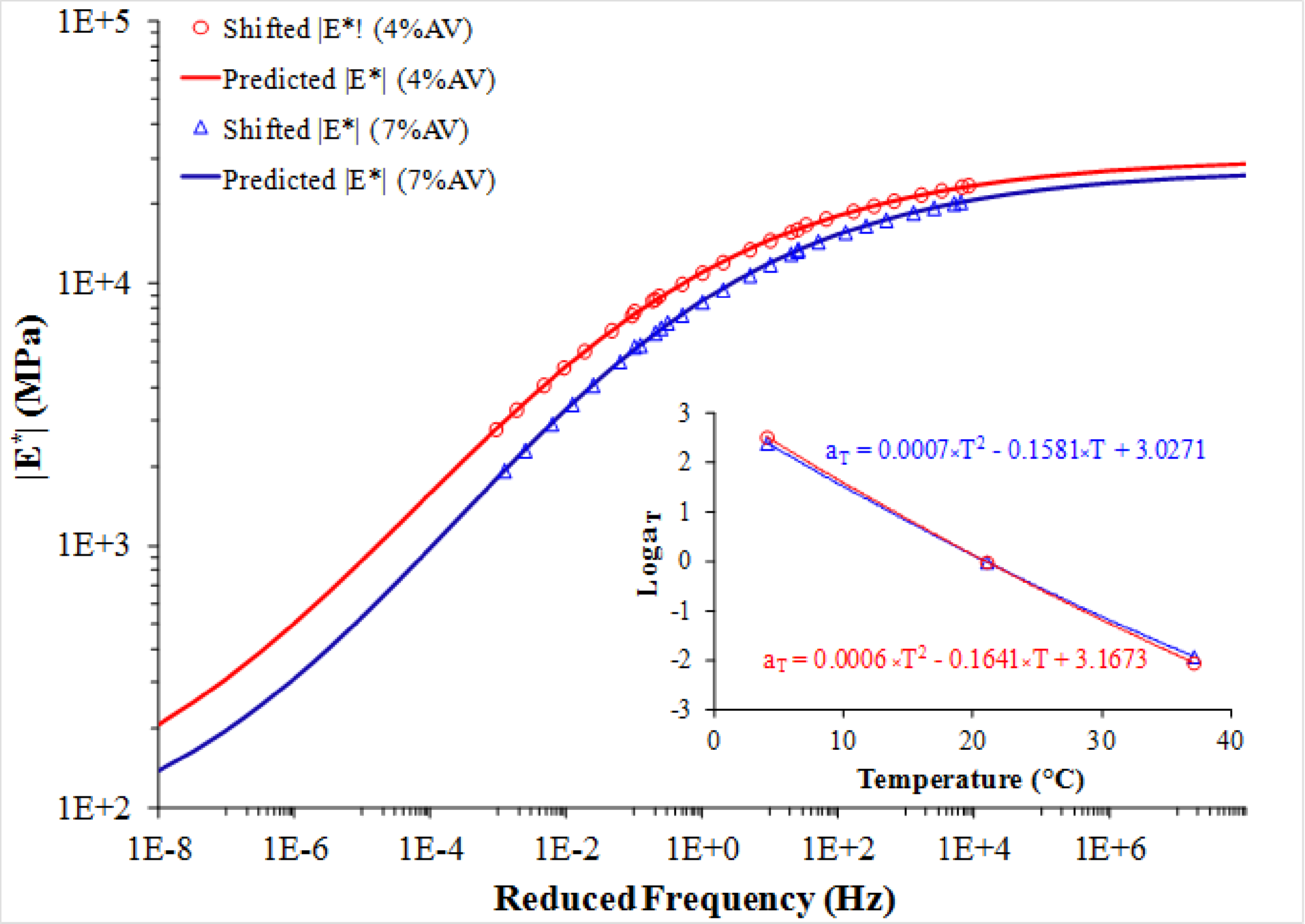


Fatigue

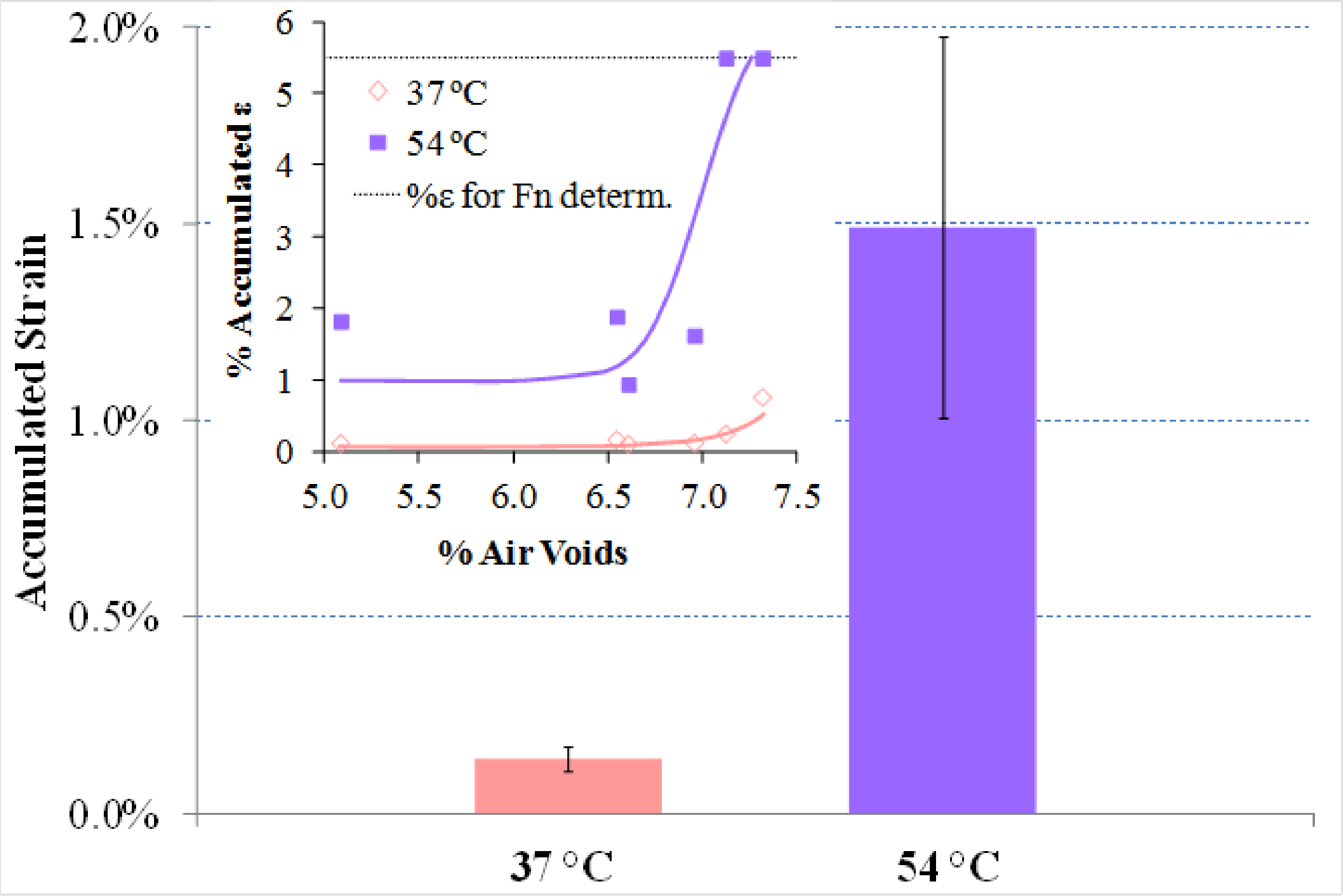


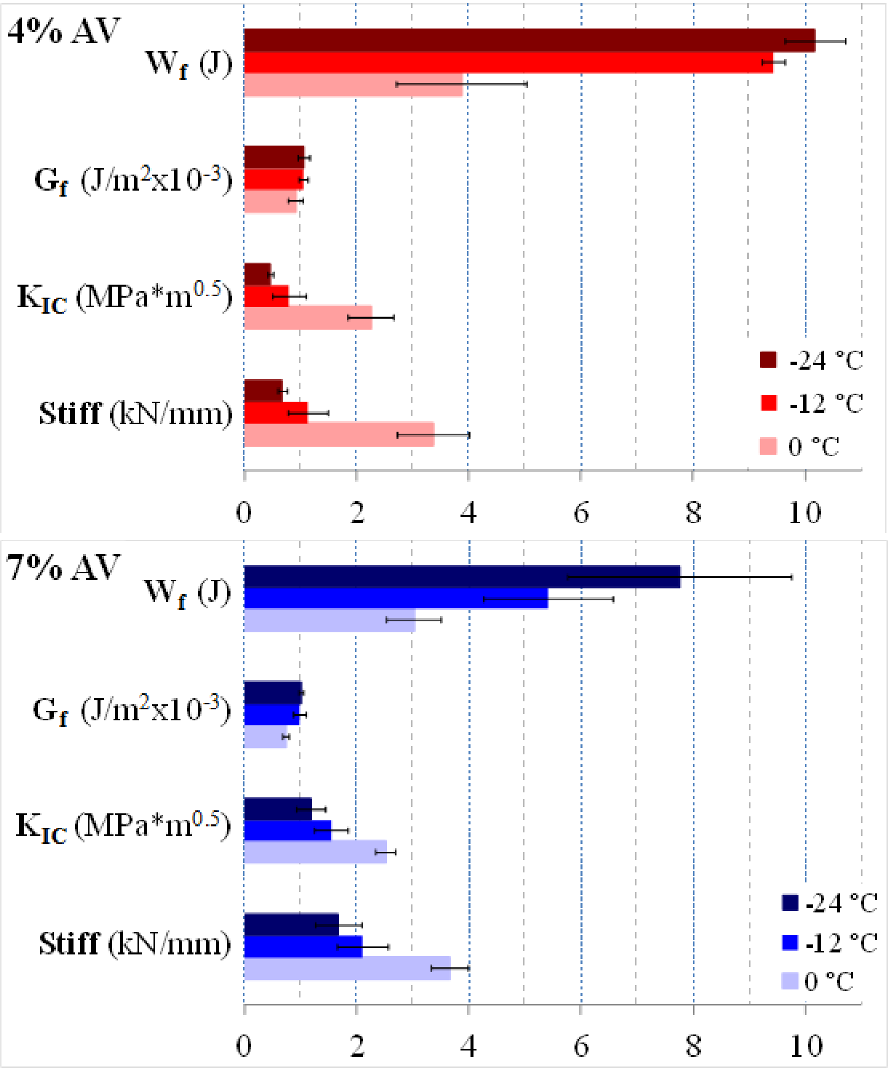
600
500
400
300
200
100
0
Cumulative Dissipated Energy (MJ/m³)
7% AV
4% AV
CDE = 0.0884×Nf^0.6552
R² = 0.9806
CDE=0.0274×Nf^0.7483
R² = 0.9943
1E+3
1E+4
1E+5
1E+6
Nf

Dynamic Modulus



Permanent Deformation




4% AV
W_f (J)
G_f (J/m^{2}x10^{-3})
K_{IC} (MPa*m$^{0.5}$)
Stiff (kN/mm)
-24 °C
-12 °C
0 °C
0
2
4
6
8
10
7% AV
W_f (J)
G_f (J/m^{2}x10^{-3})
K_{IC} (MPa*m$^{0.5}$)
Stiff (kN/mm)
-24 °C
-12 °C
0 °C
0
2
4
6
8
10

Summary of asphalt/bioasphalt/GTR

