Research Update

TPF-5(230)
Evaluation of Plant-Produced High-Percentage RAP Mixtures in the Northeast

NEAUPG

NORTH EAST ASPHALT USER/PRODUCER GROUP

Wednesday October 5th, 2011
Providence, Rhode Island

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Participating Agencies

- New Hampshire (NHDOT) - Lead Agency
- Maryland (MDOT)
- New Jersey (NJDOT)
- New York (NYSDOT)
- Pennsylvania (PennDOT)
- Rhode Island (RIDOT)
- Virginia (VDOT)
- Federal Highway Administration (FHWA)

Project Objectives

- Evaluate the performance of plant-produced RAP mixtures (in the laboratory and field) in terms of low temperature cracking, fatigue cracking and moisture sensitivity.
- Provide further understanding of the blending that occurs between RAP and virgin binder in plant-produced mixtures.
- Refine fatigue failure criteria for RAP mixtures that can be used in the Simplified Viscoelastic Continuum Damage (S-VECD) model.

Project Timeline

Year 1: Production of Phase I mixtures, laboratory testing, data analysis, and construction of field test sections.

Year 2: Phase II mixtures produced, continuation of testing, data analysis, monitoring and construction of field sections, and refinement of fatigue failure criterion.

Year 3: Final Phase II mixtures produced, completion of testing, monitoring field sections, data analysis and synthesis, and preparation of final report.

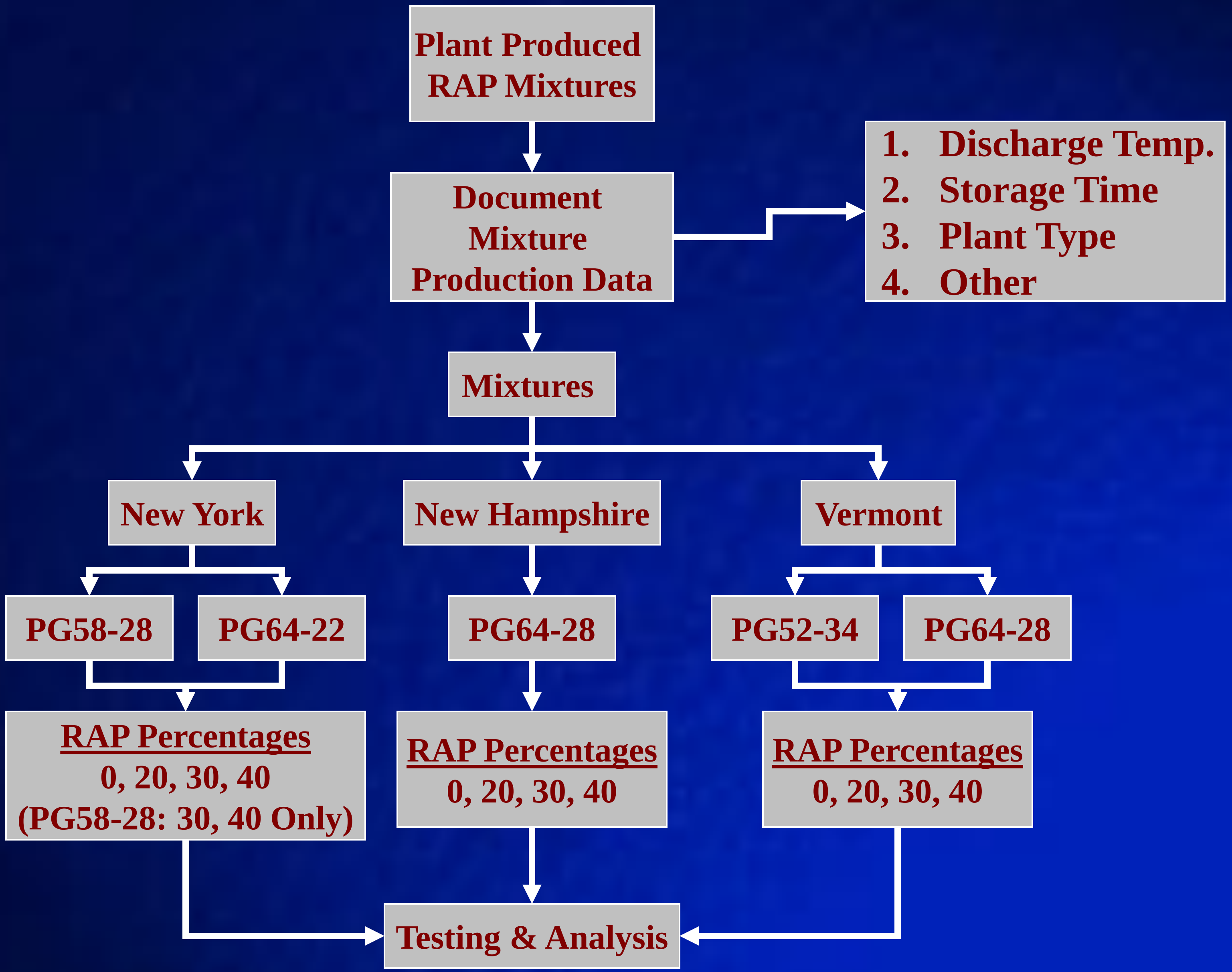
Research - Phase I

- 18 mixtures
- Evaluate the effect of plant type and binder grade on the properties of RAP mixtures
- Mixtures with different PG grade asphalts from the same plant at particular RAP percentages were collected for direct evaluation of the effect of binder grade. This was done for batch and drum plants.

Phase I Tasks

- Obtain plant produced mixtures that incorporated different percentages of RAP.
- Document construction parameters such as mixing and discharge temperatures, storage time, and plant type.
- Laboratory testing on plant compacted and laboratory compacted mixtures, tank binder and extracted & recovered binders

Phase I Experimental Plan



Phase I Testing Plan - Binders

Test	Test Method/ Reference	Lab
Performance Grade	AASHTO R29 & AASHTO M320	Rutgers
Binder Modulus and Master Curve	n/a	UMass Dartmouth
Softening Point	AASHTO T53	Rutgers
Thermal Cracking Temperature	Asphalt Binder Cracking Device	UMass Dartmouth
Critical Cracking Temperature	AASHTO R49-09	Rutgers

Phase I Testing Plan -

Mixtures Plant Compacted and Reheated

Test	Test Method/ Reference	Lab
Dynamic Modulus	AASHTO TP62 AASHTO TP79	Rutgers NCSU
Low Temperature Creep and Strength	AASHTO T322	UNH
Push-Pull Fatigue Test (S-VECD)	n/a	UNH NCSU
Moisture Sensitivity	AASHTO T283	UNH
Moisture Sensitivity	AASHTO T324	UMass Dartmouth

Additional Mixture Testing

- Overlay tester
- UMass Dartmouth Asphalt Workability Device

Phase I
Mixture Information

just show binder/rap % table

Mixtures - JMF Callanan, NY

	PG 64-22				PG 58-28	
Sieve Size	0% RAP	20% RAP	30% RAP	40% RAP	30% RAP	40% RAP
19.0	100.0	100.0	100.0	100.0	100.0	100.0
12.5	99.8	99.1	95.0	97.6	97.5	98.1
9.5	90.8	90.8	85.8	88.7	91.2	89.3
4.75	68.3	59.0	54.4	53.0	59.5	53.7
2.36	48.7	30.9	30.2	30.9	33.3	32.0
1.18	35.1	18.8	22.7	19.3	21.2	17.9
0.6	25.5	11.8	16.5	14.3	14.7	12.5
0.3	17.5	8.3	11.6	10.1	9.7	8.5
0.15	12.3	6.7	7.8	6.1	5.8	5.1
0.075	9.7	3.8	5.4	3.3	3.3	2.6
$\%P_b$	4.99	5.35	5.19	5.28	5.37	5.09
$\%P_{rep}$	0	19.0	28.4	37.7	28.4	37.7

Mixtures - JMF Pike, NH

	Percent RAP			
Sieve Size	0%	20%	30%	40%
19.0	100.0	100.0	100.0	100.0
12.5	99.1	99.2	97.7	99.6
9.5	89.6	89.1	86.8	87.7
4.75	62.0	61.4	58.9	55.2
2.36	42.3	43.4	41.7	38.8
1.18	31.7	32.8	31.7	29.9
0.6	24.0	25.8	22.8	22.2
0.3	15.5	15.3	13.7	14.0
0.15	6.9	7.3	5.8	6.5
0.075	3.0	3.7	2.6	3.2
$\%P_b$	5.9	5.7	5.3	5.5
$\%P_{rep}$	0.0	16.8	26.9	35.5

Mixtures - JMF Pike, VT

	PG 52-34				PG 64-28			
Sieve Size	0% RAP	20% RAP	30% RAP	40% RAP	0% RAP	20% RAP	30% RAP	40% RAP
19.0	100	100	100	100	100	100	100	100
12.5	100	100	100	100	100	100	100	100
9.5	98.8	98.4	98.6	97.9	99.6	98.7	97.8	98.5
4.75	78.8	79.2	75.0	76.8	76.9	81.3	77.5	75.1
2.36	51.1	51.1	48.1	48.8	48.8	53.5	48.9	46.6
1.18	31.4	30.7	29.5	29.3	29.7	32.3	29.0	26.8
0.6	19.3	19.1	18.7	18.4	18.0	19.9	17.8	15.7
0.3	10.7	11.8	11.7	11.8	9.9	11.9	11.0	9.0
0.15	6.1	7.4	7.4	7.5	5.5	7.1	7.0	4.8
0.075	3.8	4.6	4.5	4.6	3.3	4.3	4.3	4.5
$\%P_b$	6.65	6.76	6.56	6.63	6.5	6.71	6.61	6.55
$\%P_{rep}$	0.0	18.9	29.3	38.6	0.0	19.7	28.6	39.1

Phase I Mixtures – Callanan, NY

Mixture	Binder	% RAP	Discharge Temp, ºF	Laydown Temp, ºF	Agg. Temp, ºF	Silo Storage Time, hrs
12.5mm	PG 64-22	0	310	290	375	2.75
12.5mm	PG 64-22	20	320	290	410	0.75
12.5mm	PG 64-22	30	305	290	410	2.75
12.5mm	PG 64-22	40	330	290	450	3.0
12.5mm	PG 58-28	30	305	275	410	3.5
12.5mm	PG 58-28	40	330	275	450	4.0

Phase I Mixtures – Pike, NH

Mixture	Binder	RAP, %	Discharge Temp, ºF	Laydown Temp, ºF	Agg. Temp, ºF	Silo Storage Time, hrs
12.5mm	PG 64-28	0	330	300	340	6.0
12.5mm	PG 64-28	20	315	310	340	1.25
12.5mm	PG 64-28	30	335	315	340	1.0
12.5mm	PG 64-28	40	335	315	n/a	n/a

Phase I Mixtures - Pike, VT

Mixture	Binder	RAP, %	Discharge Temp, ºF	Laydown Temp, ºF	Agg. Temp, ºF	Silo Storage Time, hrs
9.5mm	PG 52-34	0	315	315	n/a	n/a
9.5mm	PG 52-34	20	324	324	n/a	n/a
9.5mm	PG 52-34	30	320	320	n/a	n/a
9.5mm	PG 52-34	40	300	295	n/a	n/a
9.5mm	PG 64-28	0	330	300	n/a	n/a
9.5mm	PG 64-28	20	300	300	n/a	n/a
9.5mm	PG 64-28	30	322	310	n/a	n/a
9.5mm	PG 64-28	40	295	295	n/a	n/a

Production Information – Callanan, NY

- Cedar Rapids counter flow drum plant.
- Production rates approximately 250 tons per hour (tph) for the 30 and 40% RAP mixtures and 300 tph for the virgin and 20% RAP mixes.

