
# Design and Performance of Reclaimed Asphalt Mixtures

**Cassie Castorena, PI**
*Associate Professor*

Department of Civil, Construction, and Environmental Engineering
North Carolina State University

**NCDOT Innovation Summit**
August 14, 2018

# Acknowledgements


- NCSU Graduate Students
  - Sonja Pape, Douglas Mocelin, Mukesh Ravichandran, and Noor Saleh

- Funding
  - NCDOT RP 2019-21, NCHRP Project 09-54

# Outline

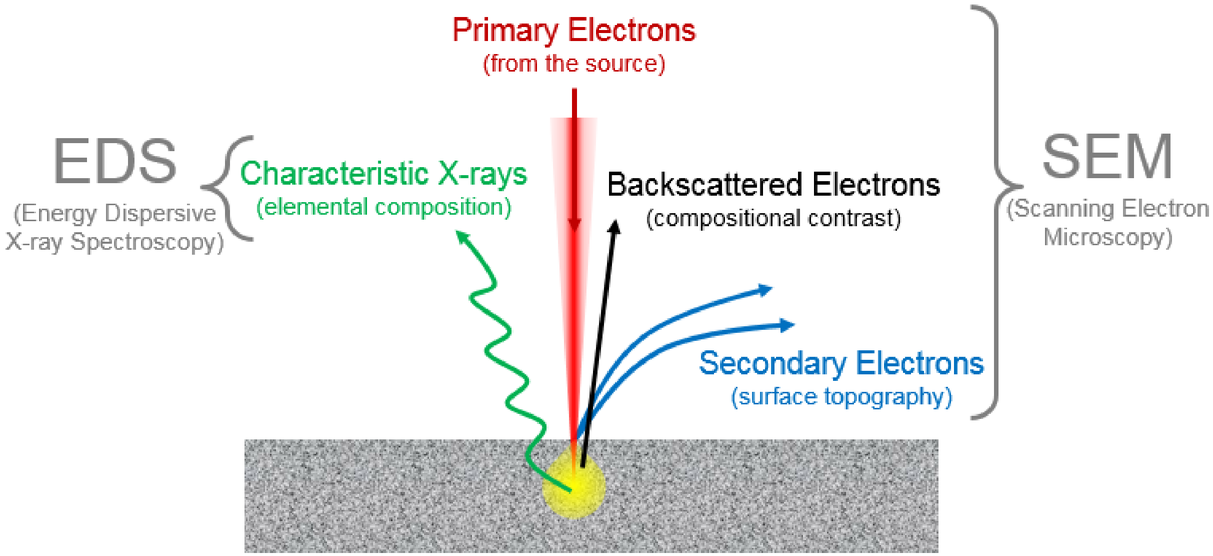
- Background
- Experimental Method to Quantify Blending in Reclaimed Asphalt Mixtures
- Systematic Study of the Effect of RAP on Cracking Performance of North Carolina Mixtures
- Summary of Findings
- Future Research Direction

# Background

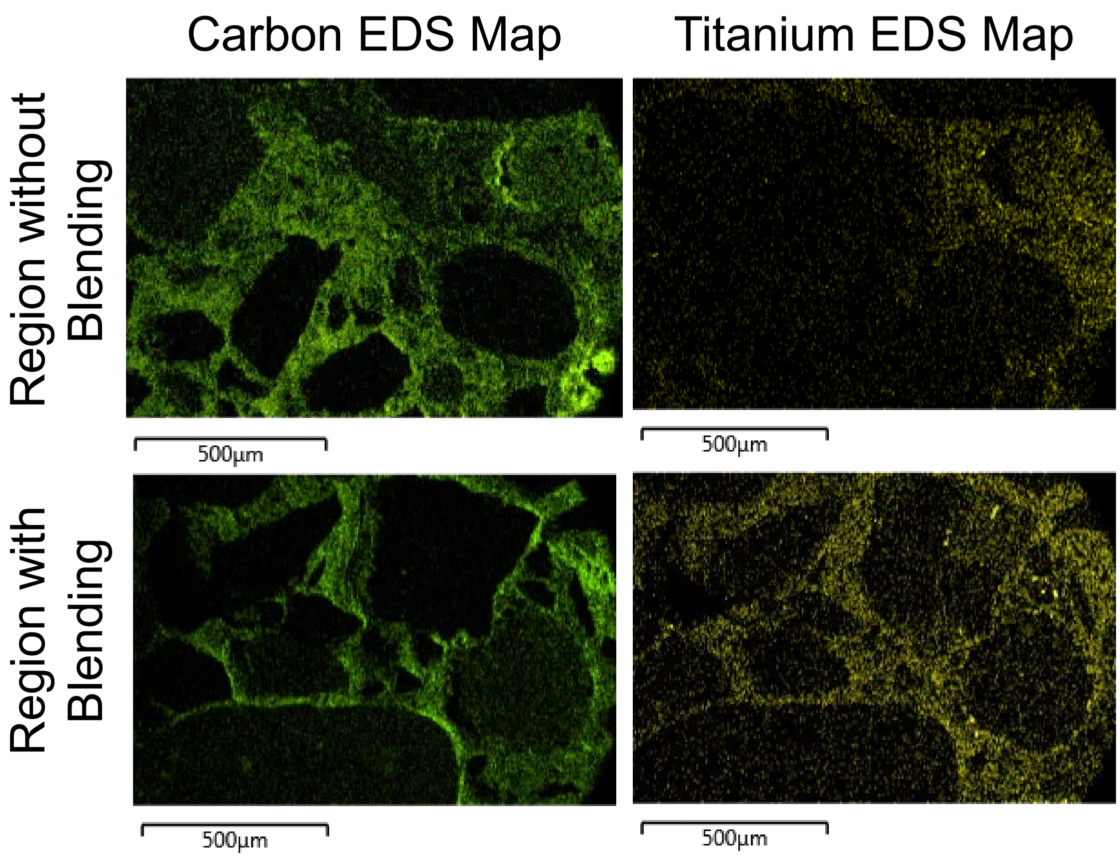
- The use of high reclaimed asphalt pavement (RAP) and reclaimed asphalt shingles (RAS) shingle content asphalt mixtures is on the rise
- Critical questions preclude reliable virgin binder grade selection and volumetric design of RAP and RAS mixtures
  - Does the recycled binder act as "black rock" or blend with the virgin asphalt?
  - How do reclaimed materials affect long-term performance?

# Experimental Method to Quantify Blending Levels in Reclaimed Asphalt Mixtures

- Energy Dispersive X-ray Spectroscopy Scanning Electron Microscopy (EDS-SEM) applied to asphalt mixtures prepared with a titanium dioxide tracer added to the virgin binder

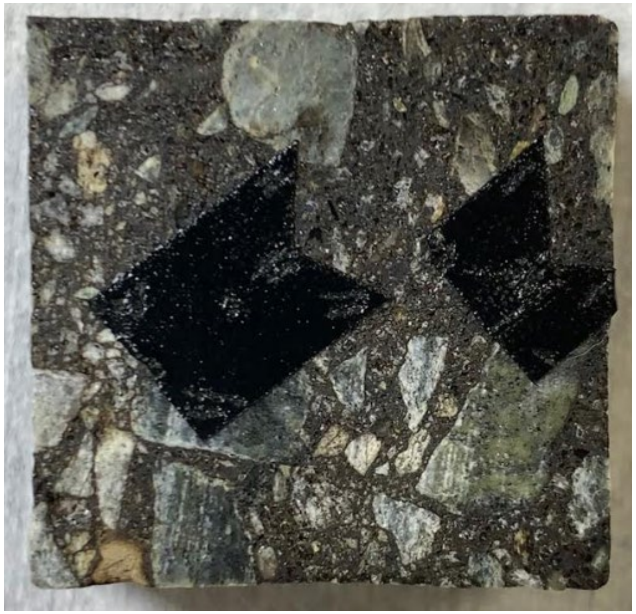


# Visualization of Blending using EDS-SEM



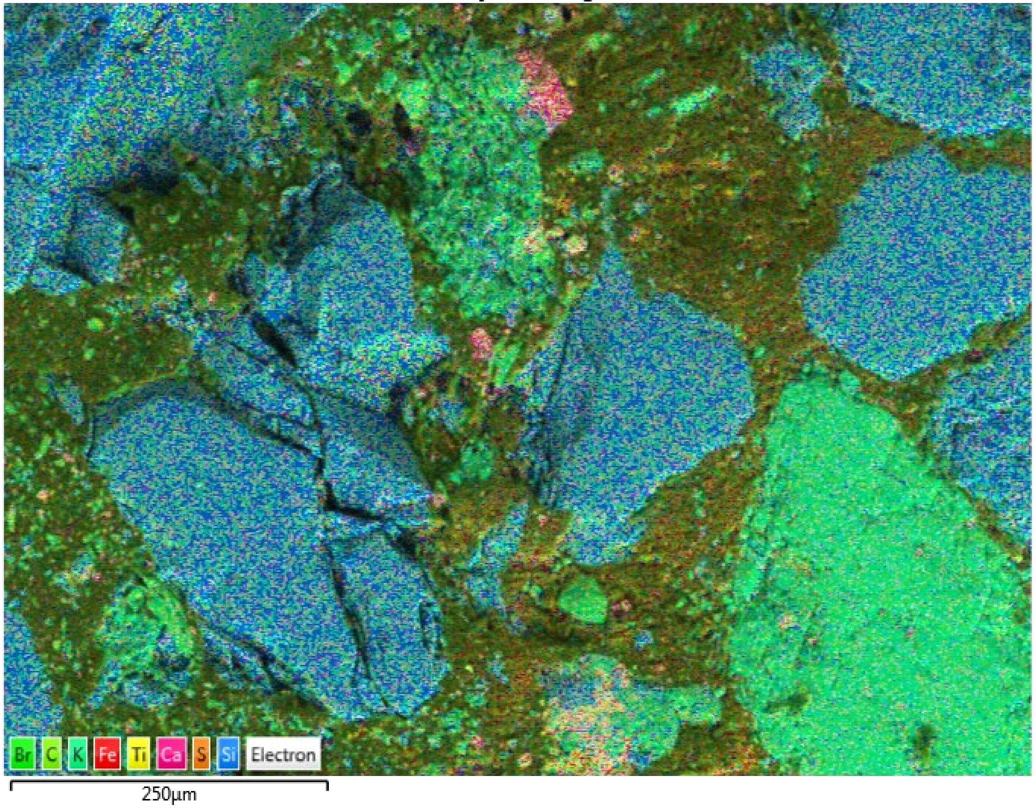
# NC Asphalt Mixture Analyzed

- RS9.5C with 25 percent RAP and 4 percent RAS
- Samples produced following AASHTO T 312 with 10 percent by mass of titanium dioxide (0.15 μm particles) added to the virgin binder using a high shear mixer
- Samples sawn into small prisms and polished prior to EDS-SEM analysis