- Blends can be produced similar to asphalt
- Need to pay attention to RTFO mass loss
- We can attain performance consistent with our standard asphalt mixtures
  - Moisture susceptibility
  - Fatigue
  - Permanent deformation
  - Thermal cracking

Introduction

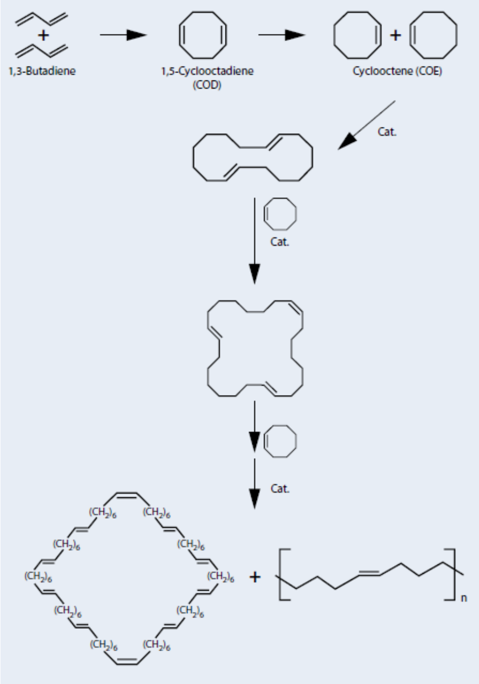
- Asphalt-rubber mixtures are used in geographical areas where rutting performance is a concern
- One challenge:
  - Higher temperatures required for mixing and compaction compared to conventional bitumen mixtures
- One solution is to use chemical modifiers to help reduce the mixing and compaction temperatures