Production Information – Pike, NH

- 2008 Gencor Ultra drum plant.
- 400 tons per hour capacity.
- Mixing times approximately 40 seconds.

Production Information – Pike, VT

- Mixtures were produced in a 1966 H&B 5-ton drop batch plant.
- The batch plant mixing times and burner set temperature varied depending on the RAP content:
  - Virgin Mix: 6 sec Dry Mix Time; 36 sec Wet Mix Time
  - 20% RAP: 10 sec Dry Mix Time; 36 sec Wet Mix Time
  - 30% RAP: 13 sec Dry Mix Time; 36 sec Wet Mix Time
  - 40% RAP: 13 sec Dry Mix Time; 36 sec Wet Mix Time

Binder Extraction & Recovery

Extraction / Recovery of Binder

- Binder from each plant produced mixture was extracted in accordance with Method A of AASHTO T164 "Quantitative Extraction of Asphalt Binder from Hot Mix Asphalt (HMA)"

- Binder was then recovered in accordance with AASHTO T170 "Recovery of Asphalt From Solution by Abson Method".

- Extraction & Recovery performed by Pike Industries, Inc.

PG Binder Grading Results

PG Grading

- All tank sampled and recovered binders were graded in accordance with AASHTO R29 “Grading or Verifying the Performance Grade of an Asphalt Binder” and AASHTO M320 “Standard Specification for Performance-Graded Asphalt Binder.”

- PG grading completed to determine impact of production parameters, virgin binder grade utilized and RAP percentage on final PG grade of the binder in the mixture.

PG Grading Results

		Continuous PG Grade (°C)			
Mixture	Type	High	Low	Inter.	PG Grade
New York 58-28	Tank 7/30/10	60.3	-30.8	17.2	58-28
	Tank 9/7/10	61.0	-34.6	18.5	58-34
	Extracted 30% RAP	69.6	-28.2	21.3	64-28
	Extracted 40% RAP	65.8	-29.3	20.5	64-28
New York 64-22	Tank 7/30/10	67.3	-26.0	22.1	64-22
	Tank 9/7/10	67.0	-25.5	21.9	64-22
	Extracted 0% RAP	67.5	-26.7	22.2	64-22
	Extracted 20% RAP	69.3	-25.9	26.6	64-22
	Extracted 30% RAP	70.9	-22.9	26.2	70-22
	Extracted 40% RAP	74.0	-18.3	26.1	70-16

PG Grading Results

		Continuous PG Grade (°C)			
Mixture	Type	High	Low	Inter.	PG Grade
New Hamp. 64-28	Tank	66.3	-29.5	19.9	64-28
	Extracted 0% RAP	66.8	-31.1	18.0	64-28
	Extracted 20% RAP	67.9	-30.0	20.9	64-28
	Extracted 30% RAP	70.6	-29.8	18.6	70-28
	Extracted 40% RAP	70.3	-29	20.3	70-28

PG Grading Results

		Continuous PG Grade (°C)			
Mixture	Type	High	Low	Inter.	PG Grade
Vermont 52-34	Tank	56.3	-32.5	12.1	52-28
	Extracted 0% RAP	56.6	-30.1	10.3	52-28
	Extracted 20% RAP	57.8	-31.4	11.9	52-28
	Extracted 30% RAP	59.1	-32.0	11.2	58-28
	Extracted 40% RAP	59.8	-32.8	12.4	58-28
Vermont 64-28	Tank	64.4	-30.2	16.6	64-28
	Extracted 0% RAP	61.7	-28.7	16.8	58-28
	Extracted 20% RAP	60.9	-30.3	15.5	58-28
	Extracted 30% RAP	63.0	-28.5	17.4	58-28
	Extracted 40% RAP	61.9	-29.0	17.0	58-28

PG Grading - Observations

- The New York mixtures (drum plant) had minimal change in the low temperature grade of the binder up to RAP contents of 40% when a PG 58-28 was used.

- The high temperature binder grade increased by one grade at the 30 and 40% RAP contents for the NY mixtures.

- For NY mixtures, when a stiffer binder (PG64-22) was used, the high temperature grade again increased by one grade at RAP contents greater than 30%. Additionally, at a 40% RAP content, the low temperature grade experience a single grade loss, increasing from a -22ºC to a -16ºC.

PG Grading - Observations

- **For the NH mixtures (drum plant) there was no change in the binder grade up to 20% RAP content.**
- **For the NH mixtures at the 30 and 40% RAP content, the high temperature grade increased by a single grade. The low temperature grade did not change.**
- **For the VT mixtures (batch plant), there was no change in the low temperature grade for the PG64-28 and the softer binder PG52-34 (actual grade was PG52-28 as confirmed by tank grading).**

PG Grading - Observations

- **For VT mixtures with the softer binder, the high temperature grade was increased by one grade at the 30 and 40% RAP contents. For the PG 64-28, there was a loss of one high temperature grade for all the mixtures, with minimal to no change in the low temperature grade.**

- **Based on analysis of storage time data and PG grade data, it would appear that stiffening, or lack of, witnessed in the asphalt binder grading may be a function of the length and temperature at which the material is stored, as well as the method of mixing (i.e. drum or batch plant).**

Binder Low Temperature Cracking Results

AASHTO R49 & ABCD

Binder Low Temperature Cracking

- The low temperature cracking characteristics of the recovered binders were evaluated due to concern that high RAP content might lead to a very stiff mixture that is susceptible to thermal cracking.

- The effect of the RAP binder on the low temperature cracking characteristics of the recovered binders was evaluated utilizing two methods: the Asphalt Binder Cracking Device (ABCD) (AASHTO TP92) and AASHTO R49 "Determination of Low-Temperature Performance Grade (PG) of Asphalt Binders."

Low Temperature Results

Mixture	Base PG Grade Binder	% RAP	ABCD Temp, °C [As-Recovered]	ABCD Temp., °C [PAV Aged]	Critical Cracking Temp., °C AASHTO R49
New York	58-28	30	-36.2	-32.9	-30.3
		40	-37.3	-33.9	-30.2
	64-22	0	-33.8	-31.7	-25.5
		20	-32.5	-31.4	-22.0
		30	-32.3	-30.4	-24.0
		40	-32.1	-30.3	-24.3

Low Temperature Results

Mixture	Base PG Grade Binder	% RAP	ABCD Temp, °C [As-Recovered]	ABCD Temp., °C [PAV Aged]	Critical Cracking Temp., °C AASHTO R49
New Hampshire	64-28	0	-35.7	-34.1	-28.0
		20	-34.6	-34.2	-28.3
		30	-33.2	-32.1	-29.6
		40	-36.2	-30.9	-28.5

Low Temperature Results

Mixture	Base PG Grade Binder	% RAP	ABCD Temp, °C [As-Recovered]	ABCD Temp., °C [PAV Aged]	Critical Cracking Temp., °C AASHTO R49
Vermont	52-34	0	-44.2	-40.5	-34.5
		20	-41.8	-39.3	-35.3
		30	-41.5	-38.6	-34.7
		40	-41.7	-38.0	-31.7
	64-28	0	-39.2	-35.0	-28.4
		20	-37.1	-32.8	-29.1
		30	-36.4	-34.7	-28.2
		40	-38.0	-33.7	-28.5

Low Temp. - Observations

- For the New York and Vermont mixtures, the data indicated the softer binder improved the resistance to low temperature cracking.

- Since recovered binders represent full blending, the data indicates that if good blending occurs in the mixtures then a softer binder will help alleviate low temperature cracking potential of the mixture.

- There were major differences between the AASHTO critical cracking temperatures and the ABCD test predicted low temperature cracking temperatures. Generally the ABCD temperatures were colder.

Mixture Reheating Procedure

Reheating Procedure

- Loose plant produced mixture were reheated in order to fabricate specimens in the laboratory. Loose mixture was obtained from each contractor in five-gallon buckets.

- The first step was to heat the five-gallon bucket of mixture, with the lid on, for one hour at a temperature 10ºC lower than the plant discharge temperature.

- Next the bucket was heated at the same temperature for one hour with the lid off the bucket. After this second hour of heating, the temperature of the mixture was checked to confirm the center of the mixture was at least 75ºC (167 ºF).

Reheating Procedure

- Next, the loose mixture in the bucket was emptied into a large pan. Material was scooped from the pan in order to achieve the mass desired for a pre-determined specific specimen size. The massed specimen was then placed into an oven that was previously pre-heated to the appropriate compaction temperature.

- The massed specimens were then allowed to reach the compaction temperature (approximately 30 minutes in the compaction oven). Upon reaching the compaction temperature, the loose plant produced mixture specimens were then compacted.

Reheating Procedure

- Each bucket of mixture was allowed to be heated only once and not allowed to be cooled and reheated again. The maximum reheating time was limited to 4 hours.

Moisture Susceptibility Results
AASHTO T324
Hamburg Wheel Tracking Device

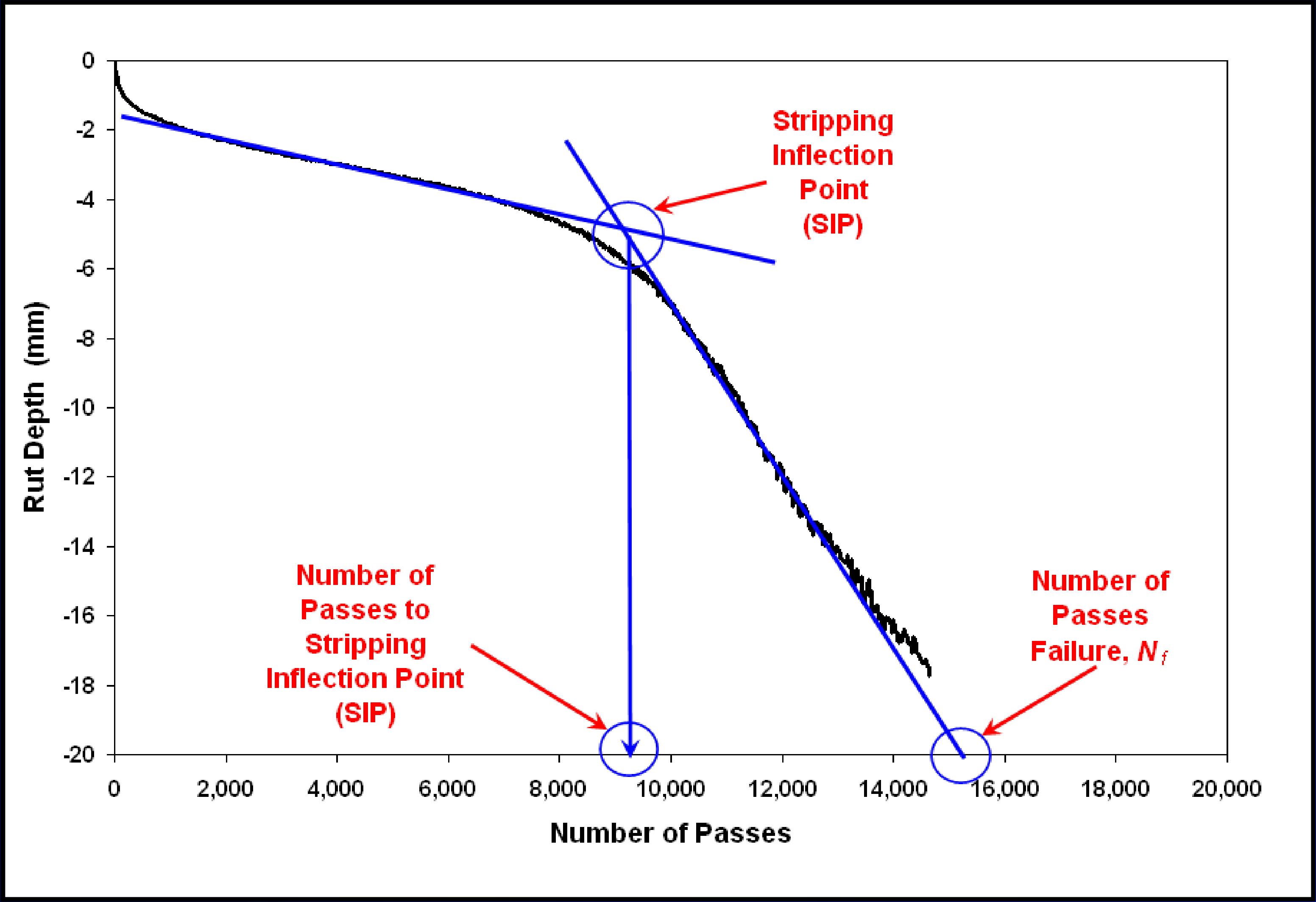
Moisture Susceptibility - Hamburg Wheel Tracking Device (HWTD)