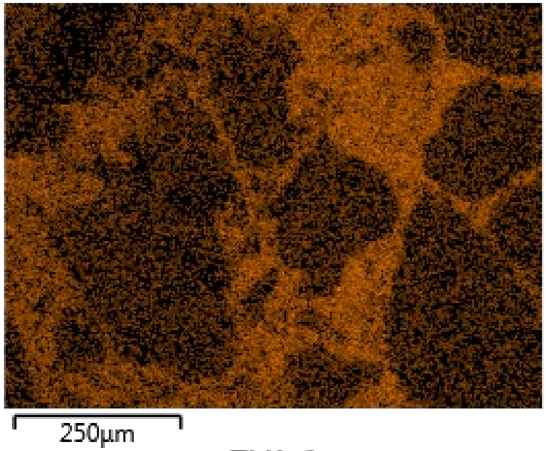


# Blending Analysis Results

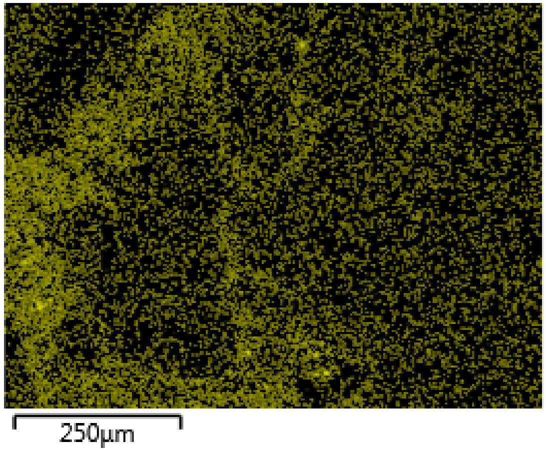
EDS Layered Image 2



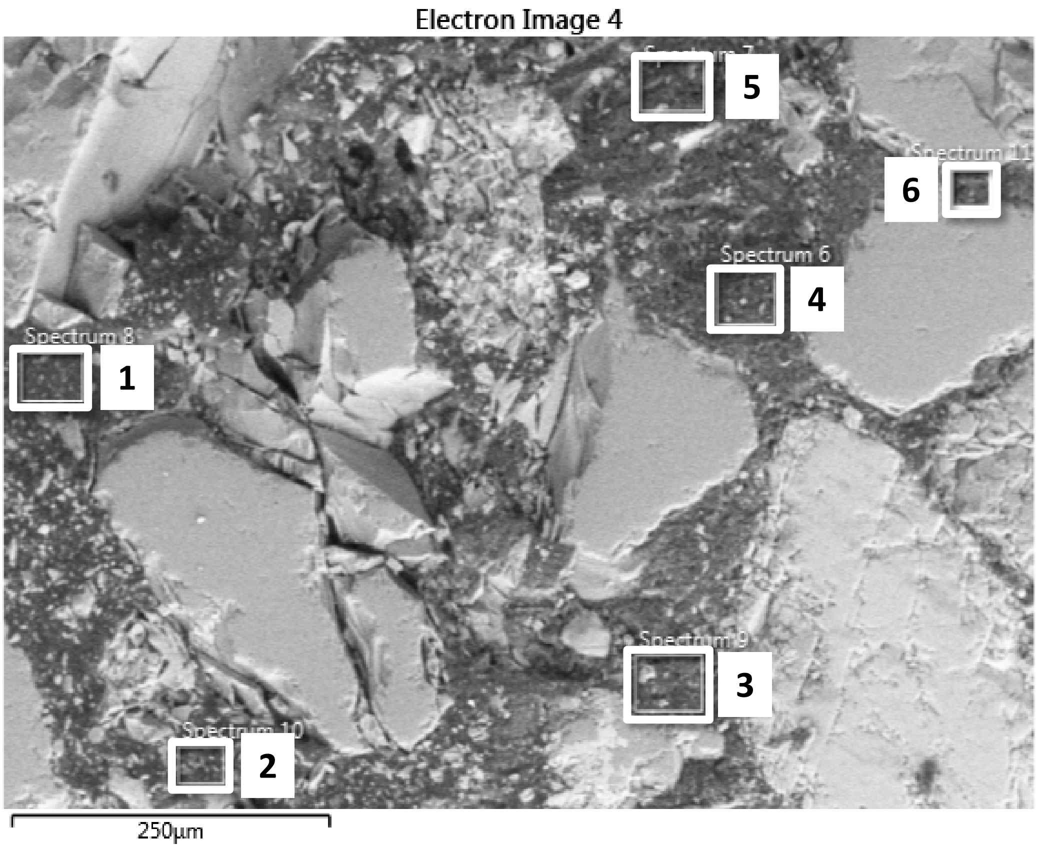

S Kα1




Ti Kα1



# Blending Analysis Results




| Area | Ti (%) |
|---|---|
| Entire | 0.5 |
| 1 | 1.8 |
| 2 | 1.4 |
| 3 | 0.4 |
| 4 | 0.3 |
| 5 | 0.2 |
| 6 | 0.2 |

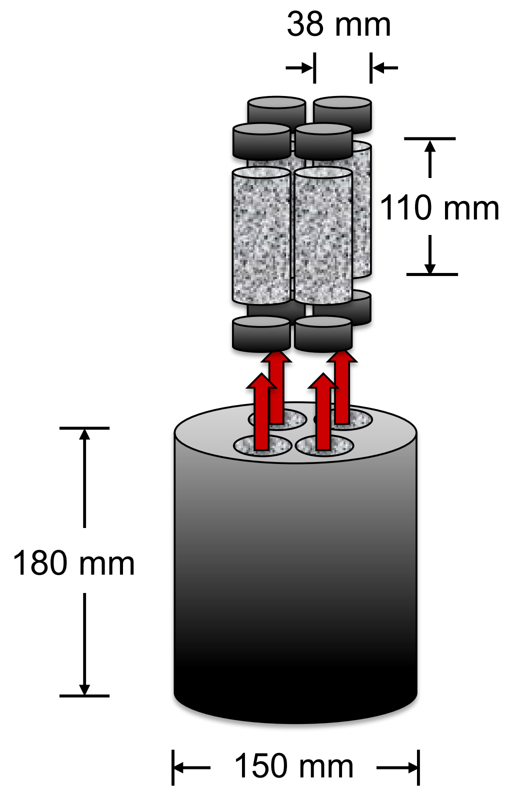
# Systematic Study of the Effect of RAP on Asphalt Mixture Cracking Performance

- RS 9.5B
  - Three RAP contents
  - Gradation kept consistent for different RAP contents
- Laboratory-mixed, laboratory-compacted samples

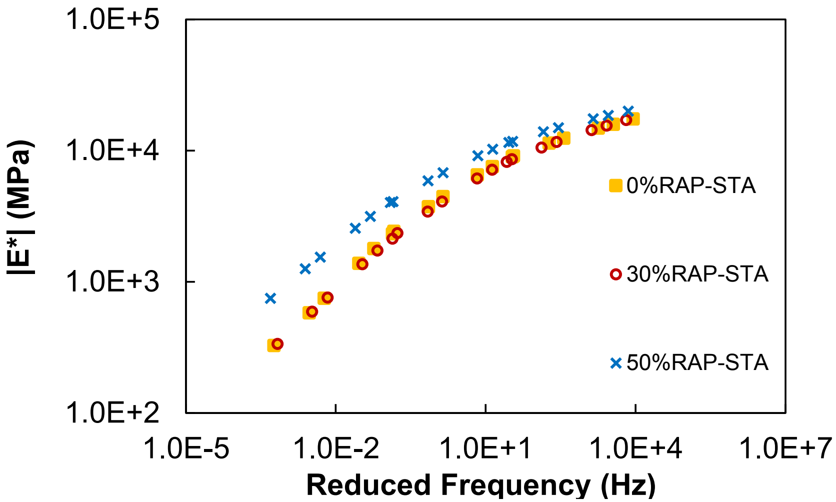
| RAP Content (%) | Virgin Binder Grade |
|---|---|
| 0 | PG 64-22 |
| 30 | PG 58-28 |
| 50 | PG 58-28 |

