Fiberless SMA – The NJ Experience
&
Recycled Plastic in Asphalt Binder and Mixtures

Presented By:

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Fiberless SMA

Fiberless SMA Acknowledgements

- Original concept from Frank Fee and Ron Corun
- 1st Supplier – Trap Rock Industries – Wayne Byard and Mike Jopko
- NJDOT
  - Materials - Eileen Sheehy (retired), Robert Sauber (retired)
  - Pavement Design – Sue Gresavage (retired), Robert Blight
- Bryan Pecht

Stone Matrix Asphalt (SMA)

- Gap graded aggregate blends with cubical shaped aggregate
- Mastic of polymer-modified asphalt binder, mineral filler and fibers
- When produced and placed correctly, known for outstanding performance

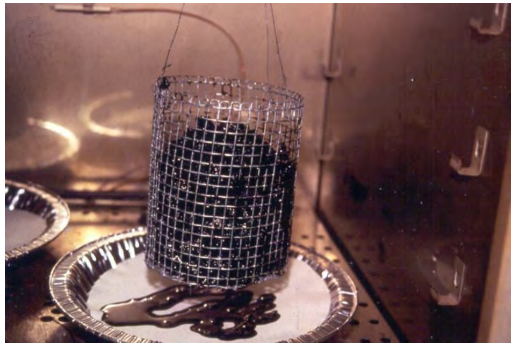
Design and Production of SMA Mixes

- Due to high asphalt contents, a potential for "draindown" of binder exists
  - Defined as liquid binder running off aggregate surface
  - Results in flushing, "fat spots" and segregated areas of heavy and low binder content

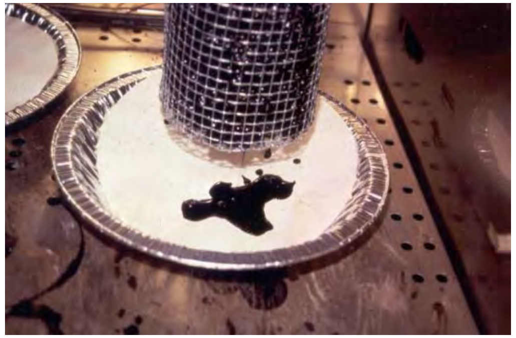
Design and Production of SMA Mixes

- To help reduce the potential of draindown, polymer-modified asphalt (PMA) and fibers used with SMA
  - PMA results in better adhesion to aggregate at higher temps than Neat binders (generally higher viscosity)
  - Fibers increase stiffness/viscosity of mastic

Neat



PMA



PMA + Fibers

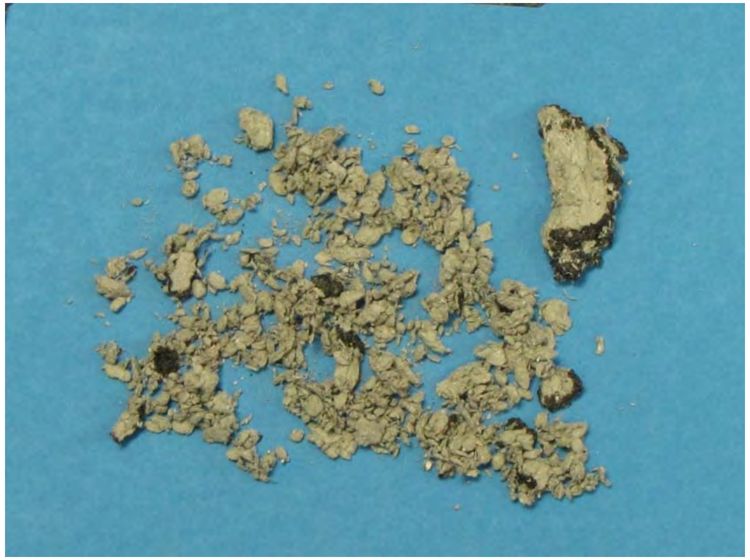
(NCAT)

Complaints About Fibers in SMA

- Cost – fibers and rental equipment
- Fibers need to be separated or "fluffed" prior to addition or clumping can occur
- Metering required and should have "sight glass" to ensure fibers flowing
- Fibers must be included in ignition oven correction factor determination
  - Impossible to separate AC and Fiber changes during production from ignition oven testing alone

Example of Fiber Issue: "Fiber Ball" in New Jersey SMA

- Found in pavement surface during visual inspection after placement
- Possibly due to the "feeding system" at the asphalt plant



Fiberless SMA Concept & Design

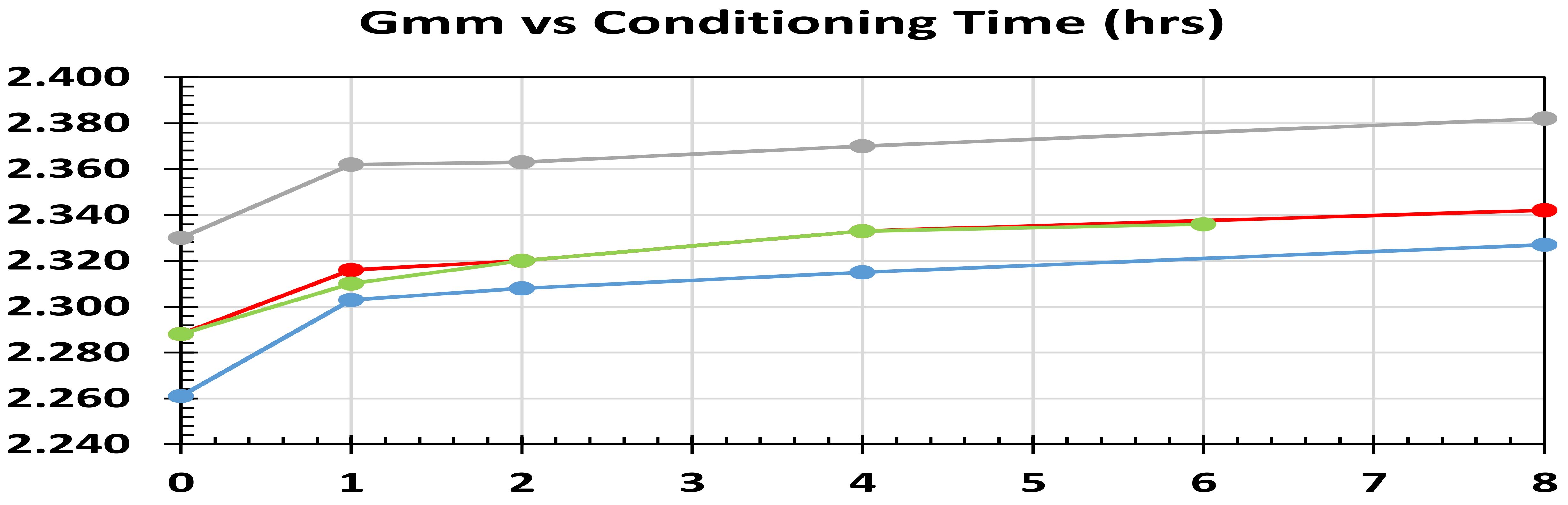
Fiberless SMA Concept

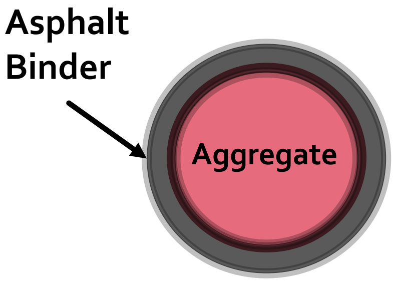
- The inclusion of fibers used to increase the viscosity of the mastic (binder, fines, fibers)
  - Increased mastic viscosity will stick to aggregate better and resist draindown
- Utilizing an asphalt binder with higher viscosity can help increase mastic viscosity (i.e. – PMA vs Neat)
  - As temperature decreases, binder viscosity increases
- Reduction in mixture temp will create compaction issues
  - Must couple mixture temp reduction with WMA additive
  - **WMA technology that does not influence binder viscosity**

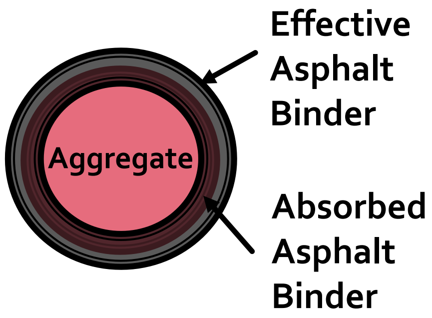
Fiberless SMA "Mixture Design"

- Utilize existing SMA design as your starting point (i.e. – asphalt content, aggregate blend)
- Determine Draindown (AASHTO T305) and compacted air voids vs Mixture Temperature
  - Example: 325, 300, 280, 255°F
    - Design: Aggregates heated 10F higher than compaction temp
    - Compaction temperature based on binder grade
  - Compare draindown & compacted air voids to allowable design/production values – determine optimum temperature range
    - Recommend to run Gmm at each temp
- Visually examine mixing process to ensure coating is taking place
  - Can utilize AASHTO T195, Degree of Particle Coating as a guide
- Make slight mixture adjustments if necessary
  - In general, have found for every 0.1% of fibers removed, asphalt plant will need to remove same amount of asphalt binder

Density – Mass to Volume Relationship





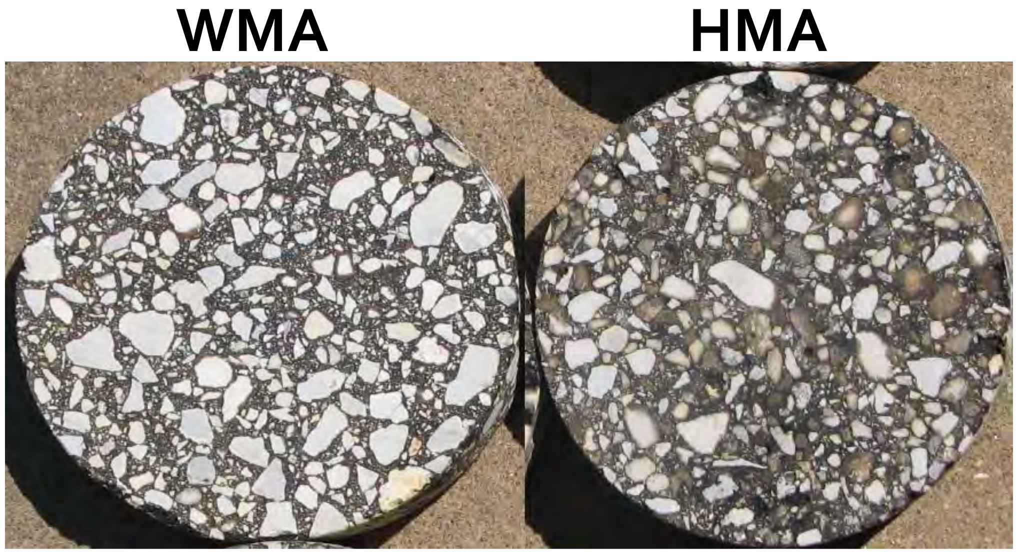


Final coated particle

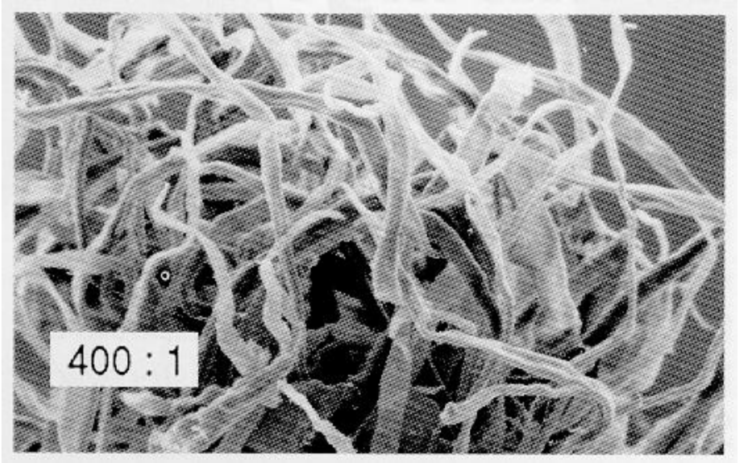
Important to note that mass never changes. Volume of particles decreases over time as absorption increases.
D = M/V; so as V decreases, D increases

Fiberless SMA "Mixture Design"

- Potential changes in optimum AC%
  - Reduction in temperature increases binder viscosity making absorption more difficult
    - Results in higher effective AC%
  - Eliminating fibers will reduce the surface area of the "solids", increasing "free" asphalt which could lead to increased draindown



(Dale Rand, TxDOT)



(John Bukowski, FHWA)

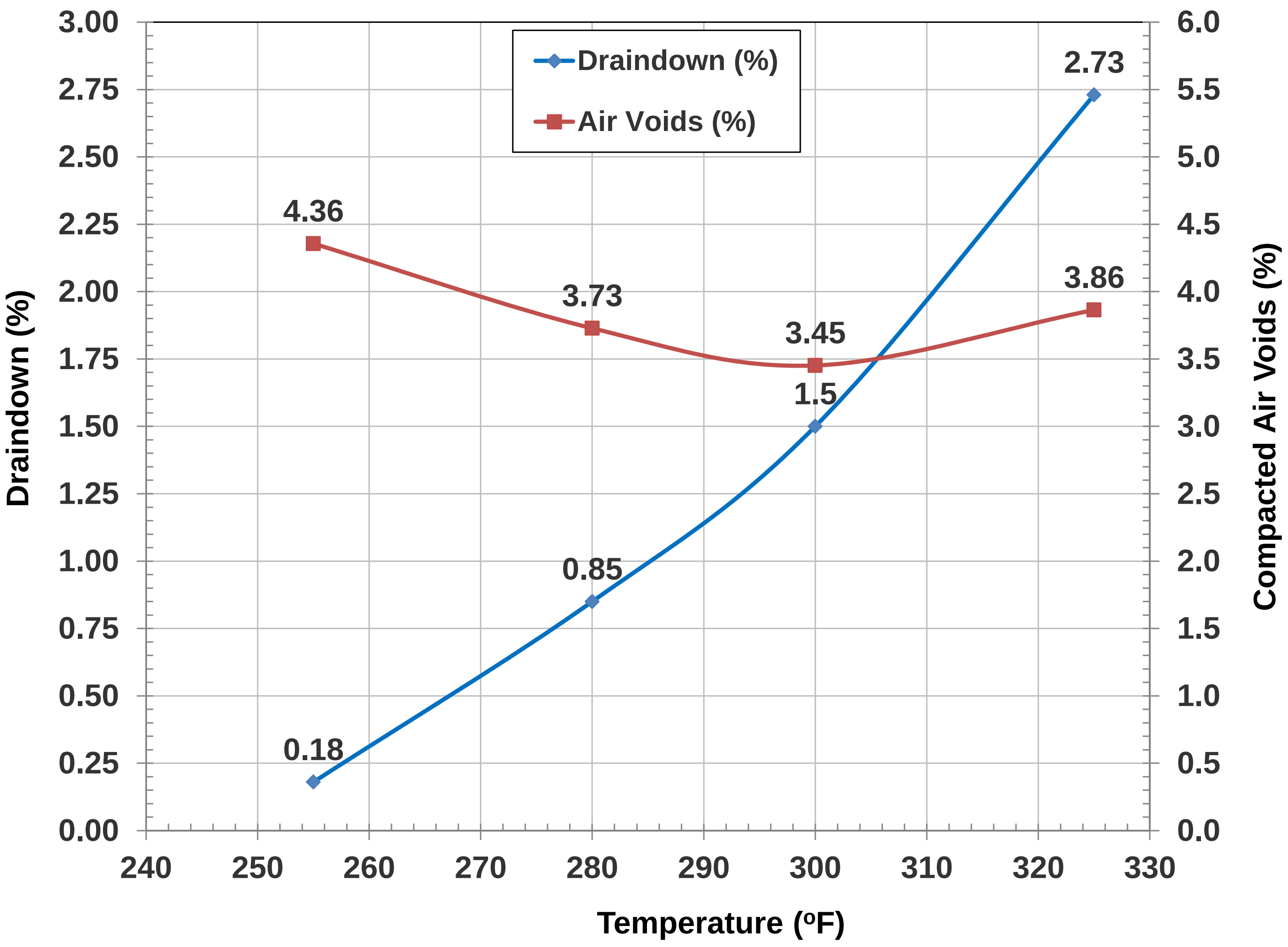
Fiberless SMA – Design Example

Design Example #1 – "Sometimes It All Goes Right"