Introduction

- Polyoctenamer (PO)
  - From monomer cyclooctene
  - 1,3 butadiene via 1,5 cyclooctadiene
  - Chemical formula

$$–(C_4H_7=C_4H_7)–_n$$

  - Crosslinks with asphaltenes and maltenes in the asphalt, and with the sulfur in the GTR's surfaces
  - Reduces tackiness of asphalt rubber mixtures
  - Prevents sinking of rubber particles
  - Serves as an anti-stripping agent
  - Recommended dosage, 4.5% by weight of GTR



Polyoctenamer Synthesis

Polyoctenamer Pellets

Outline

- Introduction
- Materials and Test Methods
- Results and Discussion
- Conclusions and Recommendations

Materials and Test Methods

- Binders
  - Binder materials
  - Laboratory binders production
  - Binders testing – Superpave Specifications
- Mixtures
  - Mixtures materials
    - Aggregate types
    - Binder types
  - Laboratory mixtures production
  - Mixtures Testing – Superpave Specifications

Materials and Test Methods (cont)

- Binder Materials
  - Base bitumen PG46-34
  - Type of rubber
    - 12% ambient GTR by weight of asphalt
  - Two percentage of Polyoctenamer (PO)
    - 0% PO
    - 4.5% PO by weight of GTR

Materials and Test Methods (cont)

- Binders
  - Binder materials
  - Laboratory binder production
  - Binders testing

Materials and Test Methods (cont)

- Laboratory Binder Production
  - Temperature of Production: 180°C
  - Initial blend speed: 1000 rpm
    - Addition of rubber
    - Addition of PO
  - Increase blend speed to 3000 rpm
  - Wait for temperature to rise back to 180°C
  - Mantain blending for an additional hour

Materials and Test Methods (cont)

- Binders
  - Binder materials
  - Laboratory binder production
  - Binder testing

Materials and Test Methods (con

- Binder Testing
  - Density (ASTM D70-99)
  - RV (viscosity) (AASHTO T316-10)
  - Dynamic Shear Rheometer (DSR) (AASHTO T315-10)
    - Unaged materials
    - Rolling Thin Film Oven (RTFO) aged materials (AASHTO T240-10)
    - Pressurized Aging Vessel (PAV) aged materials (AASHTO R28-10)
  - Bending Beam Rheometer (BBR) (AASHTO 313-10)
  - Binders Master Curves

Materials and Test Methods (cont)

- Binder Testing

Matrix of laboratory-produced binders' performance testing

Binder Type	**Test Method**						
	Density	RV	DSR Unaged	DSR RTFO-Aged	DSR PAV-Aged	BBR PAV-Aged	
			Gap	Gap	Gap	Test Temp °C.	
			1mm	1mm	2mm	-24	-30
AMB	XXX	XX	XX	XX	XX	XX	XX
AV	XXX	XX	XX	XX	XX	XX	XX

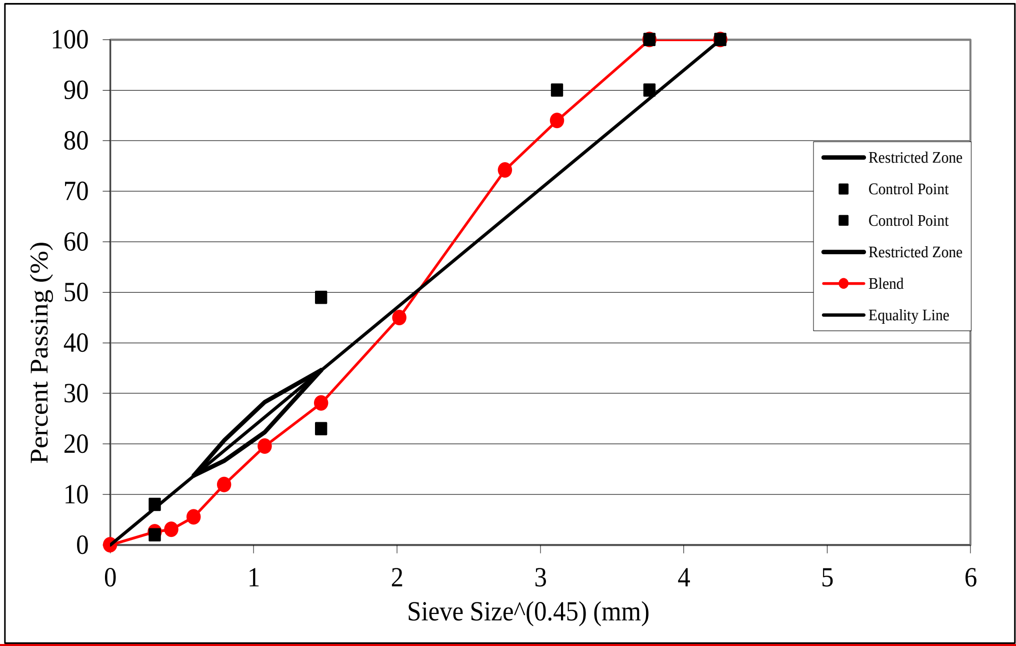
Materials and Test Methods (cont)

- Mixtures
  - Mixtures materials
    - Aggregate types
    - Binder types
  - Laboratory mixtures production
  - Mixtures Testing

Materials and Test Methods (cont)

- Mixtures Materials
  - Aggregate types
    - Limestone (3/4” and 3/8”)
    - Quartzite
    - Manufactured Sand
    - Natural Sand
    - Hydrated Lime
  - Binder Types:
    - AMB
    - AV
  - Optimum binder content = 5.6%

Aggregates blend gradation



Materials and Test Methods (cont)

- Mixtures
  - Mixtures materials
  - Laboratory mixtures production
  - Mixtures Testing

Materials and Test Methods (cont)

- Laboratory Mixtures Production
  - Same gradation for all mixtures
  - Same binder percentage
  - Mixing Temperature: 180°C
  - Curing time: 3 hours
  - Compaction Temperature: 165°C

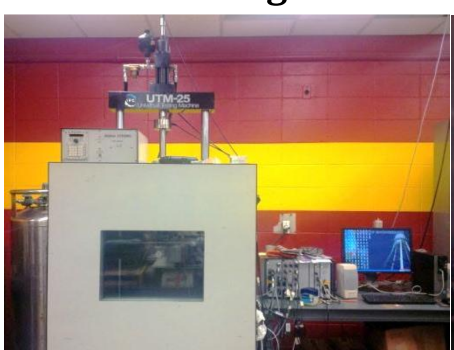
Materials and Test Methods (cont)

- Mixtures
  - Mixtures materials
  - Laboratory mixtures production
  - Mixtures Testing

Materials and Test Methods (cont)

