FLORIDA INTERNATIONAL UNIVERSITY

Evaluation of Cracking Resistance and Durability of 100% Reclaimed Asphalt Pavement Mixtures

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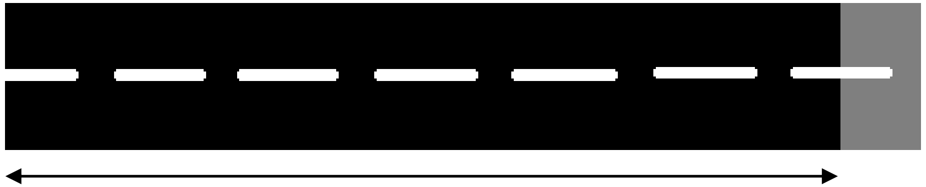
2.7 Million Miles

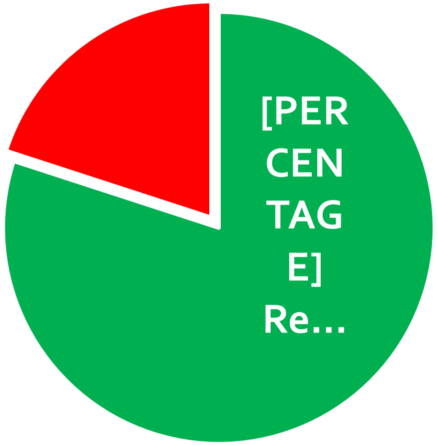


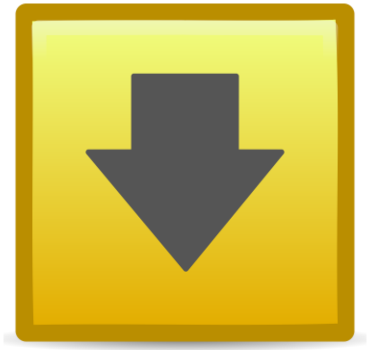
93% Asphalt

100,000,000 Tons

Reclaimed Asphalt Pavement (RAP)

