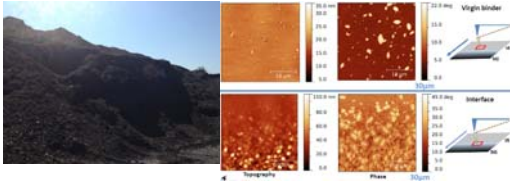



**Blending Efficiency of Asphalt Mixtures Containing Recycled Asphalt**



Mark Woods, P.E., Tennessee DOT  
 Presentation written by: Baoshan Huang, Ph.D., P.E.  
 University of Tennessee-Knoxville

**SEAUPG 2015**

*Ph.D. Students Contributed to the Study*



Dr. Sheng Zhao  
 Postdoctoral Researcher  
 Univ. of Alaska - Fairbanks

Dr. Benjamin F. Bowers  
 Research Scientist  
 VCTIR

Jason Moore  
 Ph.D. Student  
 Univ. of Tennessee  
 & Lab Manager of  
 FHWA

2

**30 Million Tons of Asphalt per Year in US**

- 145 million barrels of asphalt
- \$20 billion market value
- 550 million tons of mixture
- \$55 billion market value
- Covers over 92% pavements



**Where Does Asphalt Come from?**



**Asphalt from Refinery**

**Lake Asphalt**

**Rock Asphalt**

**Next Generation Asphalt**



**Recycled Asphalt**

- Reclaimed Asphalt Pavement (RAP)
  - Annually 100 million tons (in US)
- Recycled Asphalt Shingles
  - 11 million tons
  - Potential \$1 billion (in US)



### What Does Paving Industry Wants to Do?

- High Recycled Binder Ratio
  - High RAP/RAS (ongoing NCHRP 09-58, The Effects of Recycling Agents on Asphalt Mixtures with High RAS and RAP Binder Ratios)
- Incorporation of tear-off RAS
  - Standard required, tentatively approved in limited states
- Combining RAS with WMA
  - The mutual effect could be beneficial (ongoing NCHRP 09-55, Recycled Asphalt Shingles in Asphalt Mixtures with Warm Mix Asphalt Technologies)

### The Problem – Blending Issues

- Mix design
  - How much binder in RAP/RAS available?
- High RAP/RAS Limitation
  - Less blending may occur, causing pre-mature distresses?
- The concern over WMA
  - Lower temperature, not enough blending?
- Blending affects performance? How?

Unknown or not clear, all related to blending issues

### The Problem – Blending Issues




Regular Binder                  RAS Binder

*Knowledge Gap ?*

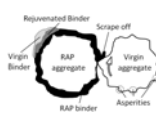
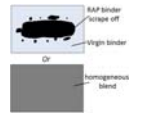
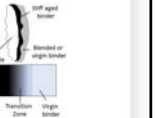
Current Blending Practice

=

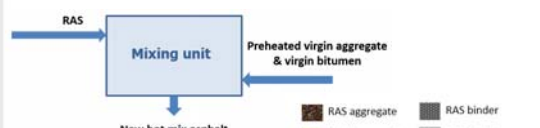
Full Implementation of Sustainable Technologies


### Blending Mechanisms

- Three Stages
  - Aged binder rejuvenation
    - How much aged binder available?
  - Blended binder homogeneity
    - How well the binders blend?
  - Long-term diffusion
    - How virgin diffuses into the old? At what conditions?


### Blending Issues\_Binder Interaction






blended binder

or




limited or no interaction  
RAS aggregate

or



blended binder


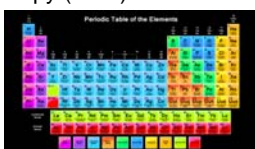
or



limited or no interaction  
Virgin aggregate

### How to Evaluate ?

- Analytical Chemistry Techniques
  - Gel Permeation Chromatography (GPC)
  - Fourier Transform Infrared Spectroscopy (FTIR)
- Direct Observation Technique
  - Atomic Force Microscopy (AFM)