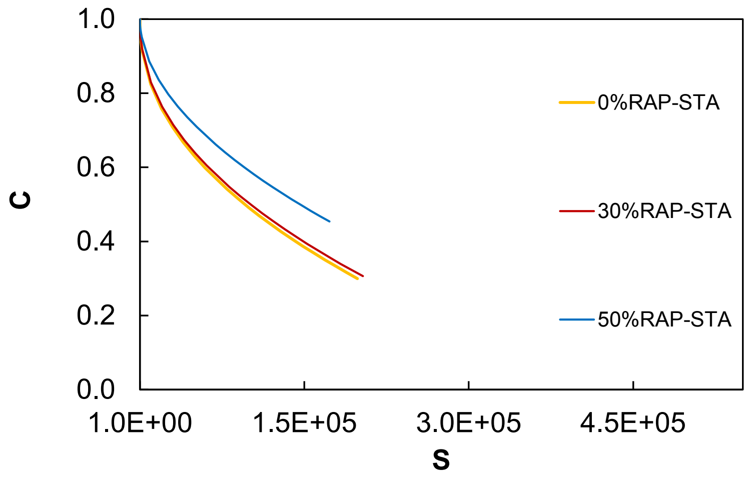
# Performance Testing

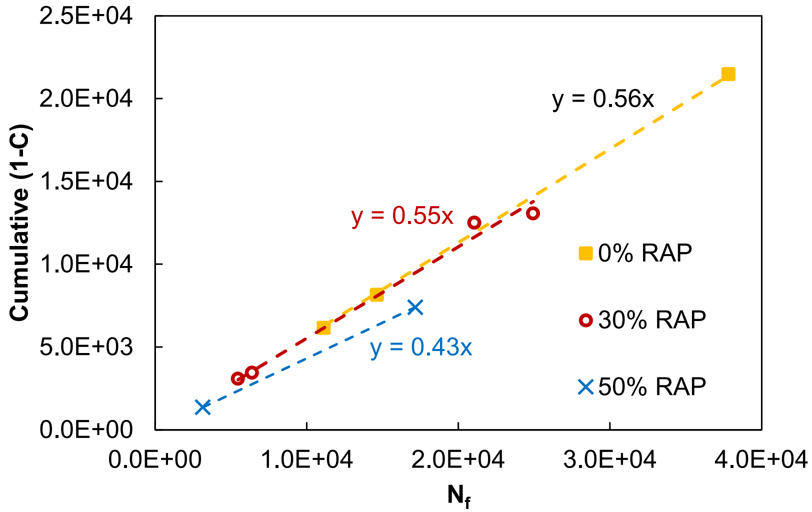
- Asphalt Mixture Performance Tester (AMPT) of small specimens
  - Preparations: AASHTO PP 99
  - Dynamic Modulus: AASHTO TP 132
  - Cyclic Fatigue: AASHTO TP 133




# Material Level Results

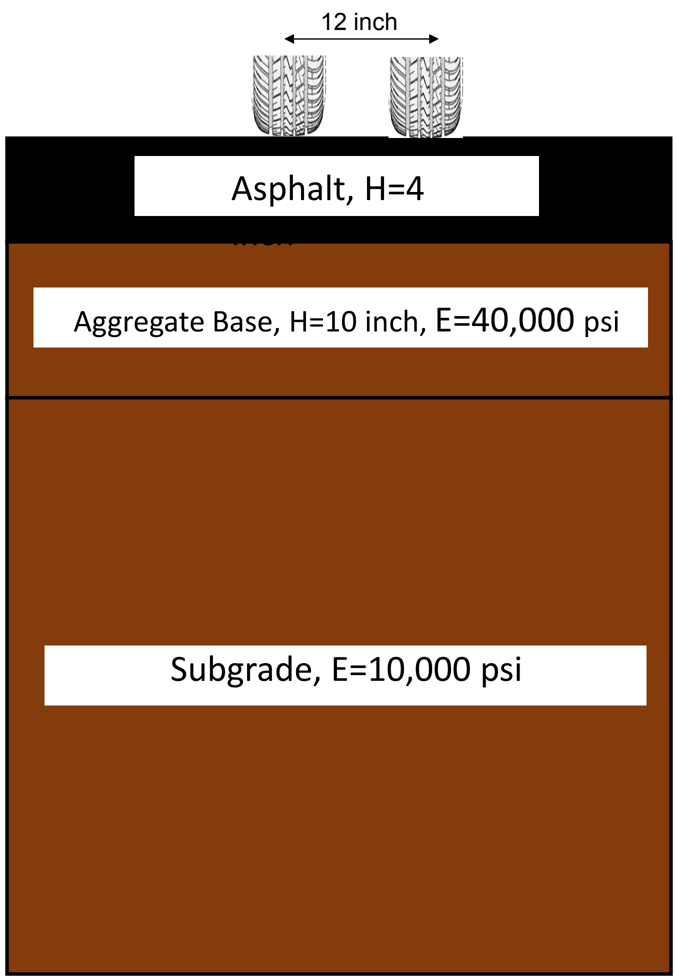


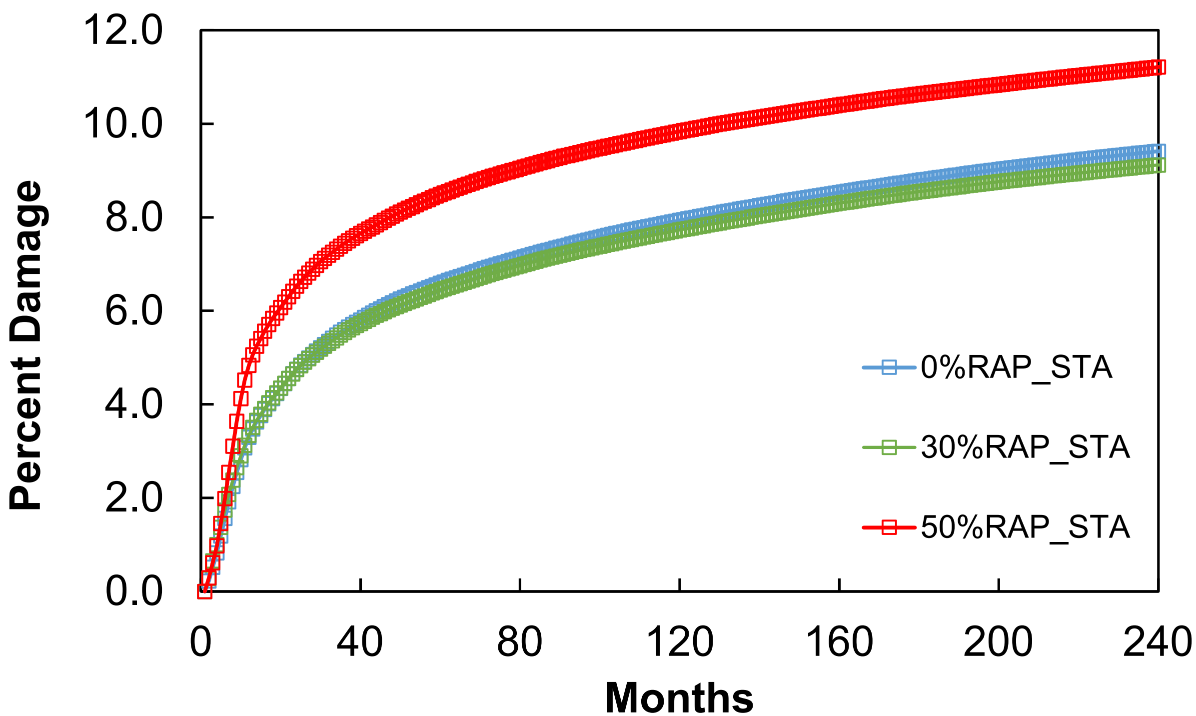



# Pavement Performance Simulations

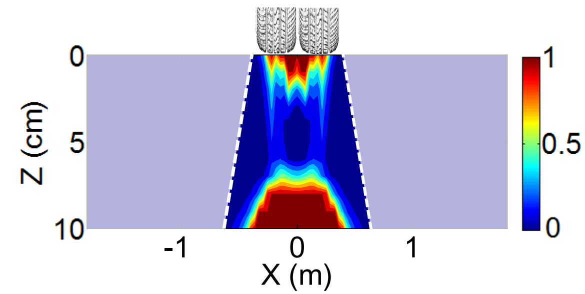
- FlexPAVE™
  - North Carolina climate
  - 1,000 daily ESALs
  - 60 mph



# Pavement Performance Simulation Results




$$\text{Percent Damage}_{D^R} = \frac{\dfrac{1 - C_{avg}}{D^R} \cdot Area_{Damaged}}{Area_{Total}}$$



# Summary of Findings

- EDS-SEM can be used to detect blending levels in reclaimed asphalt mixtures when a titanium dioxide tracer is added to the virgin binder
- A blending analysis of a NC mixture indicates poor blending between RAS and virgin binders but blending between RAP and virgin binders
- A study of the effect of RAP on the performance of NC mixtures indicates a negligible change in performance when the RAP content is increased from zero to 30 percent and increased cracking susceptibility when the RAP content is increased to 50 percent

# Future Research Direction

- Elucidate recycled binder contribution in RAP and RAS mixtures as a function of material and laboratory fabrication variables
- Evaluate the effect of blending levels on asphalt mixture performance
- Develop improved procedures for the virgin binder grade selection and volumetric design of RAP and RAS mixtures

NC STATE

Think and Do

**ncsu.edu**

# Development of a Tack Coat Quality Control Program for Mitigating Delamination in Asphalt Pavement Layers

NCDOT Research Project 2018-13

***NCDOT Research Summit***

**May 7th, 2019**

# Background

Distresses associated with poor bonding

- Slippage and shoving
- Fatigue cracking
- Potholes

**Costly Pavement Repairs**

Image: Pavement Interactive

Tack coat promote the bond between pavement layers

*Performance Factors*

- Application Rate
- Tack Coat Material
- Temperature
- Curing Time
- Existing Surface Condition

