U.S. Department of Transportation
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RAP Binder Blending Study

Audrey Copeland & Raj Dongre

RAP Expert Task Group Meeting
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Acknowledgements

- Satish Belagutti
- David Heidler
- Darnell Jackson
- Eugeniu Morari
- Scott Parobeck
- Monty Simpson

Outline

- Current Guidelines & Remaining Challenges
- Summary of current binder blending work
- Problem statement
- FHWA mini experiment
- Results Discussion & Implications
- Future Work

Current Guidelines

- AASHTO M 323 *Standard Specification for Superpave™ Volumetric Mix Design*

Recommended Virgin Asphalt Binder Grade	**Percent (%) RAP**
No change in binder selection	< 15
Select virgin binder grade one grade softer than normal	15 – 25
Follow recommendations from blending charts	> 25

- Based on significant blending between virgin and RAP binder
- Based on limited aging data & climate variability
- Did not consider processing (i.e. fractionation) or plant production effects
- Softer binder grade requirements

Remaining Challenges

- Blended virgin and RAP binder qualities
  - High RAP
  - Polymer-modified binders
- Stiffening of the mix from high RAP and cracking performance
  - Pre-mature & low temperature cracking

Source: Jones 2009 Survey

Blending thoughts…

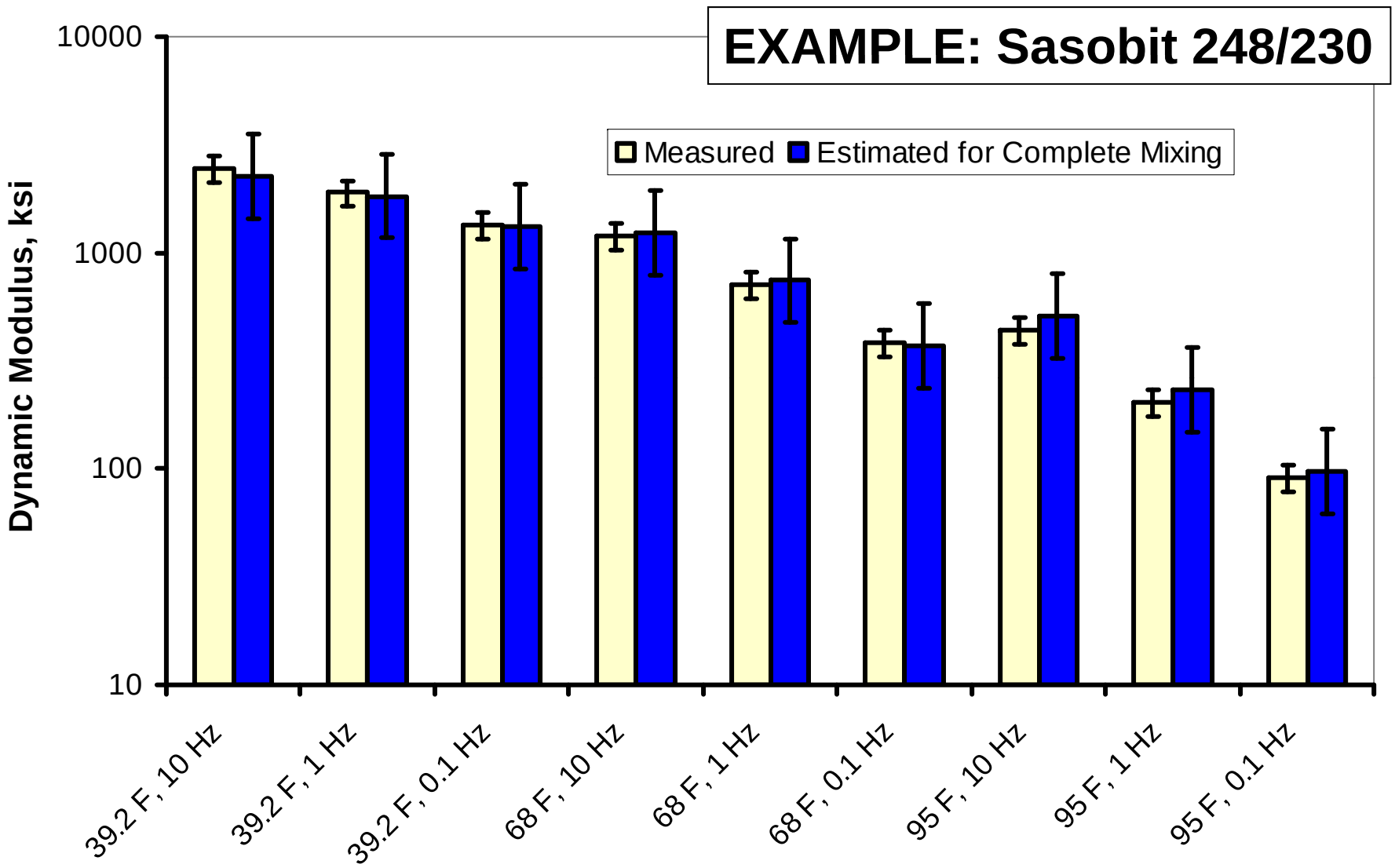
- No procedure to determine blending that “actually” occurs in the mix.
- However, do we need a method to determine blending?
- Or, do we just need to ensure we are getting required properties for performance.

Recent Blending Studies

- Determining blending based on mix properties
  - Bonaquist – WMA and HMA
  - FHWA – WMA and HMA
- Blending based on mix time and temperature
  - Grzybowski – Virgin Aggregate with RAP Aggregate

RAP + Virgin Binder Blending BONAQUIST APPROACH

- Determine volumetric properties
- **Measure** mix dynamic modulus, **E*** (AMPT)
- Extract and recover binder (assumes total blending)
- Perform DSR tests to obtain binder modulus master curve
- **Estimate E*** based on effective shear modulus, G*, using Hirsch model
- Compare estimated E* to measured E*
  - Overlap or close values indicates good mixing