- Determine Optimal Temperature for Fiberless SMA in MD
  - 12.5 mm NMAS SMA
  - 6.5% Asphalt Content
    - PG76-22
  - 0.3% Cellulose Fibers
  - 0.04% Draindown at Design
    - Specification < 0.3%

Washed Gradation		
Screen		% Pass
2"	50.00	100
1 ½"	37.50	100
1"	25.00	100
¾"	19.00	100
½"	12.50	96
3/8"	9.50	80
#4	4.75	34
#8	2.36	21
#16	1.18	17
#30	0.600	15
#50	0.300	13
#100	0.150	12
#200	0.075	9.3

Design Example #1: Compacted Air Voids vs Draindown



Design Example #1 - Results

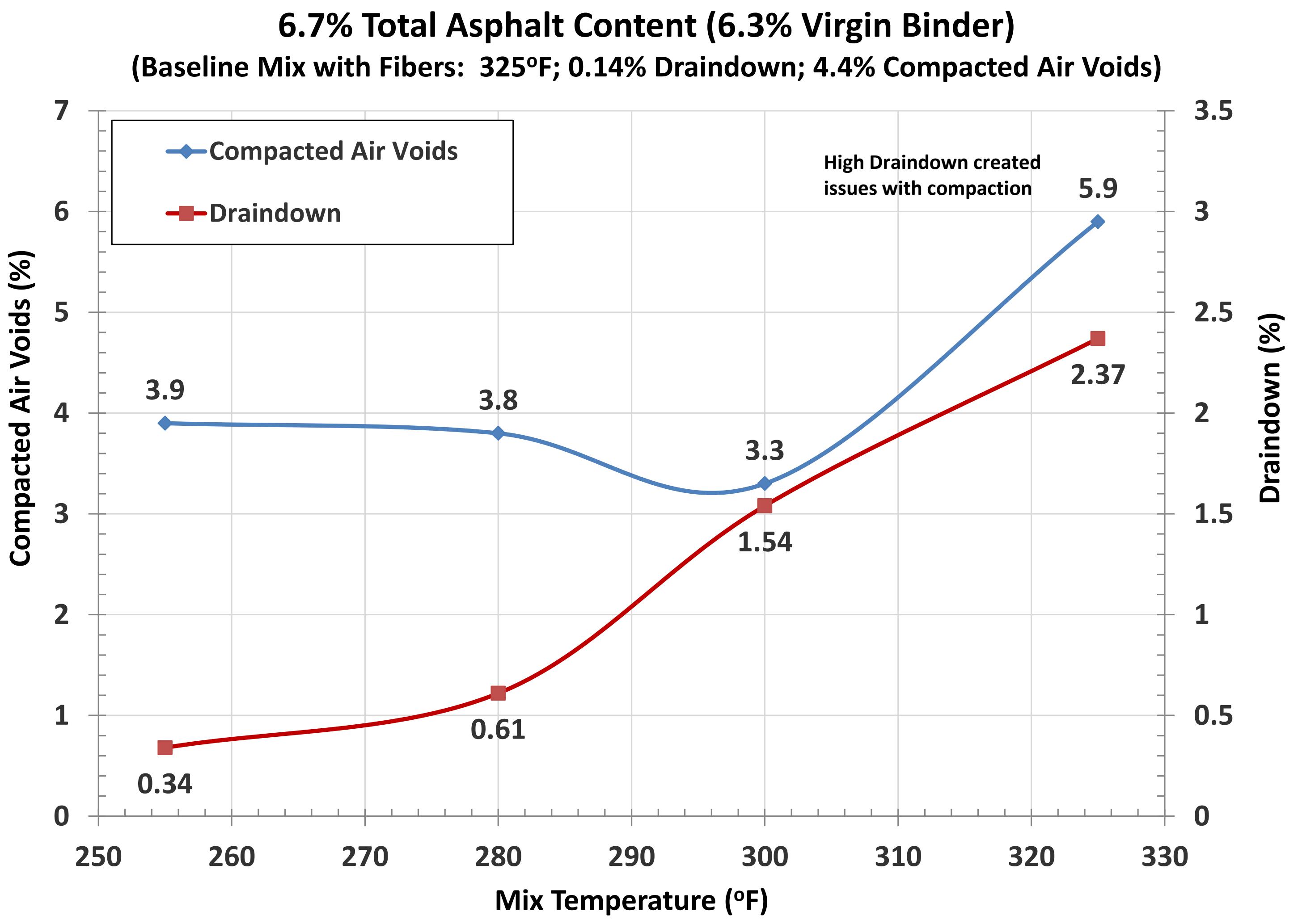
- Final Result
  - Optimal temp range for mixture between 265 and 255°F.
  - In that range;
    - Air voids slightly above 4%
    - Draindown around 0.2 to 0.25% (specification is 0.3%)
    - All aggregates coated after mixing
- Final production
  - Maintained asphalt content and slight increase filler content
    - Increased filler to help close up air voids and reduce draindown
    - Contractor and agency extremely happy with final product

Design Example #2 – "Sometimes You Need a Few Trials"

- Determine Optimal Temperature Range for Fiberless SMA in VA
  - 12.5mm NMAS SMA
  - 6.7% Total Asphalt Content
    - PG76-22
  - 15% RAP
    - 0.4% Total Binder Weight Contribution
  - 0.3% Cellulose Fibers
  - 0.14% draindown

Washed Gradation		
Screen		% Pass
2"	50.00	100
1 ½"	37.50	100
1"	25.00	100
¾"	19.00	100
½"	12.50	95
3/8"	9.50	75
#4	4.75	30
#8	2.36	19
#16	1.18	14
#30	0.600	13
#50	0.300	12
#100	0.150	11
#200	0.075	8.5

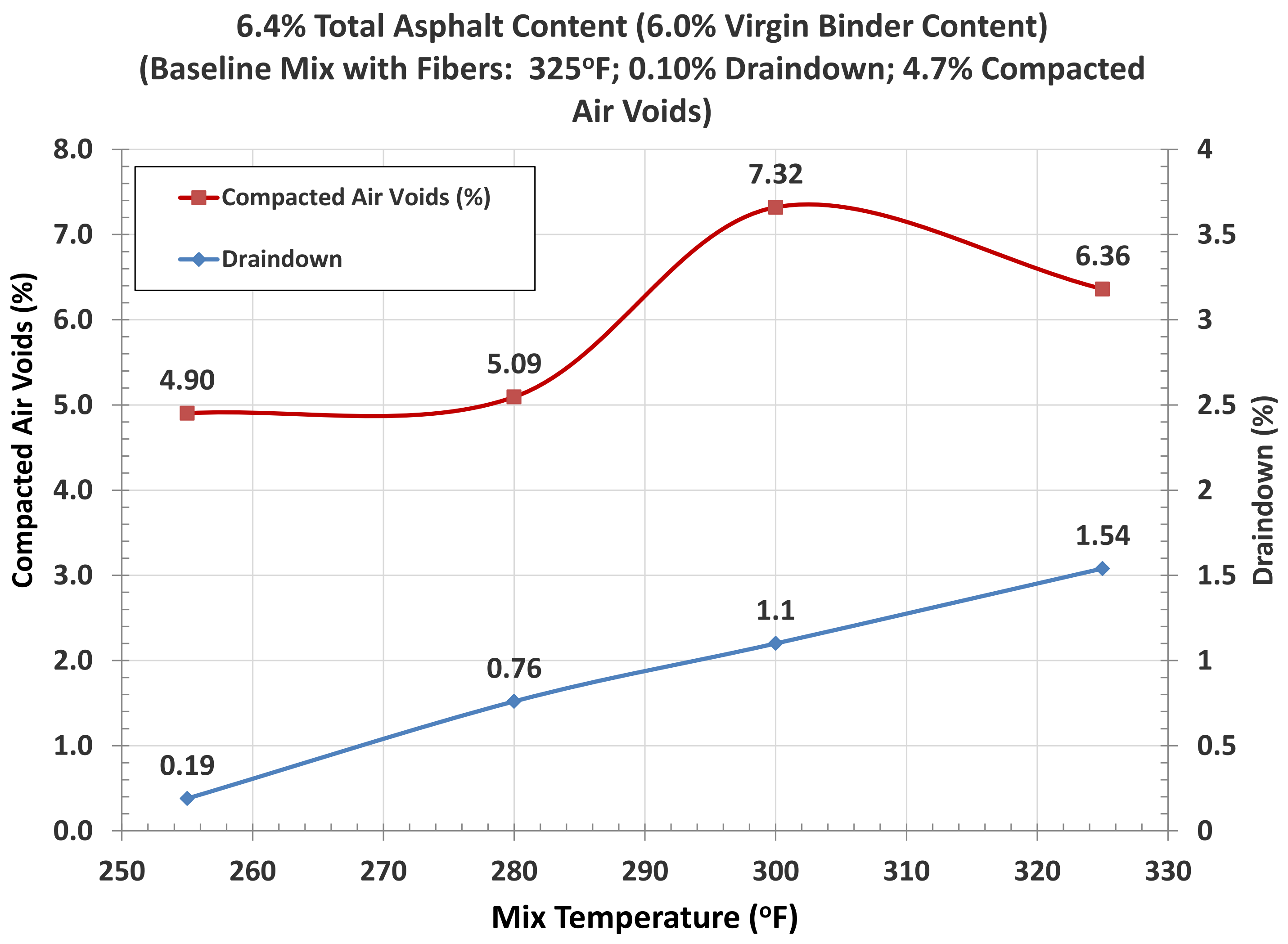
Design Example #2 – Compacted Air Voids vs Draindown



Design Example #2 – "Sometimes You Need a Few Trials"

- 1st Trial Results
  - Testing showed that air voids were slightly low and Draindown was still above specification
    - Coating easily met at all temperatures
  - For this particular mix, the elimination of fibers is creating an slightly over-asphalted mix
  - For Trial #2, asphalt content was reduced 0.3% (same % as original fibers) and testing was again conducted

Design Example #2 – 2nd Trial Results



Design Example #2 – Finals Results

- For the Design Example #2 SMA, eliminating fibers created an over-asphalted condition
  - Fibers creating surface area – taking up additional asphalt
- 2nd trial showed a reduction of 0.3% asphalt was required to maintain draindown
- Final design
  - Supplier used 6.4% total asphalt content while increasing dust to help tighten up air voids

Fiberless SMA Field and Laboratory Performance

Project #1 – New Jersey, Route 1 SB

- First project to look at fiberless SMA with WMA (2009)
- Location: Rt 1, SB in New Jersey (MP 6.5 to 7.8)
  - Rt 1 NB constructed with conventional SMA
- Trap Rock aggregate
- 12.5mm SMA
  - 6.4% AC content
  - PG76-22
  - 0.3% cellulose fibers

Washed Gradation		
Screen		% Pass
2"	50.00	100
1 ½"	37.50	100
1"	25.00	100
¾"	19.00	100
½"	12.50	94
3/8"	9.50	63
#4	4.75	28.2
#8	2.36	19.8
#200	0.075	8.8

Project #1 –NJ, Rt. 1 SB

- Air voids ranged between 3.8% to 4.4%
- Aggregate coating no issue

Mixture ID	Temperature (F)		Percent Draindown
	Mixing	Testing	
Normal SMA	325	325	0.08
WMA SMA #1 (No Fibers)	325	325	0.19
WMA SMA #2 (No Fibers)	290	290	0.08
WMA SMA #3 (No Fibers)	255	255	0.06

Supplier did own assessment of compacted air voids

Project #1 – New Jersey

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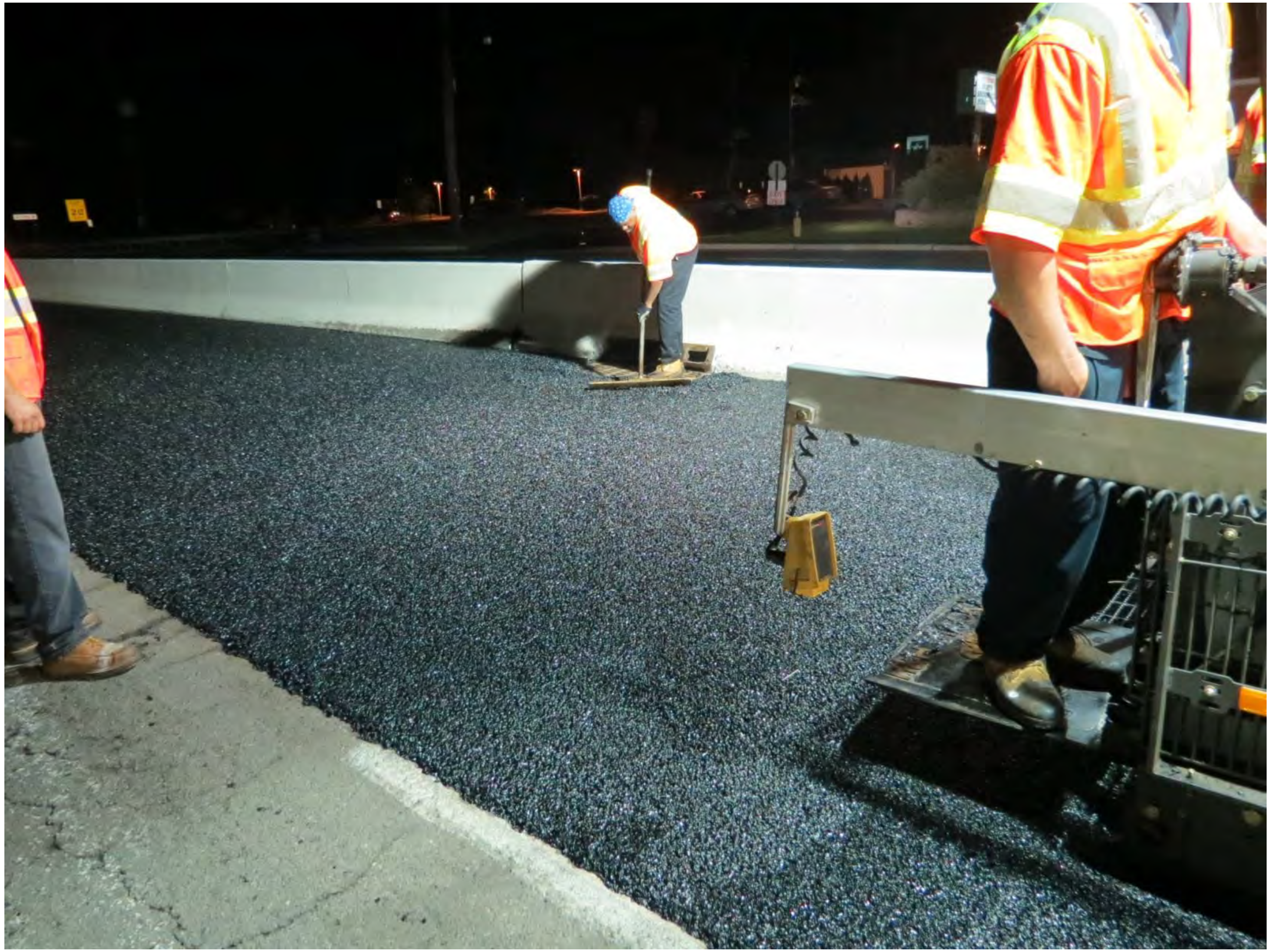
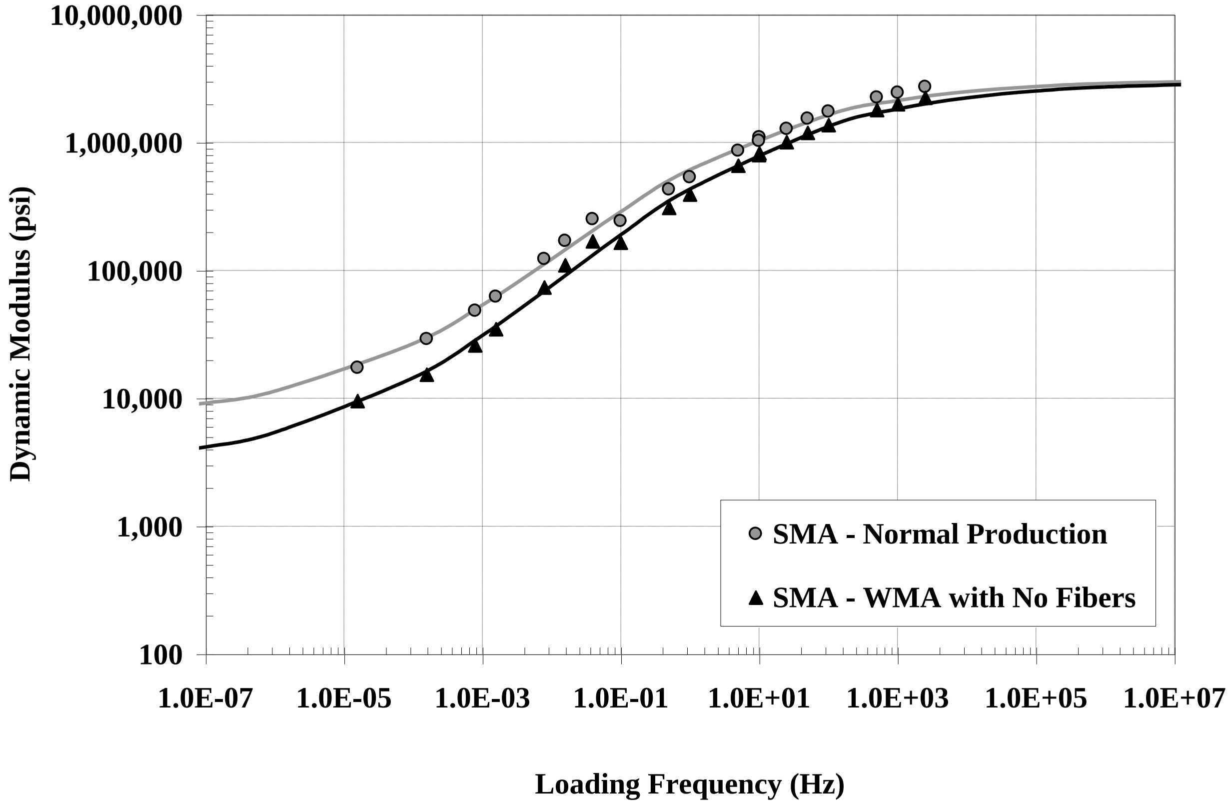