### Gel Permeation Chromatography (GPC)

- Gel Permeation Chromatography
  - Medium in solution passes through column of packed beads
  - Yields molecular weight distribution
  - Can relate to asphalt binder characteristics

### GPC – Large Molecule Size (%)

- Capable of differentiating aged binder from virgin binder
- LMS (%), of total area
- LMS (%) can be related to  $G^*$

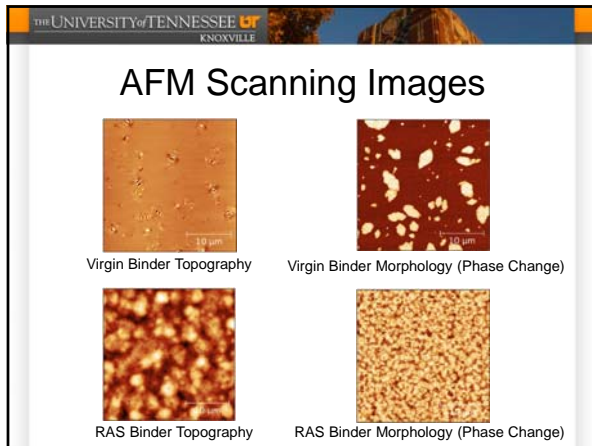
### Fourier Transform Infrared Spectroscopy (FTIR)

- Measures absorption of infrared light by a medium
- Yields a “fingerprint”
- Identifies chemical functional groups

### FTIR: Testing Process

### FTIR: Spectra Output

### Atomic Force Microscopy (AFM)



### Blending Mechanisms

- Three Stages
  - Aged binder rejuvenation
    - How much aged binder available?
  - Blended binder homogeneity
    - How well the binders blend?
  - Long-term diffusion
    - How virgin diffuses into the old? At what conditions?

### RAS Binder Rejuvenation: Methodology

Typical PG 64-22

Tear-offs: 19% AC < No. 4

- Small – Natural Sand, < No. 4
- Medium – Limestone, between No. 4 and ¼ in
- Large – Limestone, > ¼ in

Virgin Binder: 50 wt.%

RAS

Small Aggregate: 40 wt.%

Medium Aggregate

Large Aggregate: 10 wt.%

- Simulating real mixing with proper mix design
- Asphalt content – 5.5 wt.% (RAS binder + virgin)

### Particle Separation

After mixing, the particles were separated

Small particles (Virgin aggregate and RAS aggregate)

Medium particles (Virgin aggregate)

Large particles (Virgin aggregate)

Unblended RAS binder + Blended binder

Blended binder

Blended binder

### Experimental Design

Pre-blended

- Virgin Binder
- RAS
- Small Aggregate
- Medium Aggregate
- Large Aggregate

2.5% RAS: Mixing 2 min, 170°C

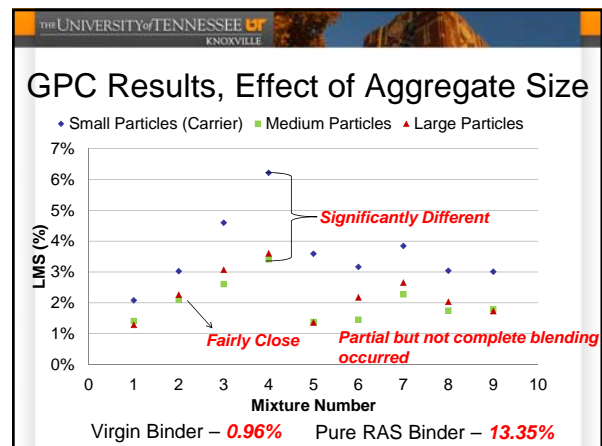
5% RAS: Mixing 30 s, 170°C; Mixing 1 min, 170°C; Mixing 2 min, 170°C; Mixing 3 min, 170°C