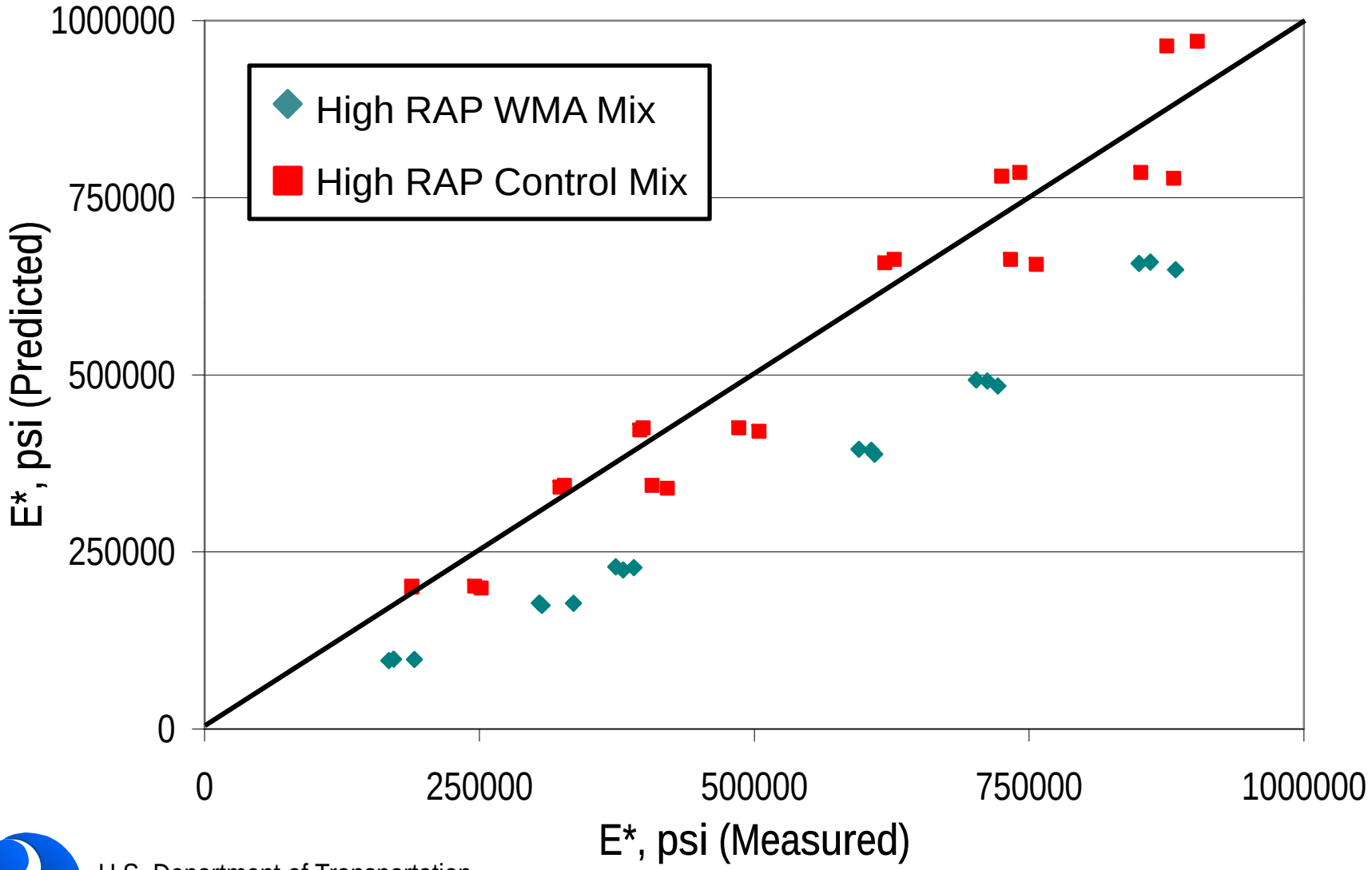
Ray Bonaquist, P.E.

RAP + Virgin Binder Blending FHWA Analysis

- Measure mix dynamic modulus, E* (AMPT)
- Extract and recover binder (assumes total blending)
- Measure recovered binder shear modulus, G* (DSR)
- Estimate Mix E* from recovered Binder G* using the Hirsch Model and Witczak Models
- Compare Estimated E* to Measured E* for the hot-mix
  - Overlap indicates good mixing

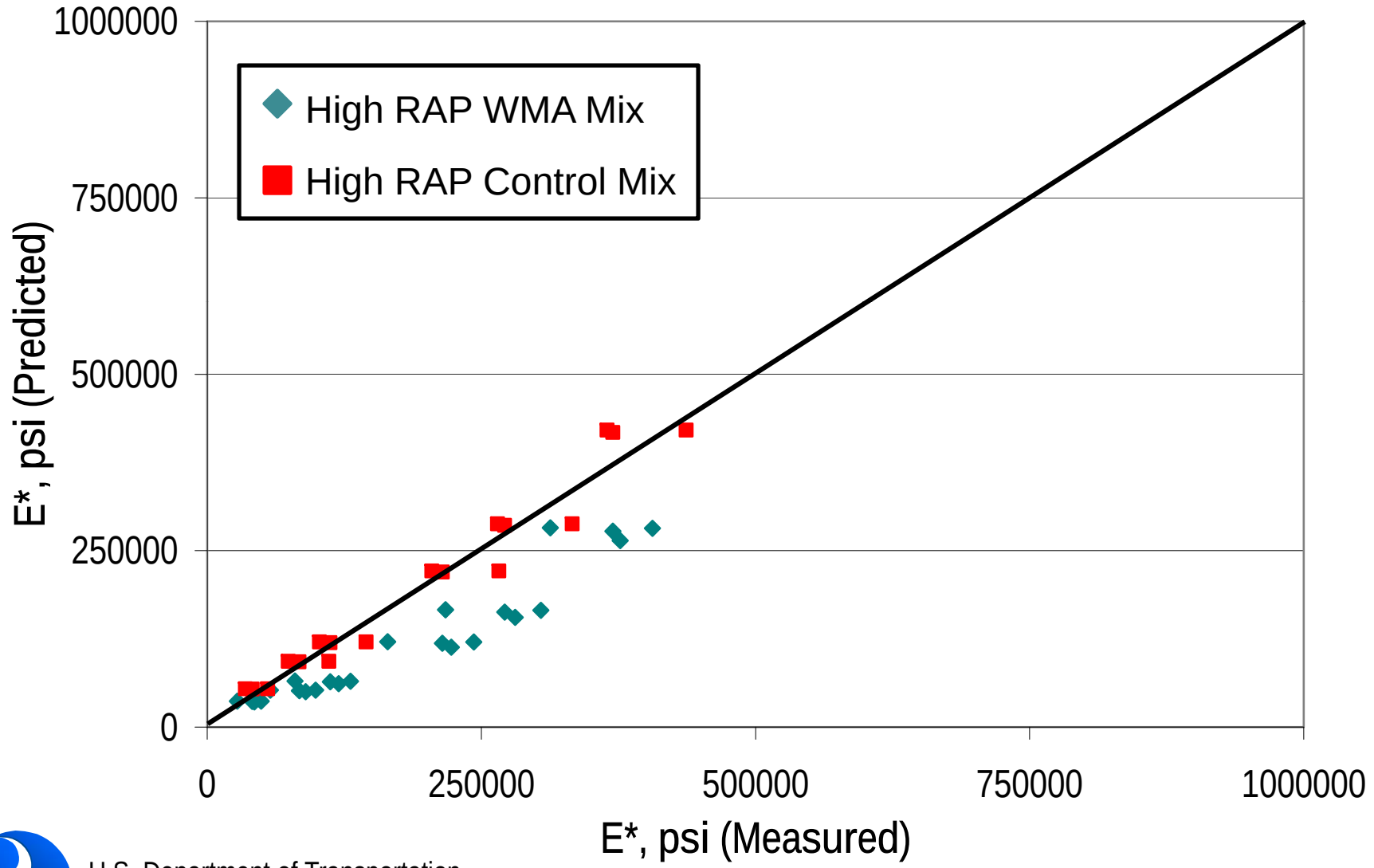
Predicted vs. Measured E* Values

(Hirsch Model at 21.1º C)