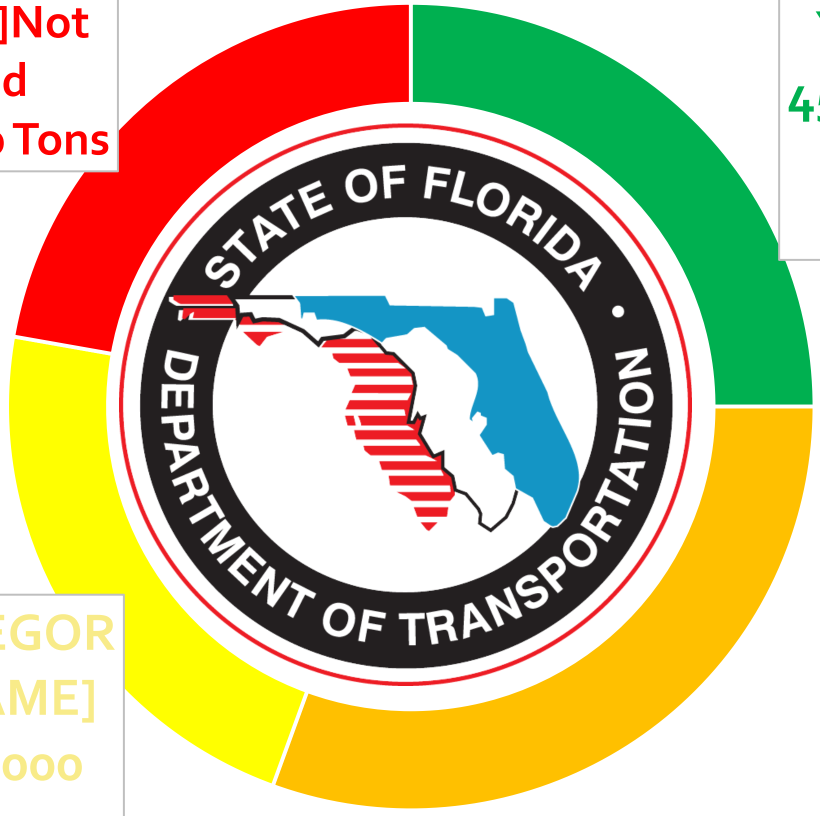
20,000,000 Tons

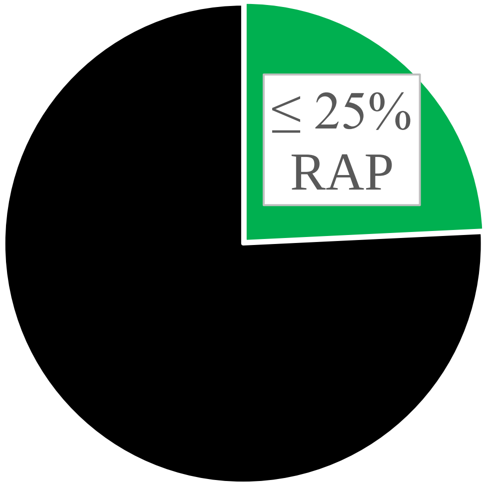




Base
Sub-base
Shoulders
Landfill

2000 Lane Miles Resurfacing per Year ✖ 2.25 inch Average Milling Depth ➡ **1.8 Million Tons RAP**

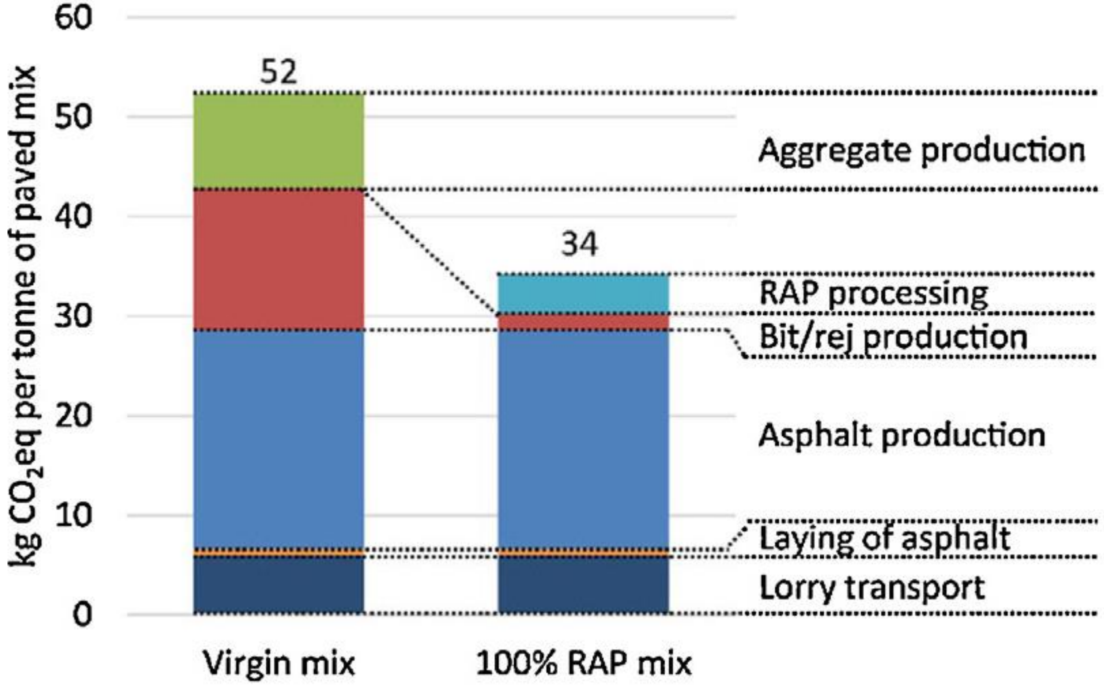


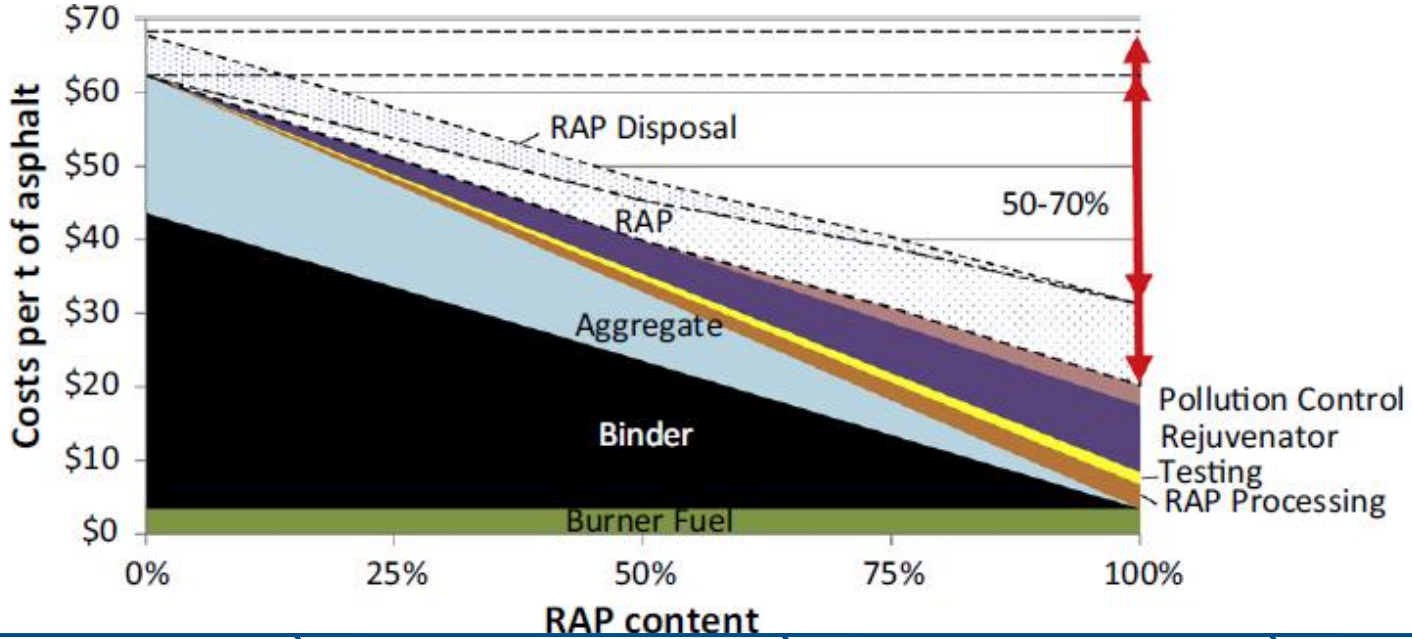


The average RAP content is under 25%
Why?

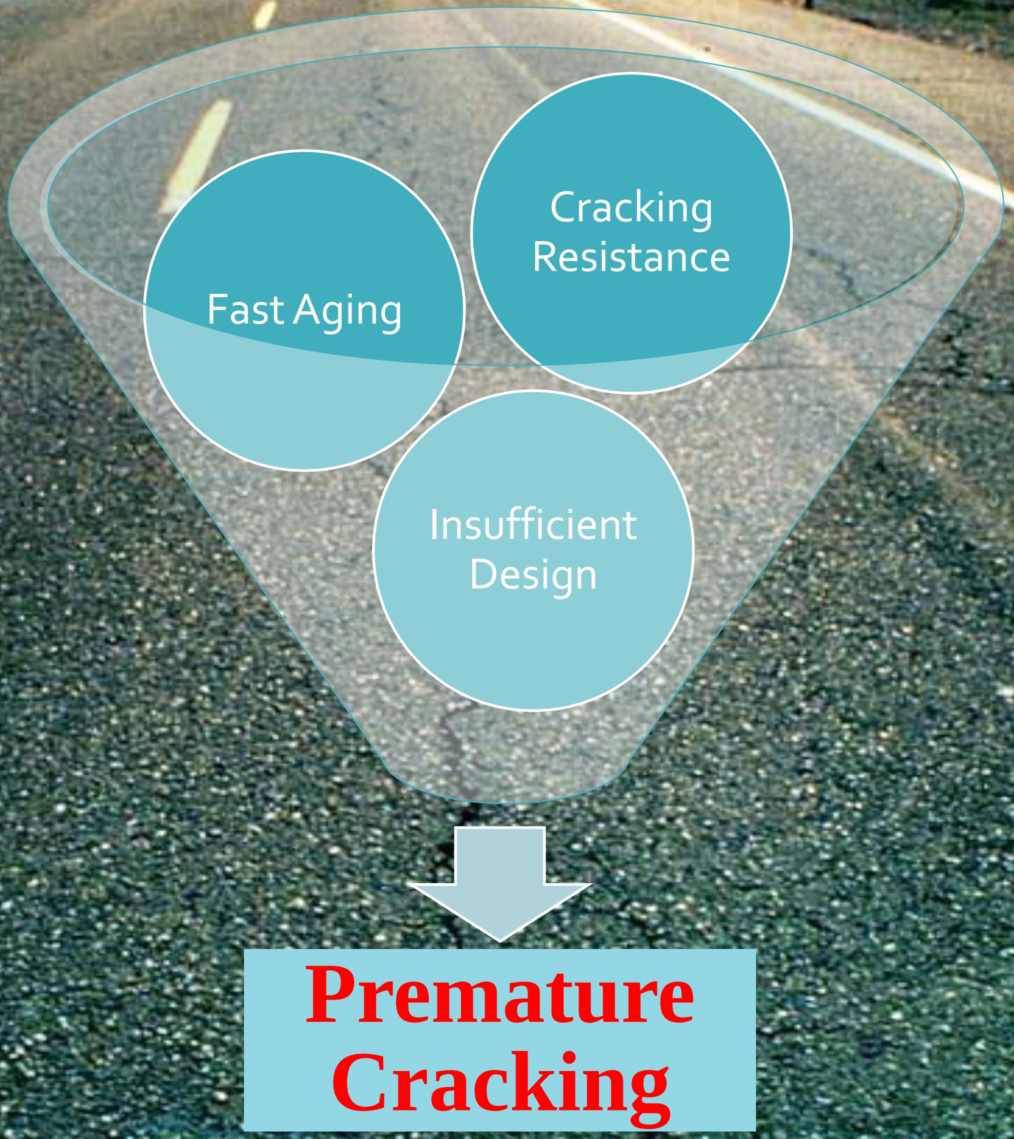
Lack of Confidence

Need for More Effective Design and Performance Verification Procedures High RAP Content Mixtures





Zaumanis, Mallick,& Frank (2014)


Fast Aging
Cracking Resistance
Insufficient Design
Premature Cracking

PERFORMANCE

- ✓ **Asphalt Binder**
- Aggregates
- Mix Design
- Construction

Asphalt Aging:

Asphalt hardens and gets brittle and prone to cracking due to weathering and construction heating