NJ, Rt 1 SB – Final Field Density

- Field Core Density
  - Normal SMA Density = 5.13% air voids
    - Produced over 315F
  - WMA SMA Density = 5.12% air voids
    - Produced under 280F

NJ Rt 1 - Dynamic Modulus for Mixture Stiffness

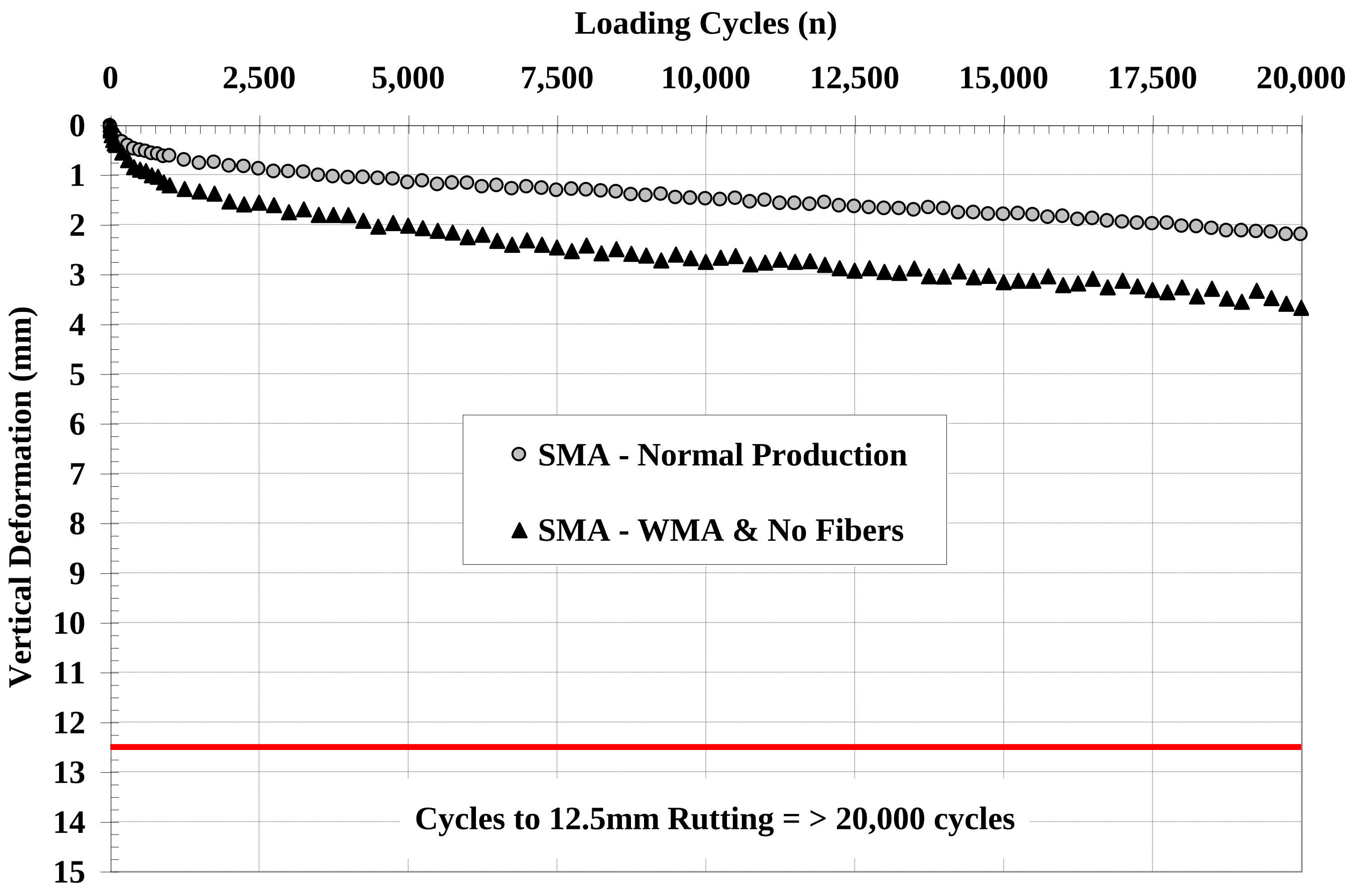


$$\log E^* = 3.750063 + 0.02932\rho_{200} - 0.001767(\rho_{200})^2 - 0.002841\rho_4 - 0.058097V_a - 0.802208\left(\frac{V_{eff}}{V_{eff}+V_a}\right) + \frac{3.871977 - 0.0021\rho_4 + 0.003958\rho_{38} - 0.000017(\rho_{38})^2 + 0.005470\rho_{34}}{1 + e^{(-0.603313 - 0.313351\log(f) - 0.393532\log(\eta))}}$$

Where:

E^*	= Dynamic Modulus, psi
η	= Bitumen viscosity, 10^6 poise
f	= Loading frequency, Hz
V_a	= Air voids content, %
V_{eff}	= Effective bitumen content, % by volume
ρ_{34}	= Cumulative % retained on the 3/4-in sieve
ρ_{38}	= Cumulative % retained on the 3/8-in sieve
ρ_4	= Cumulative % retained on the #4 sieve
ρ_{200}	= % passing the #200 sieve

NJ Rt 1 – Wet Hamburg Wheel Tracking for Stripping & Rutting Potential



NJ Rt 1 - Overlay Tester for Fatigue Cracking Potential

SMA - WMA with No Fibers			
Sample ID	**Temp (F)**	**Displacement (inches)**	**Fatigue Life (cycles)**
# 1	77 F	0.025"	10,472
# 2			27,855
# 3			16,255
Average (Trimmed Mean) =			**18,194**

SMA - Normal Production			
Sample ID	**Temp (F)**	**Displacement (inches)**	**Fatigue Life (cycles)**
# 1	77 F	0.025"	2,126
# 2			2,425
# 3			1,458
Average (Trimmed Mean) =			**2,003**

Fiberless SMA Project #1 – New Jersey Rt 1 Southbound

- For initial pilot, reduction in production temp successfully reduced draindown when fibers eliminated
  - Produced @ 275 to 285°F
  - 1st Roller Pass @ 270 to 280°F
- Field densities of with and without fibers statistically equal
- Mixture performance looked good
  - Lower production temps not aging binder as normal
    - Stiffness slightly lower
    - Large increase in fatigue resistance (higher effective AC?)

One Complaint!

Supplier and Contractor Comments/Opinions

Supplier Opinions – Wayne Byard, Trap Rock Industries, NJ

- Produced 1st Fiberless SMA and over 7 projects since 2009
  - Mix Design
    - Able to reduce asphalt binder content by 0.4% while still improving fatigue properties. Reduction in binder more than paid for addition of WMA additive
    - Fiberless eliminated the need for purchasing, delivering, stockpiling and protecting fibers – no rental costs
    - Can take an order of SMA one day and start producing the next
  - No plant modifications necessary
  - Field/Compaction
    - Workability (hand work) and compaction excellent, even as low as 265F in the northeast
    - Ship 1st load or two at normal temp to heat up MTV and paver, then go back to warm mix temps
    - No issues with material sticking to truck bodies

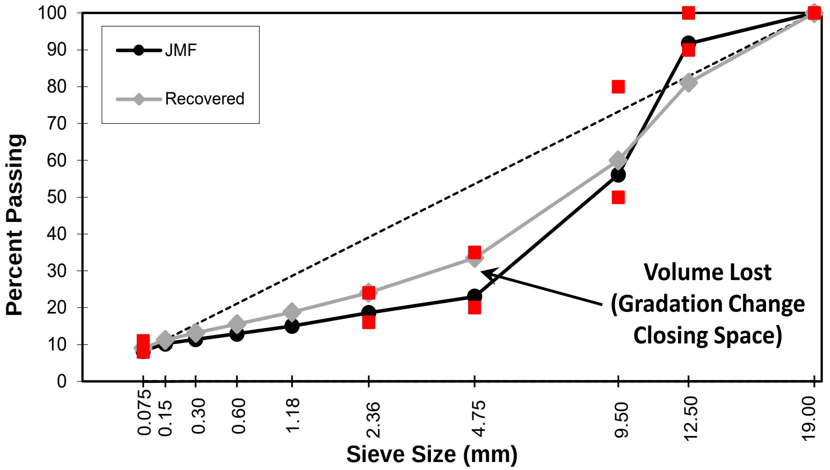
Supplier Opinions – Scott Laudone/Rich Linton, Tilcon Mt. Hope, NJ

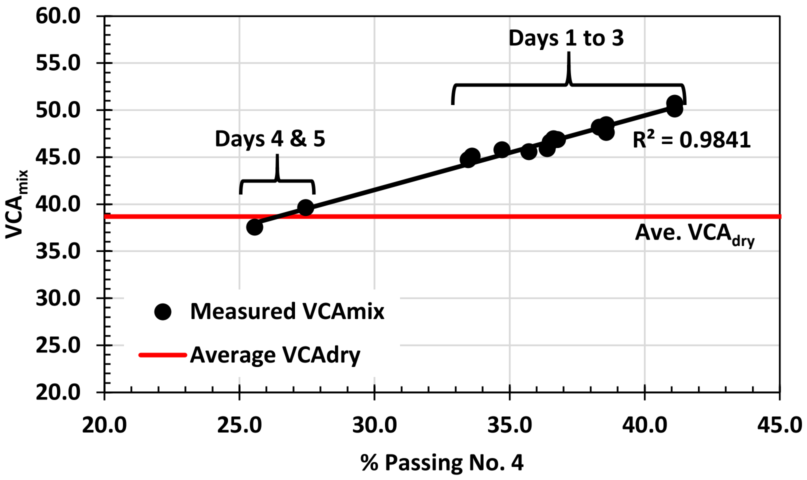
- Produced 2 Fiberless projects in north Jersey
  - Mix Design
    - Reduced asphalt content by 0.4% - lab testing at Rutgers showed good fatigue cracking performance
    - Saved costs on both no fibers and reduced asphalt content
  - Plant Production
    - No plant modifications necessary during production
    - Production 280 to 290F with PG76-22 compared to > 325F
  - Field/Compaction
    - Better workability than conventional SMA
    - Truck bodies clean
    - Compaction still as low as 170F – densities better than 94% Gmm

Things to be Careful of with Fiberless SMA!

Fiberless SMA – Things to be Careful of

- Temperature control
  - Fluctuations greatly affect draindown
    - If designing and producing to be fiberless, must maintain temperatures as fiberless
- Good SMA design and production practices
  - Gradation
    - Breakpoint sieve
  - VCA
  - Dust content





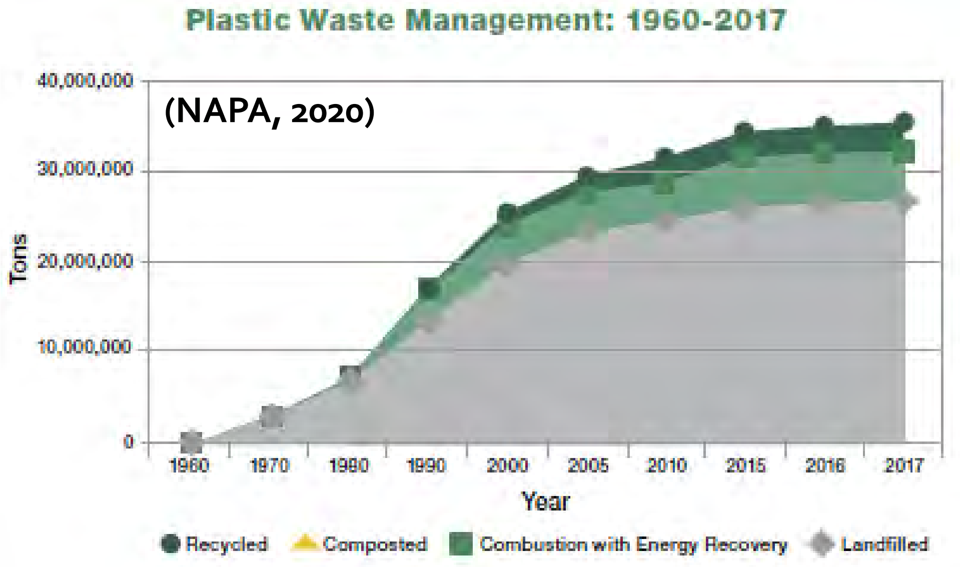
Recycled Plastic Research at Rutgers

Acknowledgements

- Asphalt Binder: Nick Cytowicz, Chris Ericson
- Asphalt Mixture: Ed Haas, Drew Tulanowski, Ed Wass Jr.
- Funding provide by University Transportation Research Center (UTRC) grant
- Large part of work conducted on NJ COVID restrictions!