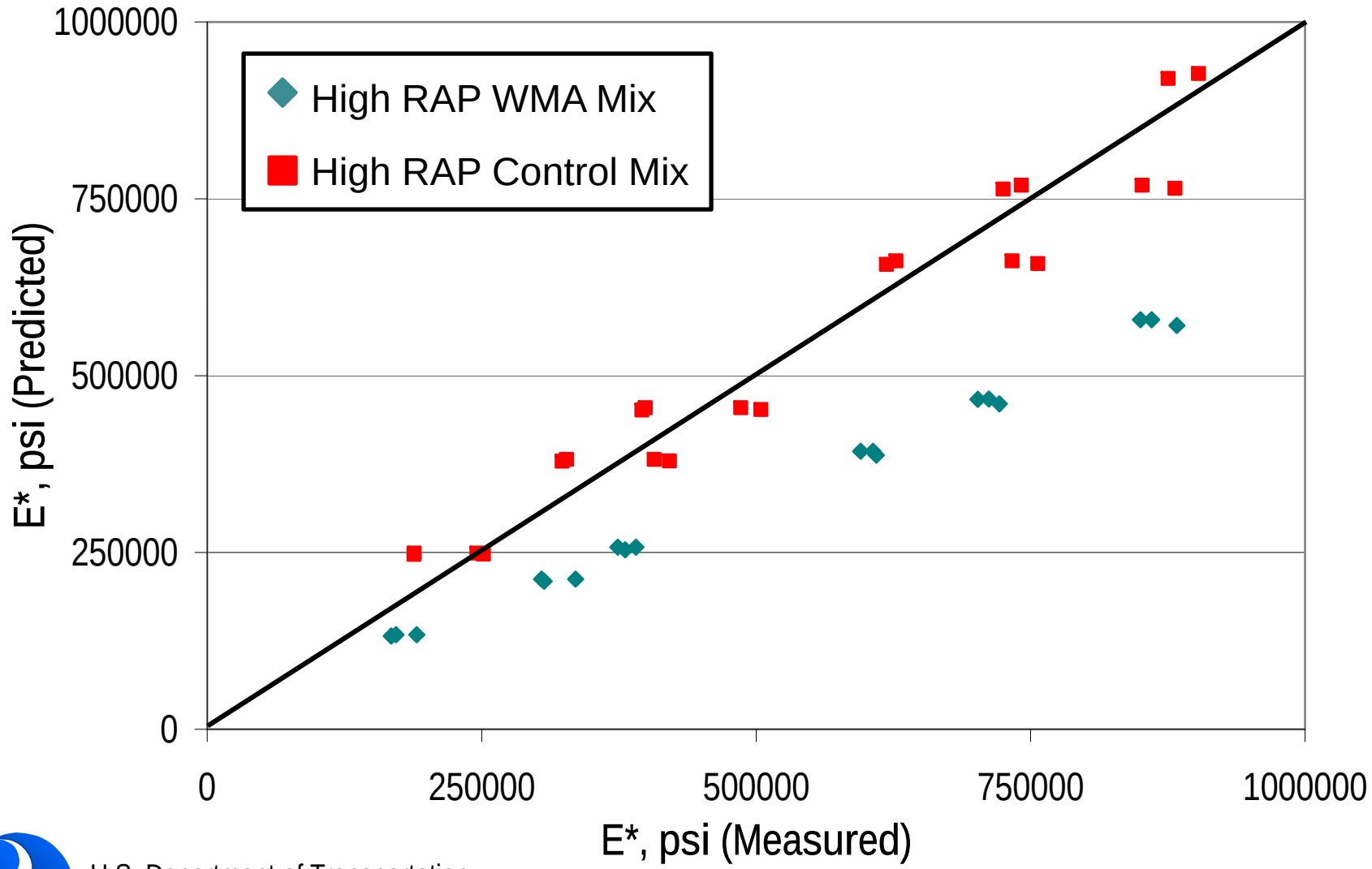
Predicted vs. Measured E* Values

(Hirsch Model at 37.8º C)