Asphalt

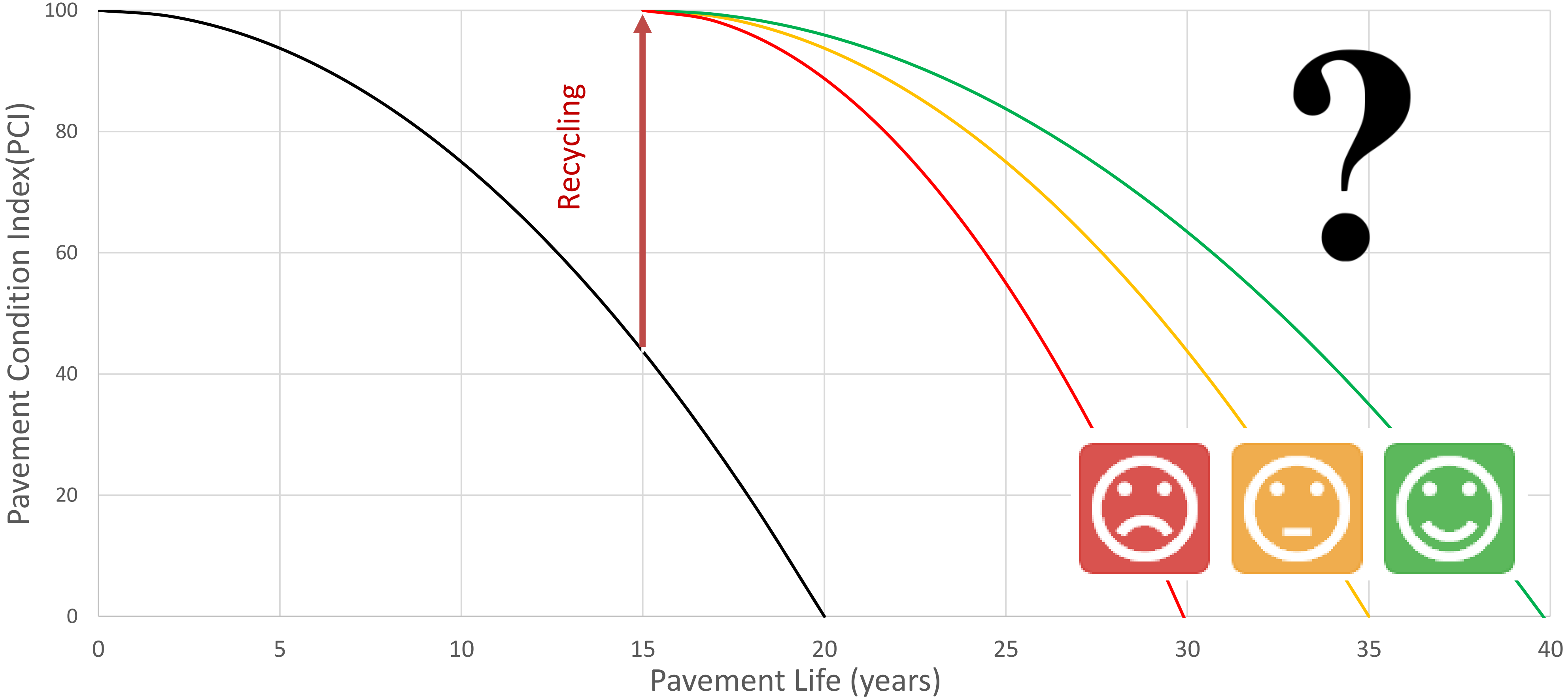
Asphaltenes | Maltenes

Rejuvenation:

Adding a recycling agent (rejuvenator) to aged asphalt to cure aging and restore its original properties

❖ **Effective rejuvenation has a major role in successful recycling**

Recycled Binder Durability



How to verify effectiveness of rejuvenation?

- **Current practice:**

Viscosity or penetration or performance grade requirements

FDOT: Pen. : 40 – 80 dmm ; Viscosity @ 160 º C : 5000 – 15000 Poises

Virgin Binder → Aging → RAP Binder → Rejuvenation → Recycled Binder

Virgin Binder ≠ Recycled Binder

Durability

Cracking Resistance

Research Objectives:

Evaluate Cracking Resistance and Durability of 100% RAP mixtures

- Compare the cracking resistance of several samples of recycled binder and mixture to that of non-recycled samples

- Monitor changes in the cracking resistance over the life of the pavement

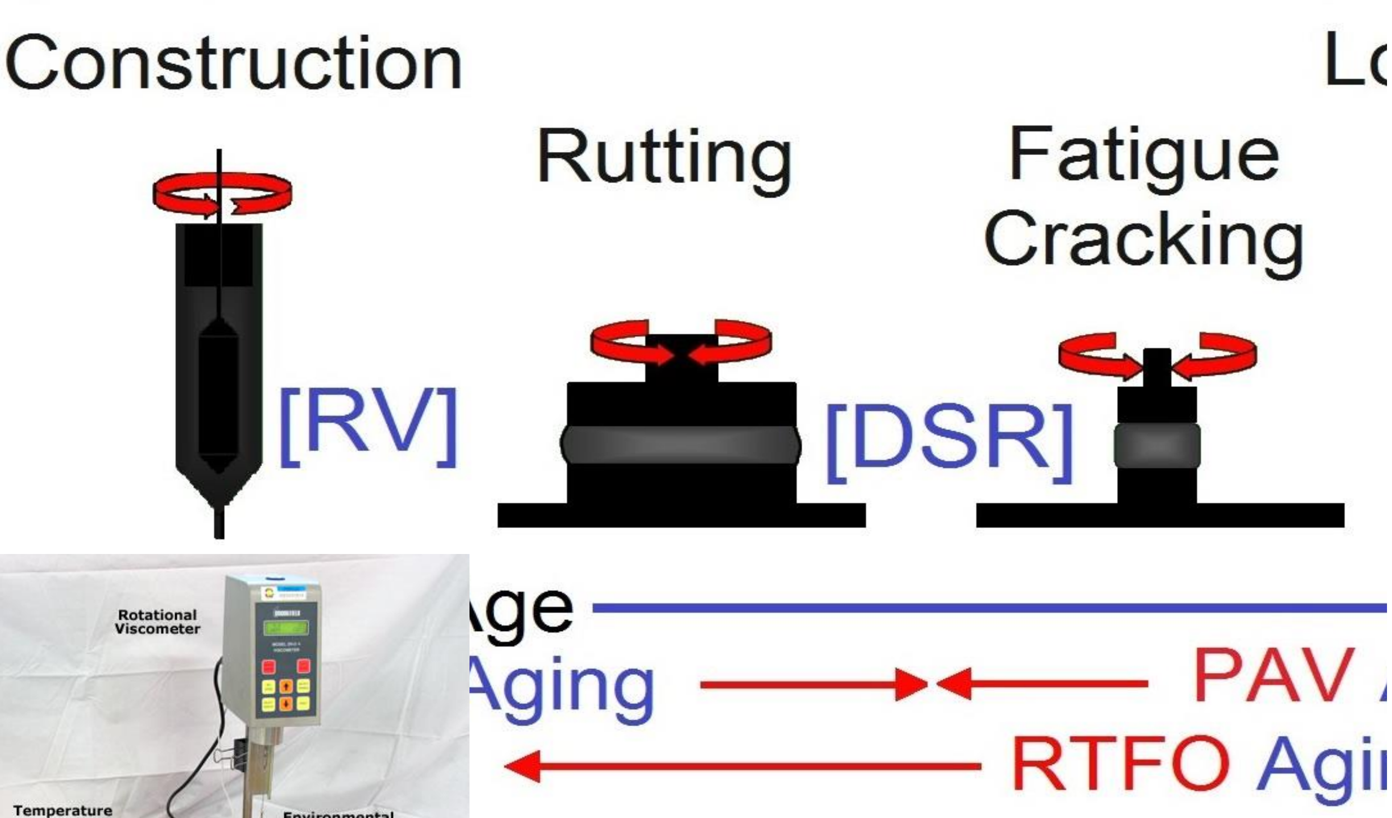
- Investigate the effect of rejuvenators on crackling resistance and durability