Recycled Plastic in HMA

- Obvious interest in finding a means to reduce landfilling of used plastic
  - Limited alternative uses
- NAPA asked if recycled plastic could be incorporated within HMA
  - Recycled rubber tires
  - Recycled asphalt shingles
  - Need to make sure pavements do not become linear landfills!



Recycled Plastic in HMA

- Some general issues to consider;
  - Consistency & Handling
    - Plastic waste stream highly variable
      - Melting points ≈212F to ≈500F
      - Differences in impact on asphalt performance
  - Micro-plastics
    - Literature shows majority of field projects have used recycled plastics with a dry process
    - Can micro-plastics be generated during production? Milling?

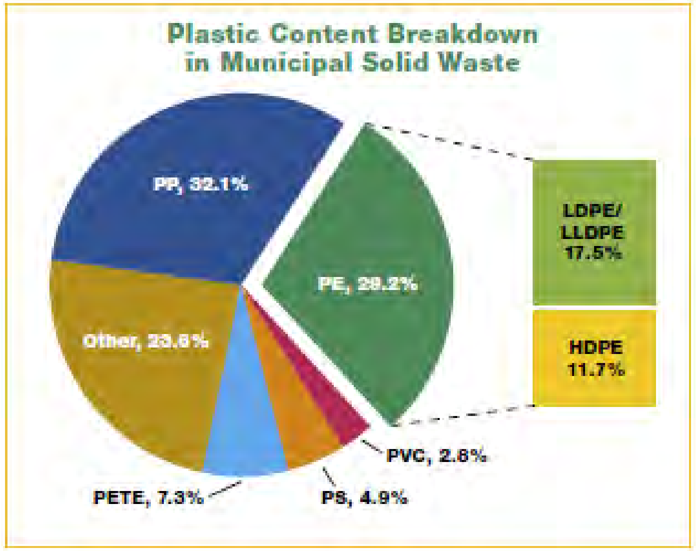
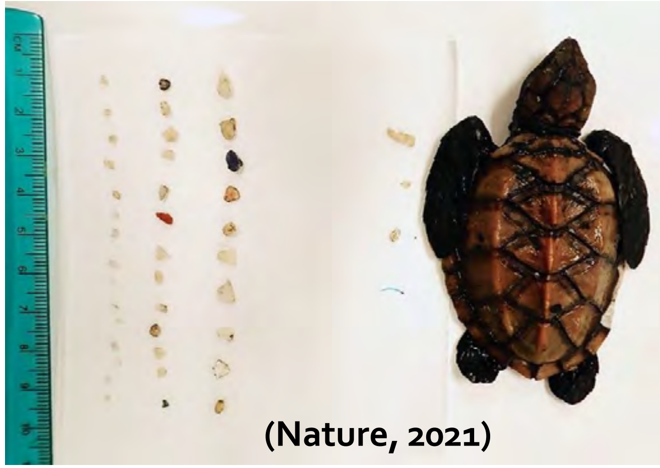


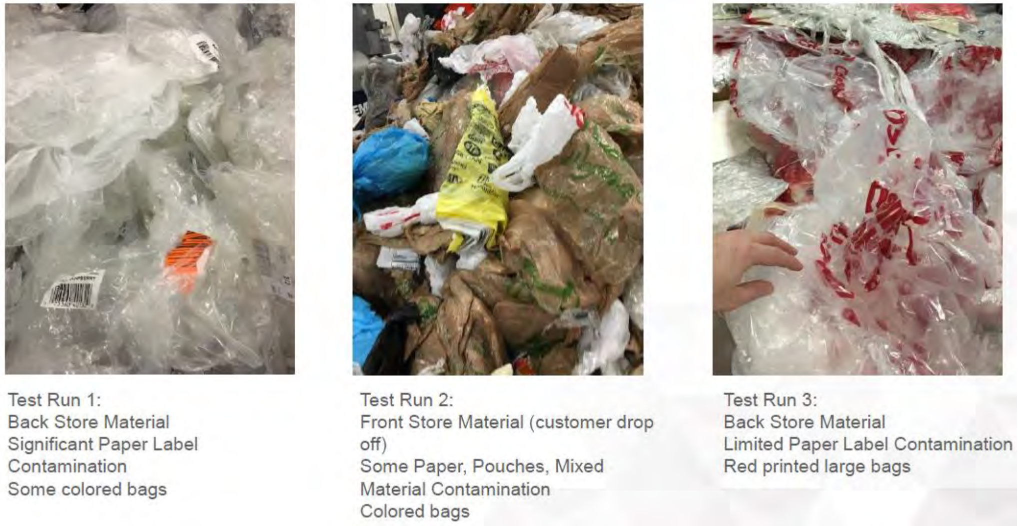
Figure 2-1. Plastic Content Breakdown in Municipal Solid Waste (DuBois, 2020; Based on EPA 2017)



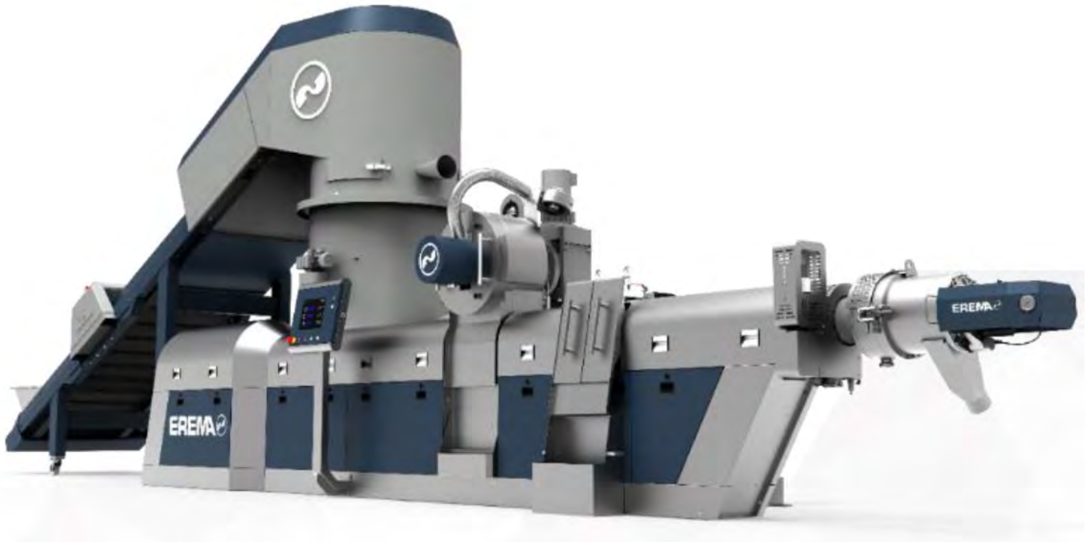
(Nature, 2021)

Recycled Plastic in HMA

- Some efforts in plastic industry to pelletize and process different waste streams
  - Provides level of sorting and consistency
  - Volume reduction & transport ease



(Plastics Industry Assoc., NEMO Meeting, 2019)



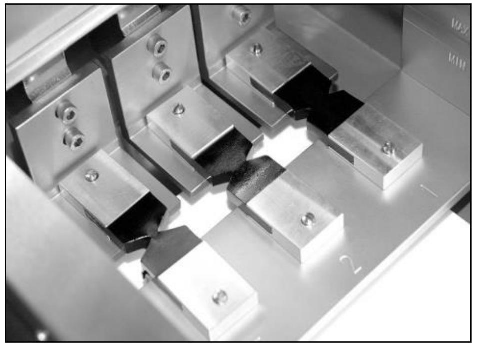
Recycled Plastic in HMA

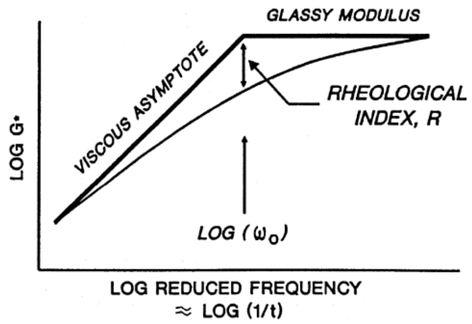
- Study evaluated "processed" recycled plastic material
  - MR6 – "complex arrangement of polyolefins"
    - Bags, electrical cable coating, food packaging, crates/boxes, outdoor furniture
  - MR8 – "thermoplastic polymer"
    - Sports equipment, CD/DVD's, drinking bottles, car parts, toys (LEGO's)
  - MR10 – "co-block polymer"
    - PVC, Teflon, injection molding

MR6 MR8 MR10

Recycled Plastic in HMA

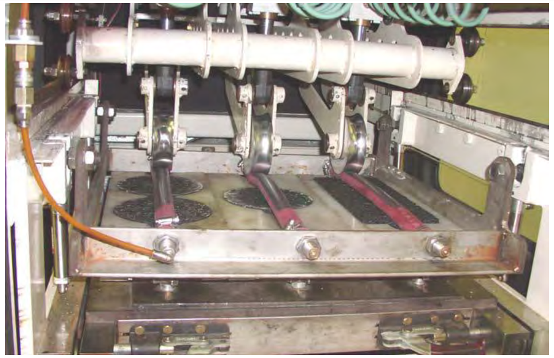
- Research workplan
  - Asphalt binder testing
    - Used to determine “optimum” dosage
    - Separation was of major importance
    - High temperature
      - MSCR, PG grading
    - Intermediate temperature
      - DENT, Glover-Rowe, Loss Tangent
    - Low temperature
      - PG grading, ΔTc, ABCD
    - Original, RTFO, 20 Hr PAV, 40 Hr PAV

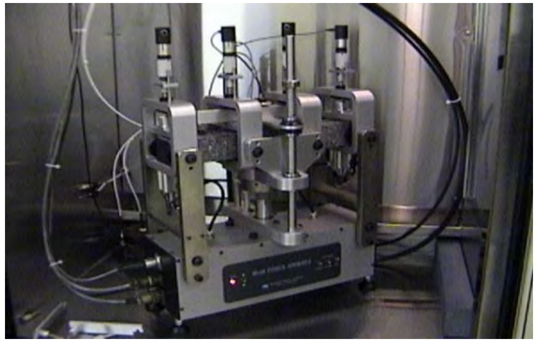




Recycled Plastic in HMA

- Research workplan
  - Asphalt mixture testing
    - Use "optimum" plastic and dosage in a wet process
    - Use a product in the dry process
    - Stiffness
      - E*
    - Rutting
      - APA, Hamburg, Flow Number, HT-IDT
    - Cracking
      - Overlay Tester, IDEAL-CT, SCB FI, Flexural Beam, DC(T)
    - Moisture Damage
      - TSR and Hamburg
    - Short-term and Long-term conditioned





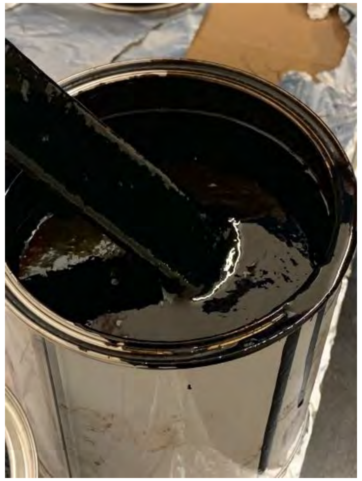
Phase 1 – Asphalt Binder

Asphalt Binder Testing

- Binders prepared using high shear mixer
  - 165C for 4 hours (as per manufacturer rec.)
    - Slotted disintegrating head on Silverson mixer
  - No crosslinker or compatibilizer used
  - Dosage rates of 3, 6, 9% by total weight of asphalt binder
  - PG58-28 & PG64-22





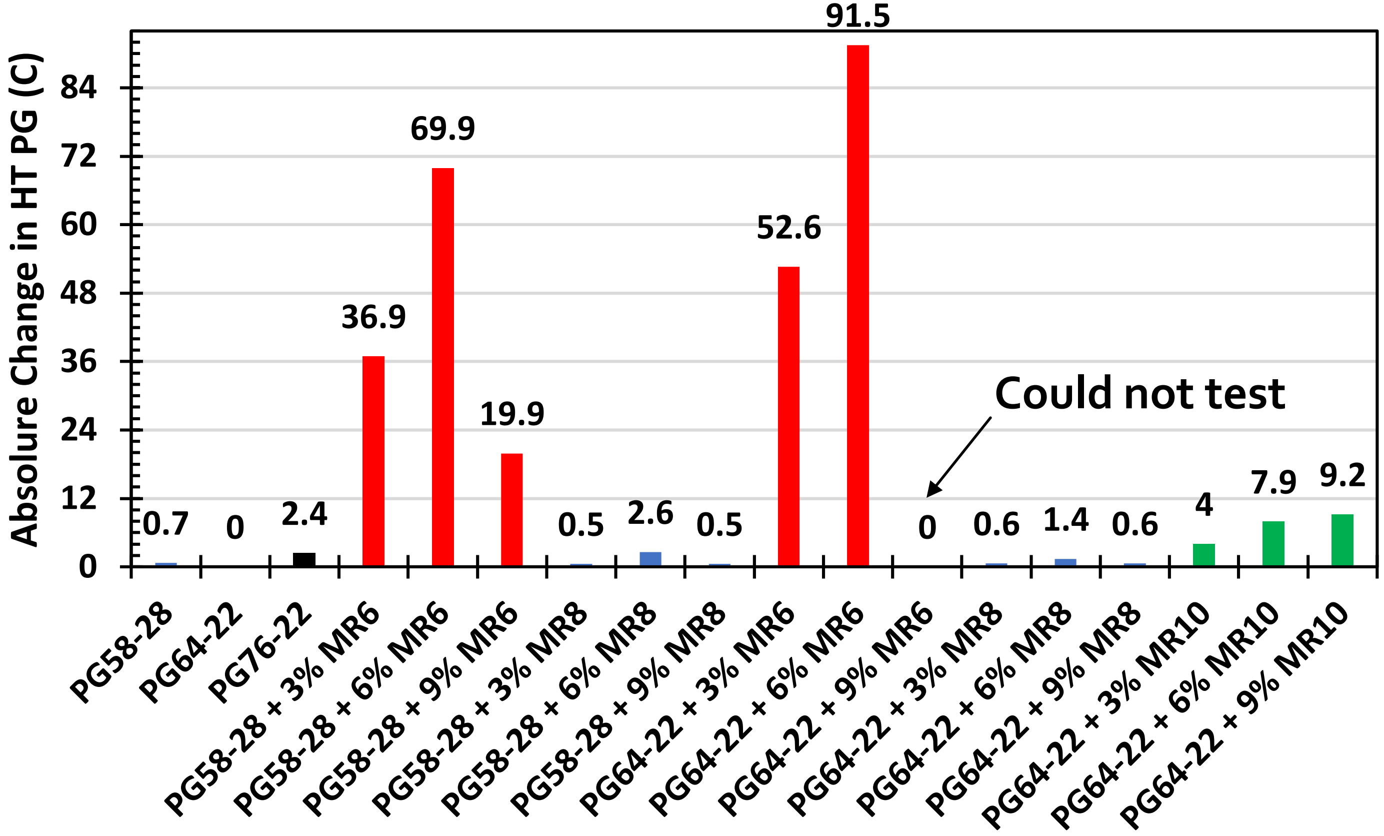


Asphalt Binder Testing

- Separation (ASTM D7173)
  - Will the modifier separate from the asphalt binder
    - Pour 50 grams of blended binder in "cigar tube" and seal
    - Maintain vertical in oven for 48 hours @ 163C
    - Remove from oven & place vertically in freezer (0 to -20C) for greater than 4 hrs
  - Remove and cut into 1/3 – place upper and lower 1/3 in container, heat and pour out contents
  - Traditionally used with softening point
    - High temperature DSR