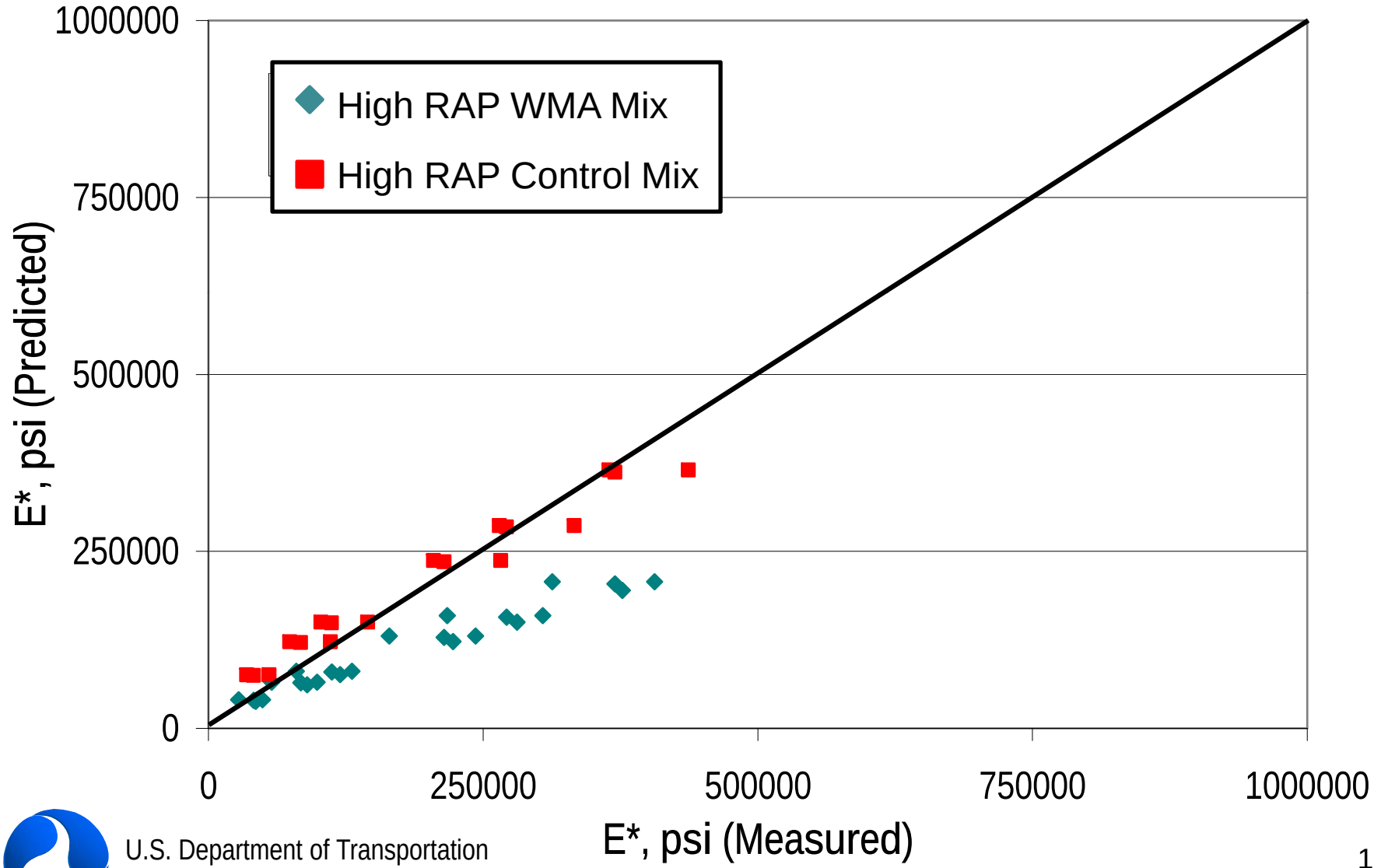
Predicted vs. Measured E* Values

(Witczak Model at 21.1º C)



Predicted vs. Measured E* Values

(Witczak Model at 37.8º C)

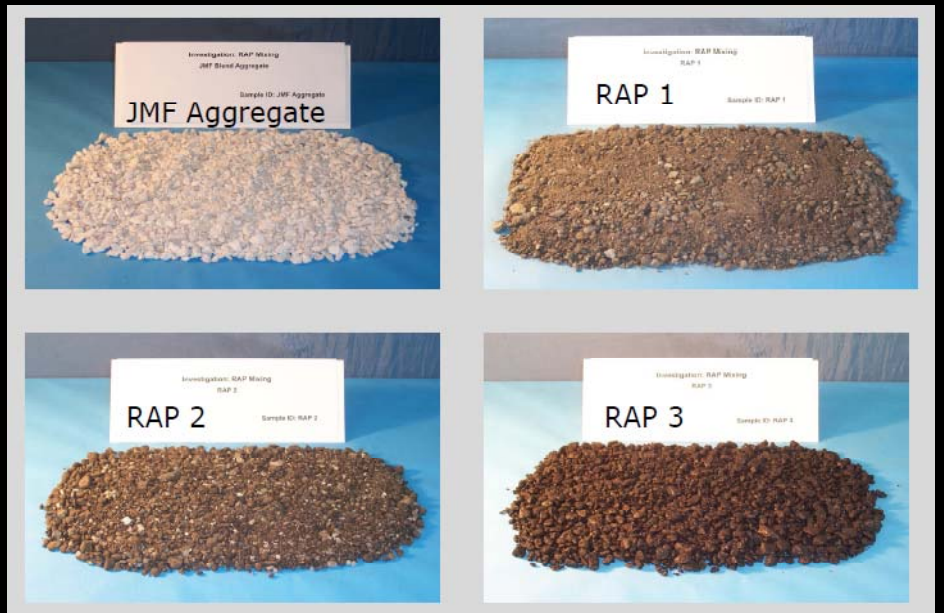


Take-away

- The method for evaluating mix blending has merit.
- Significant blending may not be happening with RAP & WMA at lower mix temperatures.
- For RAP & WMA, the measured values were higher than predicted values
  - Is significant blending necessary?

Grzybowski Summary

- Complete blending of RAP Binder and Virgin Binder Requires Very High Temperatures and Long Blend Times
  - Temperatures: 400 to 800 ºF
  - Blending times: 1, 5, and 10 minutes



Effect of Temperature on the Mix

(Virgin @ 400, 600 & 800° + RAP 1 at Ambient, Mixing Time @ 5 min.)

Effect of Temperature on the Mix

(Virgin @ 400, 600 & 800° + RAP 2 at Ambient, Mixing Time @ 5 min.)

Effect of Temperature on the Mix

(Virgin @ 400, 600 & 800° + RAP 3 at Ambient, Mixing Time @ 10 min.)