- Mixtures Testing
  - Dynamic Modulus (E*) (AASHTO TP 62-10)
  - Flow Number (FN) (NCHRP Report 547)
  - Mixtures Master Curves (AASHTO PP62-10)

Universal Testing Machine



Dynamic Modulus

Flow Number Testing

Outline

- Introduction
- Materials and Test Methods
- Results and Discussion
- Conclusions and Recommendations

Results and Discussion

- Binders Testing Results
  - Densities (ASTM D70-97) at 25°C

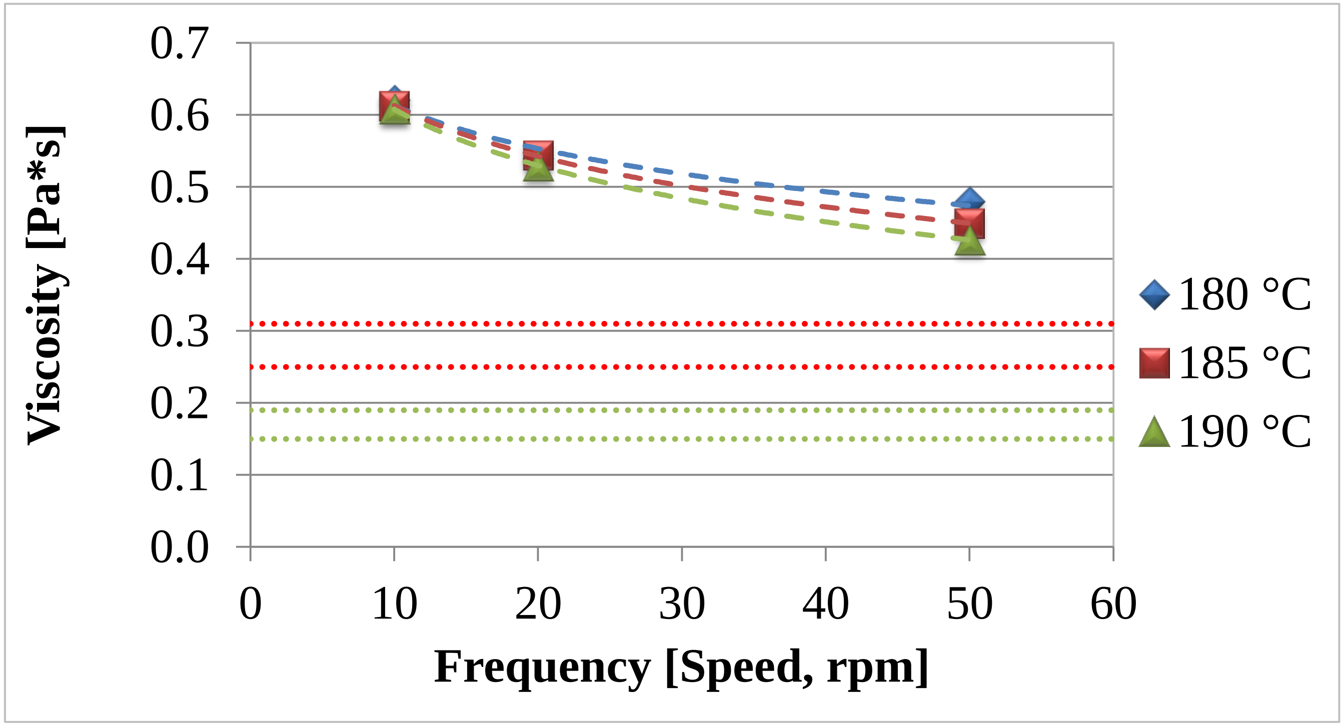
Binder Type	Density (kg/m^3)
AMB	1021
AV	1028

  - Viscosities (ASTM D4402-87)
    - Three testing temperatures
      - 180°C
      - 185°C
      - 190°C

Results and Discussion

- Binders Testing Results (Cont)
  - Viscosities (Cont)

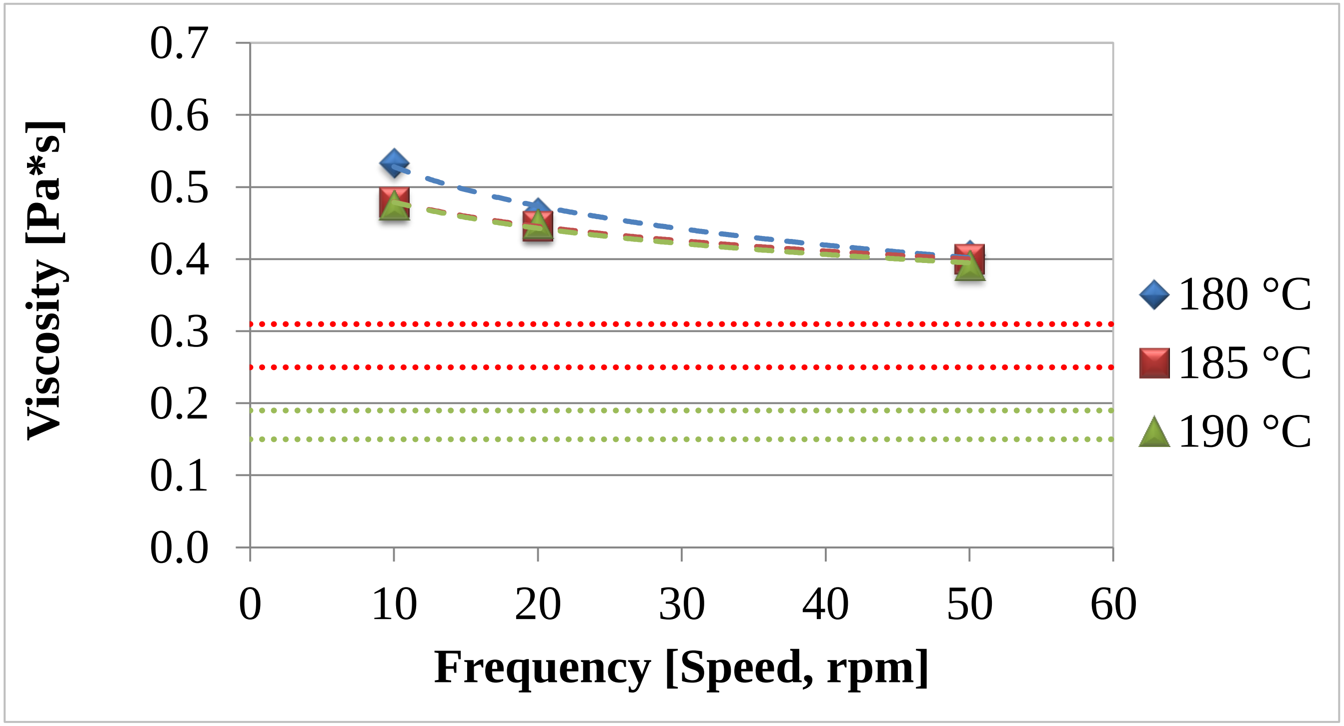
AMB Binder Viscometry Results



Results and Discussion

- Binders Testing Results (Cont)
  - Viscosities (Cont)