7.5% RAS: Mixing 2 min, 170°C

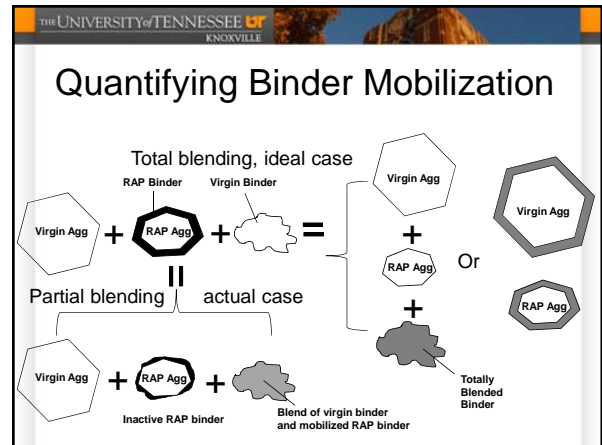
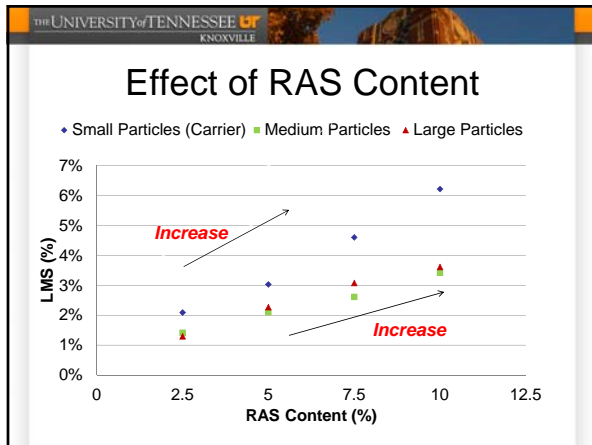
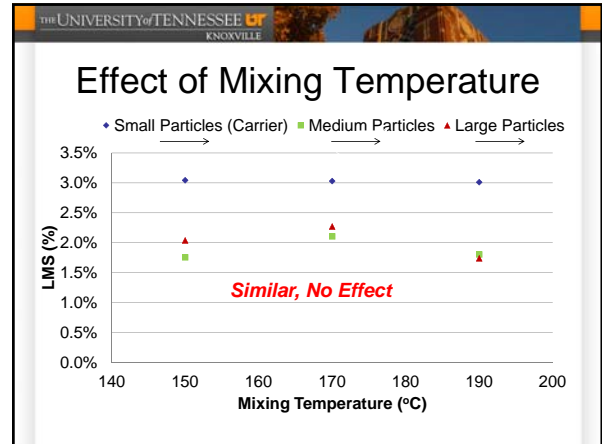
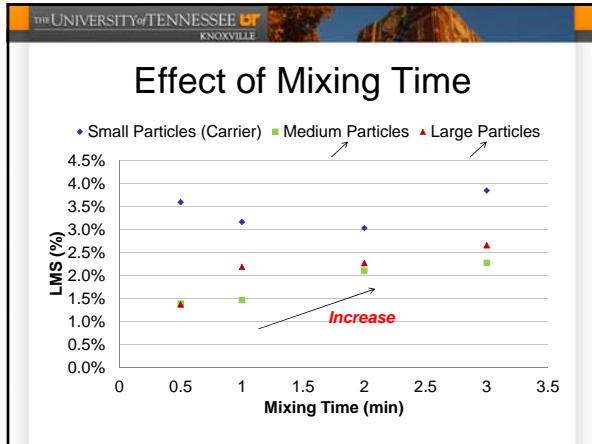
10% RAS: Mixing 2 min, 170°C

150°C, 170°C, 190°C

Parameters - Mixing time, Mixing Temperature, RAS content, Aggregate Size







### Mobilization Rate

- Definition
 
$$\text{Mobilization Rate} = \alpha_M = \frac{W_{(\text{Mobilized Old Binder})}}{W_{(\text{Total Old Binder})}}$$
- Assumption
  - RAP/RAS agg. and virgin agg. have the equal chance of obtaining the blended binder

*If virgin aggregates can be separated after mixing, RAP/RAS binder percentage of the blend can be measured.*