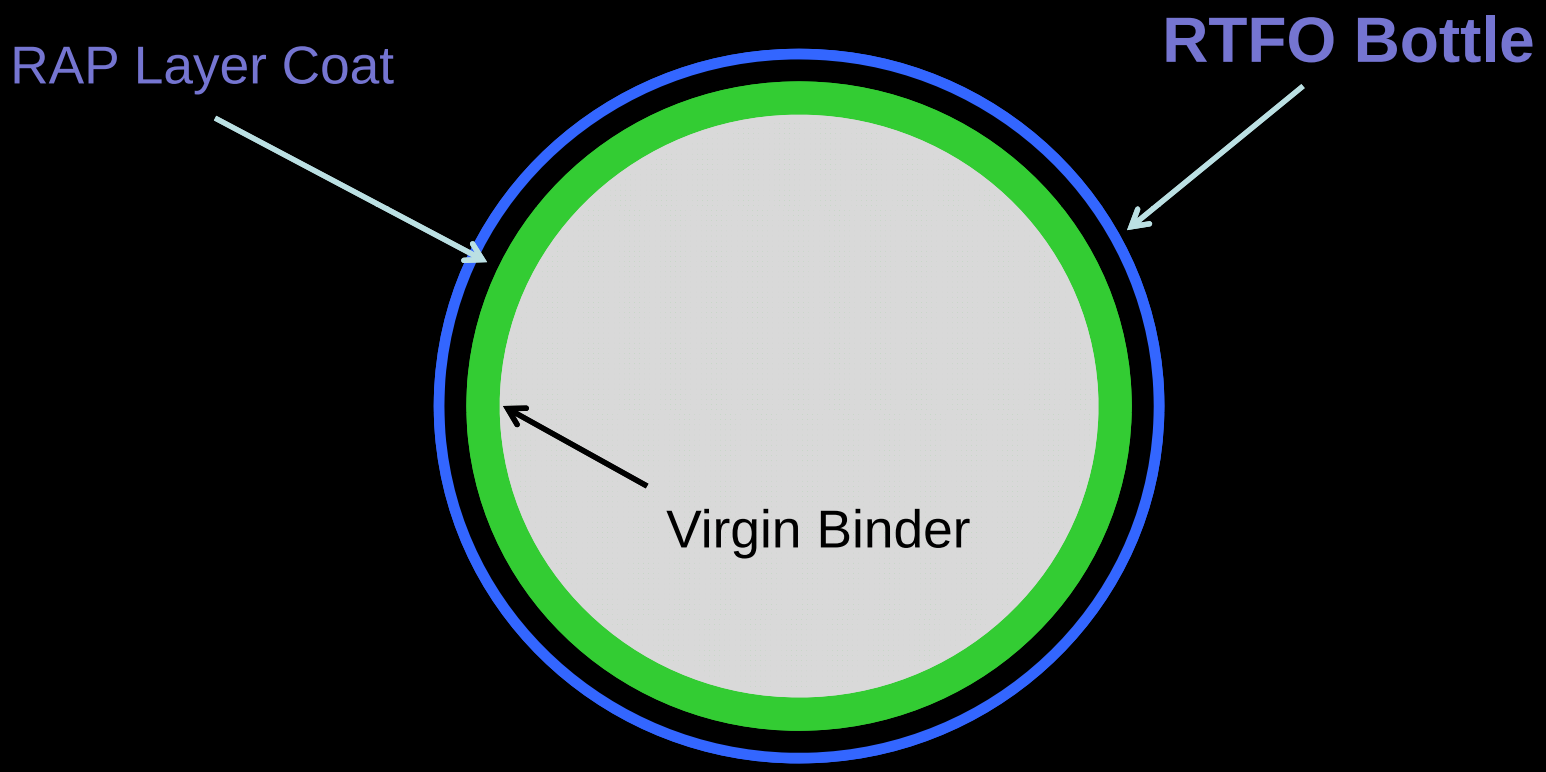
Developing Problem Statement

- Grzybowski *visually* showed that mixing time and temperature affects the extent of RAP and virgin binder blending.
- First, we're going to *quantify* what was observed.
- Next, let's hypothesize that our measurements verify that complete blending is not occurring at typical production temperatures and mixing times.
  - Does it matter?
  - In other words – Can the physical properties of mix that we desire be achieved without significant blending?

FHWA Exploratory Experiment

- Part I: Quantifying that mix time and temp have an effect on blending
  - Laboratory Simulation of RAP Binder and Virgin Binder Blending in RTFO
    - DSR
- Part II: Does blending matter for mix properties?
  - Laboratory Simulation of RAP Binder and Virgin Binder Blending in Hot-Mix
    - E* and Flow Number from AMPT Device
    - Comparison with Plant Produced Hot-Mix

Part I: RTFO Experiment



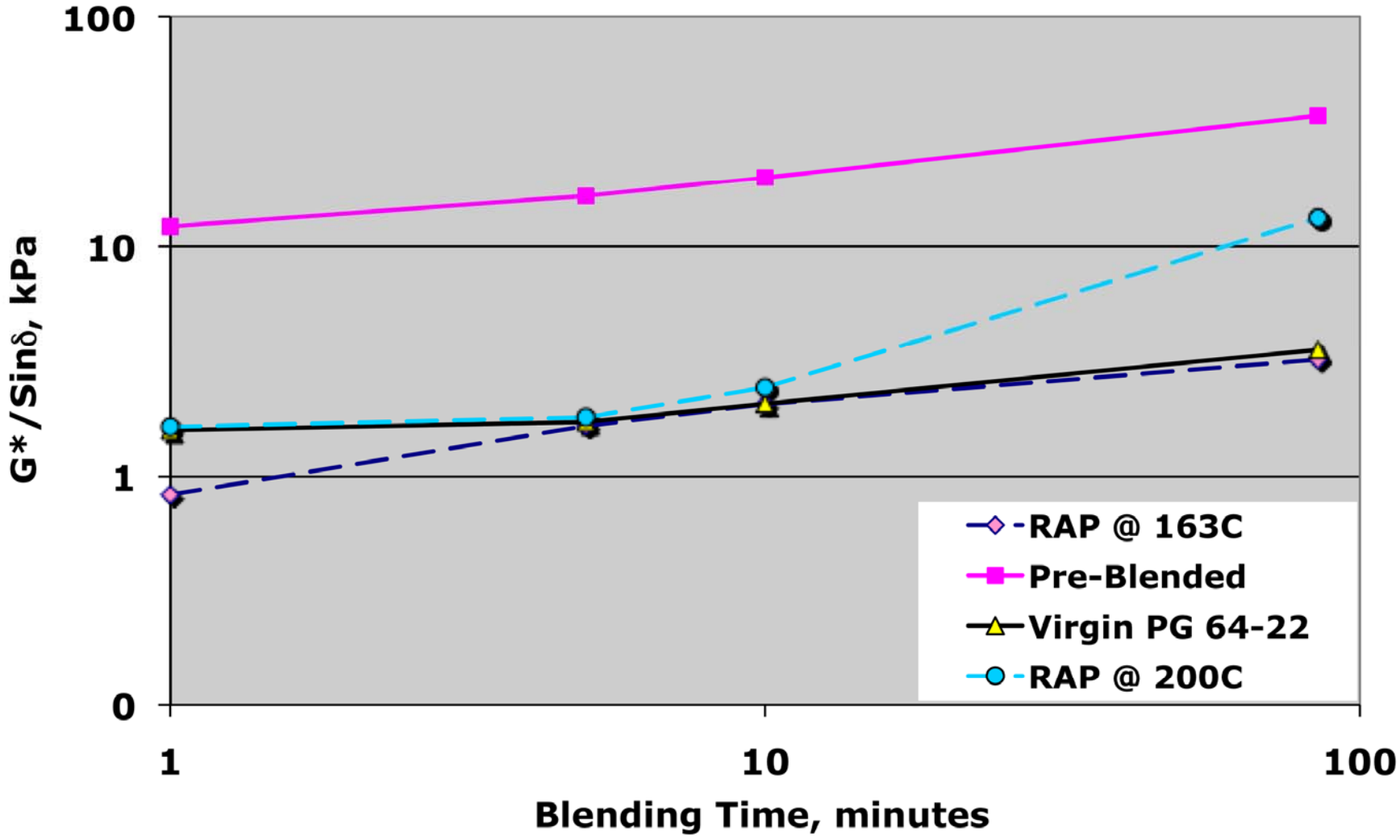
Part I: RTFO Experiment No. 1

- RAP Binder: MN Coarse Extracted RAP Binder
- Virgin Binder: PG 64-22 (AMRL 211)
- RAP Binder Temperatures
  - 163°C and 200°C
- Virgin Binder Temperature
  - 163°C and 200°C
  - Blending Times: 1, 5, 10, and 85 minutes