- HWTD testing conducted in accordance with AASHTO T324

- Water temperature of 50ºC (104ºF) during testing

- Test duration of 20,000 cycles

Stripping Inflection Point (SIP)



Phase I - HWTD AASHTO T324 Callanan, NY

Mixture	Binder	RAP, %	Discharge Temp, F	Laydown Temp, F	Plant Type	SIP
12.5mm	PG 64-22	0	310	290	Drum	7,200
12.5mm	PG 64-22	20	320	290	Drum	20,000
12.5mm	PG 64-22	30	305	290	Drum	13,400
12.5mm	PG 64-22	40	330	290	Drum	20,000
12.5mm	PG 58-28	30	305	275	Drum	17,400
12.5mm	PG 58-28	40	330	275	Drum	20,000

Phase I - HWTD AASHTO T324 Pike, NH

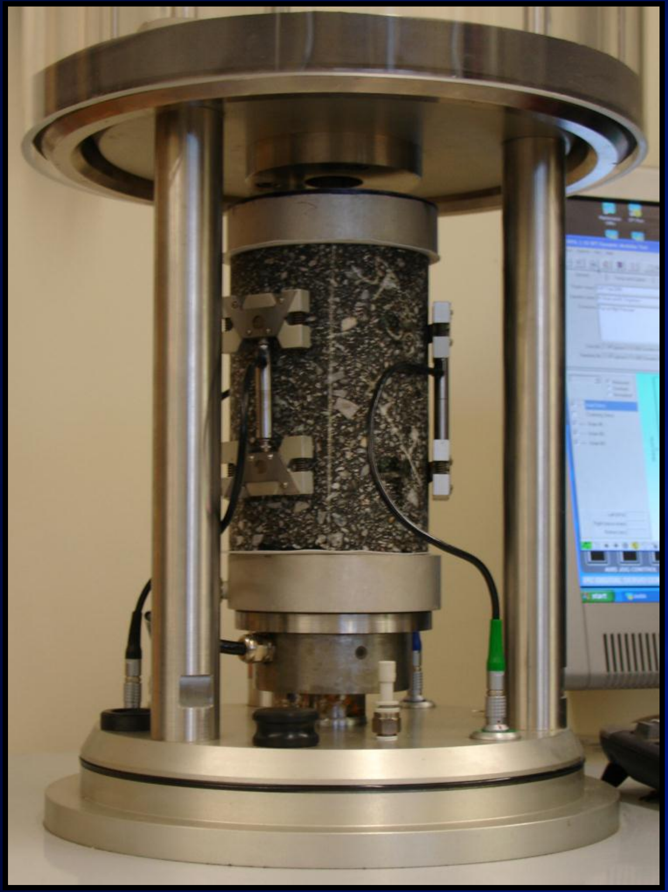
Mixture	Binder	RAP, %	Discharge Temp, F	Laydown Temp, F	Plant Type	SIP
12.5mm	PG 64-28	0	330	300	Drum	20,000
12.5mm	PG 64-28	20	315	310	Drum	20,000
12.5mm	PG 64-28	30	335	315	Drum	20,000
12.5mm	PG 64-28	40	335	315	Drum	20,000

Phase I - HWTD AASHTO T324 Pike, VT

Mixture	Binder	RAP, %	Discharge Temp, F	Laydown Temp, F	Plant Type	SIP
9.5mm	PG 52-34	0	315	315	Batch	700
9.5mm	PG 52-34	20	324	324	Batch	1,600
9.5mm	PG 52-34	30	320	320	Batch	2,050
9.5mm	PG 52-34	40	300	295	Batch	1,450
9.5mm	PG 64-28	0	330	300	Batch	1,350
9.5mm	PG 64-28	20	300	300	Batch	2,100
9.5mm	PG 64-28	30	322	310	Batch	2,650
9.5mm	PG 64-28	40	295	295	Batch	2,900

Dynamic Modulus Results
AASHTO TP62 / TP79

MIXTURE STIFFNESS – Dynamic Modulus

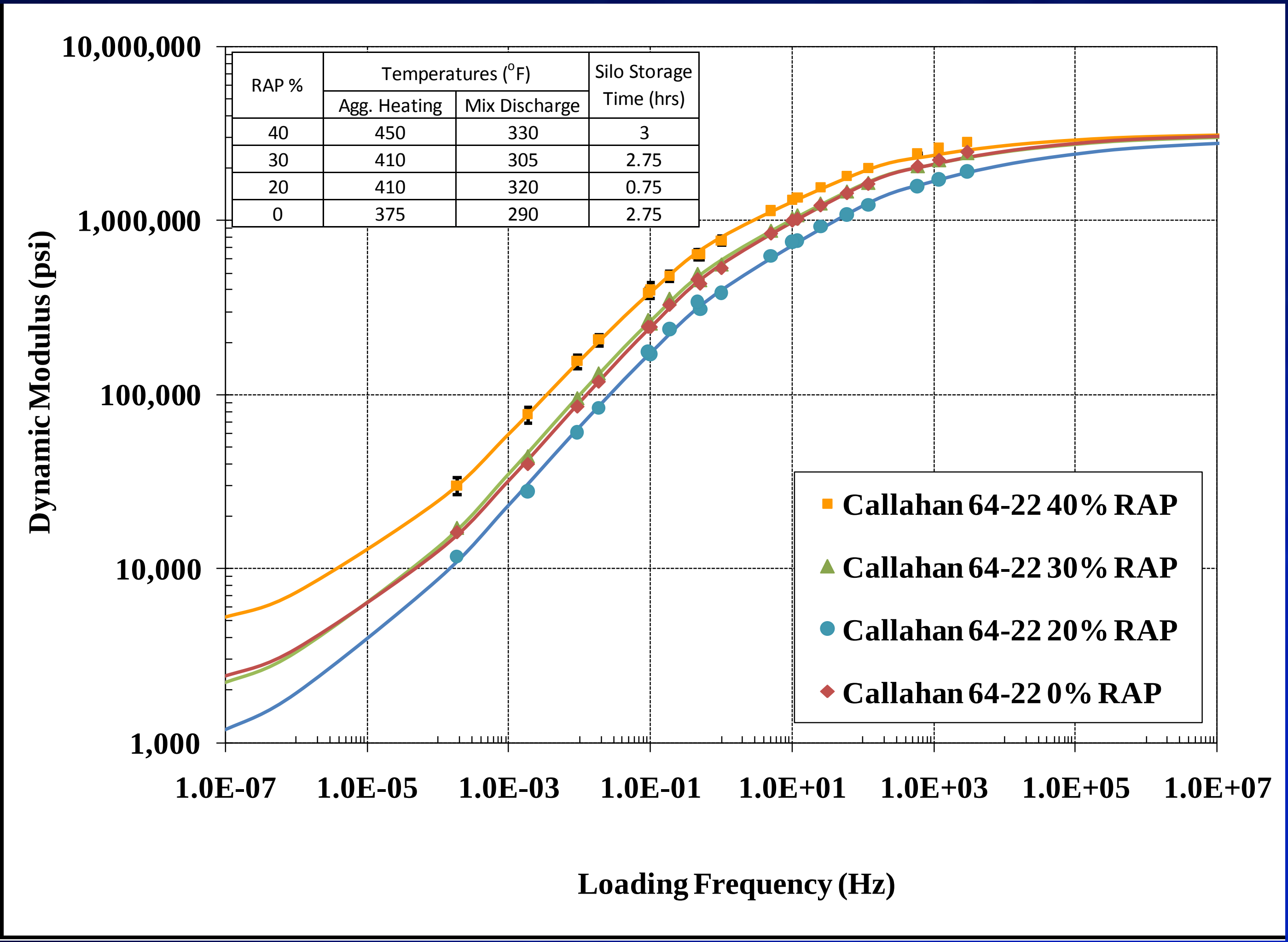


Asphalt Mixture Performance Tester (AMPT)

Temperature	Frequency
4.4°C	25 Hz, 10 Hz, 5 Hz, 1 Hz, 0.5 Hz and 0.1 Hz
20°C	25 Hz, 10 Hz, 5 Hz, 1 Hz, 0.5 Hz and 0.1 Hz
30 or 35°C	25 Hz, 10 Hz, 5 Hz, 1 Hz, 0.5 Hz, 0.1 Hz, and 0.01 Hz

Mixture Master Curve

Varying % RAP



RAP %	Temperatures (°F)		Silo Storage Time (hrs)
	Agg. Heating	Mix Discharge	
40	450	330	3
30	410	305	2.75
20	410	320	0.75
0	375	290	2.75