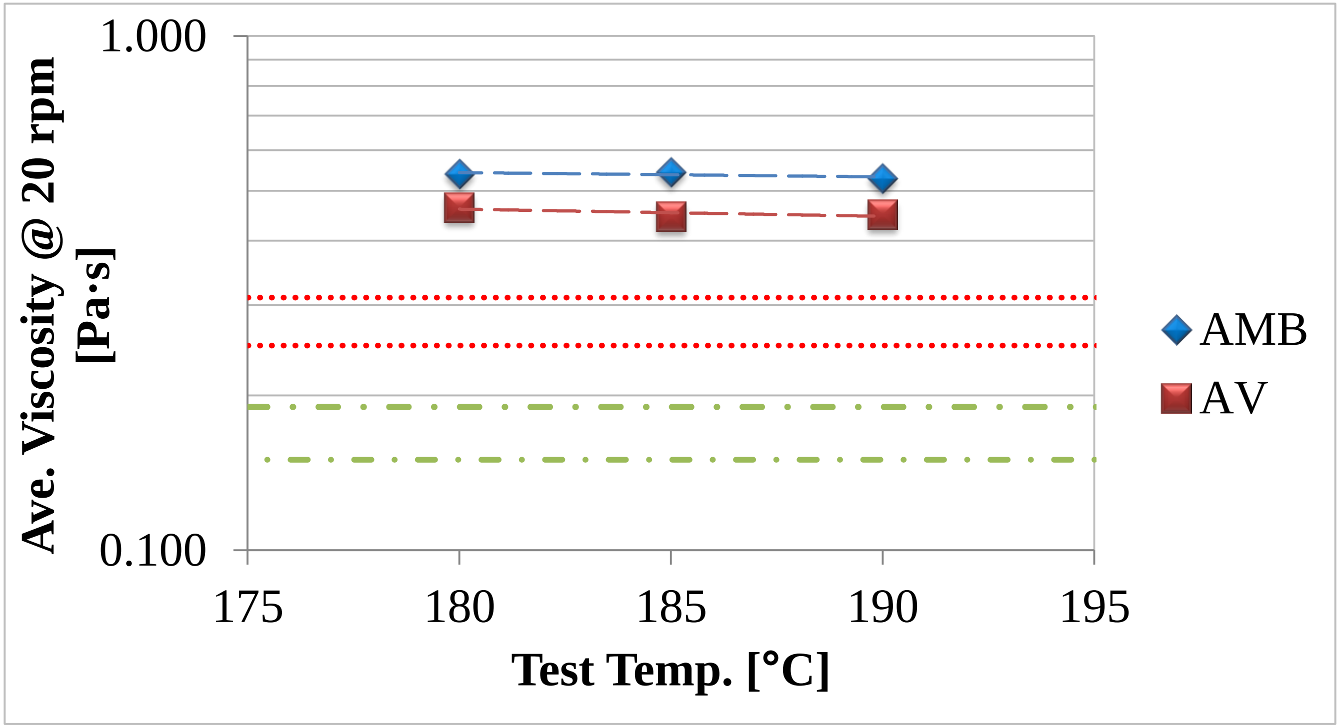
AV Binder Viscosity Results



Results and Discussion

- Binders Testing Results (Cont)
  - Viscosities (Cont)

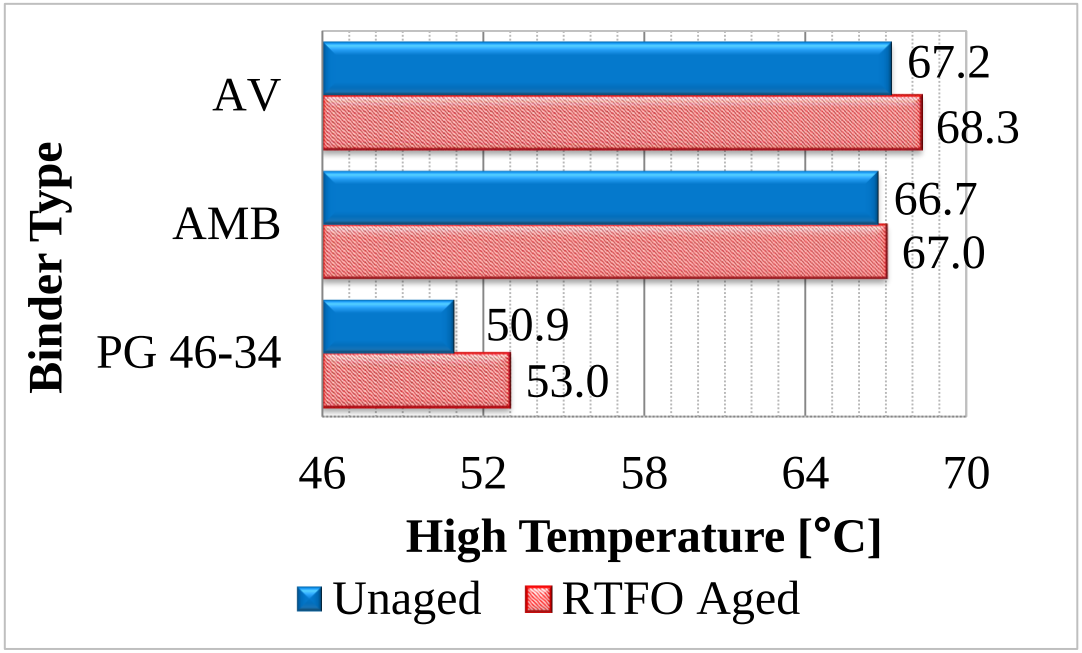
Comparison between binders @ 20 rpm



Results and Discussion

- Binders Testing Results (Cont)
  - Dynamic Shear Rheometer (DSR)
    - High Temperatures – Continuous Grading