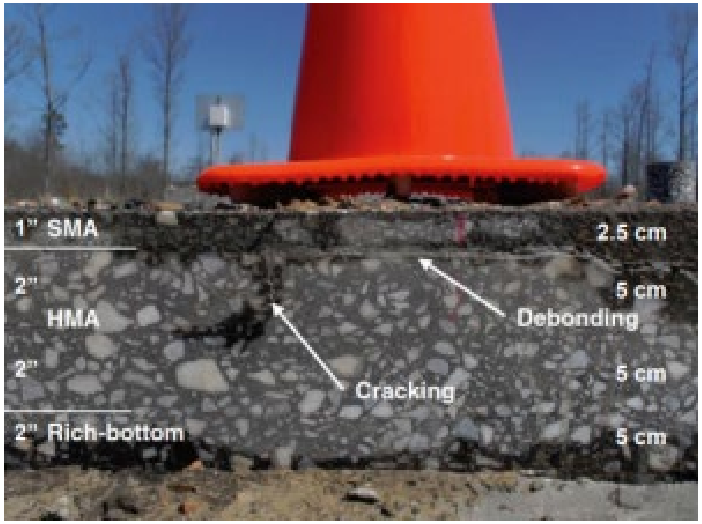
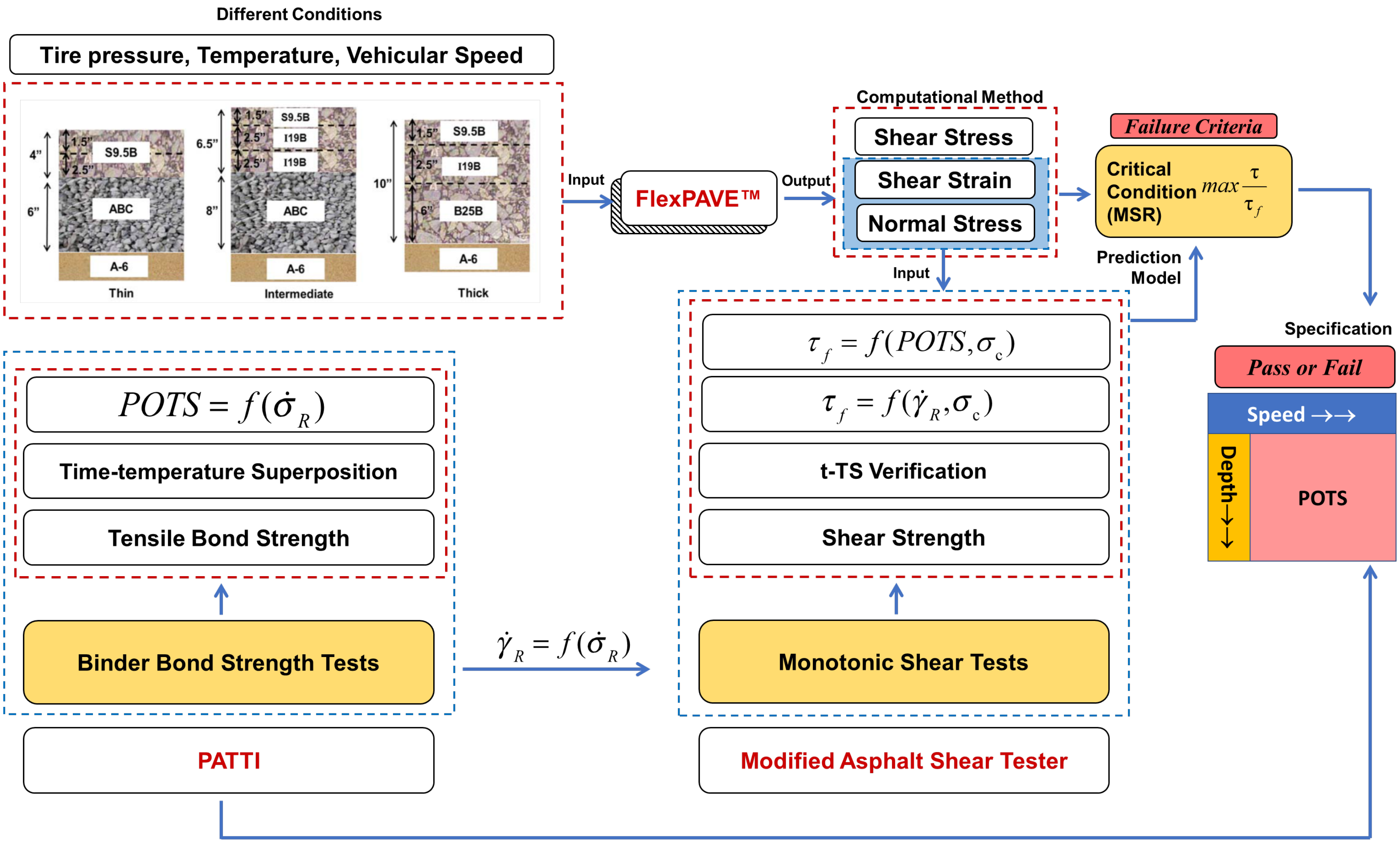
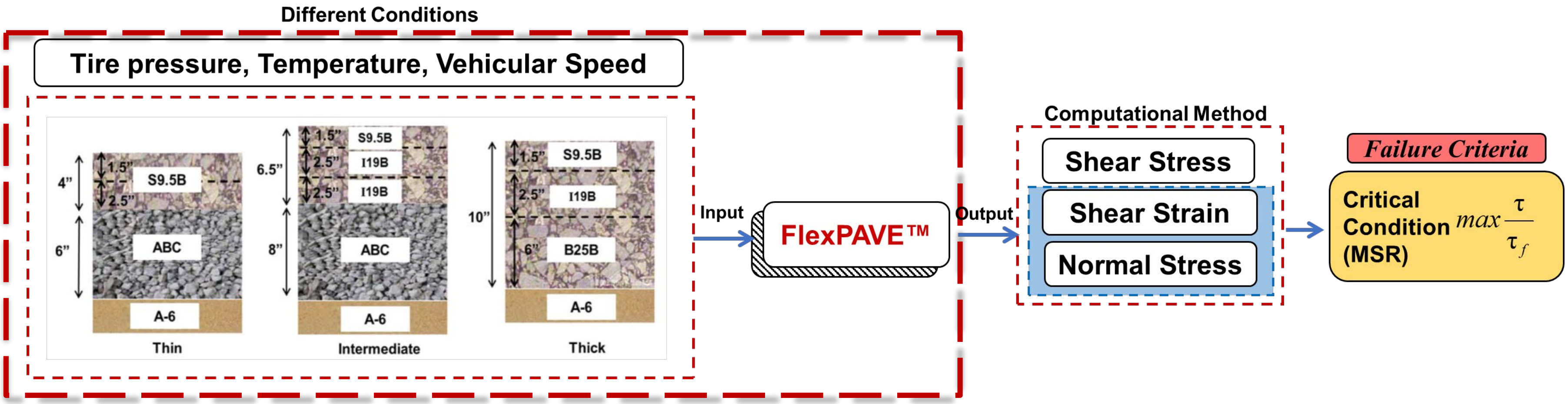