Mixture Master Curve

Varying % RAP

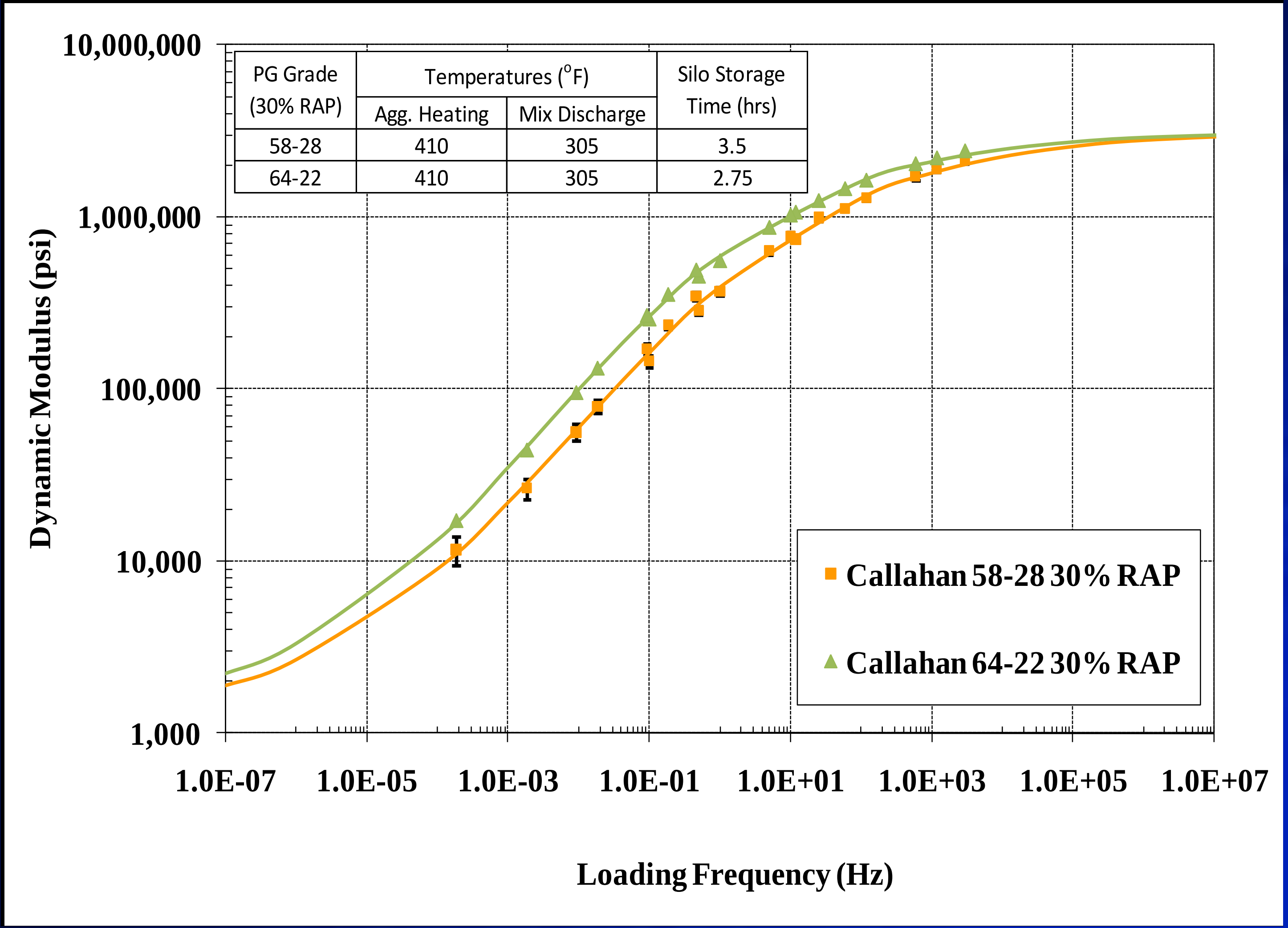
- Generally, as the RAP content increased, the stiffness of the mixtures increased. This was true for the 30% and 40% RAP mixtures.

- However, the increase in the stiffness of the 30% RAP mixture was not significant in comparison to the control mixture.

- Moreover, the 20% RAP mixture had lower |E*| than the control mixture. This mixture was stored in the silo for a much shorter time which illustrates the significance of storage time on the stiffness of the mixtures.

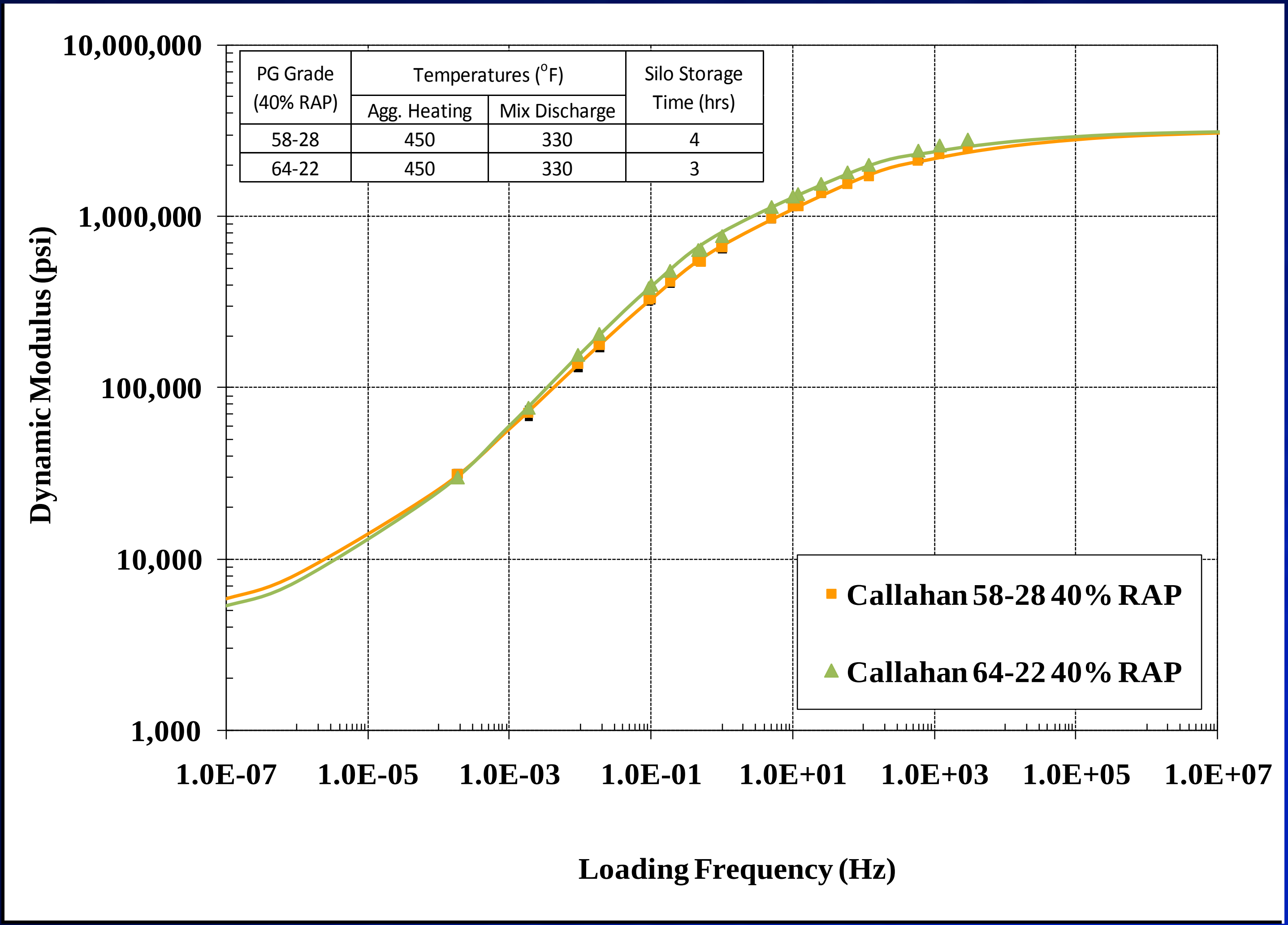
Mixture Master Curve

Same % RAP, Similar Production Parameters, Vary Binder Type



Mixture Master Curve

Same % RAP, Similar Production Parameters, Vary Binder Type



Mixture Master Curve

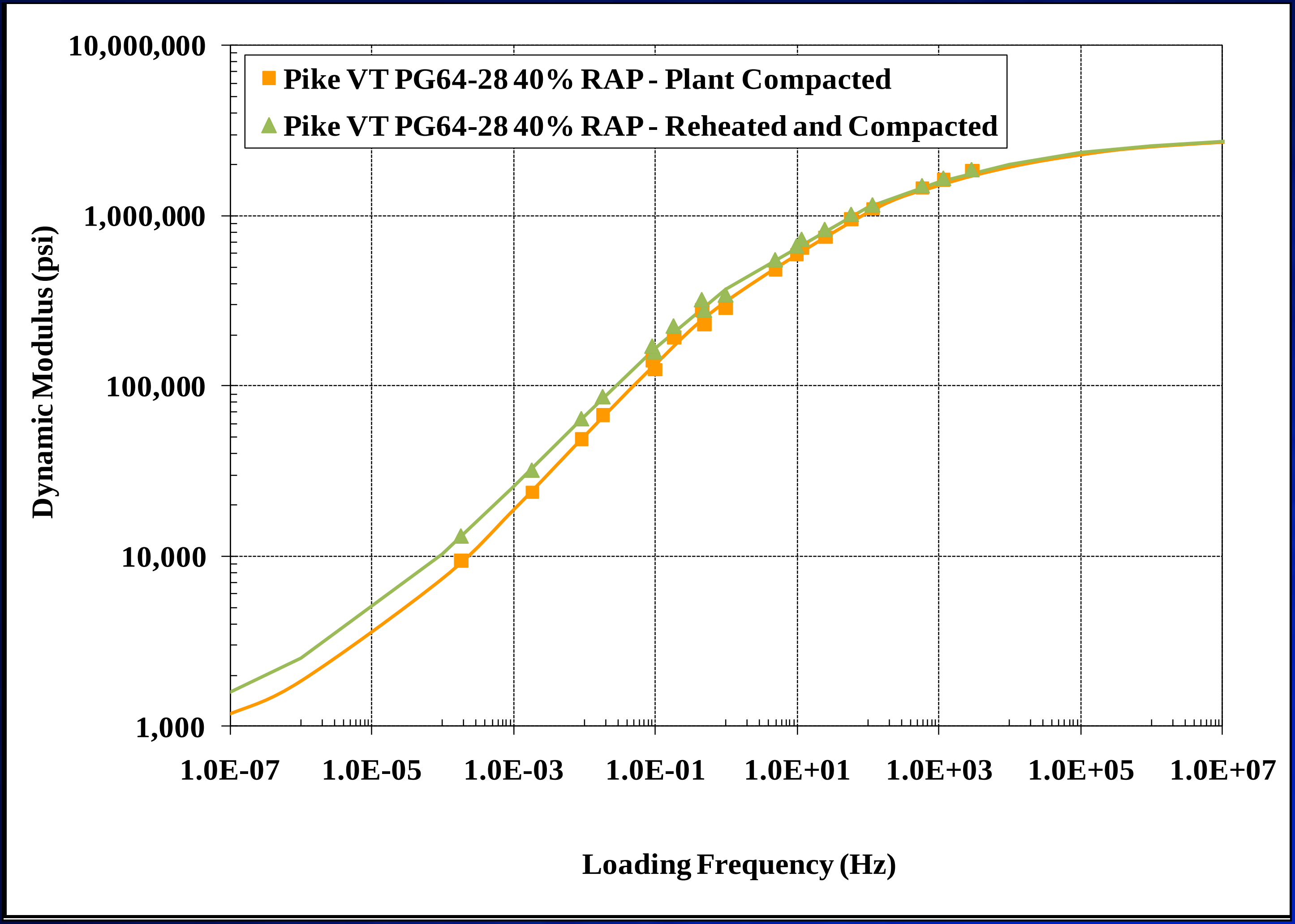
Same % RAP, Similar Production Parameters, Vary Binder Type

- Data suggests the use of a softer binder can mitigate the stiffing due to the addition of high percentages of RAP in the mixture (First Figure).

- Data also indicates that longer storage times may nullify the possible benefit of the softer asphalt binder (Second Figure).