Methodology:

	Cracking Resistance	Aging
Binder	Bending Bean Rheometer (BBR)	Pressure Aging Vessel (PAV)
Mixture	Texas Overlay Test	Accelerated Pavement Weathering System (APWS)

Methodology

Superpave Performance Grade (PG) System



Florida: PG 67-22

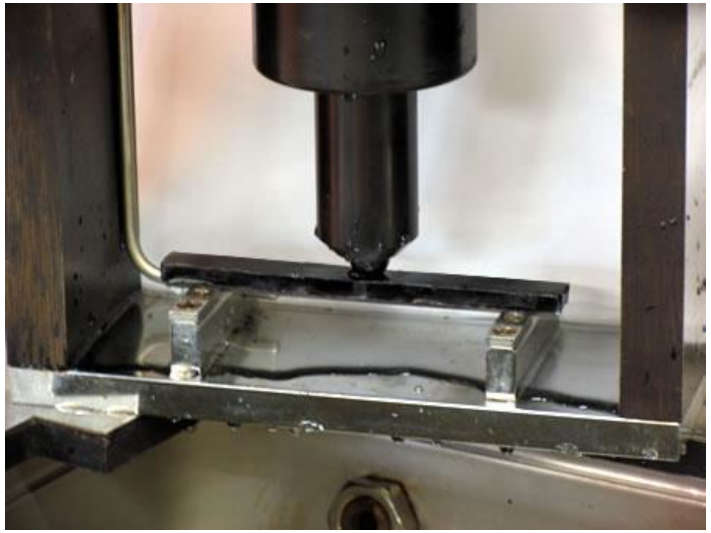
PG 64 -22

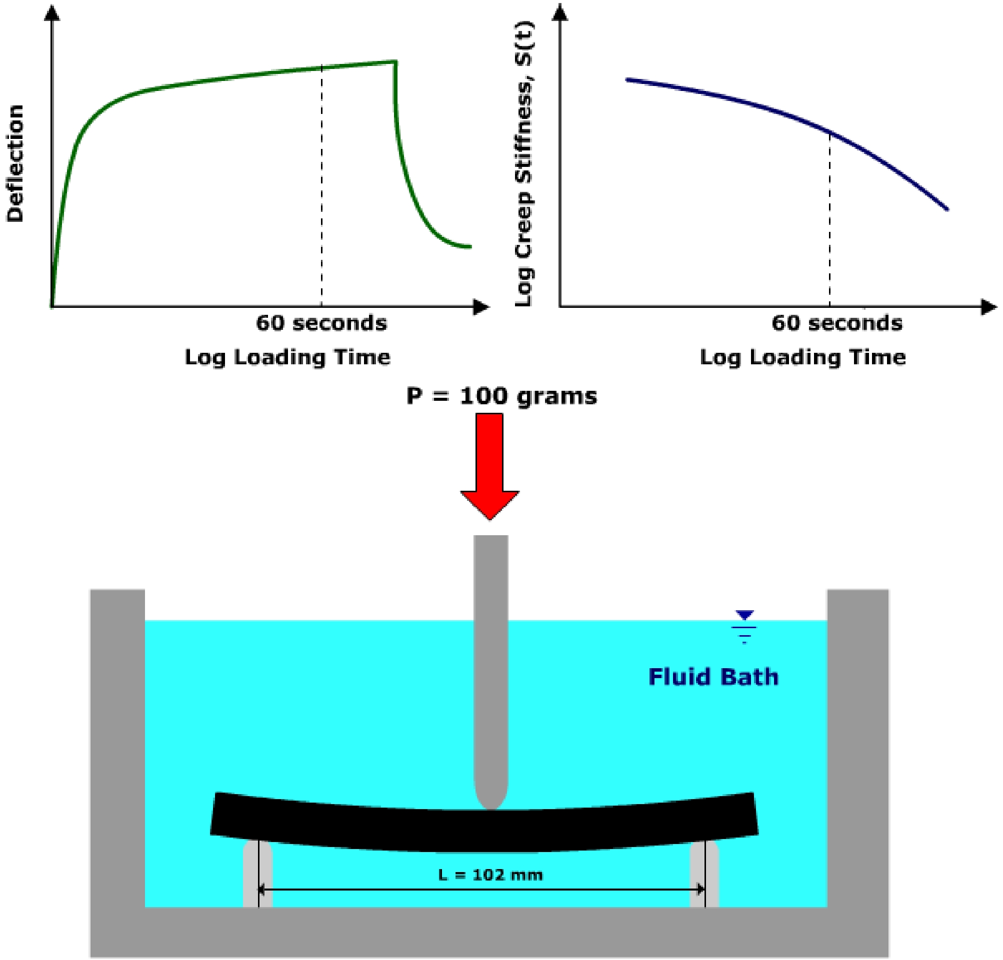
Virtual Superpave Laboratory

Performance Graded Asphalt Binder Specification (from AASHTO MP 1)

Performance Grade	PG 46			PG 52							PG 58					PG 64						PG 70						PG 76					PG 82				
	34	40	46	10	16	22	28	34	40	46	16	22	28	34	40	10	16	22	28	34	40	10	16	22	28	34	40	10	16	22	28	34	10	16	22	28	34
Average 7-day Maximum Pavement Design Temperature, °C[a]	< 46			< 52							< 58					< 64						< 70						< 76					< 82				
Minimum Pavement Design Temperature, °C[a]	-34	-40	-46	-10	-16	-22	-28	-34	-40	-46	-16	-22	-28	-34	-40	-10	-16	-22	-28	-34	-40	-10	-16	-22	-28	-34	-40	-10	-16	-22	-28	-34	-10	-16	-22	-28	-34
ORIGINAL BINDER																																					
Flash Point Temp, T 48, Minimum (°C)	230																																				
Viscosity, ASTM D 4402:[b] Maximum, 3 Pa*s, Test Temp, °C	135																																				
Dynamic Shear, TP 5:[c] G*/sinδ, Minimum, 1.00 kPa Test Temp @ 10 rad/s, °C	46			52							58					64						70						76					82				
ROLLING THIN FILM OVEN RESIDUE (T 240)																																					
Mass Loss, Maximum, percent	1.00																																				
Dynamic Shear, TP 5: G*/sinδ, Minimum, 2.20 kPa Test Temp @ 10 rad/s, °C	46			52							58					64						70						76					82				
PRESSURE AGING VESSEL RESIDUE (PP 1)																																					
PAV Aging Temperature, °C[d]	90			90							100					100						100 (110)						100 (110)					100 (110)				
Dynamic Shear, TP 5: G*sinδ, Maximum, 5000 kPa Test Temp @ 10 rad/s, °C	10	7	4	25	22	19	16	13	10	7	25	22	19	16	13	31	28	25	22	19	16	34	31	28	25	22	19	37	34	31	28	25	40	37	34	31	28
Physical Hardening[e]	Report																																				
Creep Stiffness, TP 1 Determine the critical cracking temperature as described in PP 42	-24	-30	-36	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	0	-6	-12	-18	-24
Direct Tension, TP 3 Determine the critical cracking temperature as described in PP 42	-24	-30	-36	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	0	-6	-12	-18	-24