Image: FDOT 977-37 report

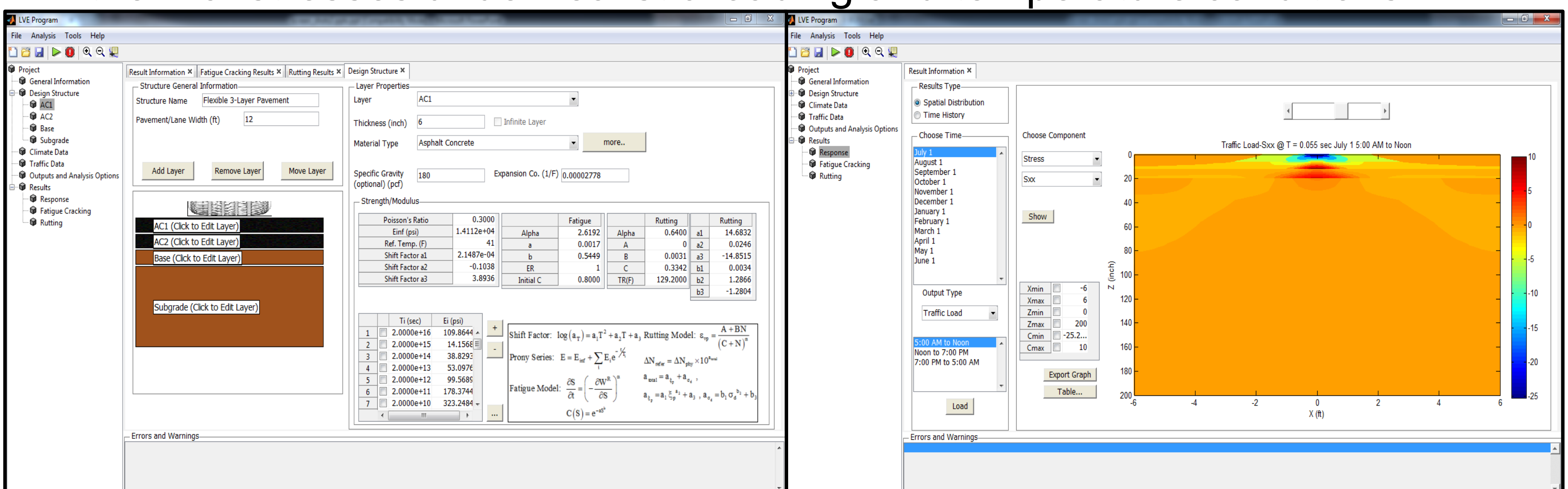
# Research Plan



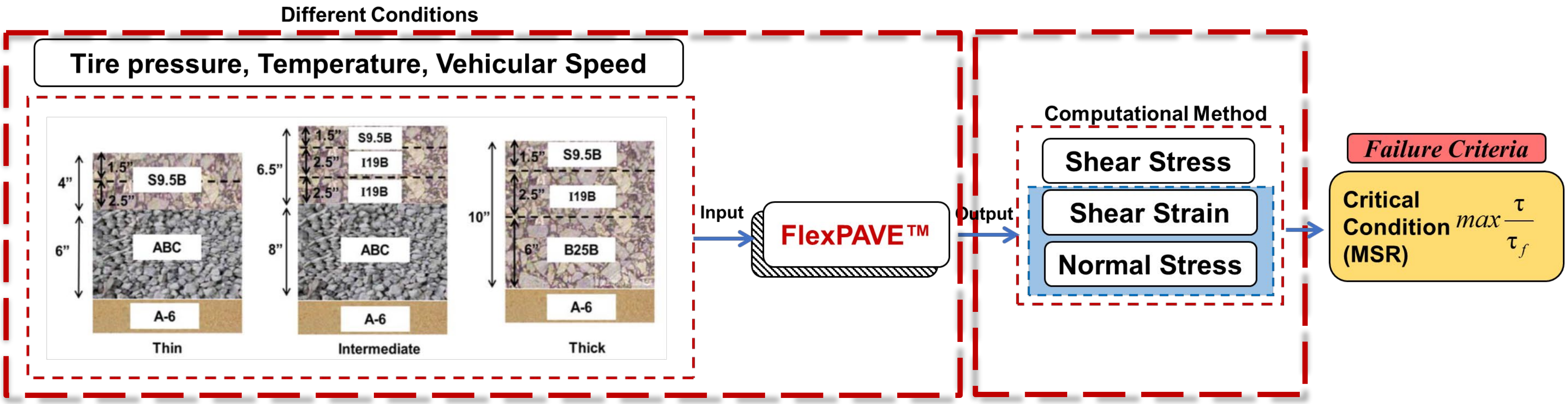
# Pavement Response Analysis

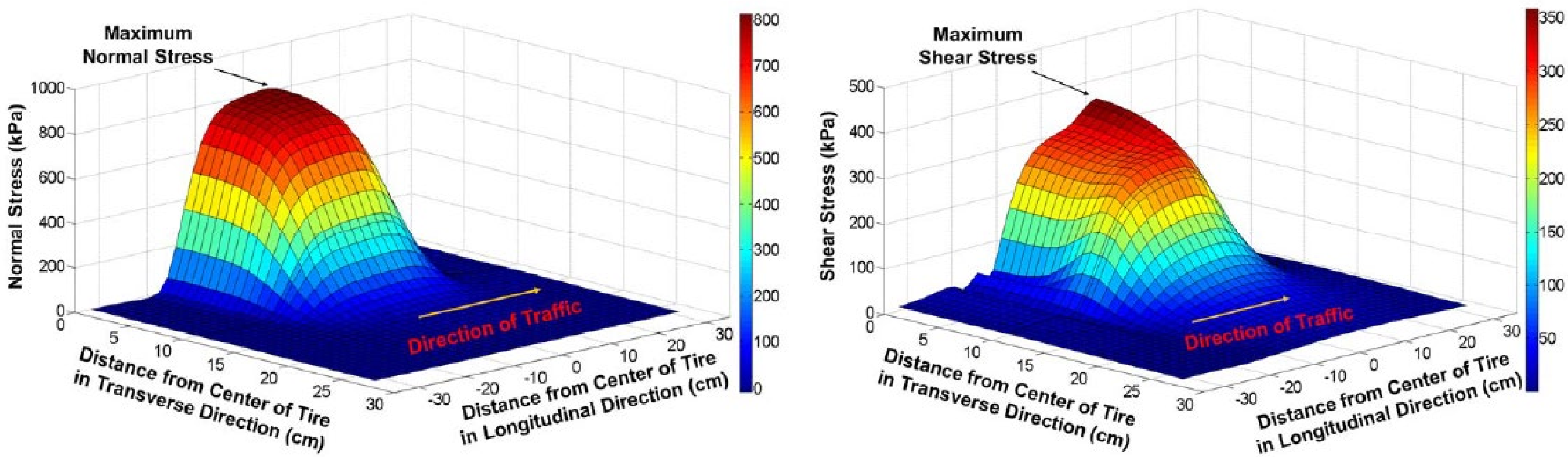



Three dimensional layered viscoelastic analysis for moving loads and thermal stresses under realistic loading and temperature conditions



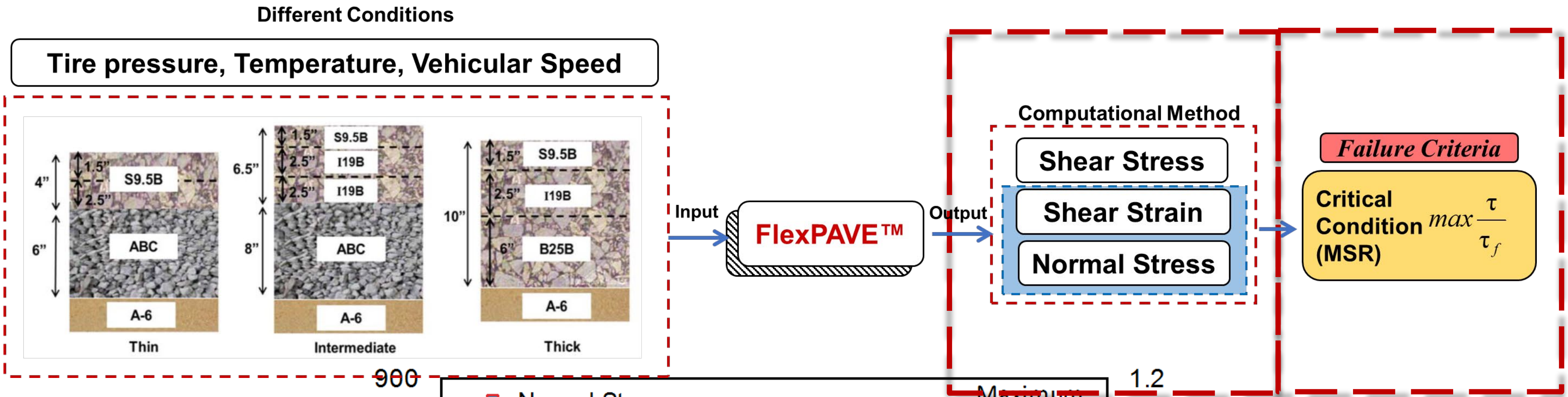
# Pavement Response Analysis

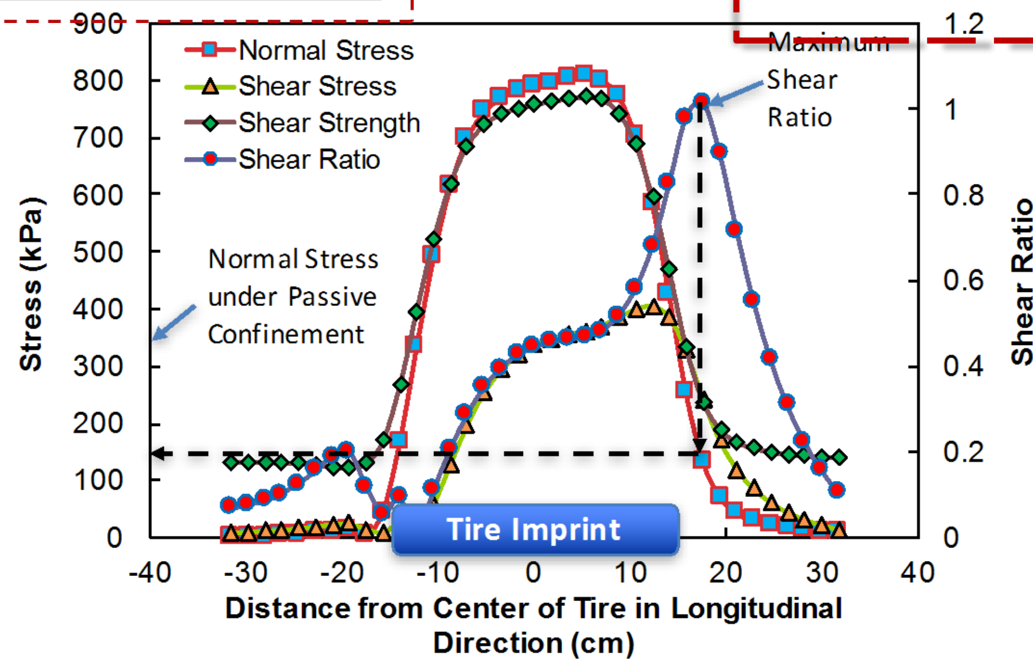



Intermediate pavement section, 80kN (18 kips), 8 km/hour (5 mph)
60°C at 3.81 cm (1.5 in.) depth under braking condition