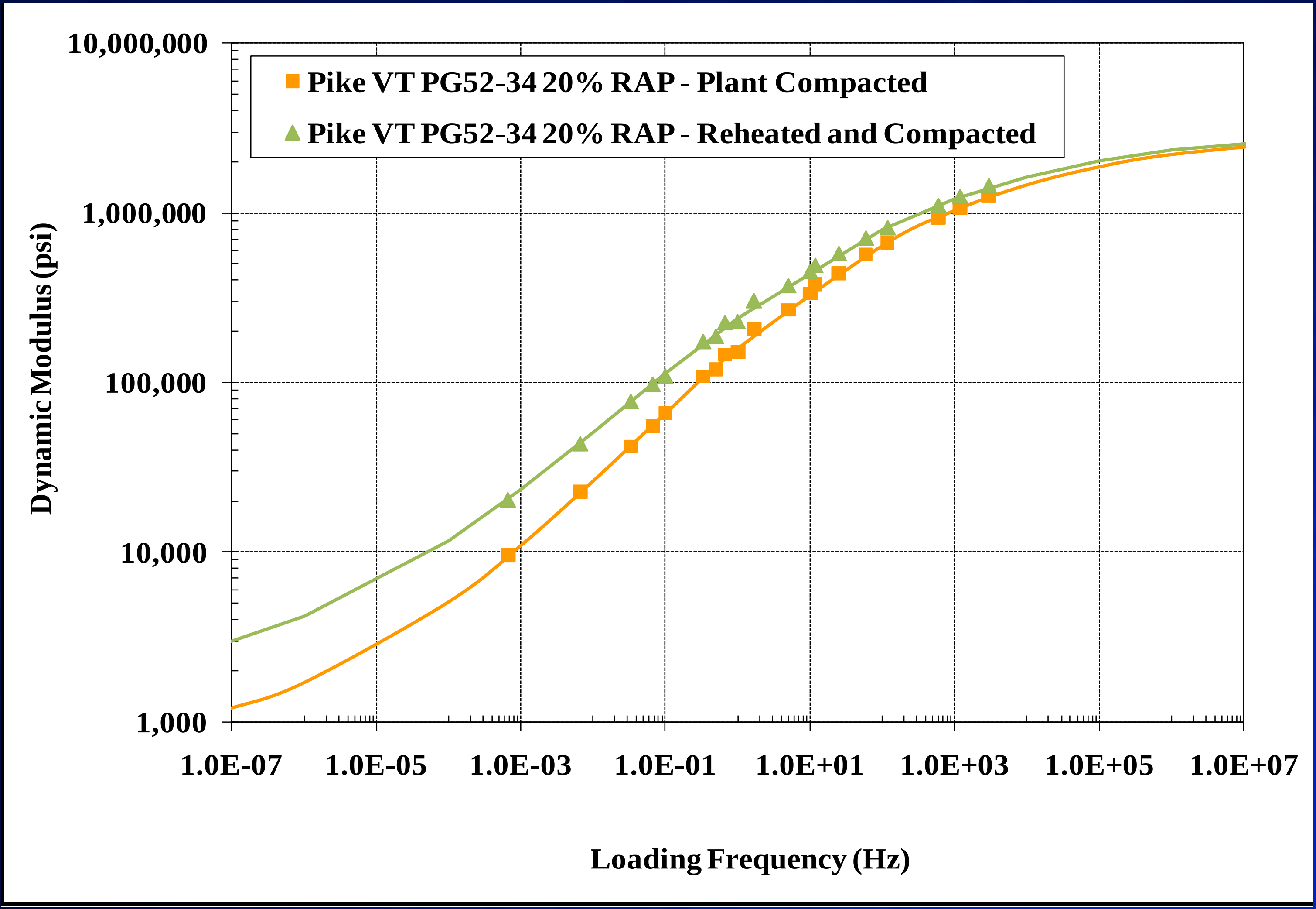
Mixture Master Curve

Plant vs. Laboratory Reheated



Mixture Master Curve

Plant vs. Laboratory Reheated



Mixture Master Curve

Plant vs. Laboratory Reheated

- The data indicated that the reheated mixture exhibited higher stiffness than the mixtures compacted at the plant. This trend was fairly consistent for the sets of mixtures tested.

Mixture Master Curve

- Overall, when averaging the dynamic modulus at the different test temperatures and loading frequencies, the increase in mixture modulus due to the addition of RAP followed the following trend:

Plant QC Lab Compacted

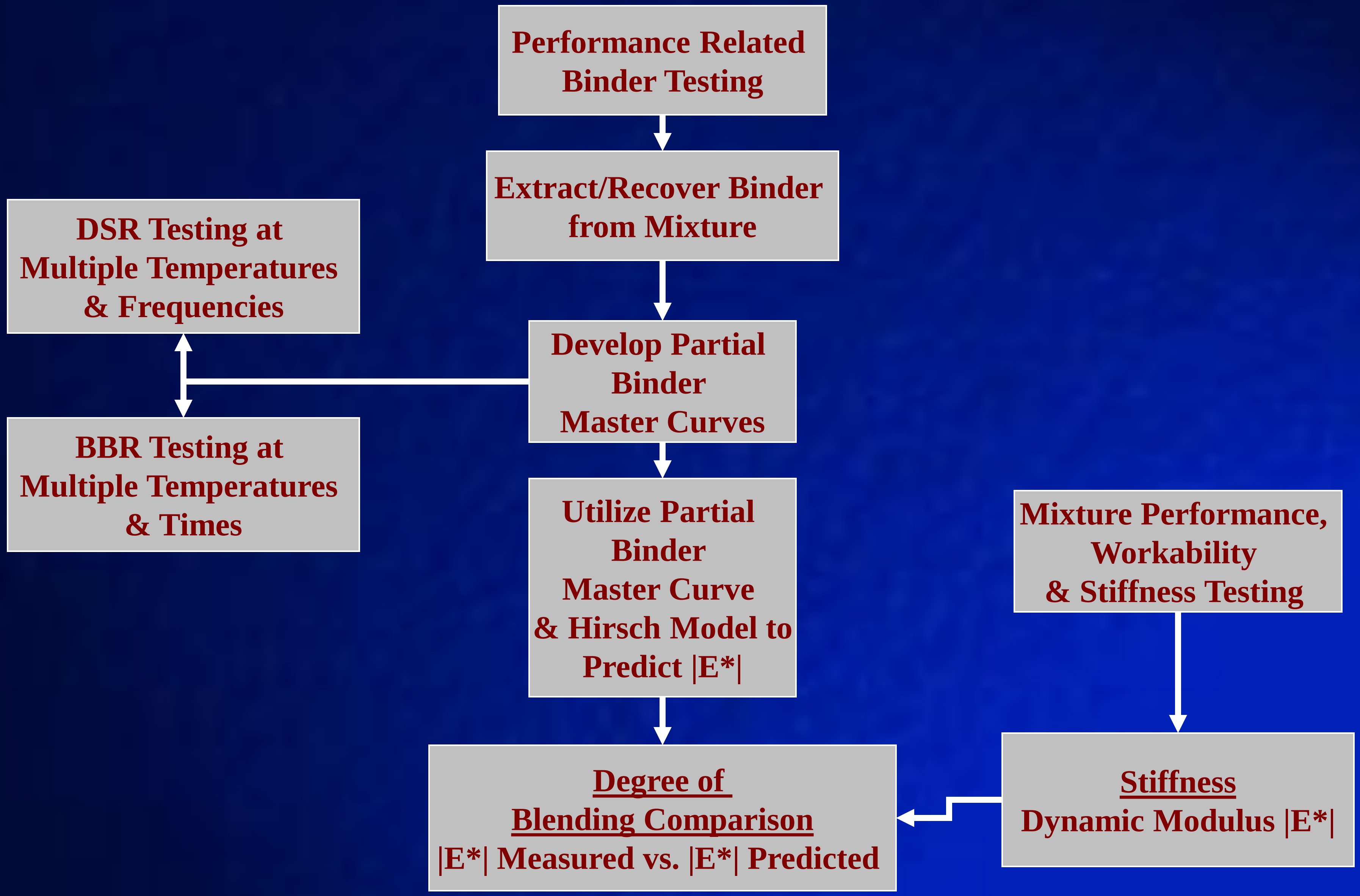
- 0 to 20% RAP: 8% increase in mixture modulus
- 0 to 30% RAP: 29% increase in mixture modulus
- 0 to 40% RAP: 49% increase in mixture modulus

Loose Mix Reheated and Compacted

- 0 to 20% RAP: 17% increase in mixture modulus
- 0 to 30% RAP: 24% increase in mixture modulus
- 0 to 40% RAP: 27% increase in mixture modulus

Recovered Binder Master Curves & Blending Analysis

Blending Analysis Methodology



Binder Master Curves

- To completely characterize the stiffness characteristics of the recovered binders, master curves were constructed.

- Master curves required Dynamic Shear Rheometer (DSR) and Bending Beam Rheometer (BBR) testing at multiple temperatures.

Binder Master Curves

	Intermediate Temperatures						Low Temperature
Test Device	Dynamic Shear Rheometer (DSR)						Bending Beam Rheometer (BBR)
Temperature, °C	10	22	34	46	58	70	-10, -16, -22, -28
Strain Level, %	0.1	1	1	5	10	10	n/a
Frequency (ω), rad/sec	0.100, 0.159, 0.251, 0.398, 0.631, 1.000, 1.59, 2.51, 3.98, 6.31, 10.0, 15.9, 25.1, 39.8, 63.1, 100						n/a
Time, sec.	n/a						8, 15, 30, 60, 120, 240

Binder Master Curves

- Data were shifted so that the resulting master curve would fit the shape of the Christensen-Anderson model given below, which is a standard model applied to asphalt binders.

$$G^*(\omega) = G_g\left[1+\left(\frac{\omega_c}{\omega_r}\right)^{\frac{\log 2}{R}}\right]^{\frac{-R}{\log 2}}$$

<u>Where:</u>

$G^*(\omega)$ = complex shear modulus
G_g = glass modulus assumed equal to 1GPa
ω_r = reduced frequency at the defining temperature, rad/sec
ω_c = cross over frequency at the defining temperature, rad/sec
ω = frequency, rad/sec
R = rheological index

Blending Analysis Procedure

- The degree of blending/mixing between the RAP and the virgin binders will have a significant impact on the volumetrics and performance of HMA containing RAP.

- A method was developed by Bonaquist to assess RAP and virgin binder blending by comparing the measured dynamic modulus |E*| of the mixtures with predicted dynamic modulus from binder testing of as-recovered binders

Steps of Blending Analysis Procedure

Step I: Construct Partial Master Curve at Reference Temperature (Tr).

Step II: Calculate G* Values Corresponding to the Test Temperature and Frequency of Measured |E*|.

Step III: Predict |E*| Values Corresponding to G* using the Hirsch Model.

Step IV: Compare Measured E* Predicted |E*|.