Asphalt Binder Testing

- Separation
  - MR6 showed greatest potential for separation
    - Mechanically and visually
  - MR8 showed lowest potential (comparable to base binders)



Asphalt Binder Testing

Base Binder	Additive	Dosage Rate	Rotational Viscosity (Pa s)		High Temperature PG Grade				Intermediate Temp PG Grade	Low Temperature PG Grade		
					Original	RTFO	MSCR @ 64C			Stiffness (S)	m-Value	ΔTc
			135C	165C			Jnr (1/kPa)	% Rec				
58-28	N.A.	0%	0.21	0.065	55.7	55.8	12.09	0.0	10.8	-33.1	-36.8	3.7
64-22	N.A.	0%	0.4275	0.117	66.6	67.1	3.28	0.0	21.7	-25.5	-24.8	-0.7
64-22	MR6	3%	0.812	0.282	73.7	74.7	1.1	3.2	26.1	-24	-21.1	-2.9
		6%	1.612	0.519	78.1	85.6	0.286	25	27.3	-23.4	-16.7	-6.7
		9%										
64-22	MR8	3%	0.463	0.127	67.2	67.1	3.04	0.8	22.7	-26.2	-23.9	-2.3
		6%	0.469	0.129	66.4	67.1	3.1	1	22.2	-26.8	-26.3	-0.5
		9%	0.5232	0.142	67.1	66.3	3.01	0.2	19.3	-27.7	-26.9	-0.8
64-22	MR10	3%	0.65	0.175	71.1	71.4	1.66	4	24.1	-24.7	-21.5	-3.2
		6%	0.884	0.243	74	74.2	1.15	9.1	24.7	-25	-20.2	-4.8
		9%	6.75	0.47	79.5	78.9	0.65	16.6	23.9	-24.3	-16.5	-7.8
76-22	N.A.	0%	1.538	0.385	78.1	78.1	0.232	68.3	22.3	-27	-26.1	-0.9

Asphalt Binder Testing

- MR6 (polyolefins)
  - Gain high temperature stiffness
  - Lose m-value (relaxation)
  - Increased viscosity

Base Binder	Additive	Dosage Rate	Rotational Viscosity (Pa s)		High Temperature PG Grade				Intermediate Temp PG Grade	Low Temperature PG Grade		
			135C	165C	Original	RTFO	MSCR @ 64C Jnr (1/kPa)	MSCR @ 64C % Rec		Stiffness (S)	m-Value	ΔTc
58-28	N.A.	0%	0.21	0.065	55.7	55.8	12.09	0.0	10.8	-33.1	-36.8	3.7
64-22	N.A.	0%	0.4275	0.117	66.6	67.1	3.28	0.0	21.7	-25.5	-24.8	-0.7
64-22	MR6	3%	0.812	0.282	73.7	74.7	1.1	3.2	26.1	-24	-21.1	-2.9
		6%	1.612	0.519	78.1	85.6	0.286	25	27.3	-23.4	-16.7	-6.7
		9%										
64-22	MR8	3%	0.463	0.127	67.2	67.1	3.04	0.8	22.7	-26.2	-23.9	-2.3
		6%	0.469	0.129	66.4	67.1	3.1	1	22.2	-26.8	-26.3	-0.5
		9%	0.5232	0.142	67.1	66.3	3.01	0.2	19.3	-27.7	-26.9	-0.8
64-22	MR10	3%	0.65	0.175	71.1	71.4	1.66	4	24.1	-24.7	-21.5	-3.2
		6%	0.884	0.243	74	74.2	1.15	9.1	24.7	-25	-20.2	-4.8
		9%	6.75	0.47	79.5	78.9	0.65	16.6	23.9	-24.3	-16.5	-7.8
76-22	N.A.	0%	1.538	0.385	78.1	78.1	0.232	68.3	22.3	-27	-26.1	-0.9

Asphalt Binder Testing

- MR8 (thermoplastic)
  - No change in high temp
  - Slight improvement in Int. & low temp
  - No significant change in viscosity

Base Binder	Additive	Dosage Rate	Rotational Viscosity (Pa s)		High Temperature PG Grade				Intermediate Temp PG Grade	Low Temperature PG Grade		
			135C	165C	Original	RTFO	MSCR @ 64C Jnr (1/kPa)	MSCR @ 64C % Rec		Stiffness (S)	m-Value	ΔTc
58-28	N.A.	0%	0.21	0.065	55.7	55.8	12.09	0.0	10.8	-33.1	-36.8	3.7
64-22	N.A.	0%	0.4275	0.117	66.6	67.1	3.28	0.0	21.7	-25.5	-24.8	-0.7
64-22	MR6	3%	0.812	0.282	73.7	74.7	1.1	3.2	26.1	-24	-21.1	-2.9
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		6%	0.884	0.243	74	74.2	1.15	9.1	24.7	-25	-20.2	-4.8
		9%	6.75	0.47	79.5	78.9	0.65	16.6	23.9	-24.3	-16.5	-7.8
76-22	N.A.	0%	1.538	0.385	78.1	78.1	0.232	68.3	22.3	-27	-26.1	-0.9

Asphalt Binder Testing

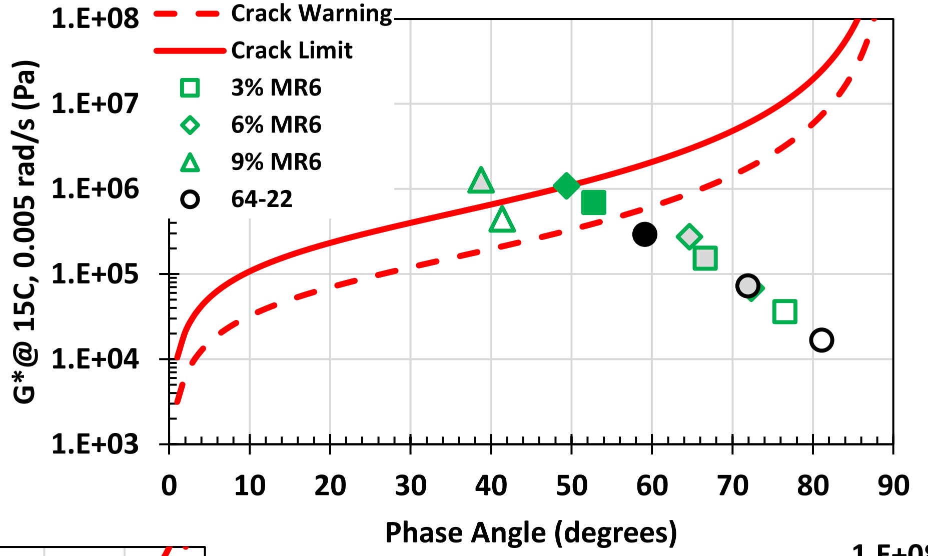
- MR10 (co-block polymers)
  - Gain high temperature stiffness
  - Lose m-value (relaxation)
  - Increased viscosity

Base Binder	Additive	Dosage Rate	Rotational Viscosity (Pa s)		High Temperature PG Grade				Intermediate Temp PG Grade	Low Temperature PG Grade		
					Original	RTFO	MSCR @ 64C			Stiffness (S)	m-Value	ΔTc
			135C	165C			Jnr (1/kPa)	% Rec				
58-28	N.A.	0%	0.21	0.065	55.7	55.8	12.09	0.0	10.8	-33.1	-36.8	3.7
64-22	N.A.	0%	0.4275	0.117	66.6	67.1	3.28	0.0	21.7	-25.5	-24.8	-0.7
64-22	MR6	3%	0.812	0.282	73.7	74.7	1.1	3.2	26.1	-24	-21.1	-2.9
		6%	1.612	0.519	78.1	85.6	0.286	25	27.3	-23.4	-16.7	-6.7
		9%										
64-22	MR8	3%	0.463	0.127	67.2	67.1	3.04	0.8	22.7	-26.2	-23.9	-2.3
		6%	0.469	0.129	66.4	67.1	3.1	1	22.2	-26.8	-26.3	-0.5
		9%	0.5232	0.142	67.1	66.3	3.01	0.2	19.3	-27.7	-26.9	-0.8
64-22	MR10	3%	0.65	0.175	71.1	71.4	1.66	4	24.1	-24.7	-21.5	-3.2
		6%	0.884	0.243	74	74.2	1.15	9.1	24.7	-25	-20.2	-4.8
		9%	6.75	0.47	79.5	78.9	0.65	16.6	23.9	-24.3	-16.5	-7.8
76-22	N.A.	0%	1.538	0.385	78.1	78.1	0.232	68.3	22.3	-27	-26.1	-0.9

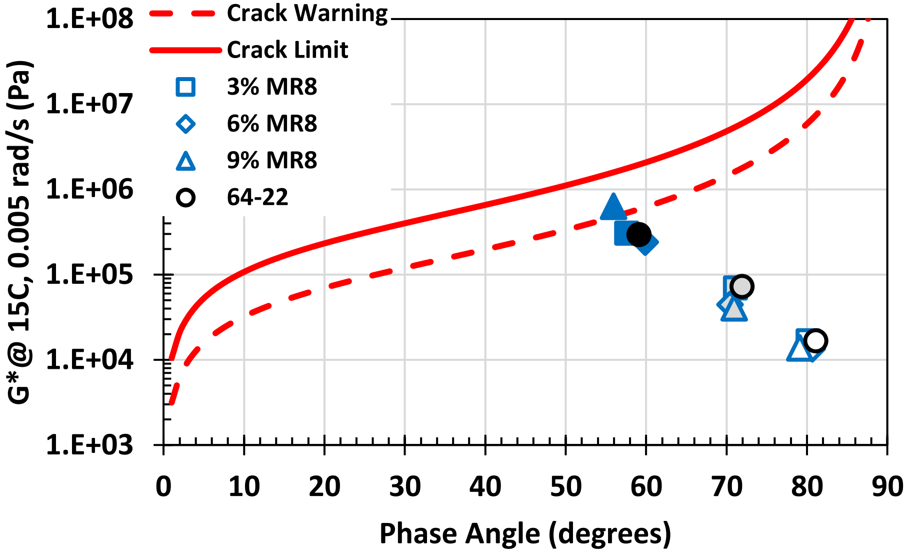
Asphalt Binder Testing

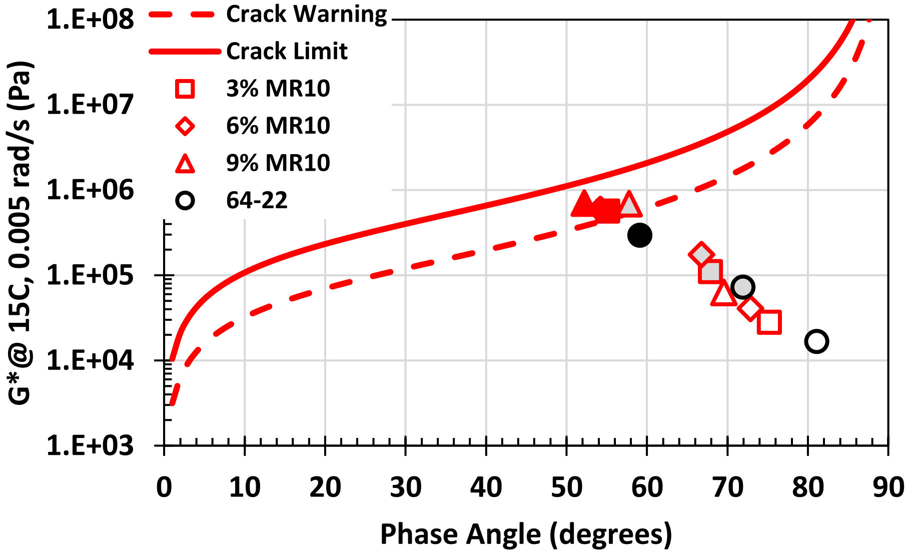
- Glover-Rowe Parameter

$$\frac{G'}{\eta'/G'} = \frac{|G^*| \cdot (\cos\delta)^2}{\sin\delta} \cdot \omega$$



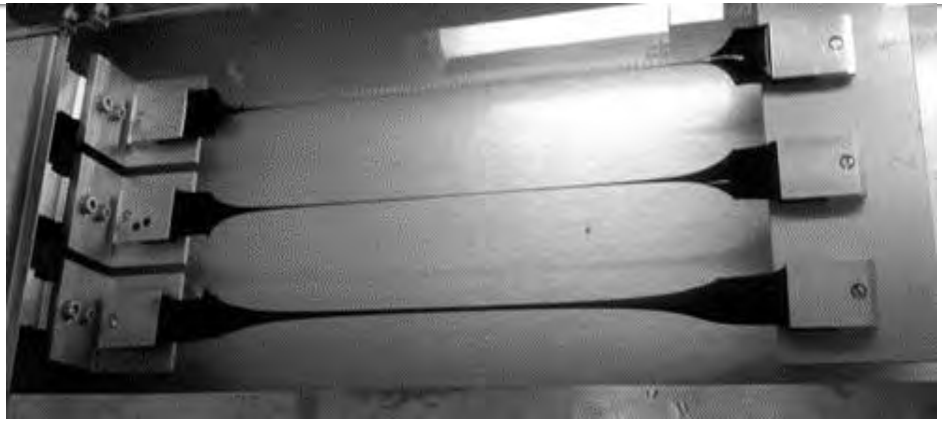
Open symbols = Original
Gray filled = RTFO
Filled = 20 hr PAV

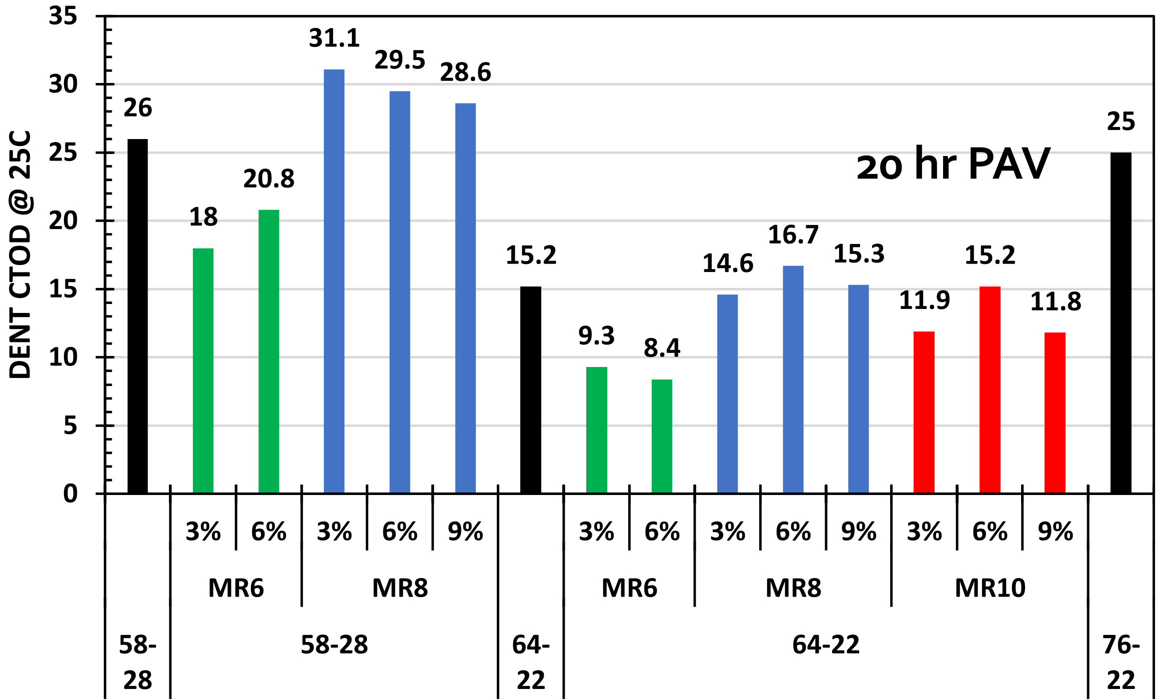




Asphalt Binder Testing

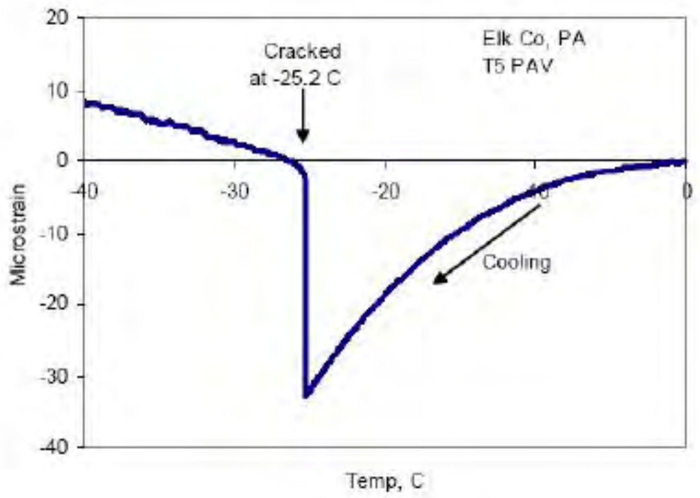
- Double Edge Notched Tension (DENT)
  - Measure of asphalt binder's ductility
  - Conducted at 25C
  - Compared crack tip opening displacement (CTOD)