Bending Beam Rheometer (BBR)





Bending Beam Rheometer (BBR)

Parameters

Creep Stiffness (S)

- The stiffness at 60 second
- Indicate the amount of thermal stresses
- PG requirement: $S \leq 300$ Mpa

stress relaxation parameter (m-value)

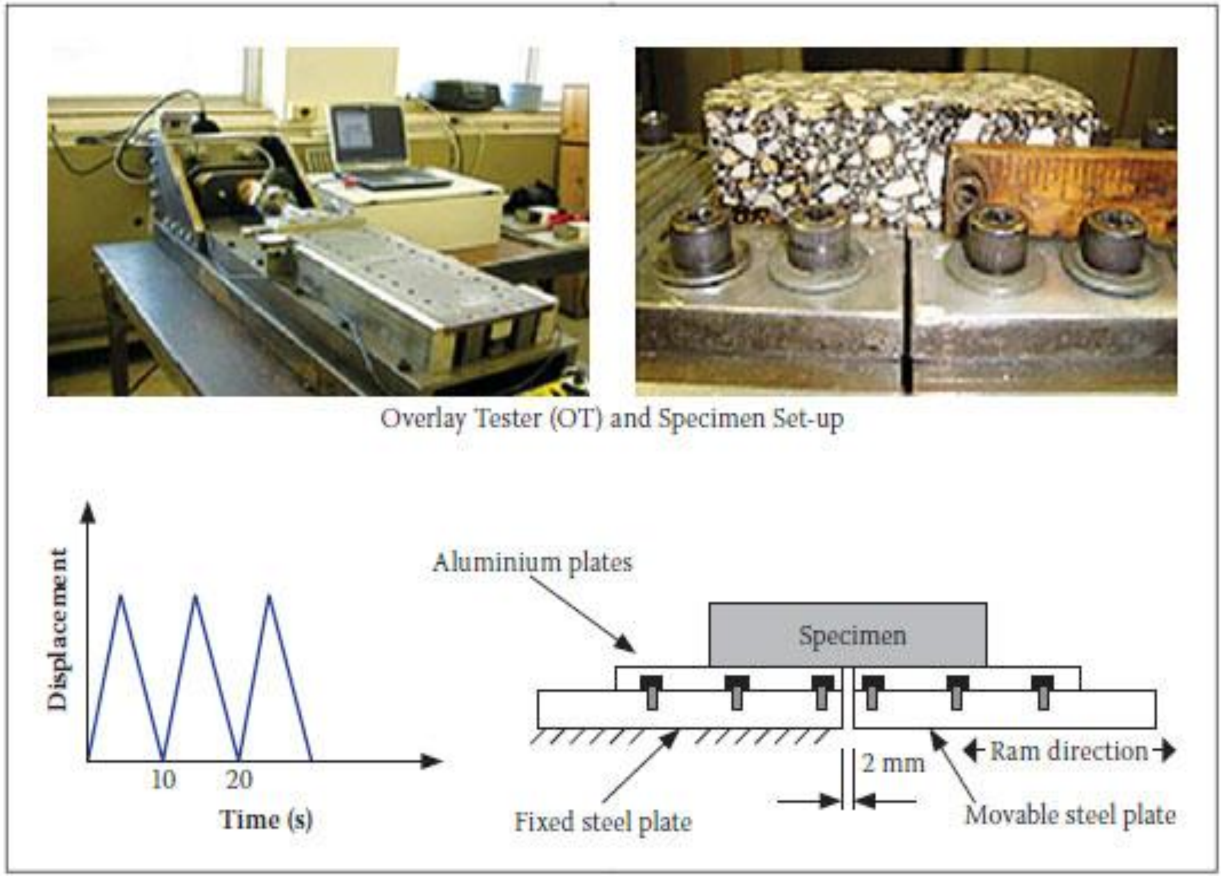
- The slope of master stiffness curve at 60 s
- Indicates the ability to relax stresses
- PG requirement: m-value ≥ 3.00

Pressure Aging Vessel (PAV)

- Simulates long-term aging of the binder using heat and pressure
- Temperature: 90, 100, or 110 °C
- Pressure: 2.1 Mpa
- Time : 20 hours
- Simulate 7-10 years in service aging

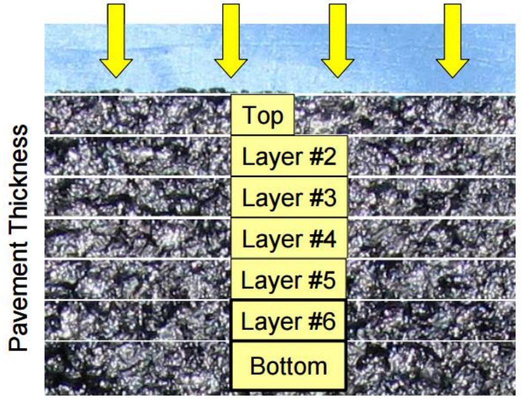
Texas Overlay Test

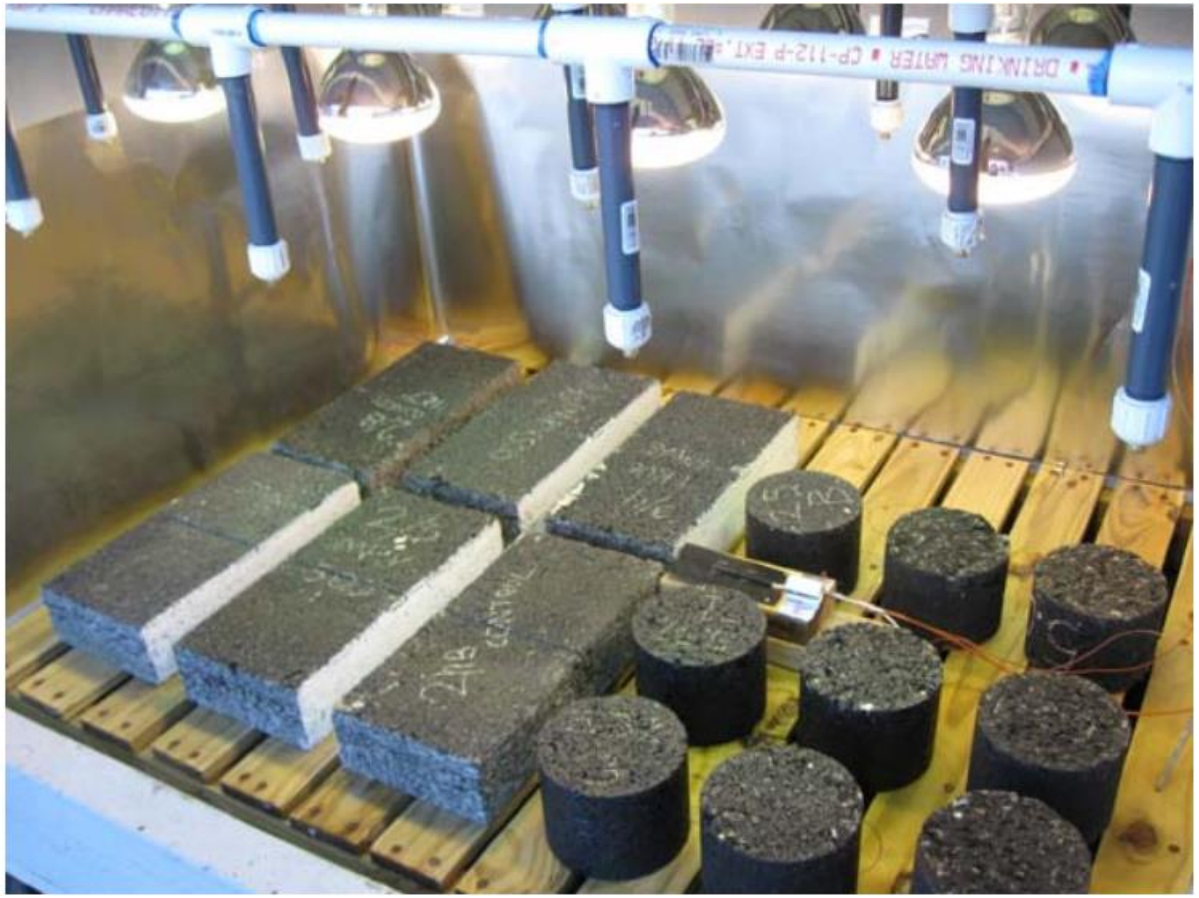
- Evaluates the susceptibility of asphalt mixtures to fatigue and reflective cracking
- Applies repeated tension loads to the specimen to simulate repeated opening and closing of pavement joints and cracks due to temperature variations and traffic loading
- Designed by
  Texas Department of Transportation