### Mobilization Rate, Calculation (e.g. RAS)

$$\begin{aligned} & \text{RAS Binder}(\%)_{\text{Blend}} \\ &= \frac{W_{(\text{Mobilized RAS Binder})}}{W_{(\text{Mobilized RAS Binder})} + W_{(\text{Virgin Binder})}} \\ &= \frac{P_{(b, \text{RAS})} \cdot \alpha_M}{P_{(b, \text{RAS})} \cdot \alpha_M + P_{(b, \text{Virgin})}} \\ \alpha_M &= \frac{P_{(b, \text{Virgin})} \cdot \text{RAS Binder}(\%)_{\text{Blend}}}{P_{(b, \text{RAS})} \cdot (1 - \text{RAS Binder}(\%)_{\text{Blend}})} \end{aligned}$$

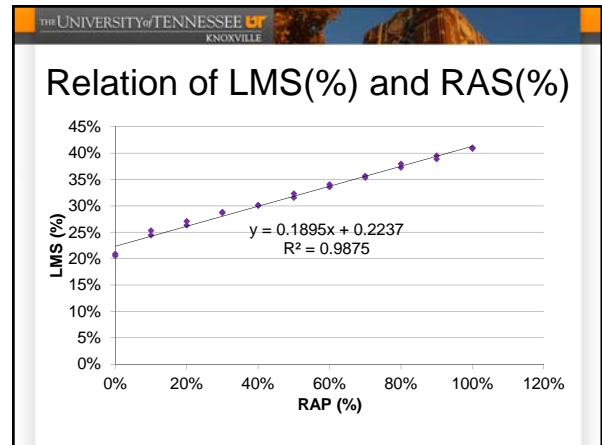
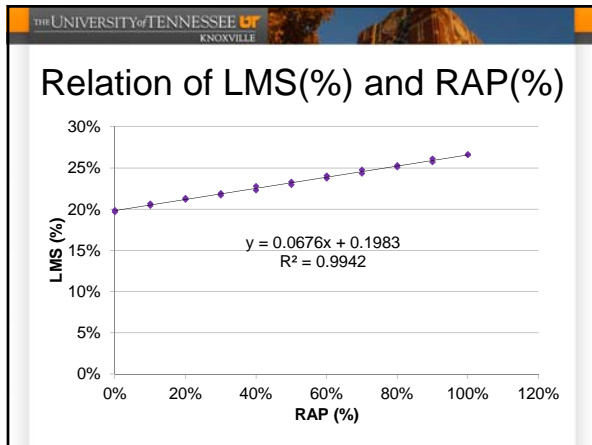
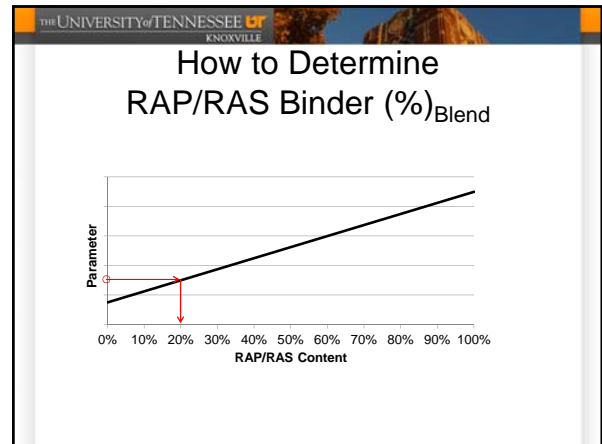
### Mobilization Rate, Example