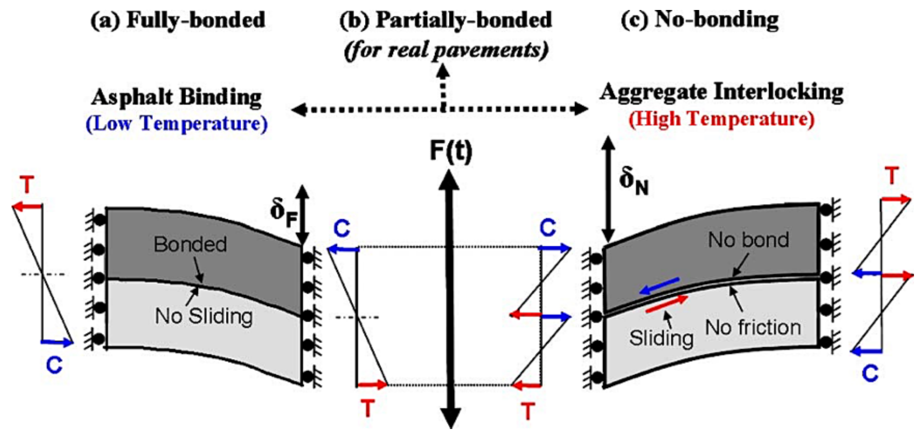
# Pavement Response Analysis



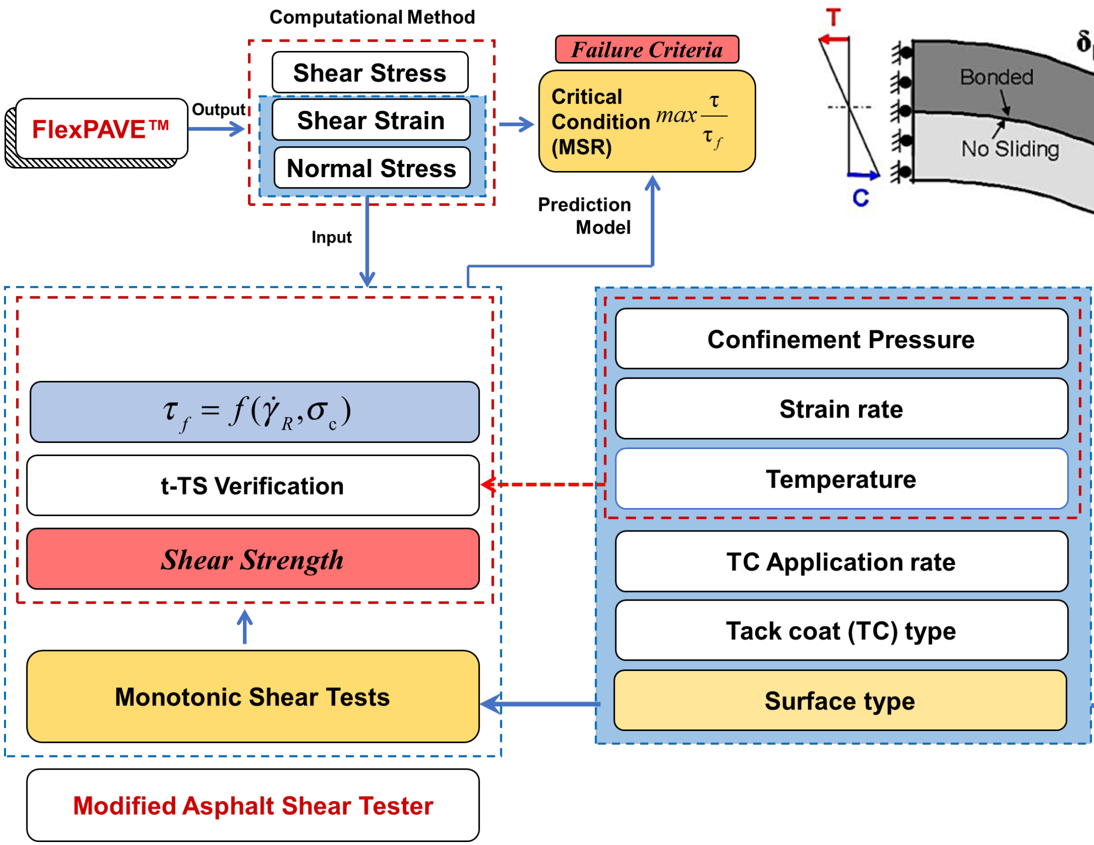




Intermediate pavement section, 80kN (18 kips), 8 km/hour (5 mph) 60°C at 3.81 cm (1.5 in.) depth under braking condition

# Interface Shear Strength

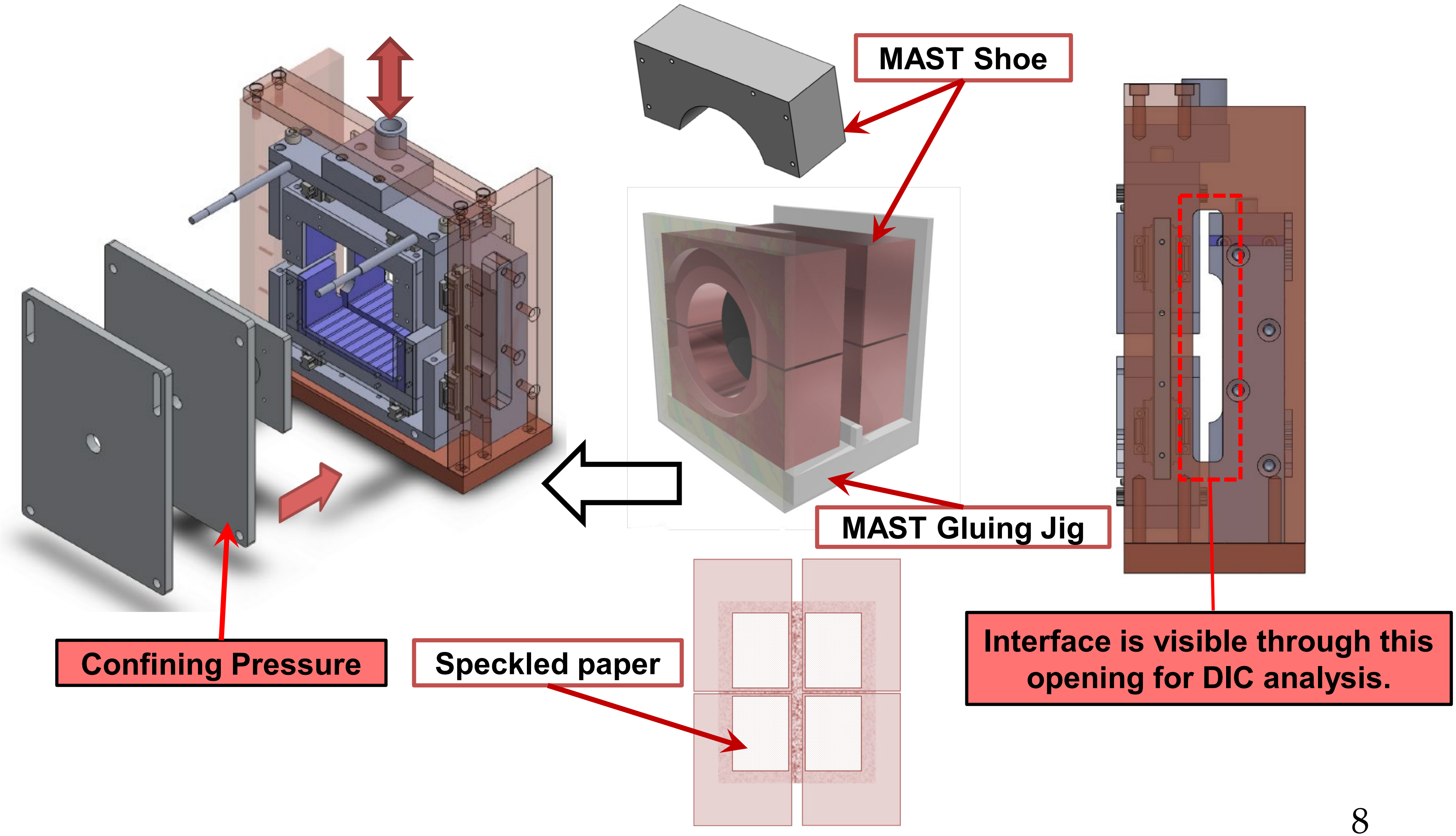



Kim et al. 2011



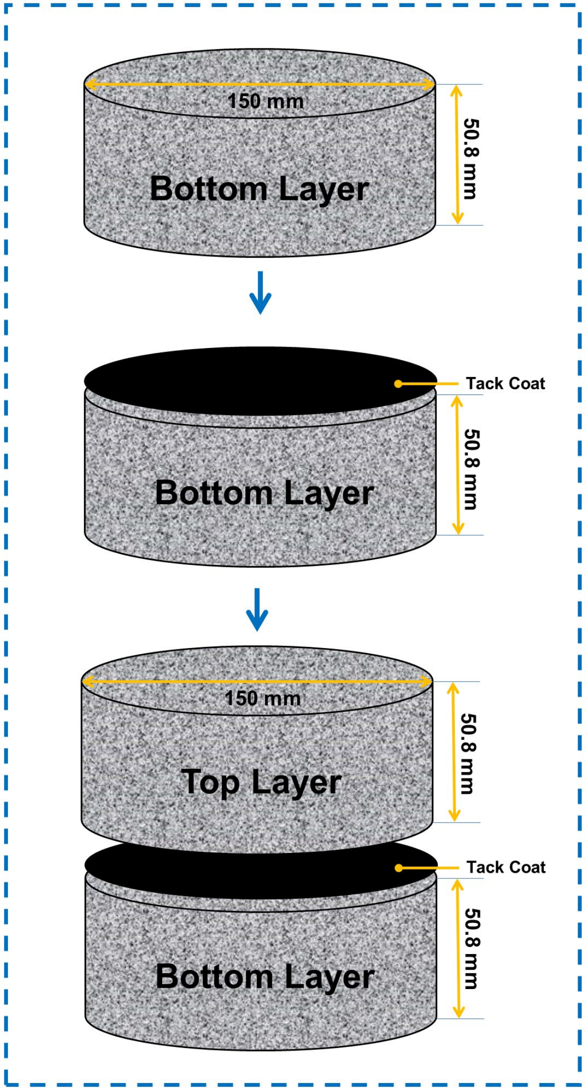
# Interface Shear Strength

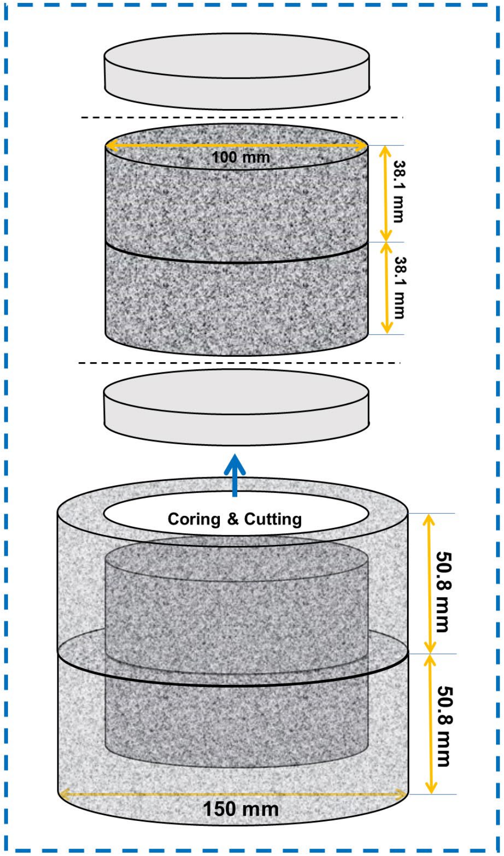
## *Modified Asphalt Shear Tester (MAST)*