Asphalt Pavement Weathering System (APWS)

- ❖ **Accelerated pavement weathering**
- ❖ **Simulates natural pavement weathering (top to down) with parameters such as moisture (rain), UV (sunshine) and temperature**
- ❖ **Incorporates full-depth samples**





Binder Tests

- **Aging (PAV):**

  Standard: 20 hours (Plus RTFO)

  Extended: 60 hours

- **Virgin Binder: Two samples PG 67-22**

  True High Temperature Grade: Binder 1: 68.36 °C; Binder 1: 71.63°C

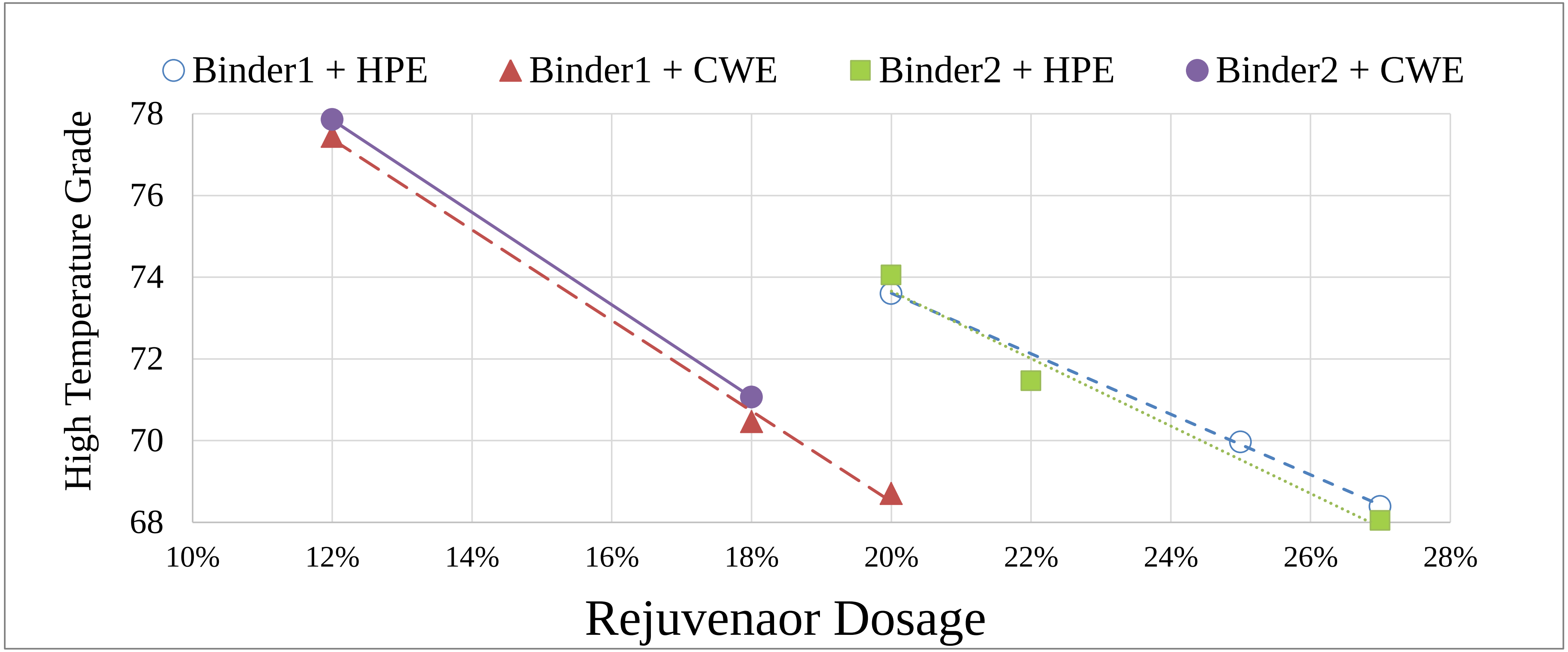
- **Rejuvenators:**

  HPE: Heavy Paraffinic Distilled Solvent Extract

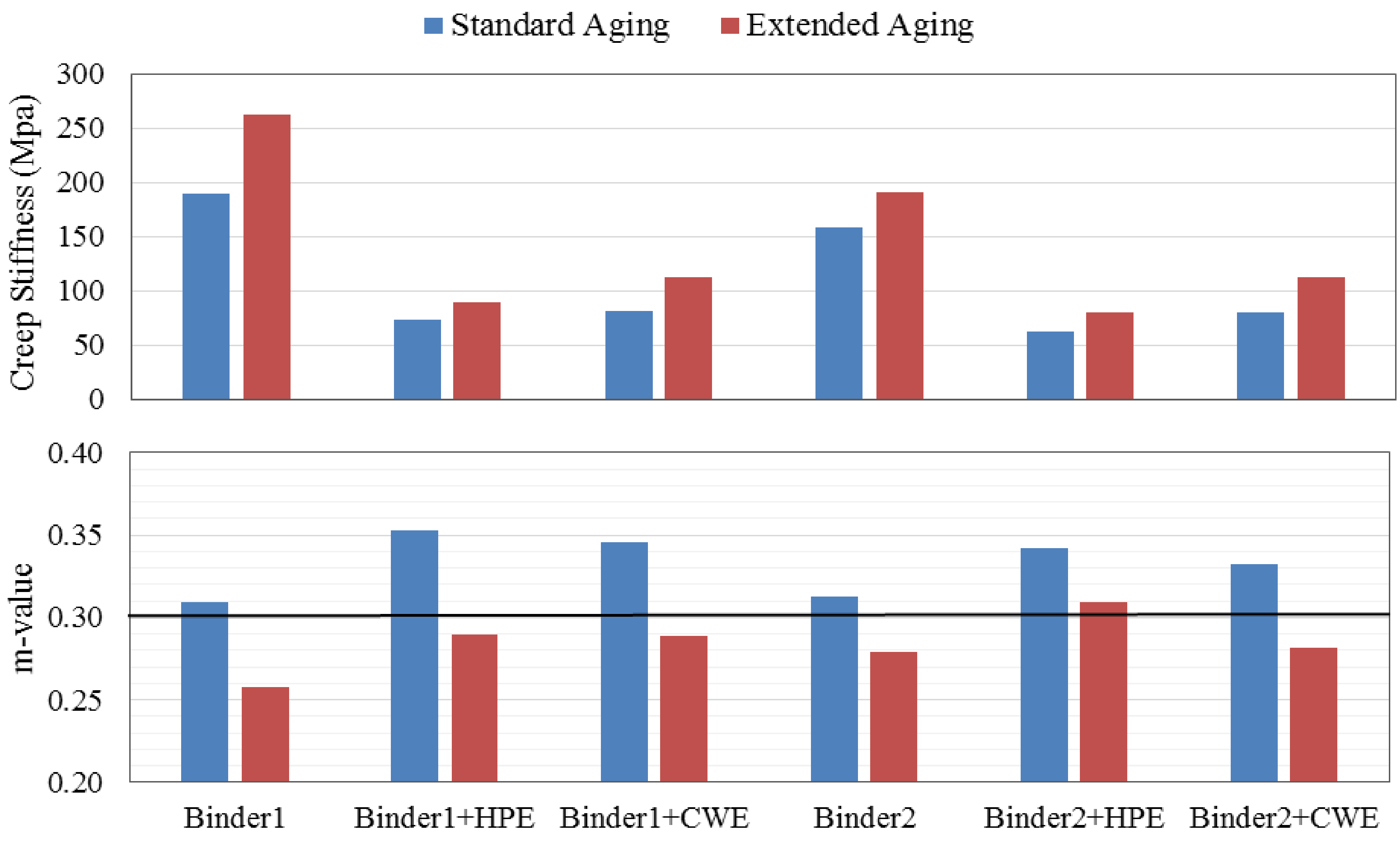
  CWE: Water-based Emulsion From Wax Free Naphthenic Crude With Residue Content Of 60%