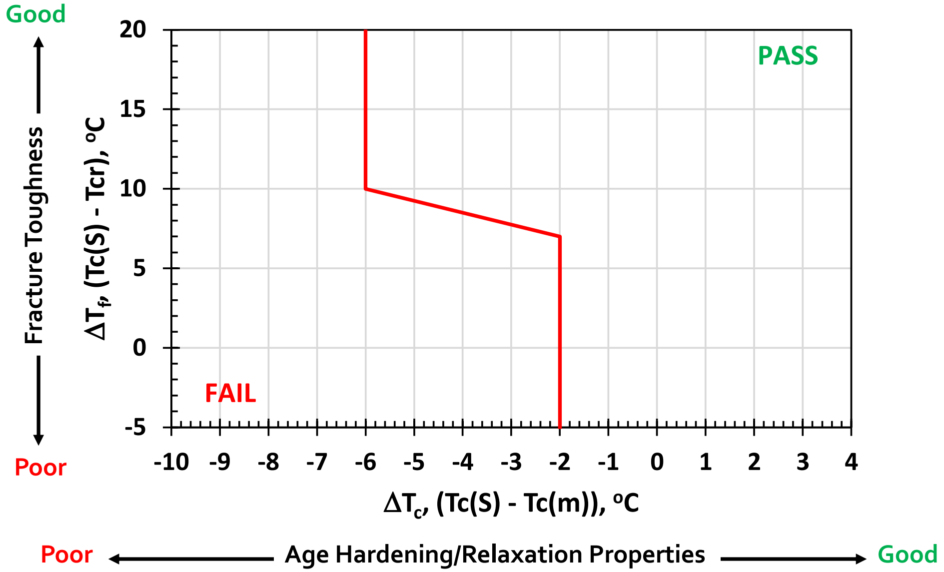




Asphalt Binder Testing

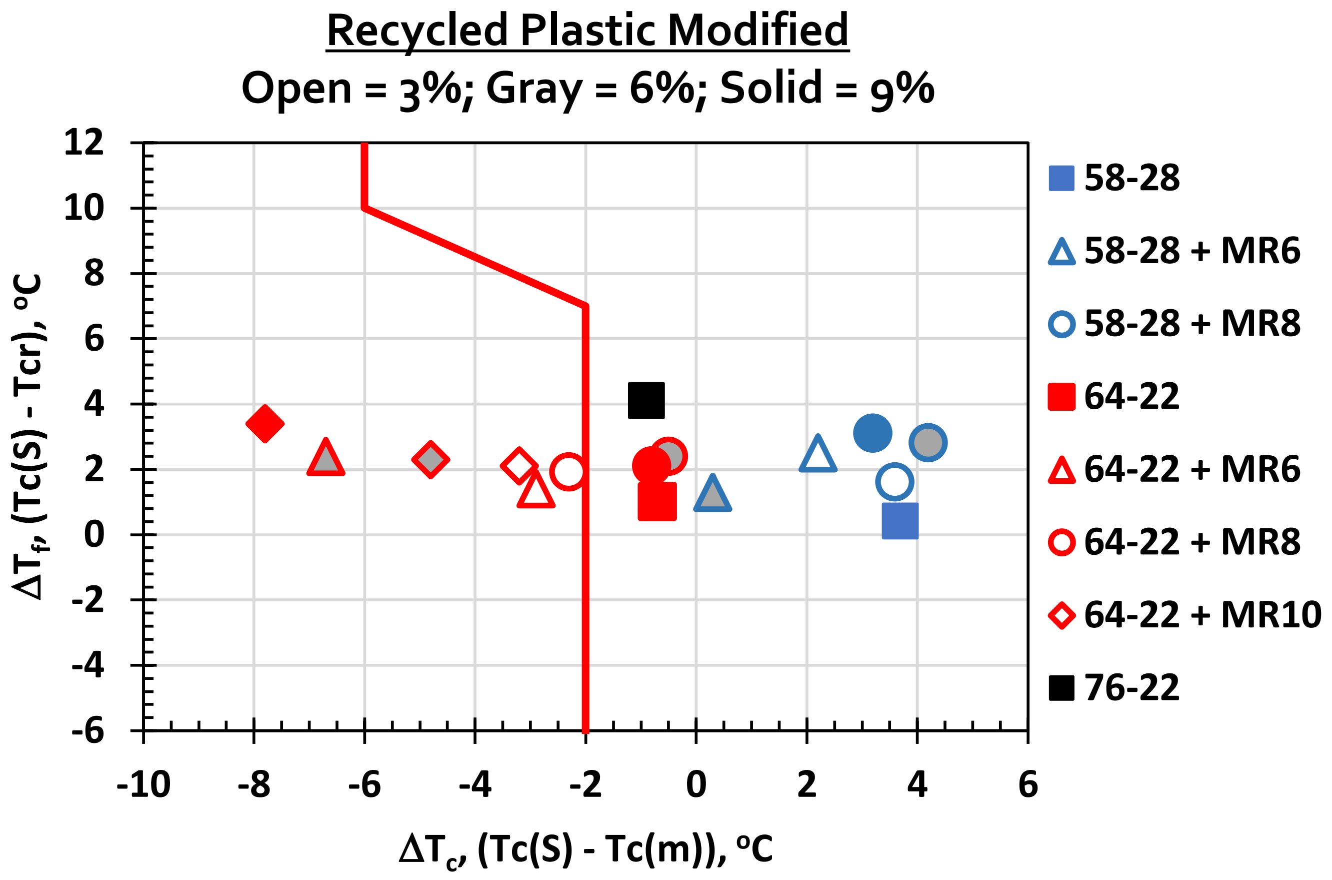
- Asphalt Binder Cracking Device (ABCD)
  - The ABCD determines the critical cracking temperature due to thermally induced stress
  - Asphalt binder poured between an invar and latex mold to form a ring
  - Chamber cools the specimens at -20°C per hr
  - Strain gauge determines when "cracking" occurs; specimen temperature when this occurs is determined as T_{cr}
  - NCHRP 9-60 recommends to use in conjunction with ΔT_c

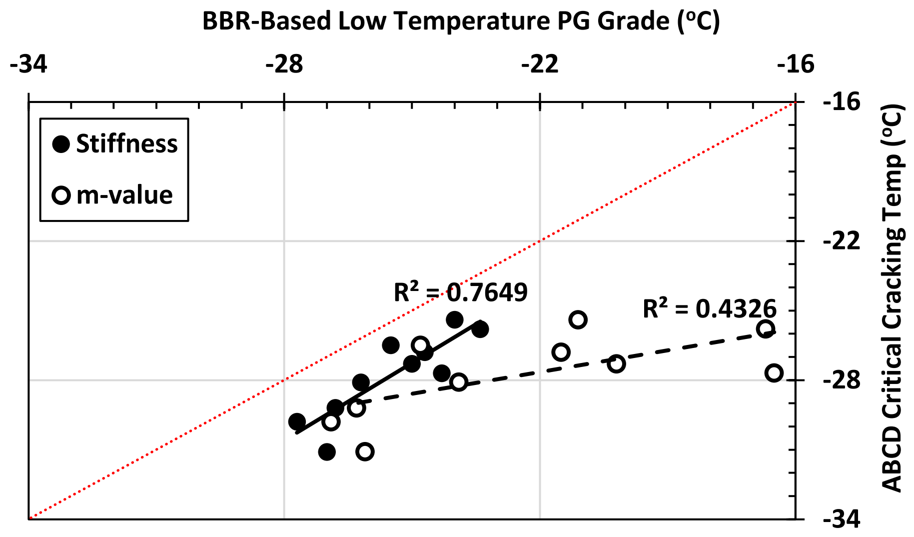


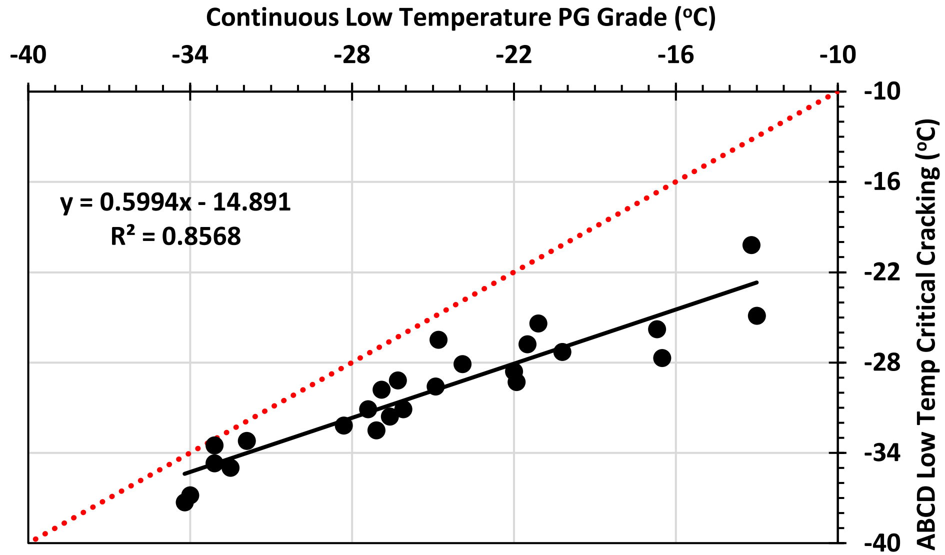


Asphalt Binder Testing

- ABCD Testing Results







Asphalt Binder Conclusions

- The MR8 (Thermoplastic) resulted in the better performance
  - Little to no change in HT; slight improvement in LT; lower potential to separate; best for "fatigue" analysis
- MR6 (PP/PE) pulled PG grade warmer and separated
- MR10 (Co-block) pulled PG grade warmer but not as bad for separation

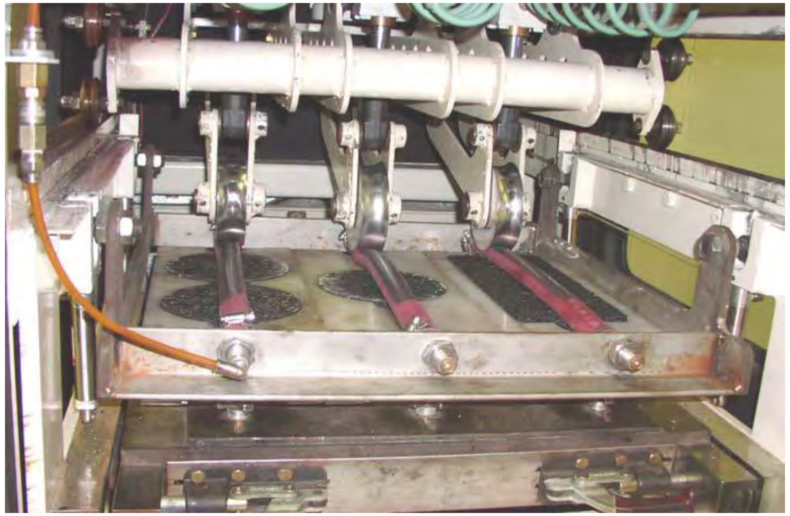
Phase 2 – Mixture Study

Mixture Study

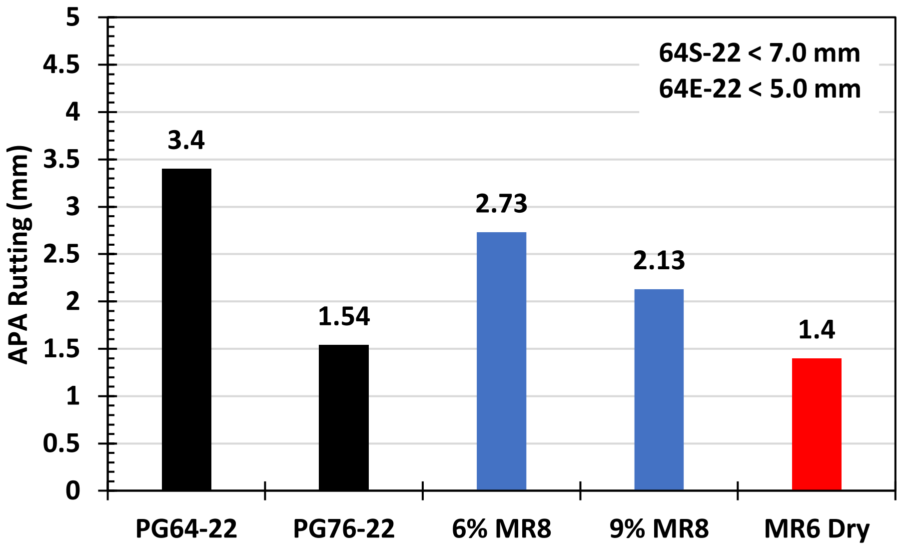
- Wet Process
  - Selected MR8 at 6% to 9% by total weight of binder based on binder results
- Dry Process
  - Selected MR6 at 1% by weight of mix
  - Used dry in other projects (VTRC, 2021)
- 9.5mm NMAS, Trap Rock aggregate
  - 6.1% asphalt content
  - No RAP
  - VMA = 17.1%
- Short-term (4 hrs, 135C) and Long-term Conditioned (24 hrs, 135C)