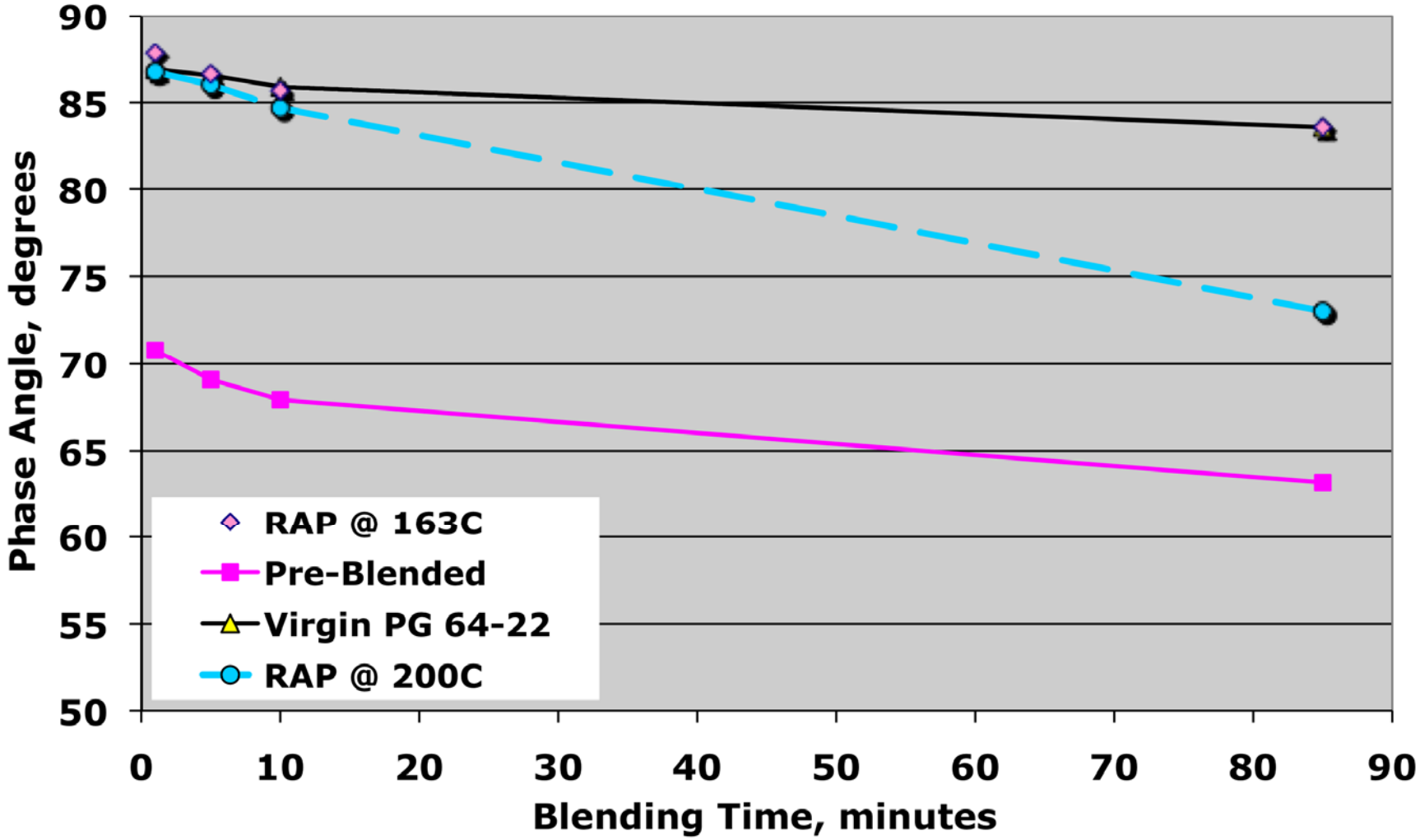
Part I: RTFO Experiment No. 2

- RAP Binder: MD SHA Extracted RAP Binder
- Virgin Binder: PG 64-22 (NuStar)
- RAP Binder Temperatures
  - 135°C
- Virgin Binder Temperature
  - 163°C
  - Blending Times: 1, 5, 10, and 85 minutes