Binder Tests

Softening Curves



Aging	Binder	Rejuvenator	Temp. (^{0}C)	Creep Stiffness (MPa)	m-value	Stiffness Critical Temp. (°C)	m-value Critical Temp. (°C)	High Temp. True Grade (°C)
Standard Aging RTFO + 20 hours PAV	Binder1	Original	-12	190	0.309	-25.4	-22.7	87.7
			-18	430	0.228			
		HPE	-12	72.8	0.353	-31.5	-25.9	83.4
			-18	178	0.27			
		CWE	-12	81.1	0.346	-31.4	-26.8	81.9
			-18	187	0.288			
	Binder2	Original	-12	159	0.313	-27.5	-24.2	91.4
			-18	319	0.277			
		HPE	-12	62.3	0.342	-30.9	-24.2	88.2
			-18	180	0.229			
		CWE	-12	80.3	0.332	-33.5	-27.8	86.7
			-18	160	0.299			
Extended Aging 60 hours PAV	Binder1	Original	-6	143	0.299	-23.3	-15.8	96.6
			-12	263	0.258			
			-18	475	0.202			
		HPE	-6	46.1	0.319	-33.5	-19.9	93.4
			-12	89.8	0.29			
			-18	169	0.258			
		CWE	-6	55.3	0.311	-31.3	-19.0	93.0
			-12	112	0.289			
			-18	212	0.241			
	Binder2	Original	-6	105	0.31	-26.0	-17.9	101.4
			-12	191	0.279			
			-18	374	0.223			
		HPE	-6	36.5	0.372	-29.4	-22.6	94.6
			-12	79.8	0.309			
			-18	233	0.205			
		CWE	-6	58.4	0.309	-32.4	-18.0	96.3
			-12	112	0.282			
			-18	198	0.265			


Standard Aging
Extended Aging
Creep Stiffness (Mpa)
300
250
200
150
100
50
0
m-value
0.40
0.35
0.30
0.25
0.20
Binder1
Binder1+HPE
Binder1+CWE
Binder2
Binder2+HPE
Binder2+CWE

Discussions:

- ❖ Recycled samples had significantly lower creep stiffness than virgin binders. Also the m-value was generally higher for recycled samples.
- ❖ By increasing the aging from the standard to the extended aging, the stiffness of all samples increased and their m-value dropped.
- ❖ Even after 60 hours of PAV aging, the stiffness of recycled binders was lower than the stiffness limit for PG67-22 (S≤ 300 MPa at -12°C). However, in most cases the m-values were too low and did not meet the requirement (m ≥ 0.300 at -12^0C)
- ❖ Both Rejuvenators enhanced the cracking resistance as characterized by a lower creep stiffness and higher m-value.

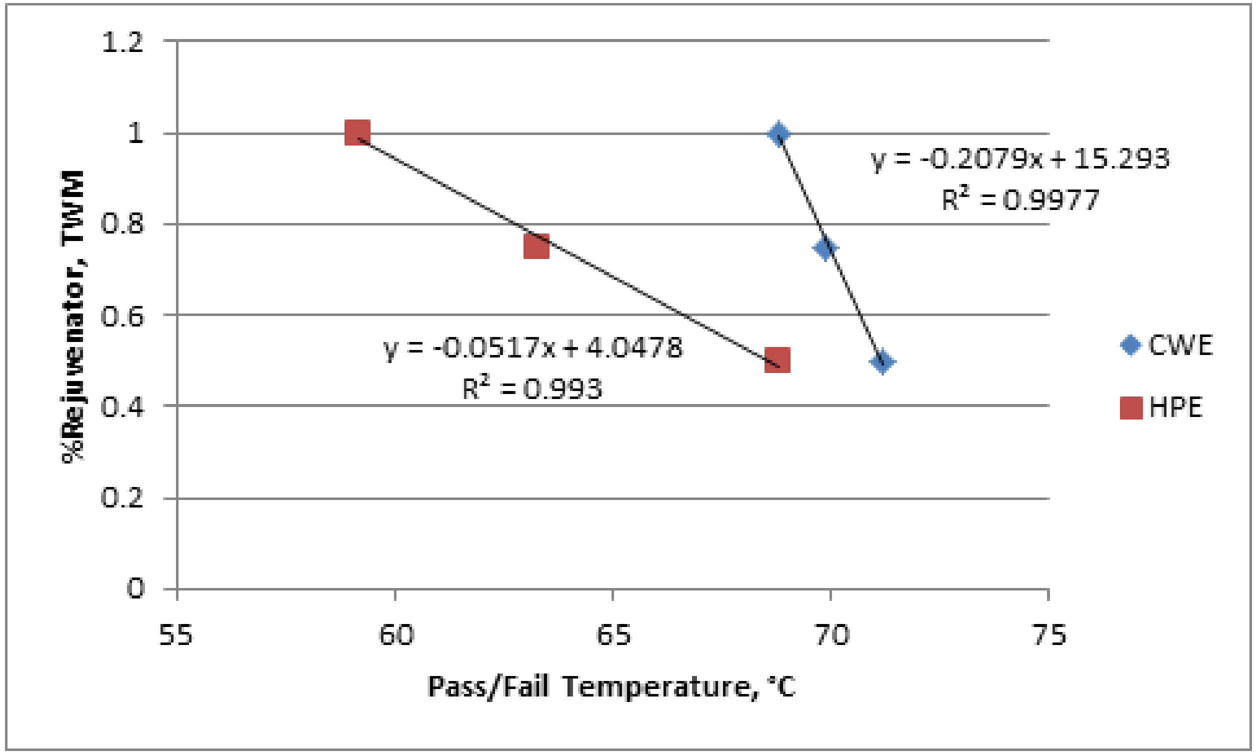
Mixture Tests

- Texas Overlay Test for:
  - Recycled and new mixture
  - Before and after APWS aging
- Two recycled mixtures and two Control (new) mixtures
- APWS aging for 3000 and 6000 hours
- A 3,000-hour APWS exposure simulates the aging that occurs in the field in 7 to 10 years