RAS Percentage	RAS Binder Content	Mixture Binder Content
5%	20%	6%

$P_{(b, RAS)} = 5\% \times 20\% = 1\%$   
 $P_{(b, Virgin)} = 6\% - 1\% = 5\%$

If RAS Binder (%)<sub>Blend</sub> = 10%,

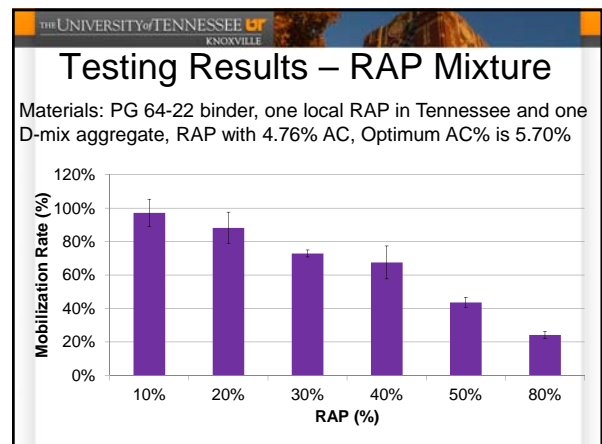
$$\alpha_M = \frac{P_{(b, Virgin)} \cdot RAS\ Binder\ (\%)_{Blend}}{P_{(b, RAS)} \cdot (1 - RAS\ Binder\ (\%)_{Blend})}$$

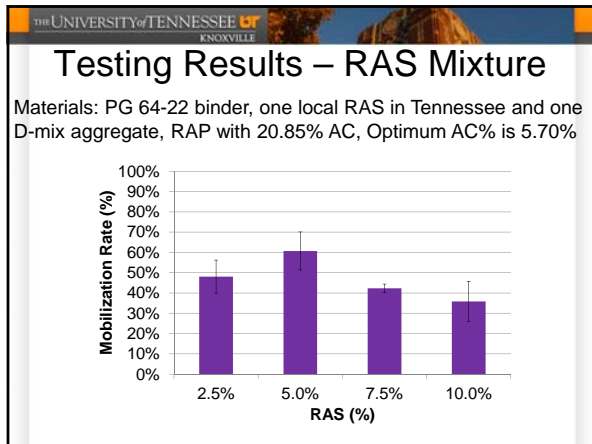