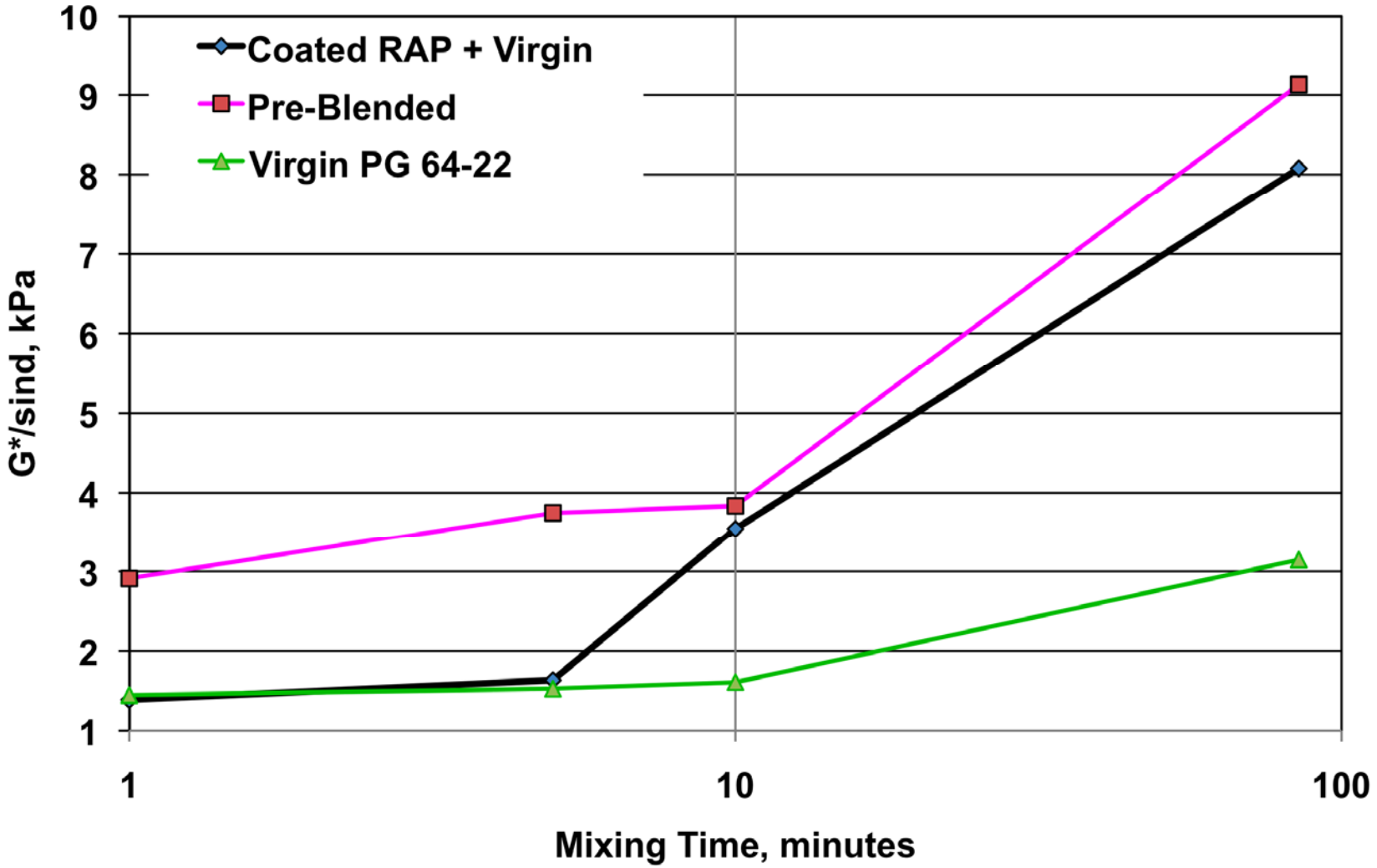
MN Coarse RAP



MN Coarse RAP



MD SHA Fine RAP

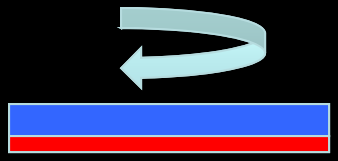


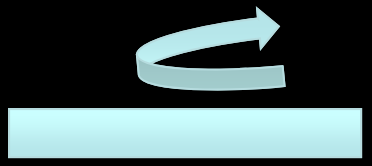
Does Blending Matter?

- It is possible to produce RAP mix properties without the virgin binder and RAP binder actually blending
  - Composite Effect
- How to Demonstrate?
  - Binder Experiment
  - Hot-mix Experiment

Binder Experiment Composite Effect

- Test in DSR at 76ºC
  - Virgin Binder layer on top of RAP binder layer
    - 75% Virgin binder layer (0.375 g)
    - 25% RAP binder (0.125 g)
  - Pre-blended RAP+Virgin binder in one layer
    - 0.500 g of pre-blended RAP+Virgin binder



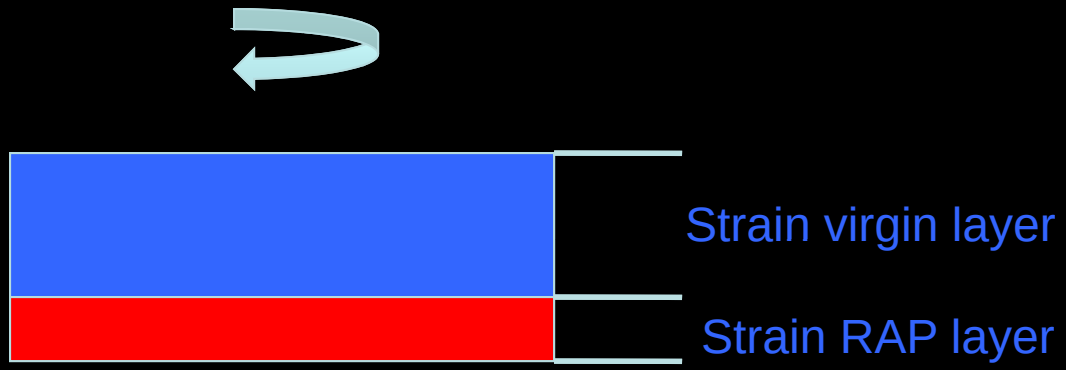


Binder Experiment Composite Effect

- Results – DSR at 76°C

Sample Type	G*/sinδ, kPa	Phase Angle, deg
Pre-Blended	1.58	84.5
Layered	1.40	83.1
Virgin PG 64-22	0.362	89.0

Binder Experiment
How Composite Effect?