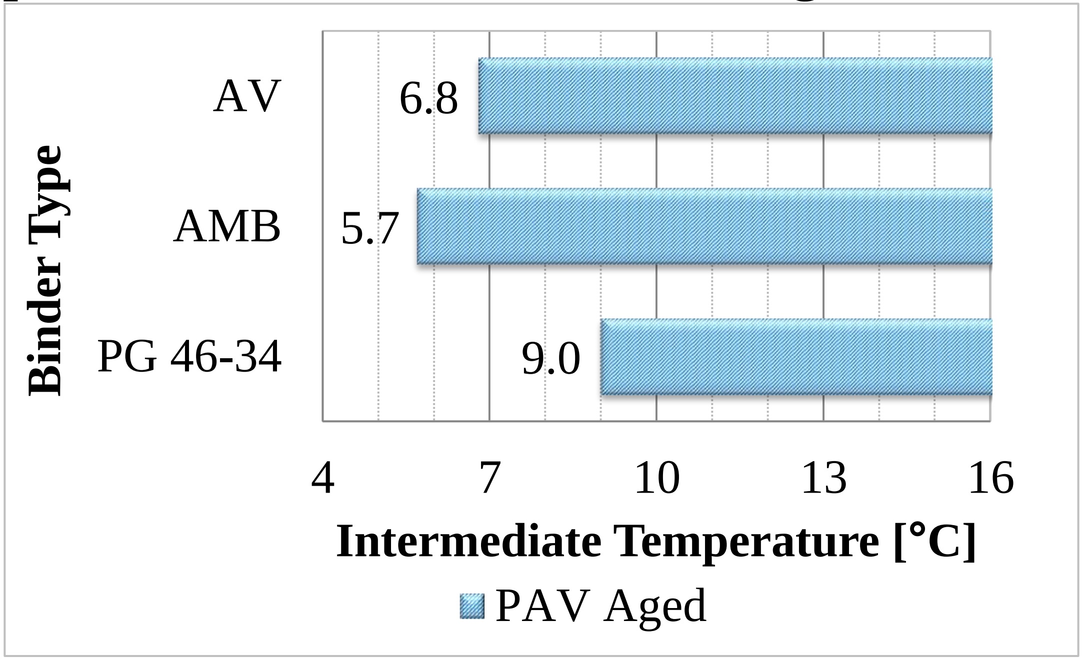
	High Temperature	
	Continuous Grading, °C	
Binder Type	Unaged	RTFO Aged
PG 46-34	50.9	53.0
AMB	66.7	67.0
AV	67.2	68.3



Results and Discussion

- Binders Testing Results (Cont)
  - Dynamic Shear Rheometer (DSR) (Cont)
    - Intermediate Temperatures – Continuous Grading

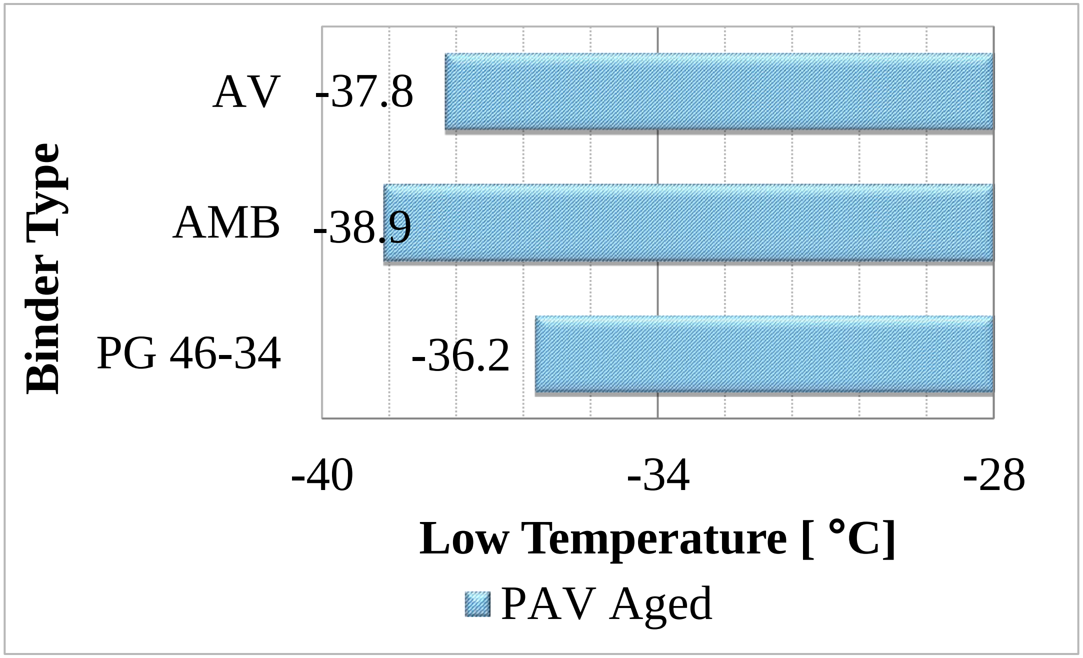
	Intermediate Temperature
	Continuous Grading, °C
Binder Type	PAV Aged
PG 46-34	9.0
AMB	5.7
AV	6.8



Results and Discussion

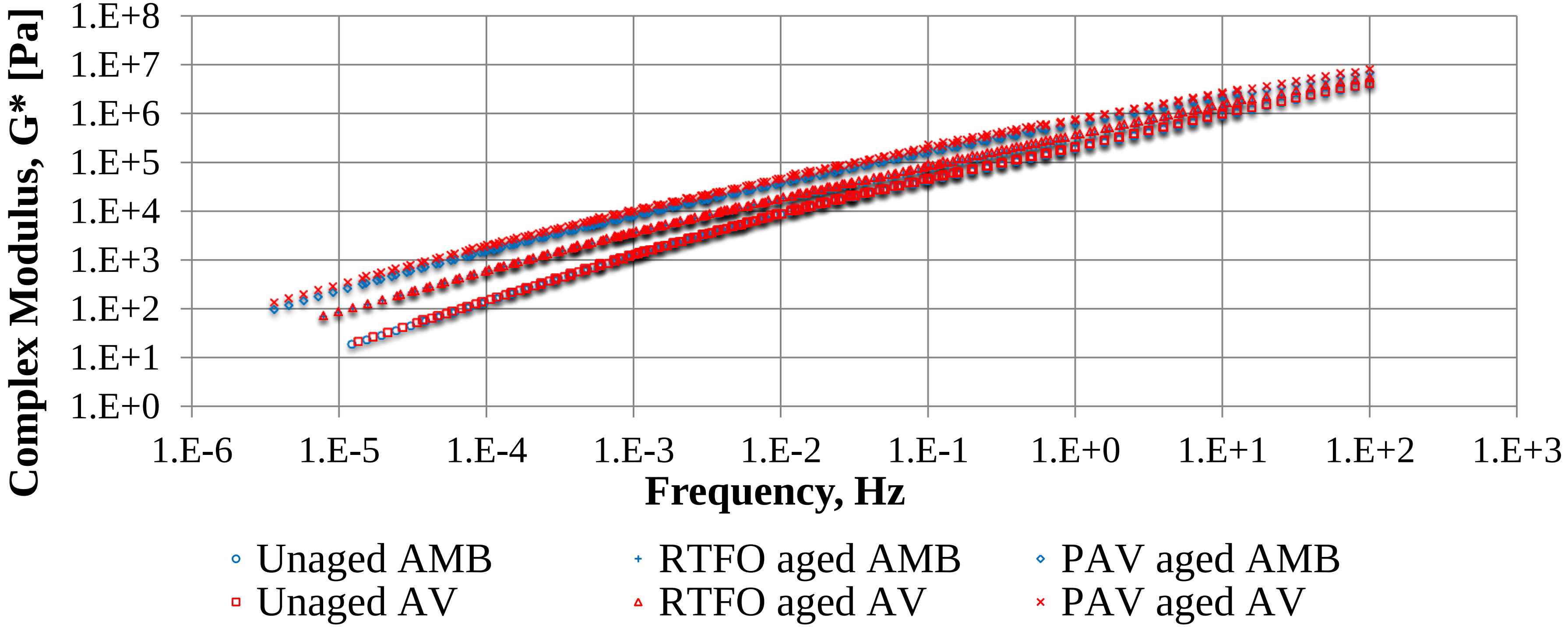
- Binders Testing Results (Cont)
  - Bending Beam Rheometer
    - Low Temperatures – Continuous Grading