$$= \frac{5\% \times 10\%}{1\% \times 90\%} = 56\%$$


### Experimental Design

- **Tracking materials** (Round Aggregate)
  - Passing 3/8", retain on No. 4
  - The same gradation with the control mix

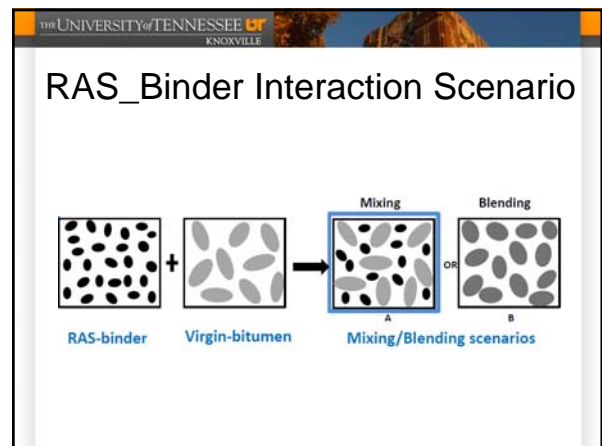
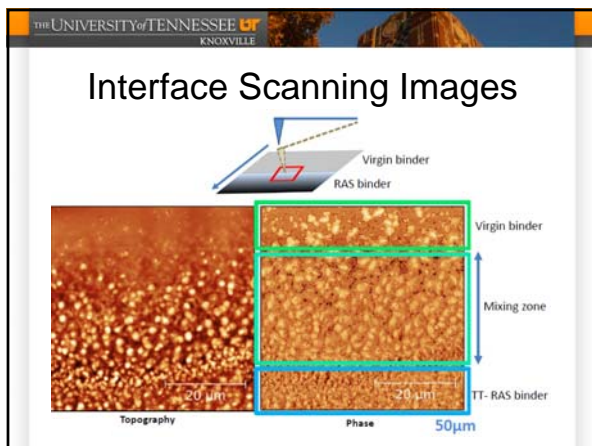
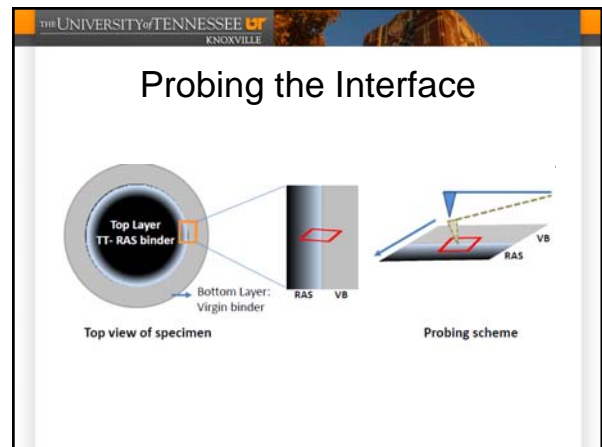
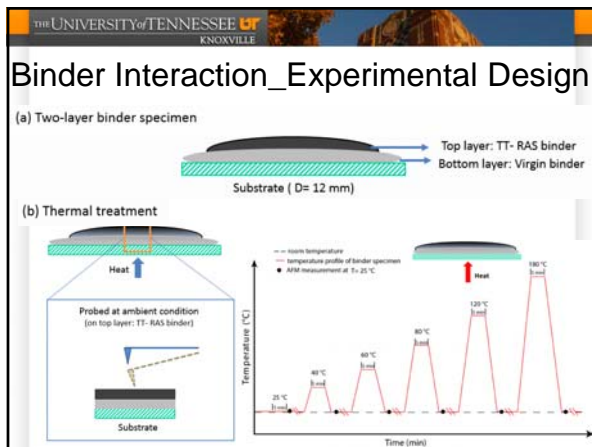
RAP Content	RAS Content
10%	2.5%
20%	5.0%
30%	7.5%
40%	10%
50%	
80%	