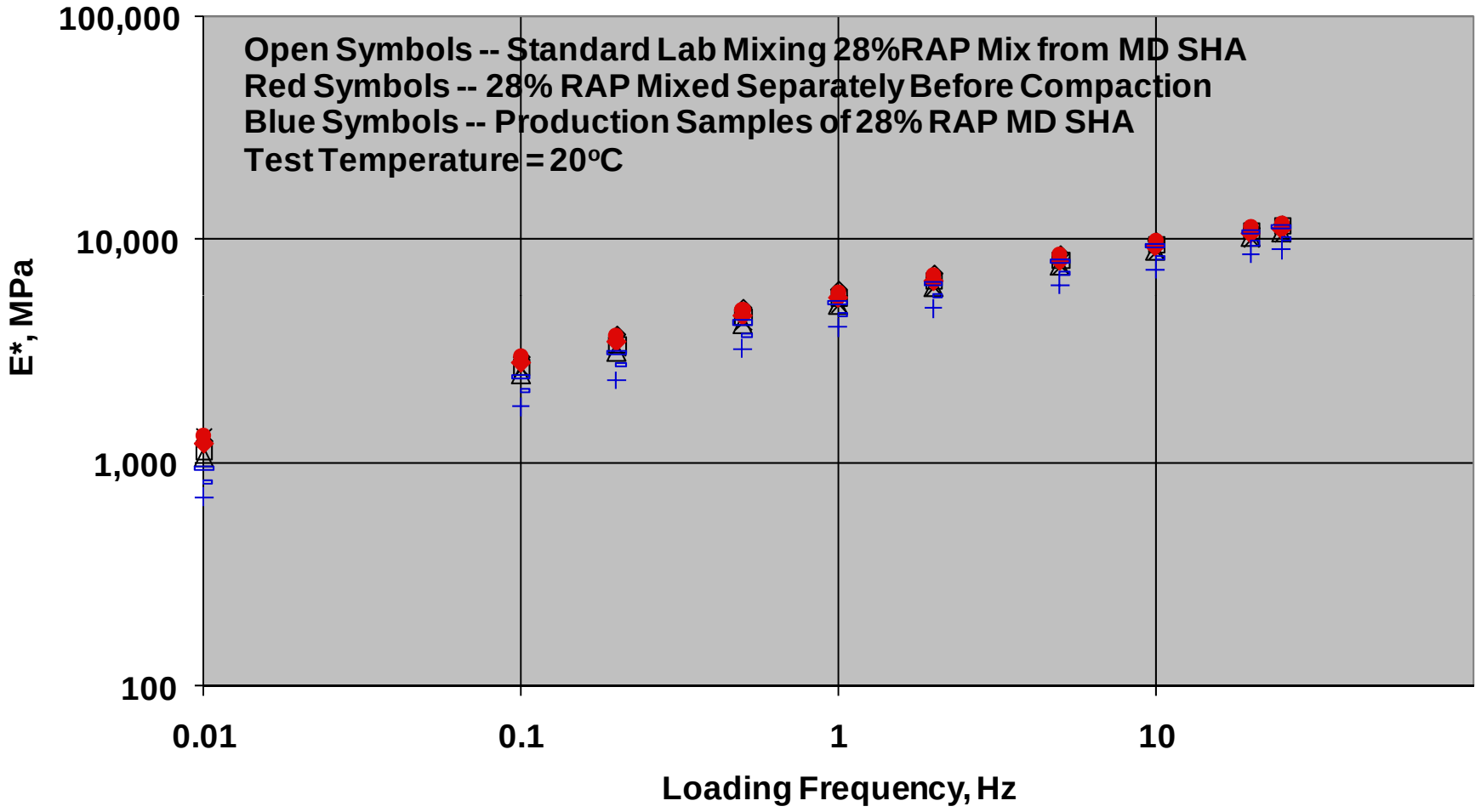
Hot-Mix Experiment Composite Effect

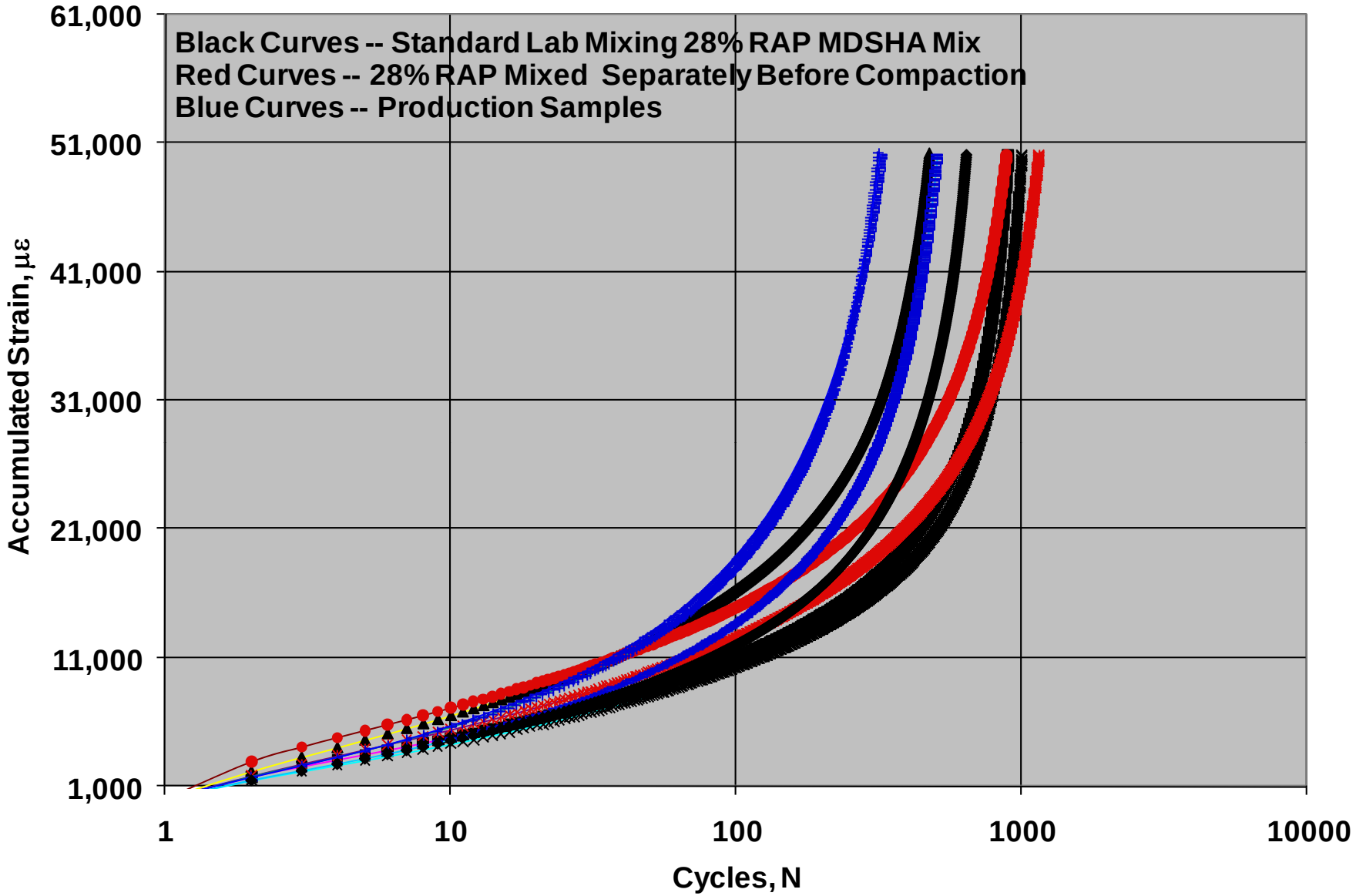
- MD SHA Approved 28% RAP Mix
  - Obtained RAP and Virgin Aggregate
  - PG 64-22 binder (NuStar)
  - Plant Produced Mix Samples

FHWA Hot-Mix Experiment

- Laboratory Blending
  - Virgin and RAP aggregates mixed using normal bucket mixer (pre-blended)
  - Virgin and RAP aggregates mixed separately
    - Mixed together immediately before compaction
- Short Term Oven Aged for 4 hours
- AMPT Testing
  - 20ºC E* at various frequencies
  - 58ºC Flow Number unconfined

MD SHA 28% RAP Mix




Black Curves -- Standard Lab Mixing 28% RAP MDSHA Mix
Red Curves -- 28% RAP Mixed Separately Before Compaction
Blue Curves -- Production Samples
61,000
51,000
41,000
31,000
21,000
11,000
1,000
Accumulated Strain, με
1
10
100
1000
10000
Cycles, N

Hot-Mix Summary

Hot-Mix Type	Strain at FN %	FN Tertiary Flow	E* at 10 Hz MPa	Phase Angle degrees
Pre-Blended	1.83	267	9,295	20.0
Separate	2.27	381	9,645	19.6
Prod	2.01	142	8,404	21.6

What have we learned?

- RAP binder and Virgin Binder Blending
  - Not 100% blended with reasonable time and temperature
  - Blending may not be necessary to produce properties similar to blended binder because of composite effect
- Hot-Mix blending
  - Standard lab mixing, mixing separately, and plant produced mixes gave similar properties

Implications

- Blend charts – should they be used if they assume 100% blending?
  - Grade softening for high RAP mixes
- The real issue may be proper homogenous mixing of RAP and Virgin aggregate
  - Plant operation and parameters control that
  - Bonaquist procedure for plant mixing homogeneity for high RAP mixes is needed
    - Binder extraction may be meaningless!

Future Steps

- Further verification of the binder and mix exploratory study
  - Include other RAP and virgin combinations
  - Evaluate different size RAPs
- Low temperature properties
  - Marasteanu BBR sliver test
  - Fracture – semi-circular bending test

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Thank you!

Questions?