	Low Temperature
	Continuous Grading, °C
Binder Type	PAV Aged
PG 46-34	-36.2
AMB	-38.9
AV	-37.8



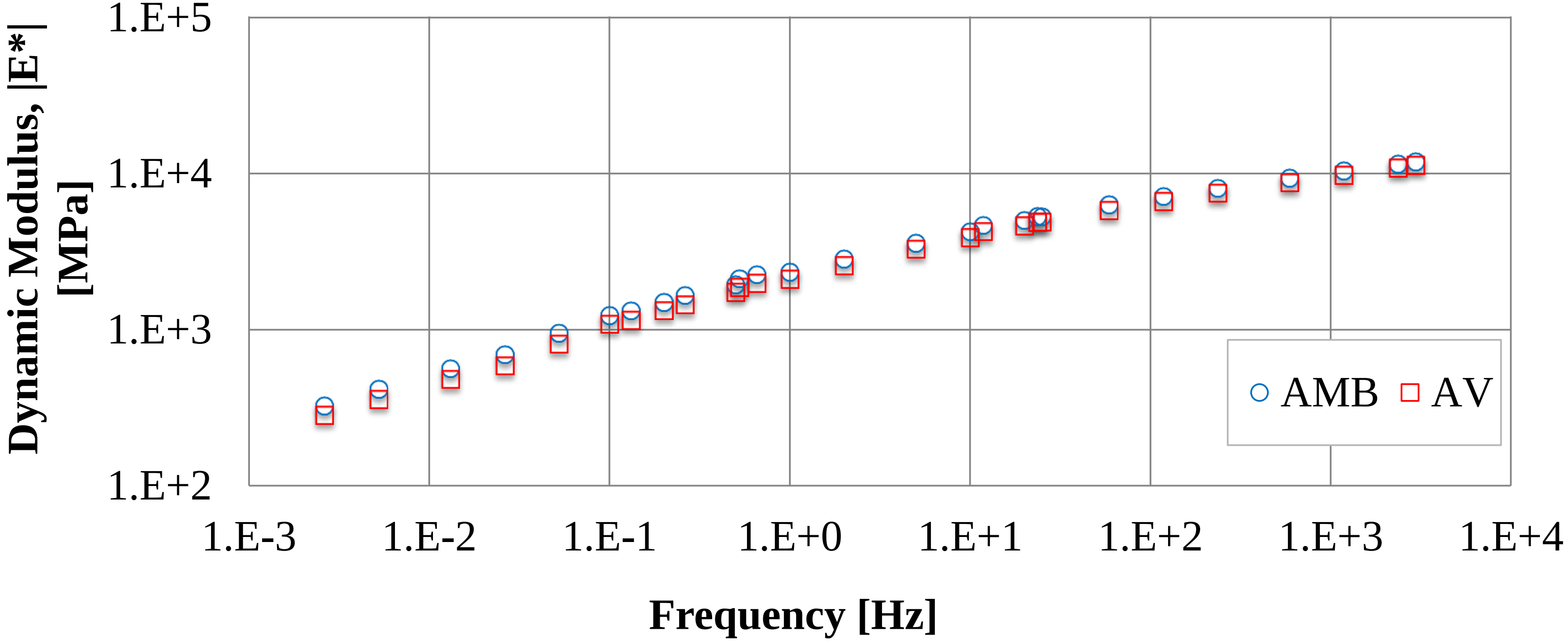
Results and Discussion

- Binders Testing Results (Cont)
  - Binders Master Curves



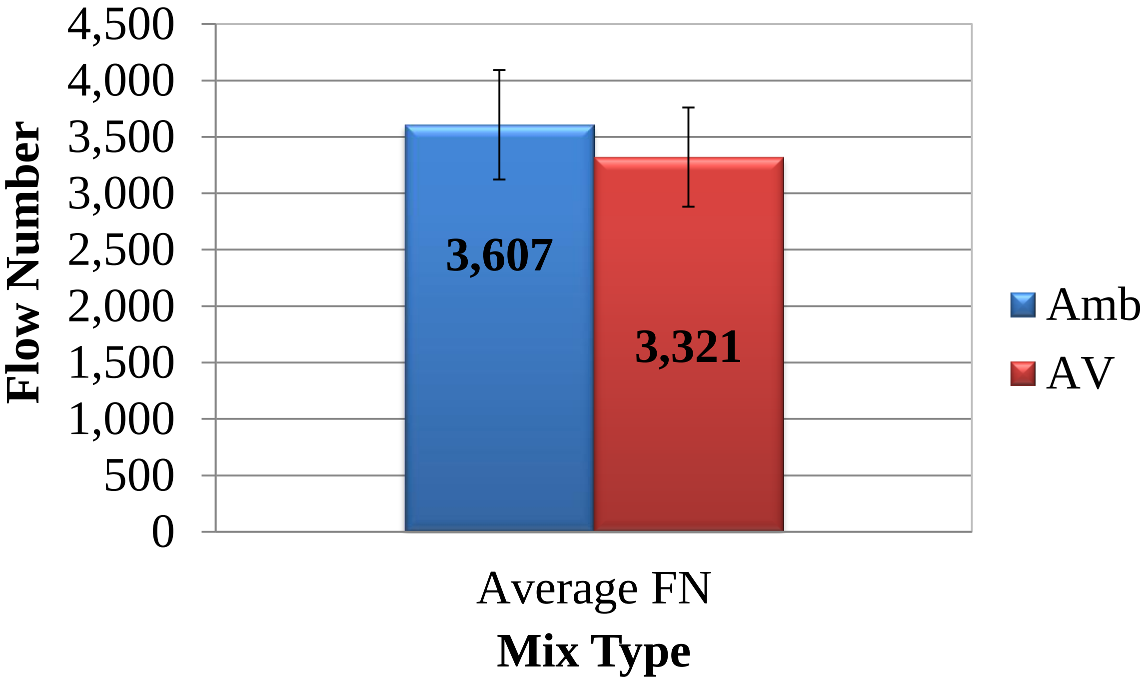
Results and Discussion

- Mixtures Testing Results
  - Dynamic Modulus (|E*|)