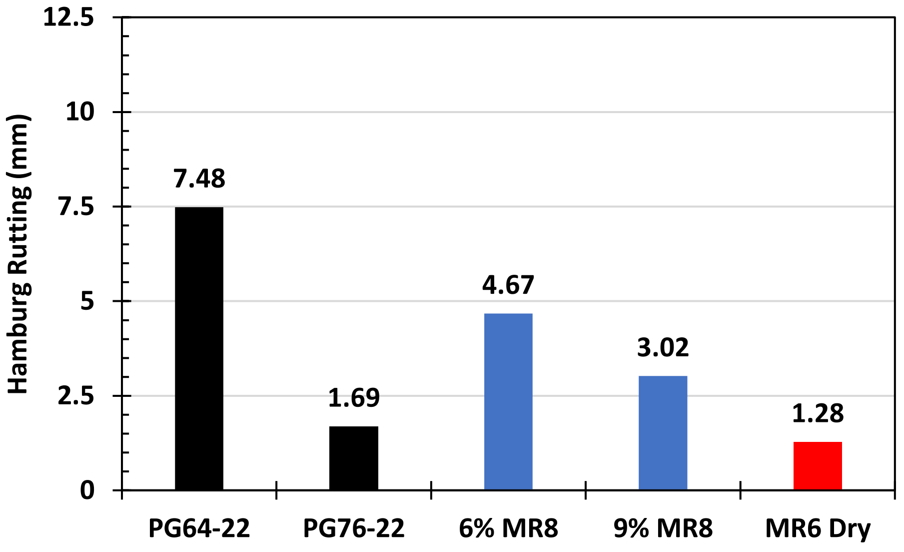
Rutting

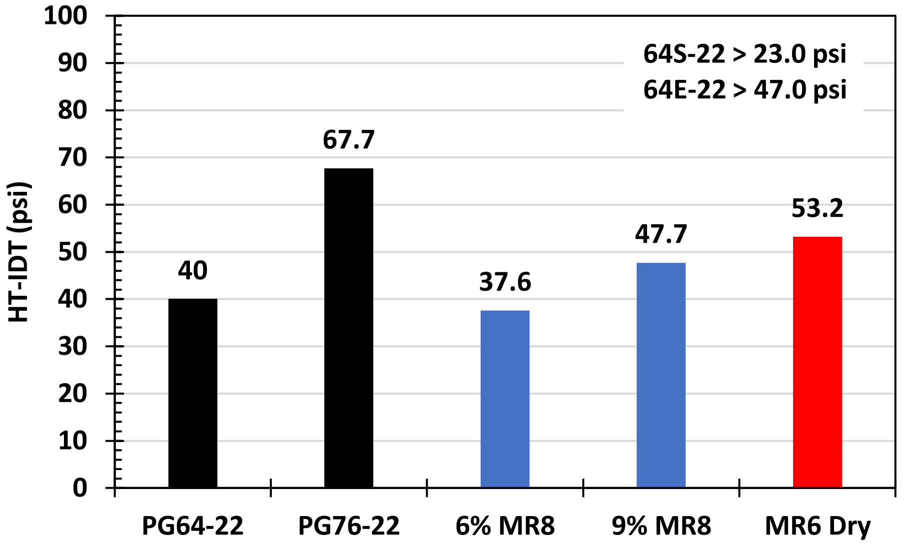
- Rutting evaluated using;
  - Asphalt Pavement Analyzer (64°C)
  - Hamburg (50°C)
  - High Temperature IDT (44°C)
  - AMPT Flow Number (54°C)
- Mixtures were only conditioned for short term conditioning

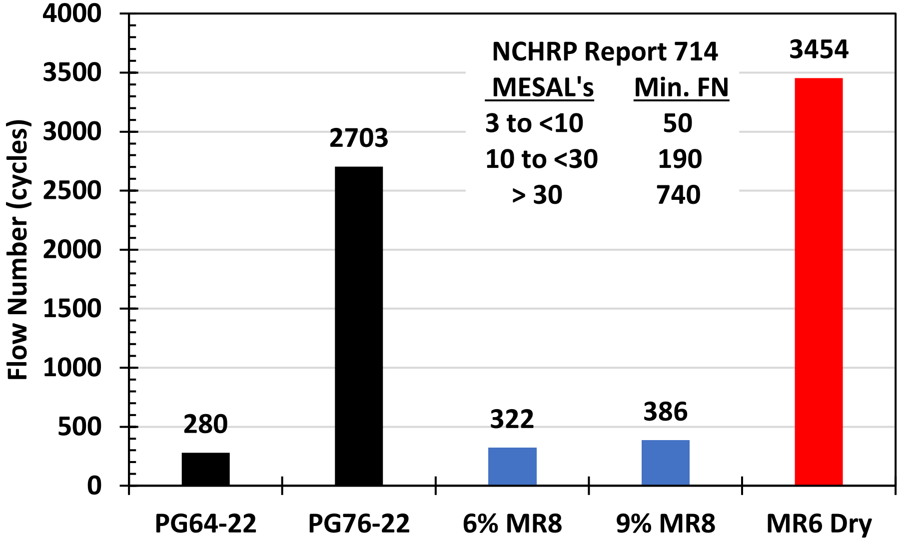


Rutting Results



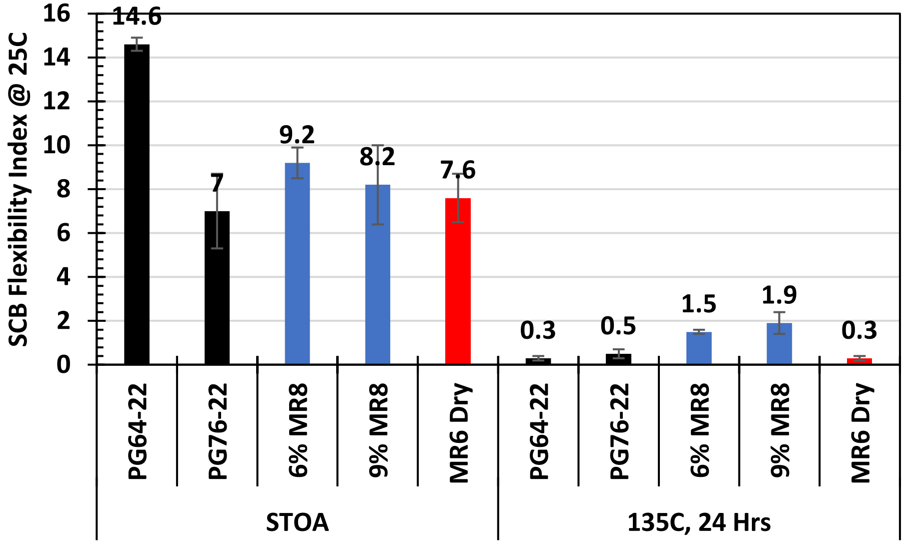




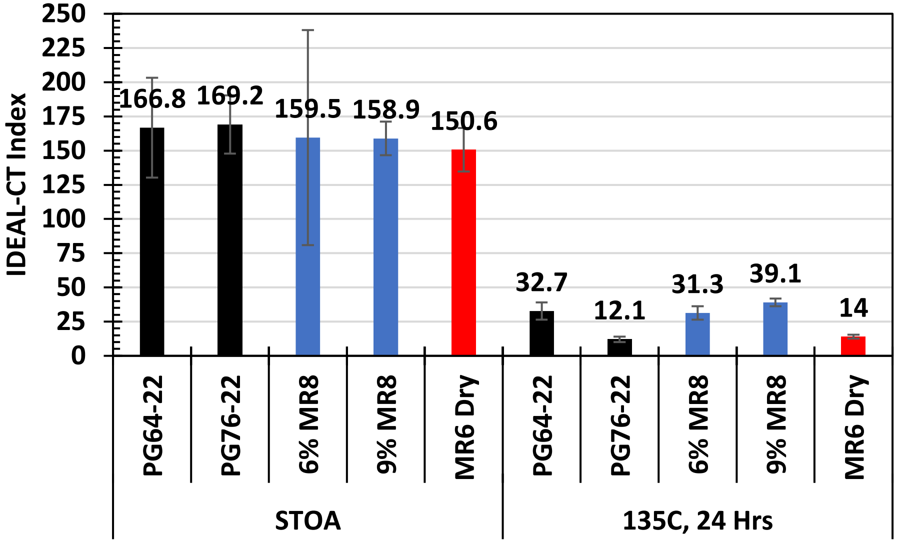


Fatigue Cracking Results

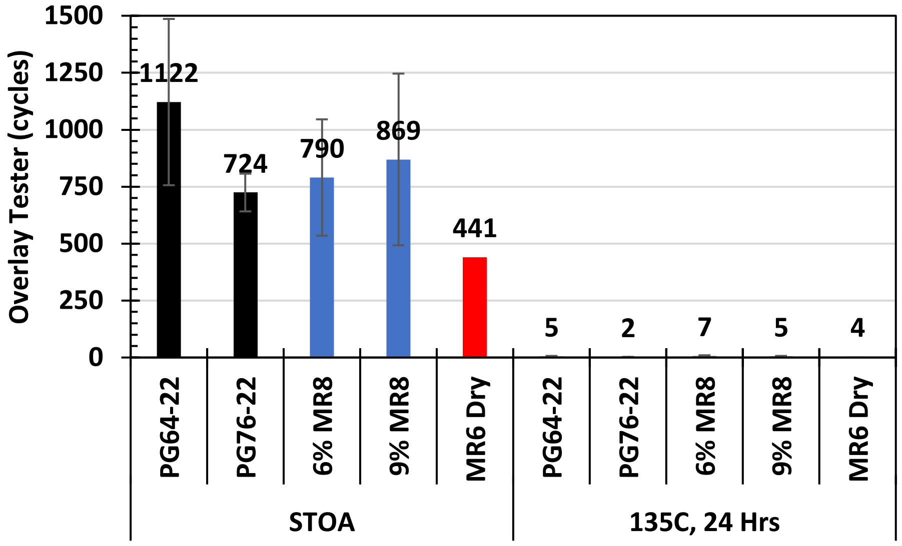
SCB FI



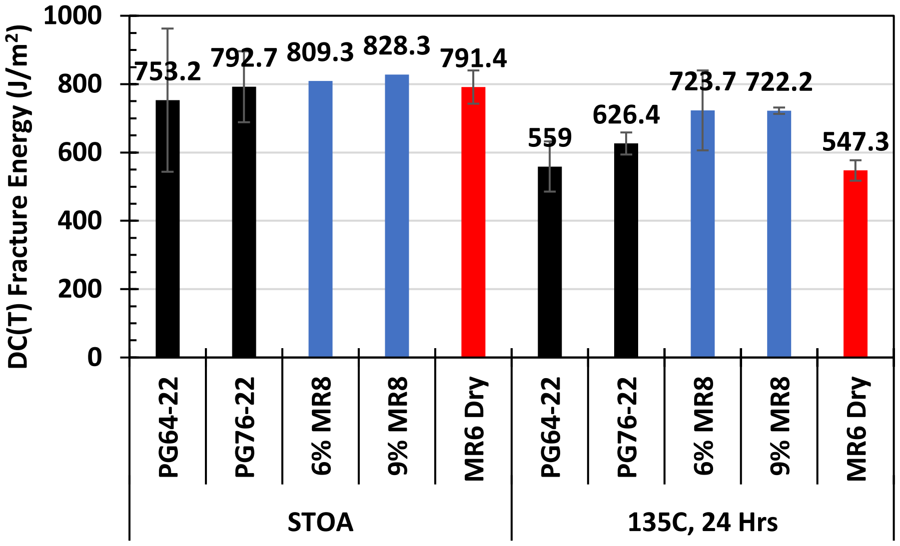
IDEAL-CT



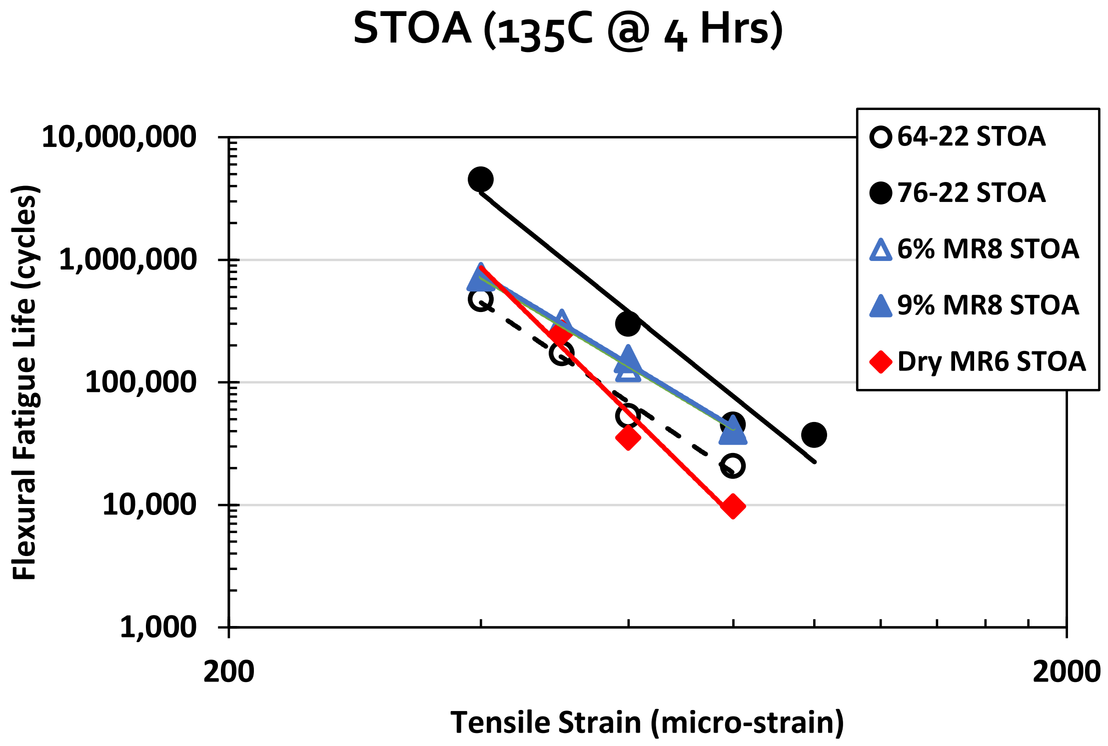
OT

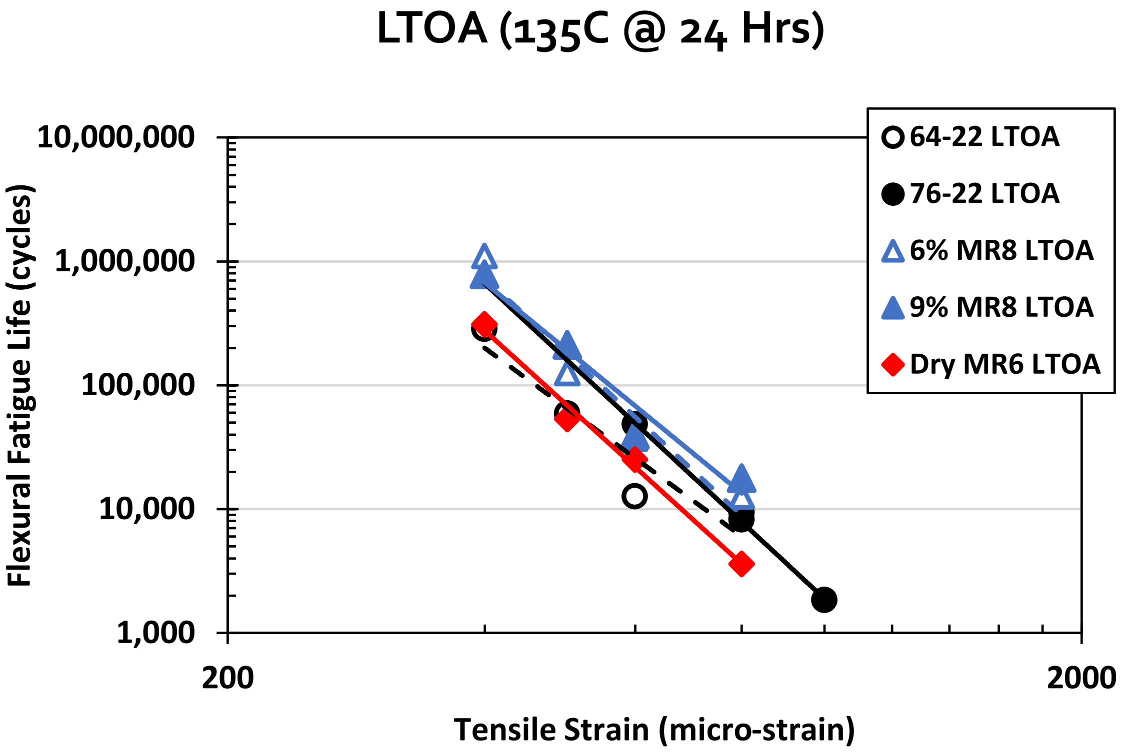


DC(T)