# Interface Shear Strength

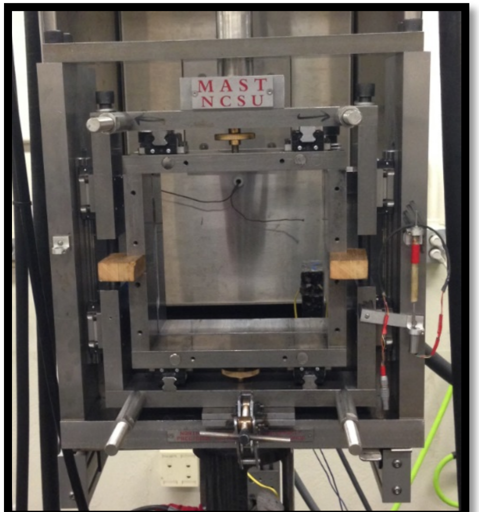
## *MAST specimen preparation*

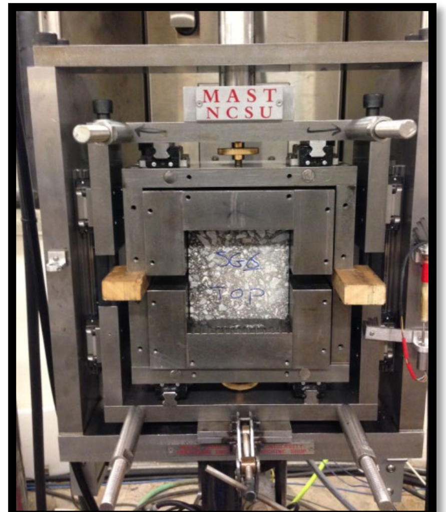


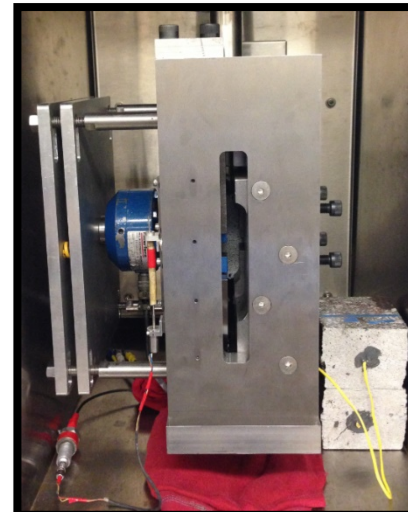



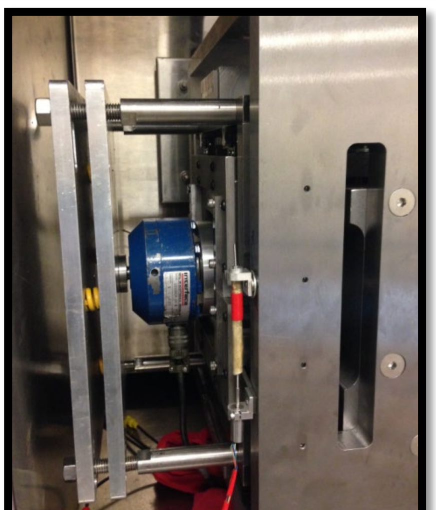

# Interface Shear Strength

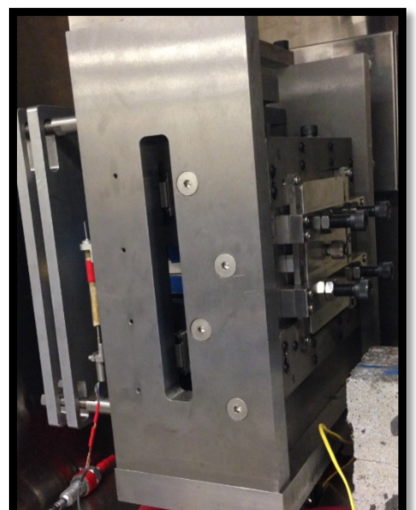
## *MAST Test Setup*



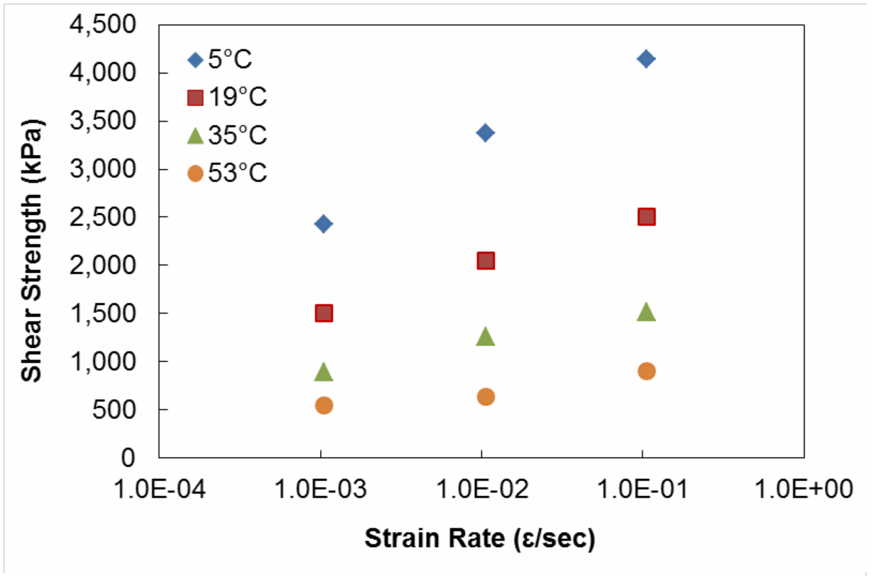



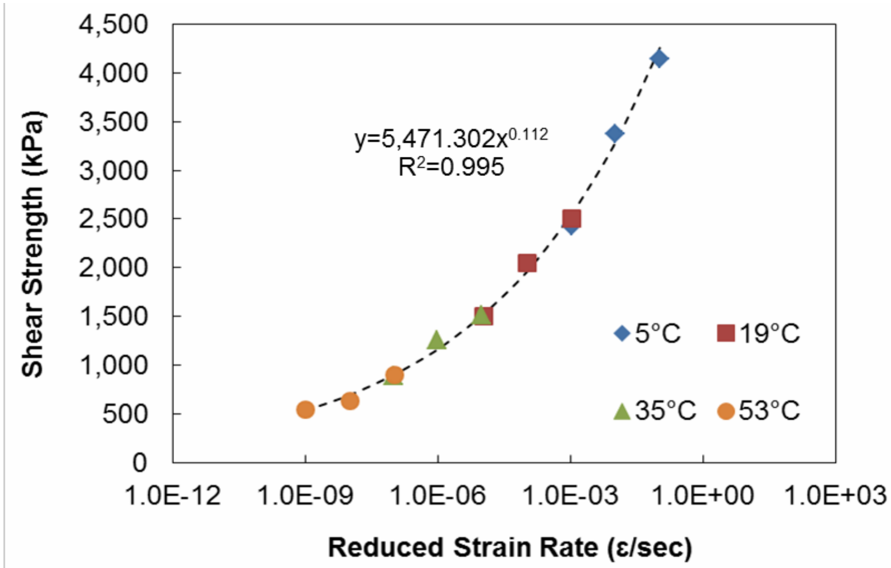


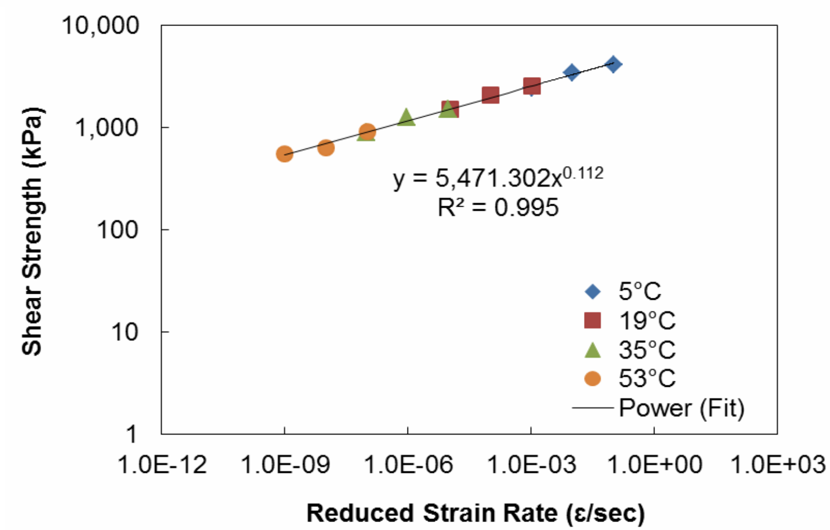


# Interface Shear Strength

## *Prediction Model*



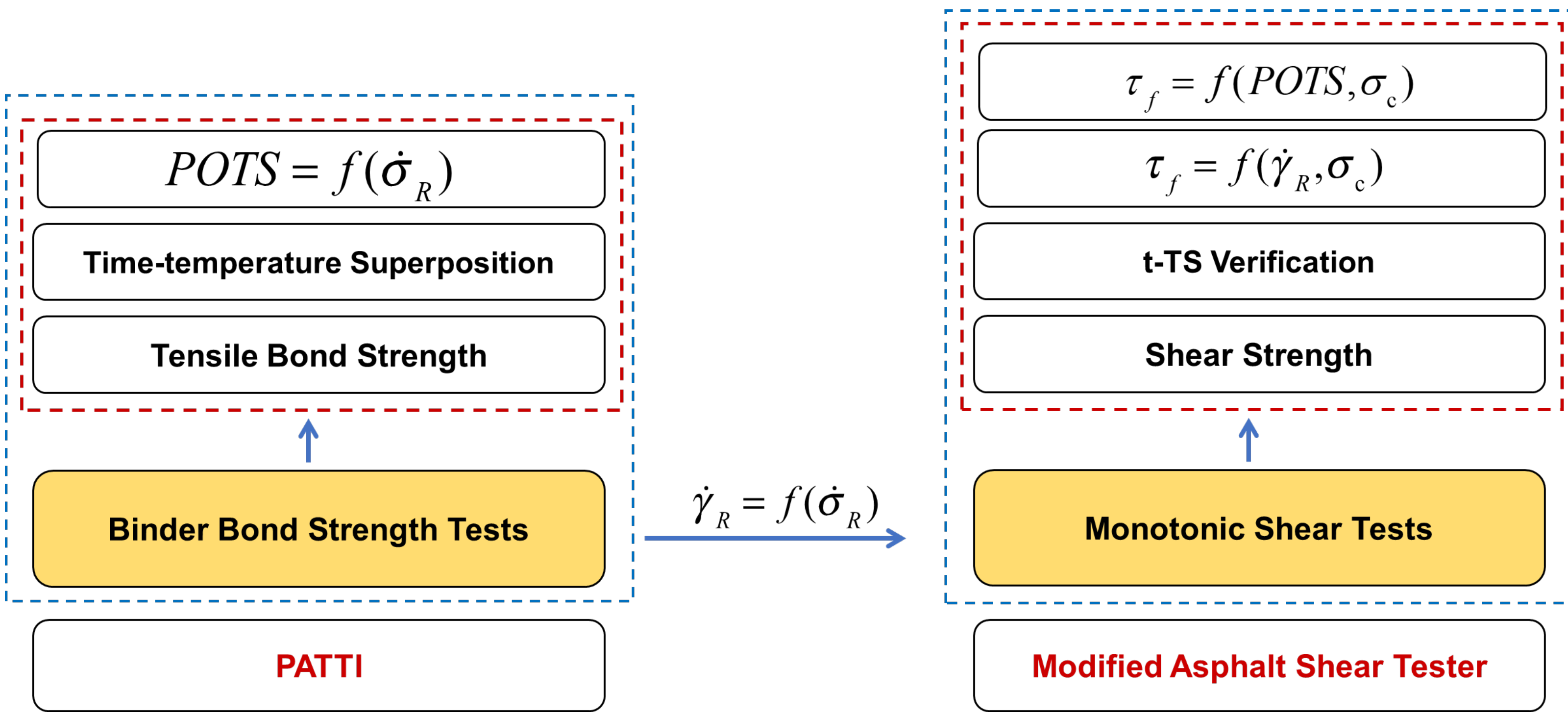




***Failure Criteria***

**Critical Condition** $max \frac{\tau}{\tau_f}$

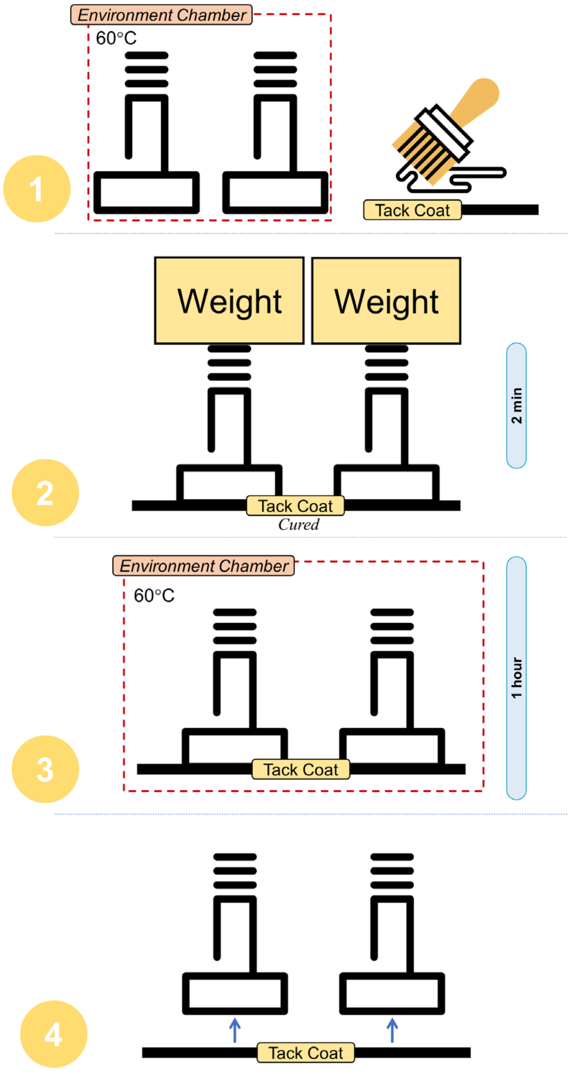
$$\tau_f = (a \times \dot{\gamma}_R^b) \times \sigma_c + c \times \dot{\gamma}_R^d + e \times \sigma_c$$

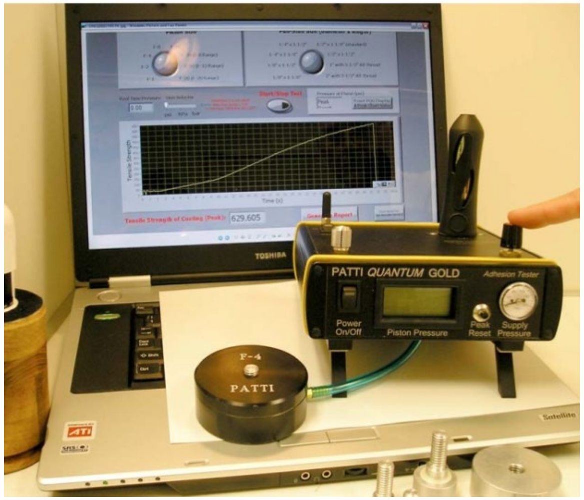
# Binder Bond Strength

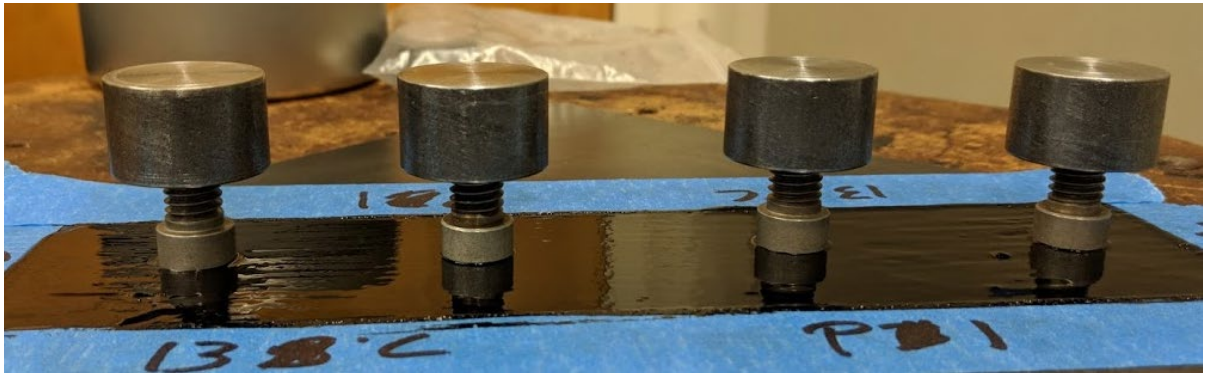