Results and Discussion

- Mixtures Testing Results (Cont)
  - Flow Number



Outline

- Introduction
- Literature Review
- Experimental Plan and Testing
- Results and Discussion
- Conclusions and Recommendations

Conclusions and Recommendations

- Binders
  - Densities
    - Addition of PO will increase the density of asphalt-rubber (AR) binders
  - Viscosity
    - **PO will decrease the viscosity of AR binders**
    - There is a particle effect due to the rubber that affects the viscosities readings
    - There is a need to reevaluate only the liquid part of AR binders to obtain the correct mixing and compaction temperatures

Conclusions and Recommendations

- Binders
  - DSR (high temperatures)
    - Final performance grading for the two AR binders are the same, PG64
    - PO does not affect the final performance grading of AR at high temperatures

Conclusions and Recommendations

- Binders
  - DSR (intermediate temperatures)
    - Final performance grading for the two AR binders are the same, 7°C
    - PO does not affect the final performance grading of AR at intermediate temperatures
    - Addition of PO will improve the continuous grading of the PAV aged materials

Conclusions and Recommendations

- Binders
  - BBR (low temperatures)
    - Final performance grading of the two AR binders are the same, PG-34
    - PO does not negatively affect the final performance grading of AR at low temperatures
  - Master Curves
    - The behavior of the AR binders was found to be very similar between them for each type of aged materials

Conclusions and Recommendations

- Binders
  - This study did not include separation tests on the laboratory-produced binders. It is recommended to evaluate in future research how the addition of PO can influence over the stability of AR binders.

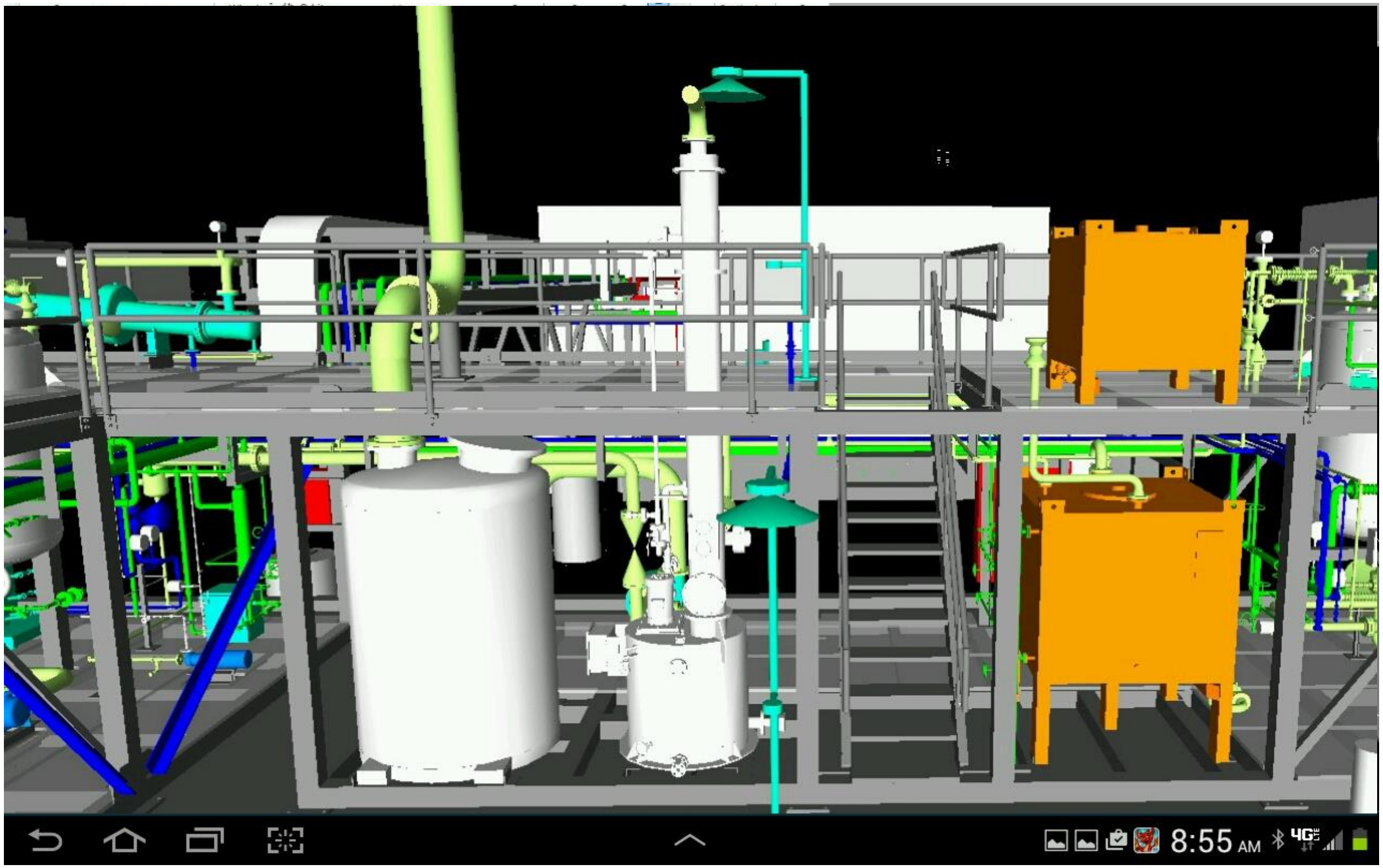
Conclusions and Recommendations

- Mixes
  - Master Curves
    - Addition of PO did not influence negatively the |E*| performance at high, intermediate and low temperature of AR mixes
  - Flow Number
    - Addition of PO did not affect either the rutting performance of AR mixes

Conclusions and Recommendations

- Evaluate the fatigue cracking performance by means of the beam fatigue test of the AR mixes
- Evaluate the thermal cracking performance of the AR mixes through the semi-circular bend (SCB) geometry test

The Future



Thanks!
Questions?