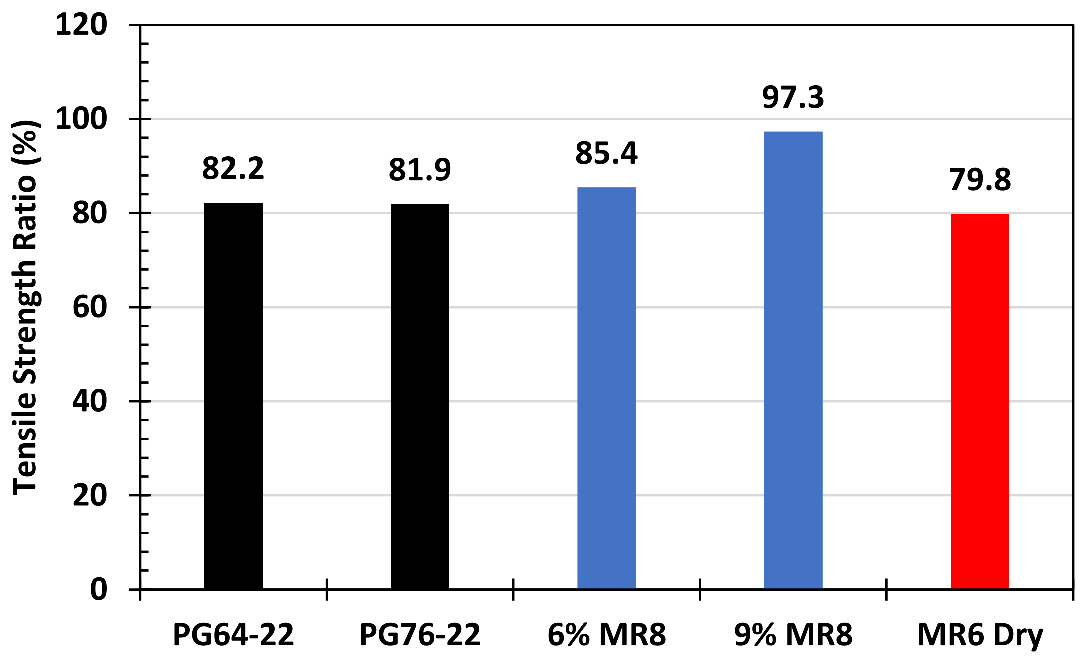
Fatigue Cracking Results – Flexural Beam

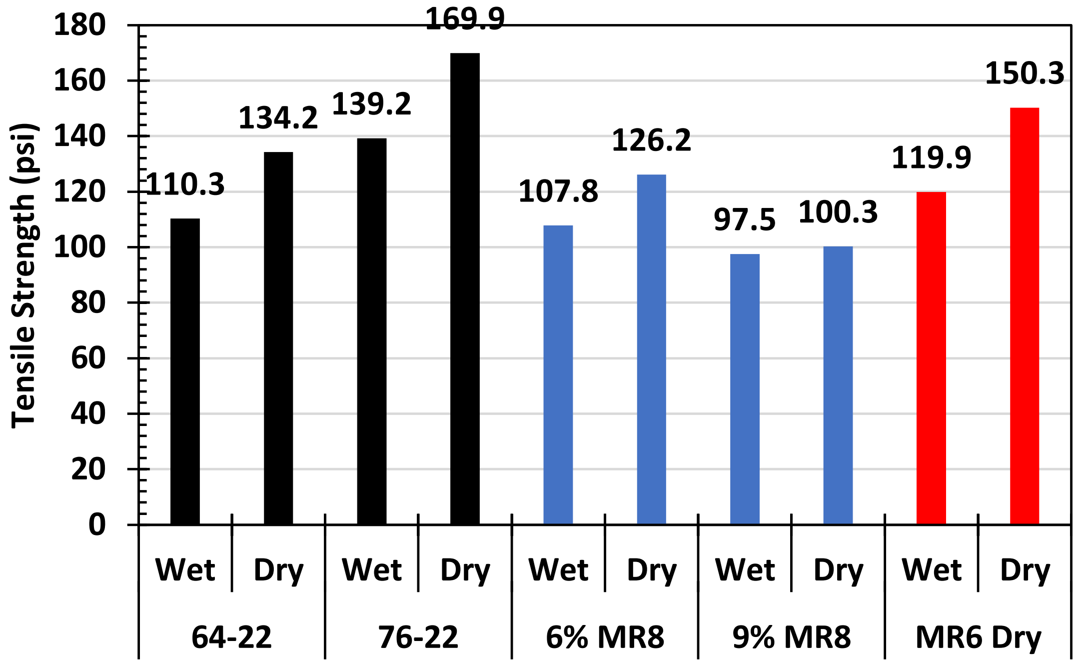




Moisture Damage Potential

- No mix showed an inflection point during Hamburg testing





Moisture Damage Potential

MR8 (Wet Process; 9% by Wt. of Binder)

MR6 (Dry Process; 1% by Wt. of Mix)

Other Considerations

Volumetrics

- Inclusion of plastic will impact the volumetrics of your design and production
  - Statistically significant when using the dry process
  - Need to take into account for Gmm and Gsb

Mix Type	Gmm (g/cm³)
64-22	2.670
76-22	2.670
6% MR8	2.683
9% MR8	2.682
1% Dry MR6	2.628

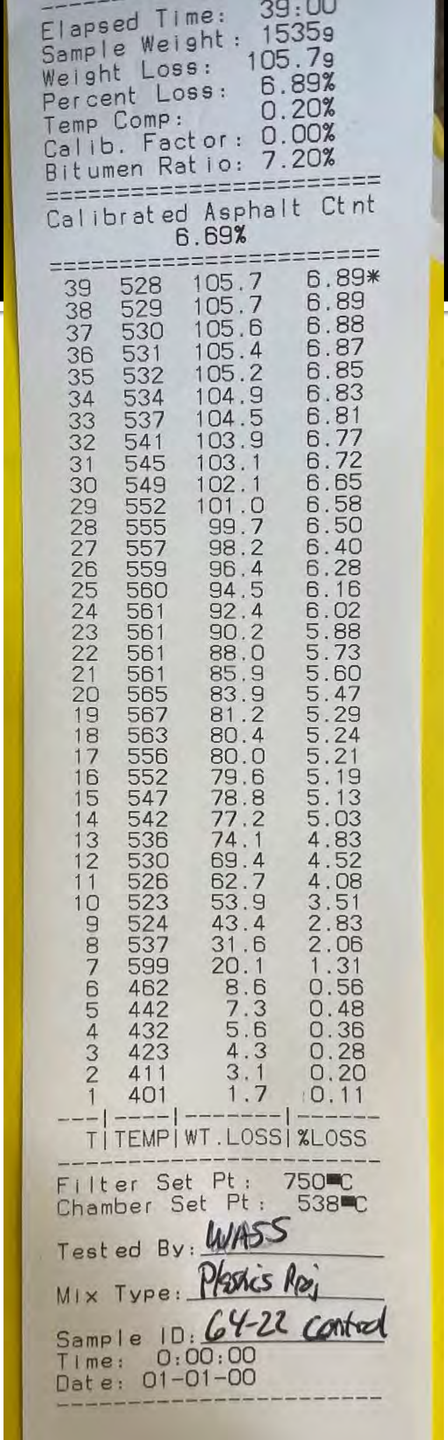
Mix Type	Gsb (g/cm³)
Wet Process	2.964
Dry Process	2.897

Solvent Extraction

- Recycled plastic remaining as part of aggregate
  - Some will float during washed gradation

Ignition Oven

- Recycled plastic will come up as mass loss in dry process
- Will need to include in correction factor (similar to fibers in SMA and OGFC)
  - Design AC%: 6.1%
  - Burn (Control): 6.14% loss
  - Burn (Dry MR6): 7.06% loss
    - Additional 1% from the addition of plastic at 1% by total weight of mix



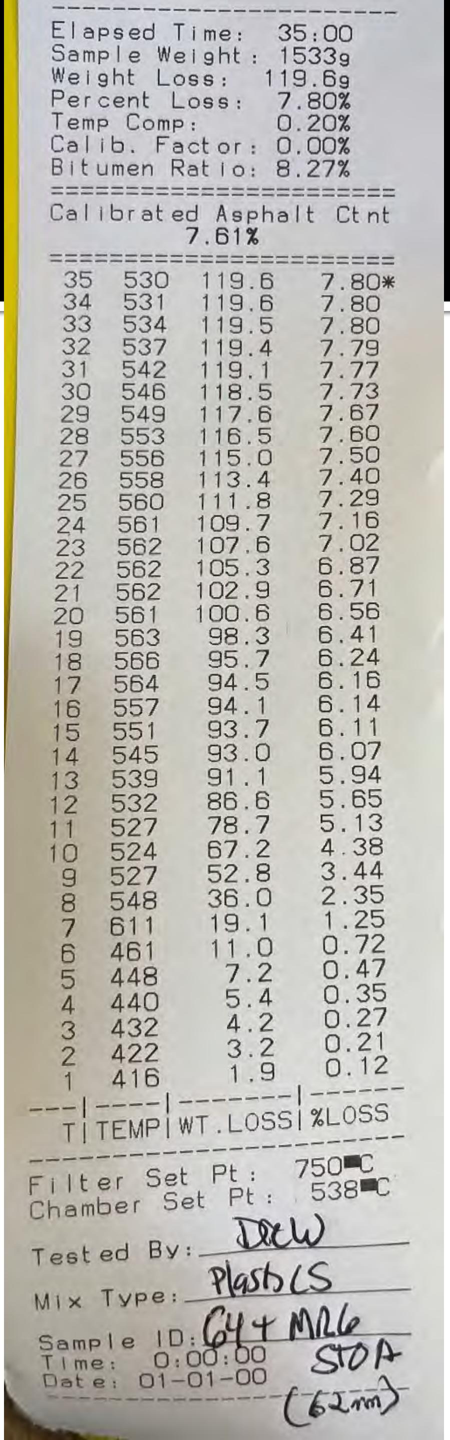
Elapsed Time: 39:00
Sample Weight: 1535g
Weight Loss: 105.7g
Percent Loss: 6.89%
Temp Comp: 0.20%
Calib. Factor: 0.00%
Bitumen Ratio: 7.20%

Calibrated Asphalt Ctnt
6.69%

T	TEMP	WT.LOSS	%LOSS
39	528	105.7	6.89*
38	529	105.7	6.89
37	530	105.6	6.88
36	531	105.4	6.87
35	532	105.2	6.85
34	534	104.9	6.83
33	537	104.5	6.81
32	541	103.9	6.77
31	545	103.1	6.72
30	549	102.1	6.65
29	552	101.0	6.58
28	555	99.7	6.50
27	557	98.2	6.40
26	559	96.4	6.28
25	560	94.5	6.16
24	561	92.4	6.02
23	561	90.2	5.88
22	561	88.0	5.73
21	561	85.9	5.60
20	565	83.9	5.47
19	567	81.2	5.29
18	563	80.4	5.24
17	556	80.0	5.21
16	552	79.6	5.19
15	547	78.8	5.13
14	542	77.2	5.03
13	536	74.1	4.83
12	530	69.4	4.52
11	526	62.7	4.08
10	523	53.9	3.51
9	524	43.4	2.83
8	537	31.6	2.06
7	599	20.1	1.31
6	462	8.6	0.56
5	442	7.3	0.48
4	432	5.6	0.36
3	423	4.3	0.28
2	411	3.1	0.20
1	401	1.7	0.11

Filter Set Pt: 750■C
Chamber Set Pt: 538■C

Tested By: WASS
Mix Type: Plastics Proj
Sample ID: 64-22 control
Time: 0:00:00
Date: 01-01-00



Elapsed Time: 35:00
Sample Weight: 1533g
Weight Loss: 119.6g
Percent Loss: 7.80%
Temp Comp: 0.20%
Calib. Factor: 0.00%
Bitumen Ratio: 8.27%

Calibrated Asphalt Ctnt
7.61%

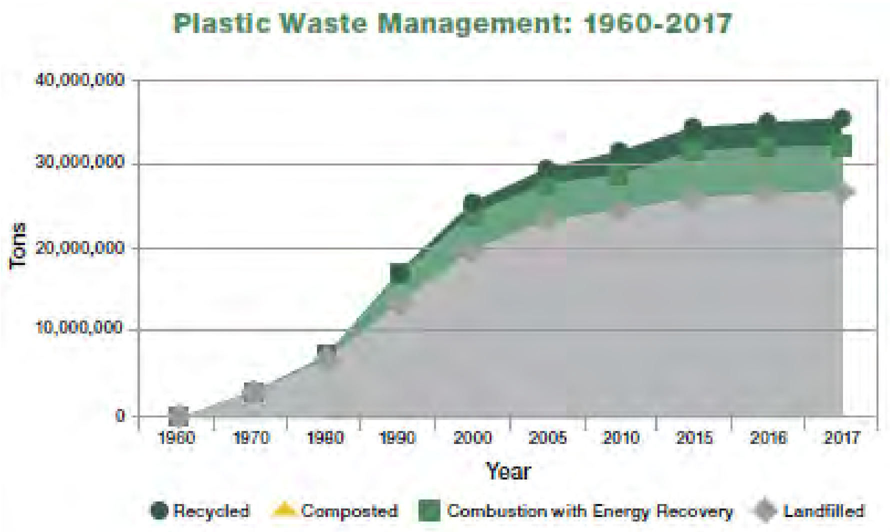
T	TEMP	WT.LOSS	%LOSS
35	530	119.6	7.80*
34	531	119.6	7.80
33	534	119.5	7.80
32	537	119.4	7.79
31	542	119.1	7.77
30	546	118.5	7.73
29	549	117.6	7.67
28	553	116.5	7.60
27	556	115.0	7.50
26	558	113.4	7.40
25	560	111.8	7.29
24	561	109.7	7.16
23	562	107.6	7.02
22	562	105.3	6.87
21	562	102.9	6.71
20	561	100.6	6.56
19	563	98.3	6.41
18	566	95.7	6.24
17	564	94.5	6.16
16	557	94.1	6.14
15	551	93.7	6.11
14	545	93.0	6.07
13	539	91.1	5.94
12	532	86.6	5.65
11	527	78.7	5.13
10	524	67.2	4.38
9	527	52.8	3.44
8	548	36.0	2.35
7	611	19.1	1.25
6	461	11.0	0.72
5	448	7.2	0.47
4	440	5.4	0.35
3	432	4.2	0.27
2	422	3.2	0.21
1	416	1.9	0.12

Filter Set Pt: 750■C
Chamber Set Pt: 538■C

Tested By: Drew
Mix Type: Plastics
Sample ID: 64+MR6
Time: 0:00:00
Date: 01-01-00
STOP
(62min)

Conclusions & Future

- The type of recycled plastic will significantly impact asphalt performance
  - Wet process vs Dry process?
  - Selection of plastic type?
- Moving forward in NJ, pilots proposed
  - Ran through Associated Asphalt Paulsboro facility as proof of concept
  - Moving forward to 2 to 3 pilot projects in NJ in 2022
  - Part of FHWA study to evaluate equipment to identify presence of micro-plastics



As Ted Lasso reminded us..
"Be curious, not judgmental…"

Thank you for your time!

Thomas Bennert, Ph.D.
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Rutgers University
bennert@soe.rutgers.edu
609-213-3312