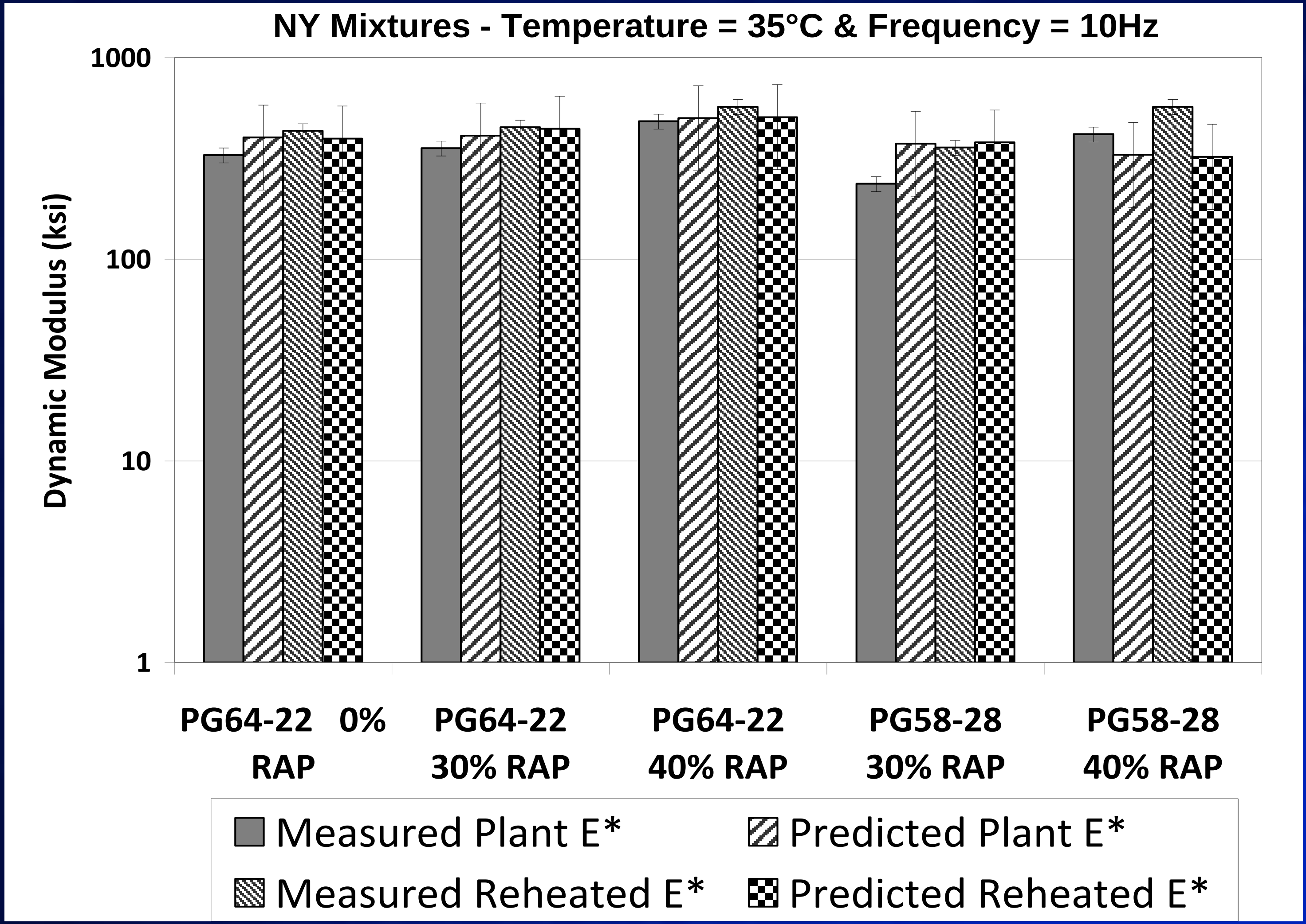
Quality of Blending

- At each temperature and frequency of dynamic modulus test, a measured |E*| (provided by testing) and a predicted |E*| (provided by steps I to III) were collected.
- The predicted and measured |E*| were then compared statistically to determine if good or poor degree of blending exists.
- The confidence interval (error bars) was calculated for the measured and the predicted |E*| .

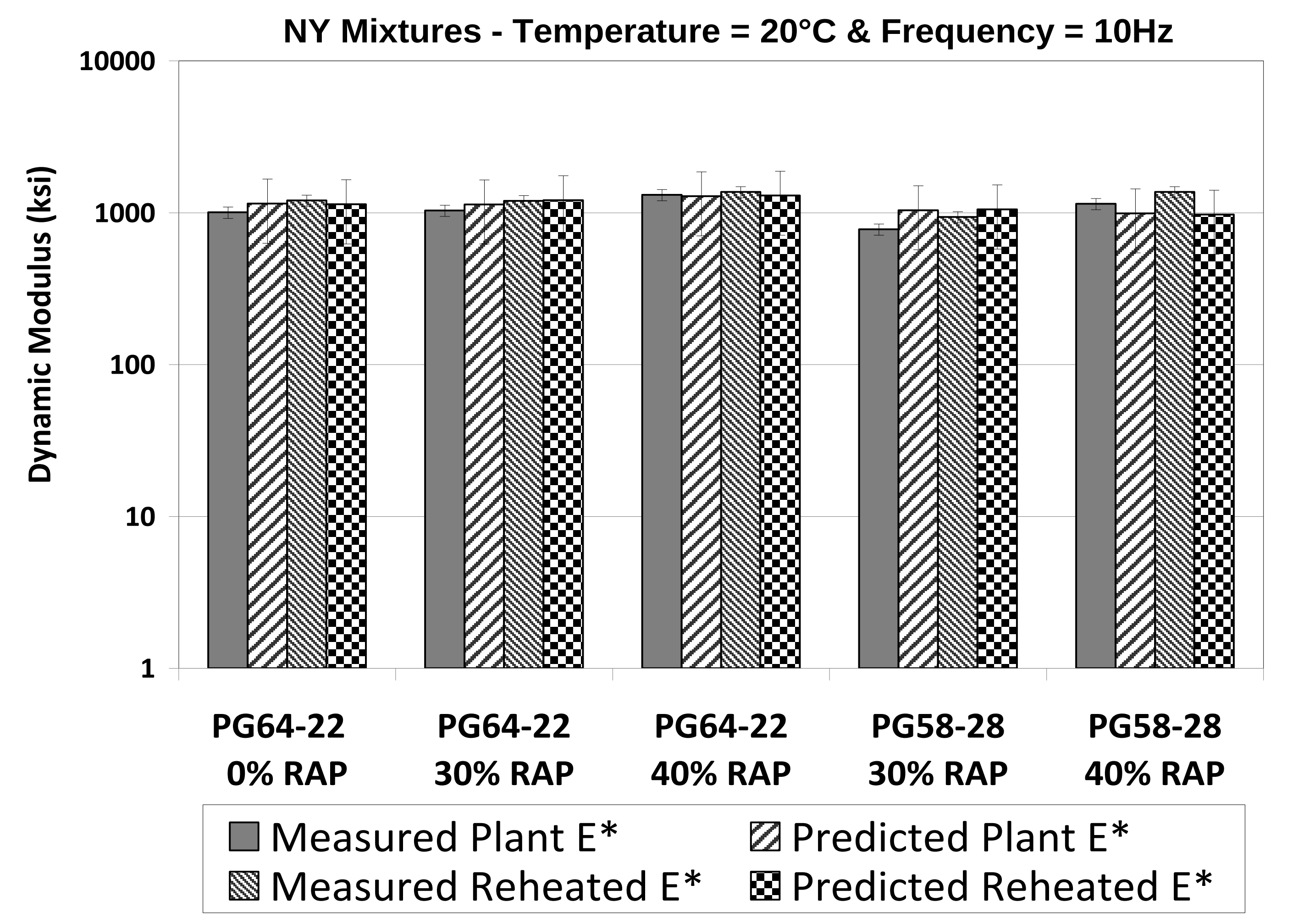
Quality of Blending

- If the two confidence intervals overlap, it is concluded that a good degree of blending exists.