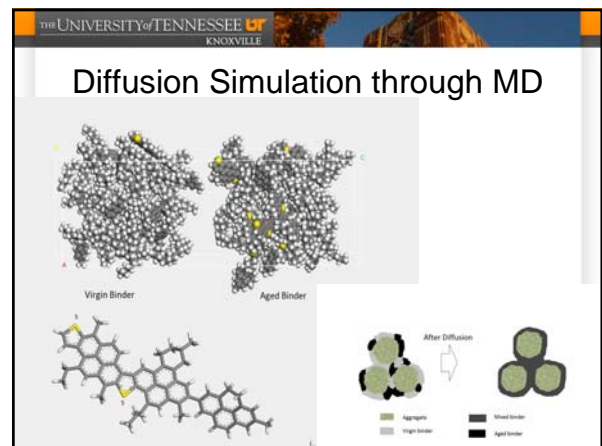
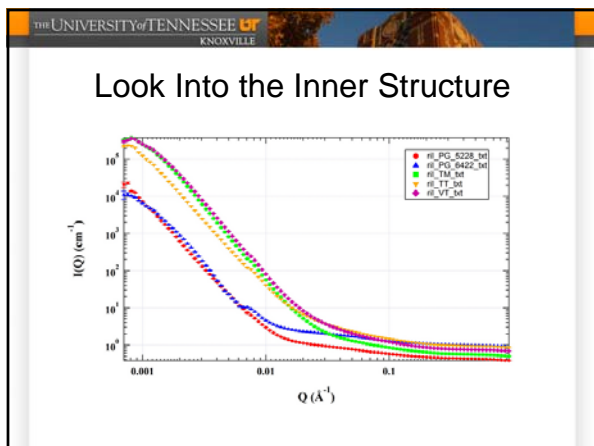
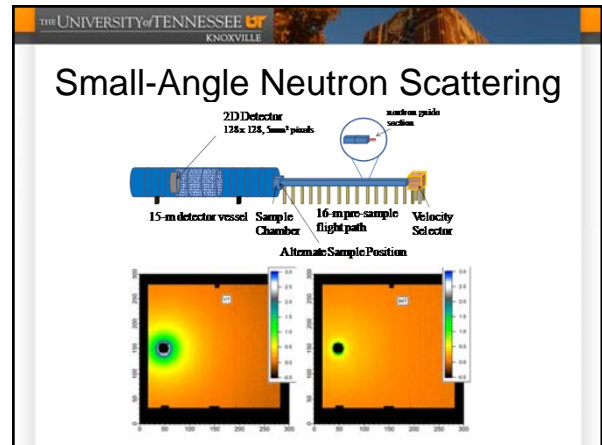
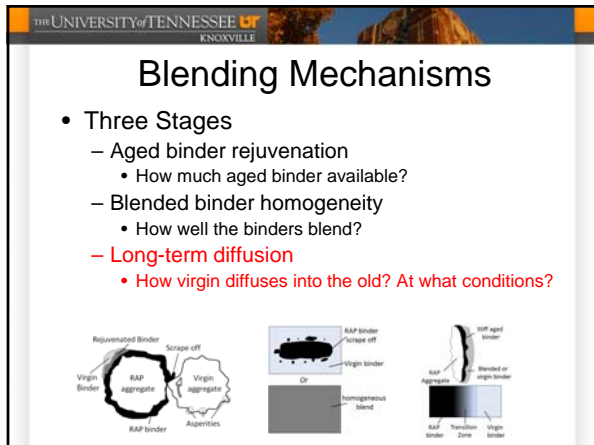
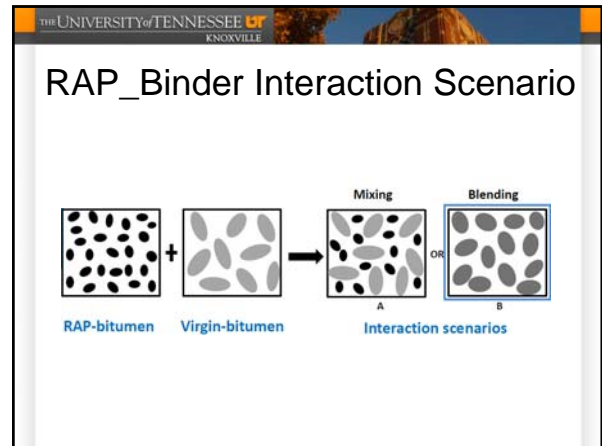
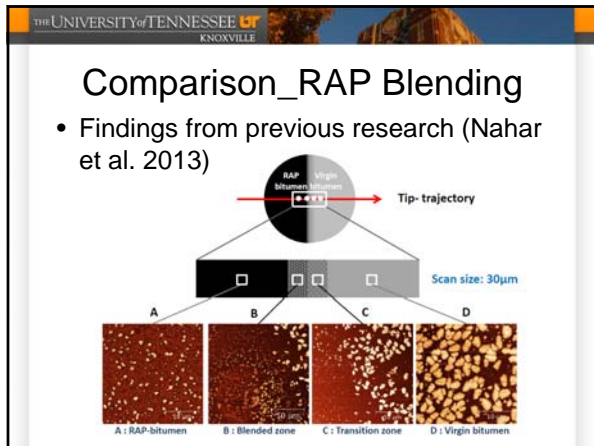





### Blending Mechanisms

- Three Stages
  - Aged binder rejuvenation
    - How much aged binder available?
  - **Blended binder homogeneity**
    - How well the binders blend?
  - Long-term diffusion
    - How virgin diffuses into the old? At what conditions?







THE UNIVERSITY OF TENNESSEE   
KNOXVILLE

### Summaries and Conclusions

- Blending of recycled AC into virgin AC is complicated
- Aged binder mobilization can be quantified by GPC
- Blended binder homogeneity can be characterized through AFM and other procedures
- Molecular dynamics and advanced materials testing procedures can be used to characterize diffusion of asphalt
- blending efficiency/uniformity research may help develop better recycling technology in asphalt pavement

THE UNIVERSITY OF TENNESSEE   
KNOXVILLE



*QUESTIONS ?*