Sample Preparation

Recycled Mixtures

- Two recycled samples (CWE and HPE)
- RAP obtained from a hot in-place recycling project in Florida, USA
- Rap binder recovered to characterize and establish softening curves
- The same rejuvenators used for binder test used for rejuvenating the RAP
- 3% screening sand



Sample Preparation

Control Mixtures

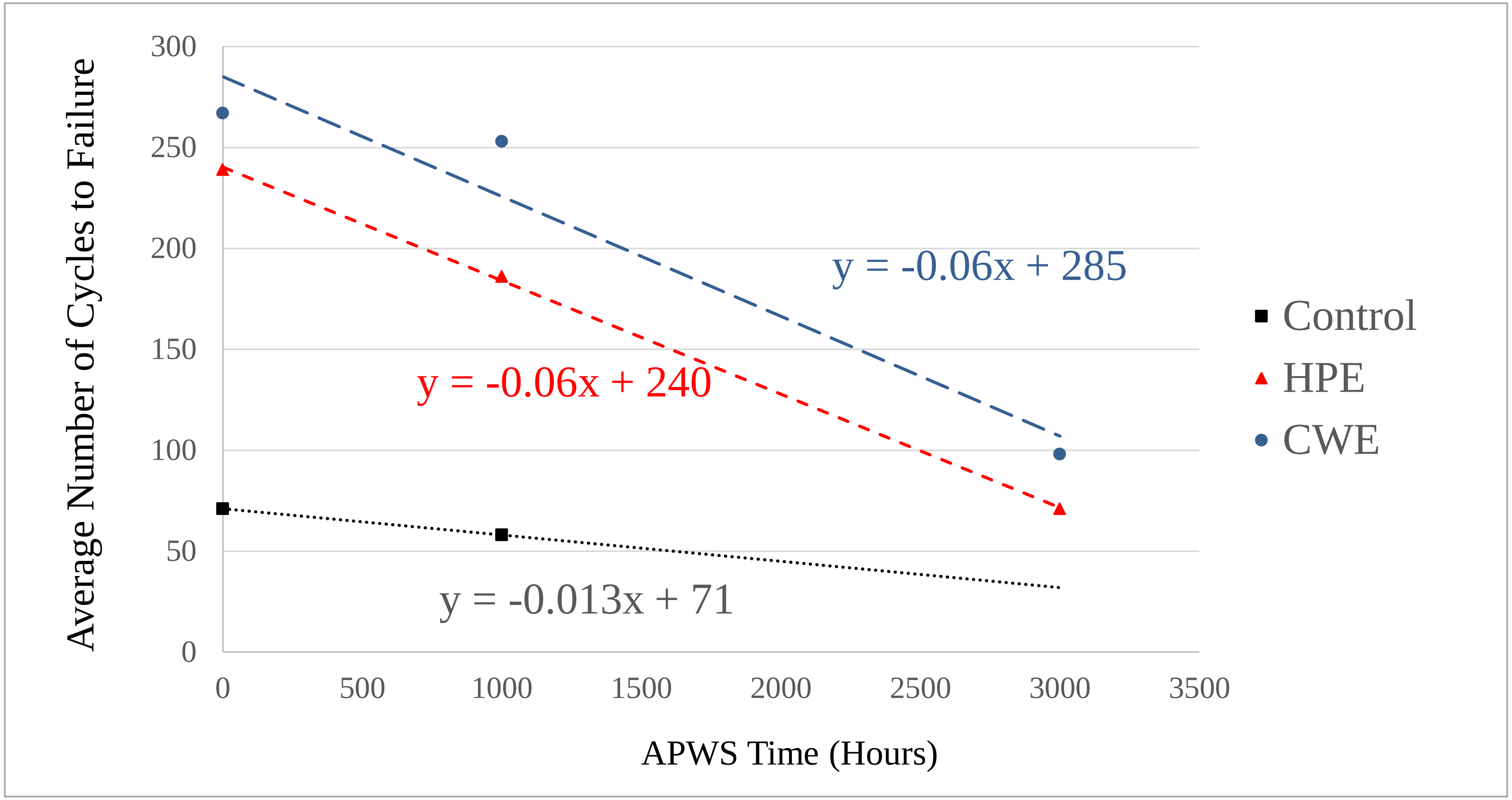
- Control I:
  - Aggregate extracted from the RAP using ignition oven
  - Mixed with PG 67-22 virgin binder with a binder content similar to the RAP (6.3%)
- Control II: Mixtures commonly used in Florida

➢ All pills prepared using Gyratory Compactor with 50 gyrations

Results

Mixture	Replicate	Starting Load, kN	Final Load, kN	Decline in Load, %	Cycles to Failure	Average Number of Cycles to Failure (ANCF)
0 Hours						
Control I	1	2.185	0.153	93	55	71
	2	1.724	0.117	93.2	72	
	3	2.325	0.159	93.2	86	
Control II	1 (SP)	4.230	0.282	93.3	104	63
	2 (SP)	0.155	0.008	94.7	62	
	3 (FC)	2.582	0.175	93.2	24	
HPE	1	1.653	0.112	93.2	384	239
	2	1.759	0.12	93.2	145	
	3	1.797	0.119	93.4	189	
CWE	1	1.576	1.109	93.1	347	267
	2	1.742	0.118	93.2	144	
	3	1.707	0.118	93.1	310	
1000 Hours						
Control I	1	2.435	0.167	93.1	36	58
	2	2.438	0.168	93.1	79	
HPE	1	2.213	0.151	93.2	186	186
	2	2.135	0.147	93.1	98	
	3	2.386	0.167	93	275	
CWE	1	2.53	0.174	93.1	153	253
	2	2.721	0.19	93	256	
	3	2.526	0.174	93.1	349	
3000 Hours						
HPE	1	2.987	0.23	93.2	75	71
	2	2.55	0.17	93.4	66	
CWE	1	2.927	0.199	93.2	58	98
	2	2.663	0.18	93.3	137	

Results


Average Number of Cycles to Failure
300
250
200
150
100
50
0
0
500
1000
1500
2000
2500
3000
3500
APWS Time (Hours)
y = -0.06x + 285
y = -0.06x + 240
y = -0.013x + 71
Control
HPE
CWE

Discussions

- The Average Number of Cycles to Failure (ANCF) was considered an indication of susceptibility of mixtures to fatigue and reflective cracking
- Both recycled samples performed much better than both control samples at the initial stage (before aging) . Their ANCF was significantly higher, meaning that they had much better cracking resistance
- The ANCF decreases with increased APWS aging time.
- The rate of decrease in the ANCF with APWS time was considerably faster for recycled mixtures than for the control I.
- However, even at the end of 3,000 hours, recycled samples had an equally good or better resistance to cracking when compared with un-aged control samples.

Discussions - Continued

- The recycled samples which were rejuvenated by CWE were found to have a better performance than those rejuvenated by HPE

- **Limitations:**

- The variability of Texas Overlay Test results

- The variability of the air voids between the control and recycled samples

- The relatively small size of this experiment.

Conclusions

- Generally, recycled binders had significantly better cracking resistance than virgin binders. This fact was observed in both binder and mixture testing. This observation confirms that a properly recycled pavement can be even more resistant to cracking than a new pavement

- In the binder testing, no consistent trend was observed in comparing the rate of decrease in cracking resistance of rejuvenated and virgin binders due to aging.

- The cracking resistance of recycled samples dropped faster. But because of the significant difference in the initial values, even after aging recycled samples had a better cracking resistance

- The cracking resistance of recycled mixtures was affected by the type of rejuvenator.

Thank You