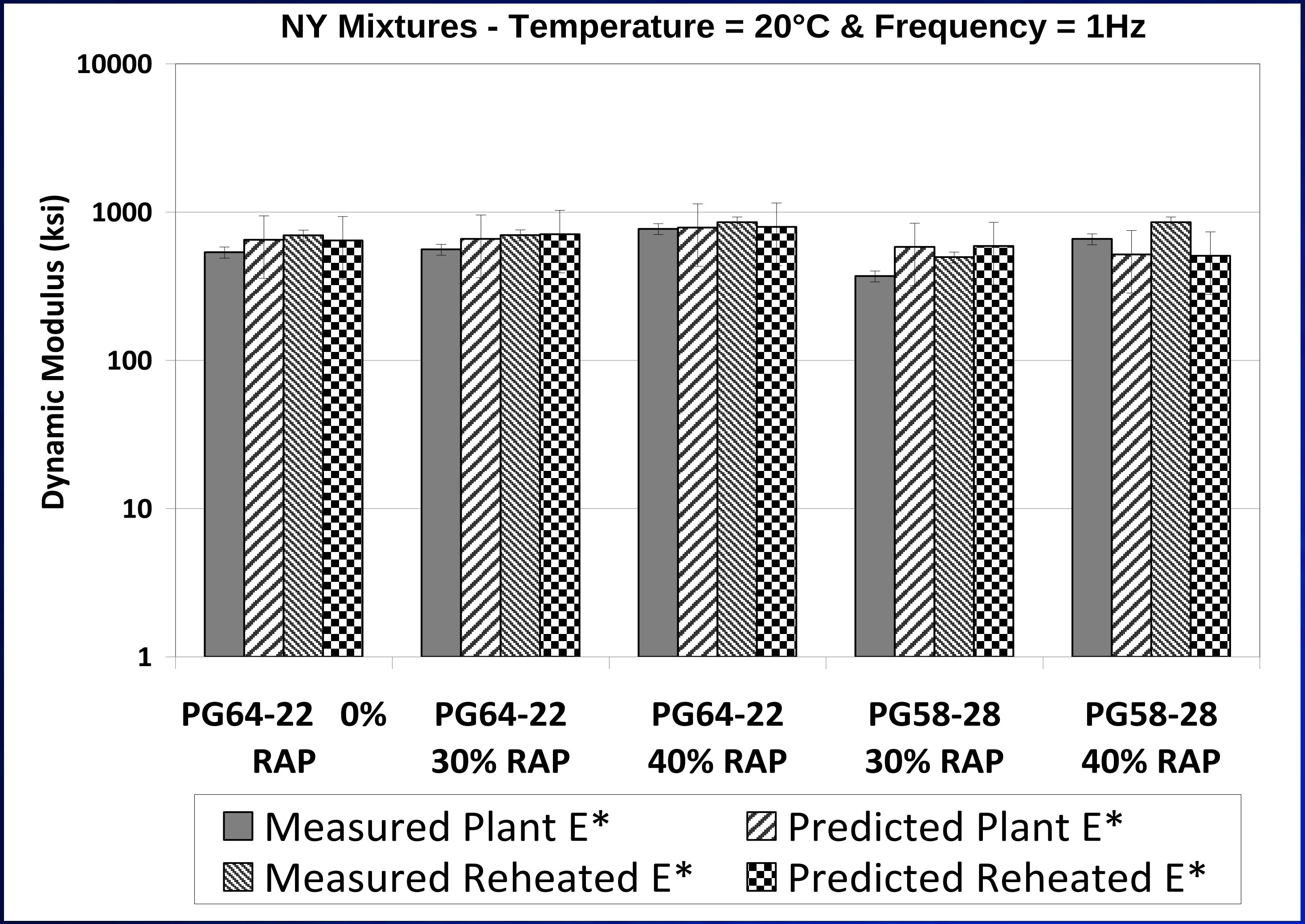
Blending Analysis – NY 35C/10Hz



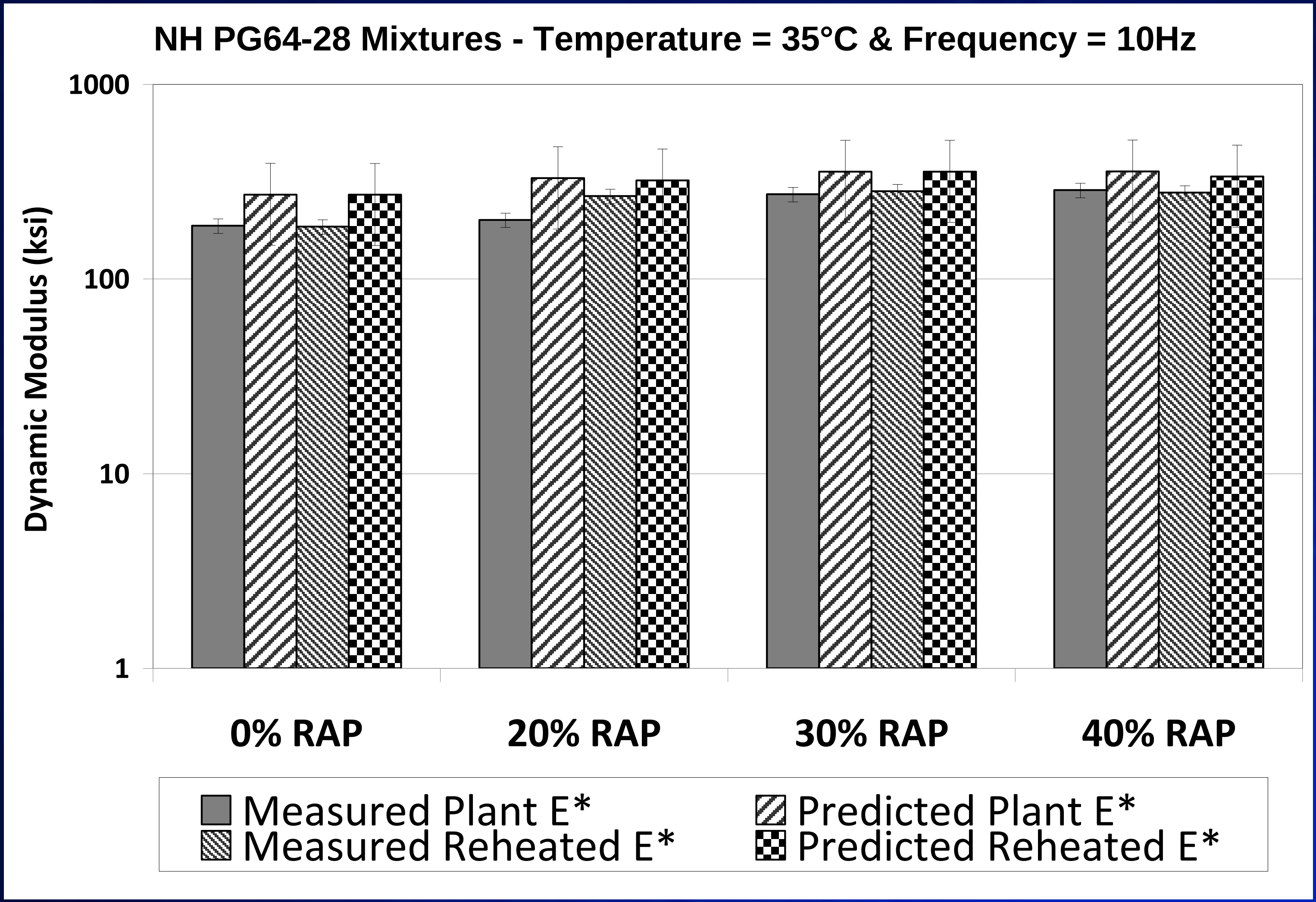
Blending Analysis – NY 20C/10Hz



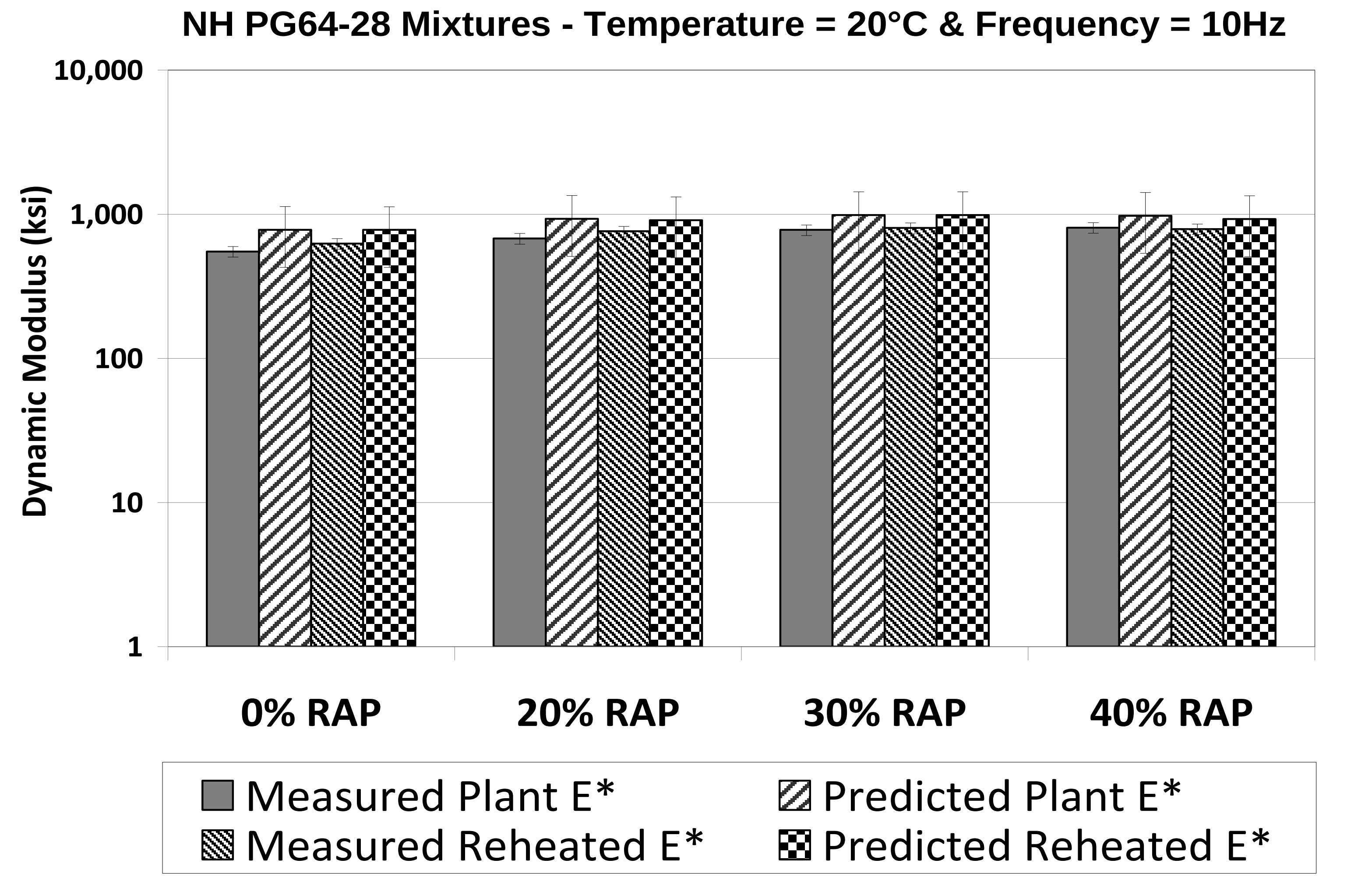
Blending Analysis – NY 20C/1.0Hz



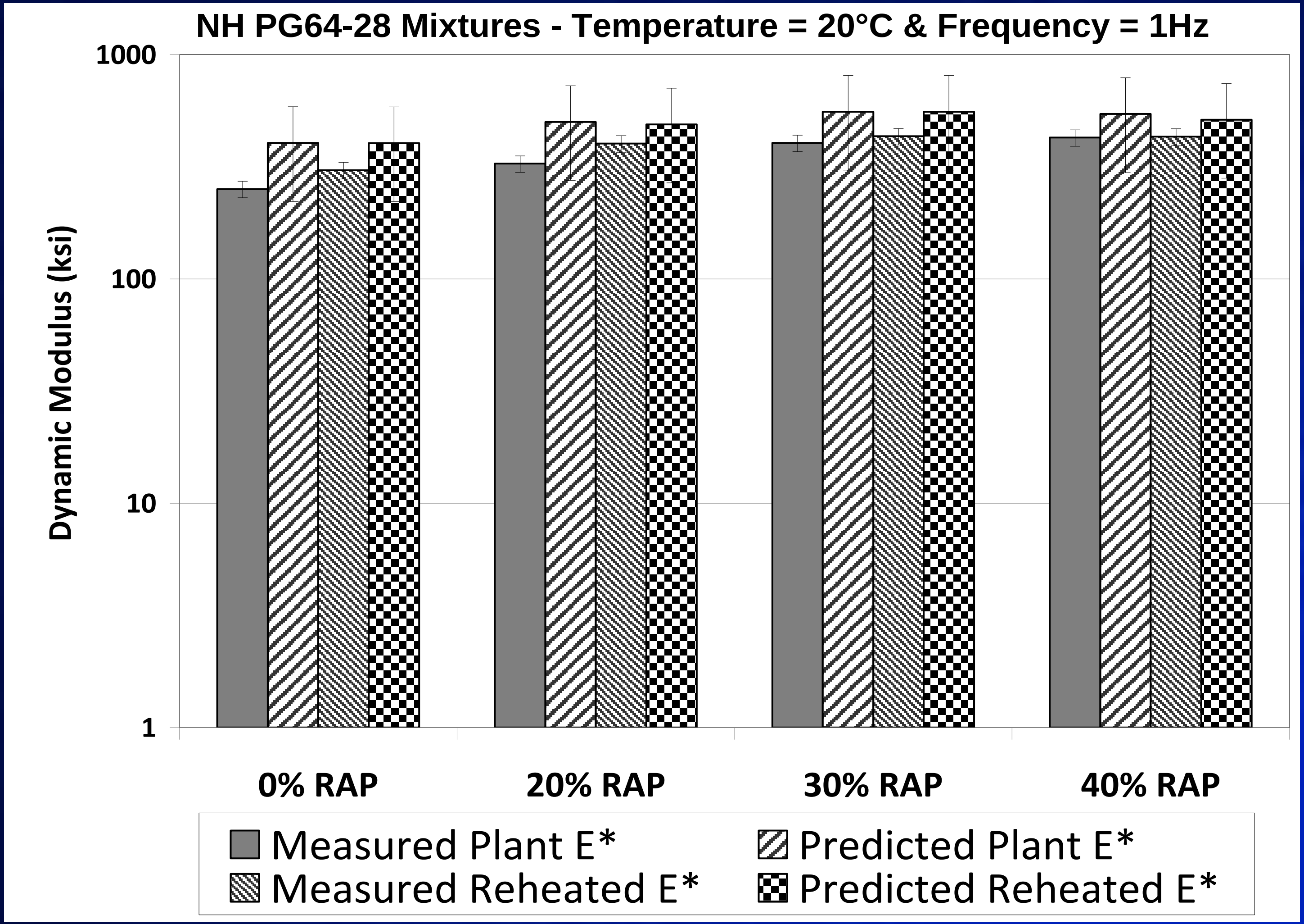
Blending Analysis – NH 35C/1.0Hz



Blending Analysis – NH 20C/10Hz



Blending Analysis – NH 20C/1.0Hz



Observations

- For the majority the test data indicated there was a good degree of blending for all of the mixtures tested.

- The quality of blending may have been affected by the plant discharge temperatures. In some cases mixtures with lower discharge temperatures showed less agreement between predicted and measured |E*|.

Mixture Cracking

Texas Overlay Test

- Test Temperature = 15ºC (59ºF)
- Test Termination at 1,200 cycles or 93% Load reduction
- Testing in accordance with Tex-248-F

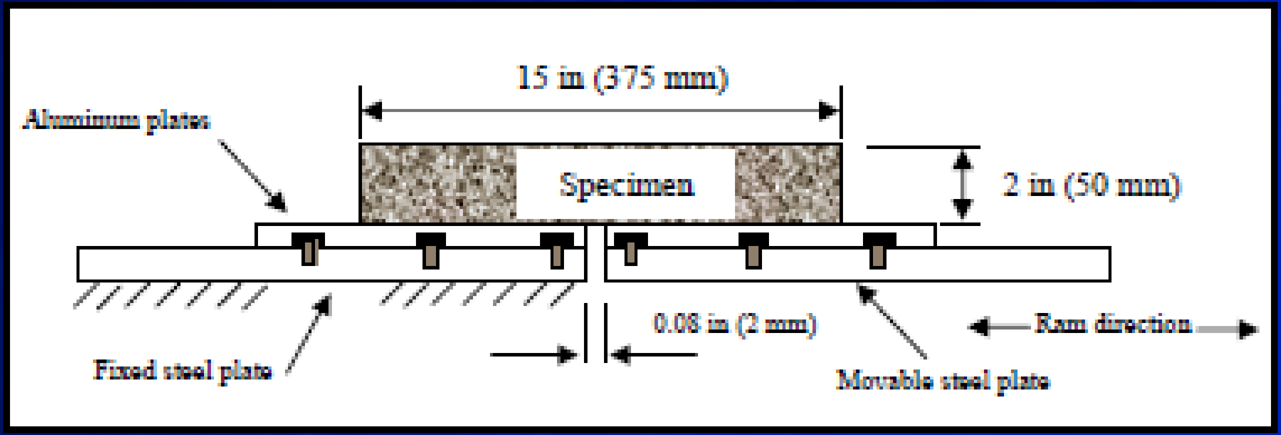


Diagram from: Zhou and Scullion "Overlay Tester: A Rapid Performance Related Crack Resistance Test" Report No. FHWA/TX-05/0-4467-2 (2005).

Overlay Test Results – NY Mixtures

Mixture	NMAS	Percent RAP	Binder Grade	Average OT Cycles to Failure
New York	12.5 mm	0%	PG64-22	111
		20%	PG64-22	121
		30%	PG64-22	90
		40%	PG64-22	22
		30%	PG58-28	70
		40%	PG58-28	13

Overlay Test Results – NH Mixtures

Mixture	NMAS	Percent RAP	Binder Grade	Average OT Cycles to Failure
New Hampshire	12.5 mm	0%	PG64-28	279
		20%	PG64-28	68
		30%	PG64-28	113
		40%	PG64-28	50

Overlay Test Results – VT Mixtures

Mixture	NMAS	Percent RAP	Binder Grade	Average OT Cycles to Failure
Vermont	9.5 mm	0%	PG52-34	1,200
		20%	PG52-34	1,200
		30%	PG52-34	217
		40%	PG52-34	112
		0%	PG64-28	1,032
		20%	PG64-28	127
		30%	PG64-28	126
		40%	PG64-28	44

Overlay Test - Observations

- Generally, the cracking resistance was reduced as the percentage of RAP in the mixture increased.

- This data agrees with the stiffness testing which indicated that the addition of RAP stiffened the resultant mixture. Stiffer mixes generally are more susceptible to cracking at moderate to high levels of deflection.

Overlay Test - Observations

- The data indicated that the use of the softer grade binder for the New York mixtures did not have the desired effect of improving the cracking resistance of the mixtures.

- The softer binder improved the cracking characteristics of the Vermont RAP mixtures.

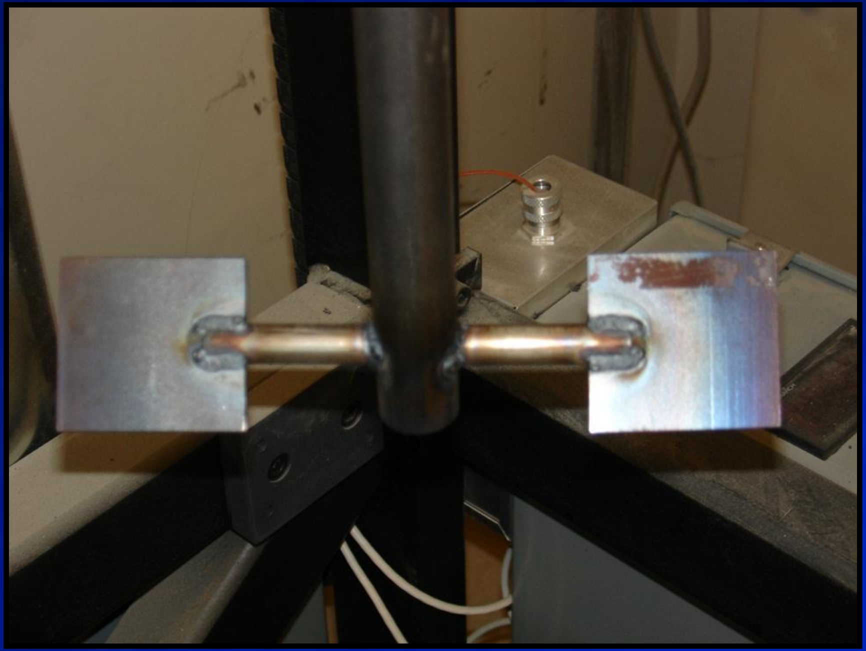
Mixture Workability

Mixture Workability

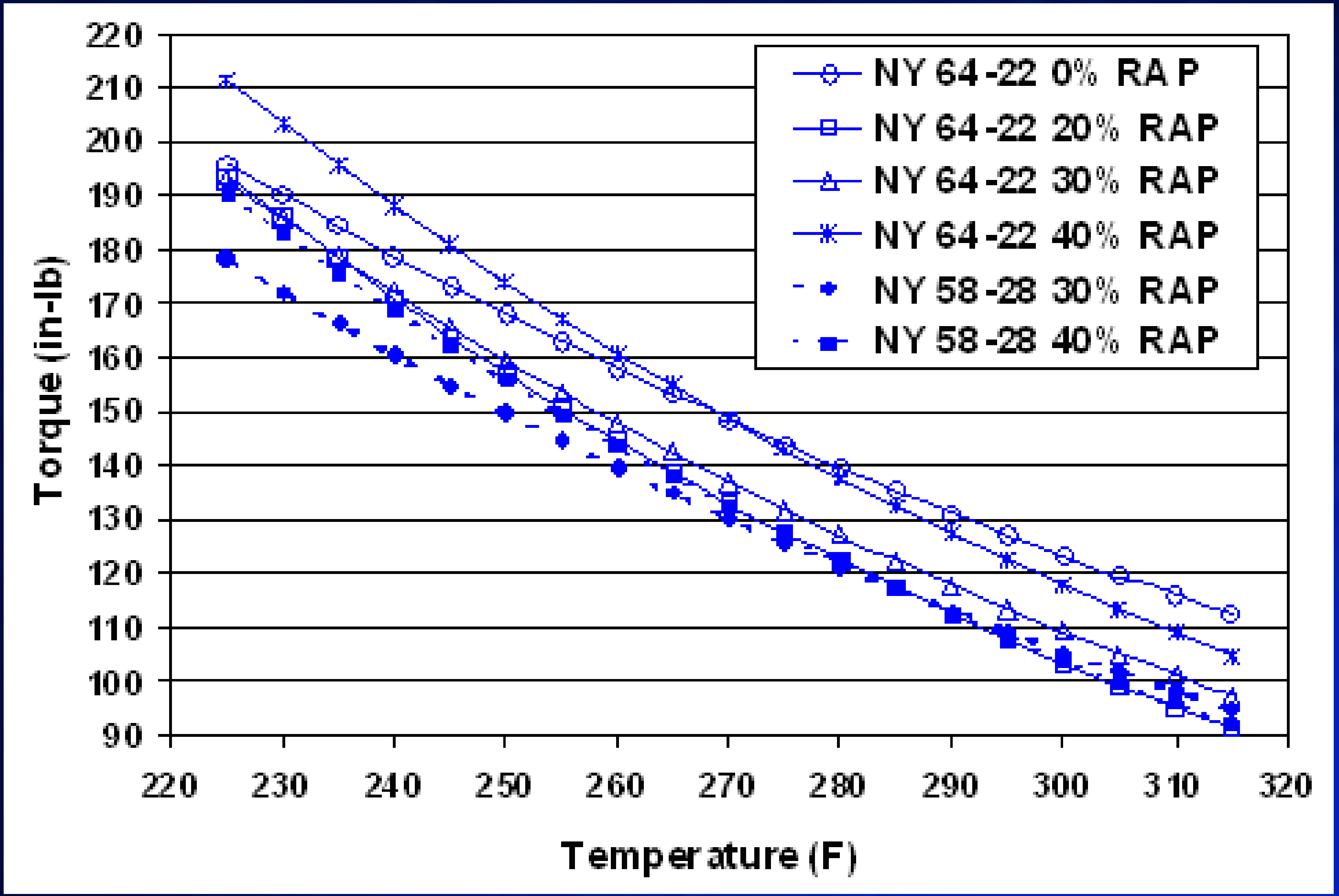
- **Because of the potential decrease in mixture workability due to the incorporation of RAP in the mixtures, workability evaluations of each of the plant produced mixtures were completed.**

- **These evaluations were conducted using a HMA workability device developed by the University of Massachusetts Dartmouth Highway Sustainability Research Center (HSRC).**

Asphalt Workability Device (AWD)



Workability Results – Callanan, NY



Mixture Workability - Observations

- For the Phase I mixtures, the addition of RAP to the mixtures decreased the mixture workability as compared to the respective control mixture without RAP.
- The workability reductions were generally larger as the amount of RAP increased.
- The NY data suggested that the use of the softer binder could improve the workability of RAP mixtures to a level comparable to the control mixture produced with the stiffer binder.

Conclusions

- The test results collected in this study showed that both plant production and silo storage practices, as well as how the material is handled prior to specimen fabrication (i.e. – reheating loose mix or not) will have an impact on the mixture performance.

- In general, discharge temperatures and silo storage factors were found to highly influence mixture stiffness and cracking properties.

Conclusions

- The data indicated that the reheated mixtures exhibited significantly higher stiffness than the mixtures compacted at the plant. Also, the sensitivity of mixture stiffness to increased RAP content decreased when reheated as compared to the sensitivity (or change in dynamic modulus) found when evaluating the plant QC lab compacted specimens.

Conclusions

- The analysis method used to evaluate the degree of blending between the RAP and virgin binders illustrated that certain production parameters (discharge temperature) may have an impact on the relative degree of blending between the RAP and virgin binders.

Conclusions

- The Overlay Tester results showed that the cracking resistance was reduced as the percentage of RAP in the mixture increased.

- This data agrees with the stiffness testing of the mixtures and the rheological parameters obtained from constructing the master curves for the as-recovered and PAV aged binders.

Conclusions

- The data indicated that the use of the softer grade binder for the New York mixtures did not have the desired effect of improving the cracking resistance of the mixtures. However, the softer binder improved the cracking characteristic of the Vermont RAP mixtures.

Conclusions

- Among the New Hampshire and the New York mixtures, only the New York mixture with 30 percent RAP failed moisture damage in the HWTD. The discharge temperature for this mixture was lower (305°F) than all the mixtures that passed the moisture susceptibility test which were discharged above 320°F.

Conclusions

- The workability data indicated that the addition of RAP decreased the mixture workability as compared to the respective control mixture without RAP.

- The workability reductions were generally larger at higher RAP contents. Data suggested that the use of the softer binder could improve the workability of RAP mixtures.

Research - Phase II

- Additional mixtures evaluated based on preliminary results obtained during Phase I
  - Higher PG grade mixtures
  - Silo storage study

Thank You