# Binder Bond Strength

## *Pneumatic Adhesion Tensile Testing Instrument (PATTI)*



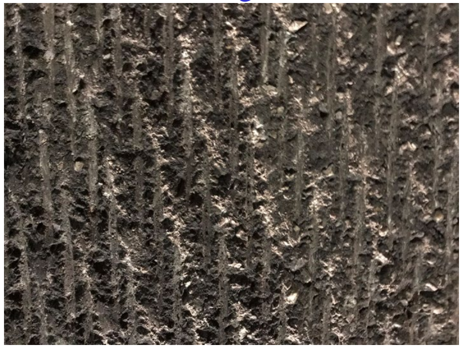
# Interface Shear Strength

## *RP 2018-13 Experimental Design*

| Factors | Conditions | | | | |
|---|---|---|---|---|---|
| Tack coat type | CRS-2 | CRS-1h | NTCRS-1hM | Ultrafuse | No tack |
| Test temperature | 5°C, 19°C, 35°C, 53°C | | | | |
| Application rate | 0.0452 L/m$^2$ (0.01 gal/yd$^2$), 0.136 L/m$^2$ (0.03 gal/yd$^2$), 0.226 L/m$^2$ (0.05 gal/yd$^2$) | | | | |
| Loading rate | 50.8 mm/min (2 in./min), 5.08 mm/min (0.2 in./min), 0.508 mm/min (0.02 in./min) | | | | |
| Confinement (normal stress) | 69 kPa (10 psi), 276 kPa (40 psi), 483 kPa (70 psi) | | | | |
| Surface | Ungrooved Surface (U) | | Grooved Surface (G) | | |

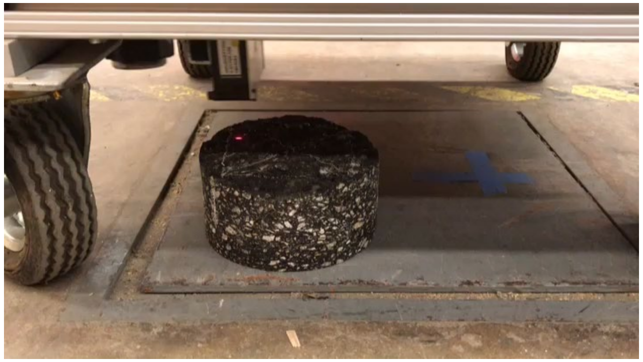
# Milled Surfaces

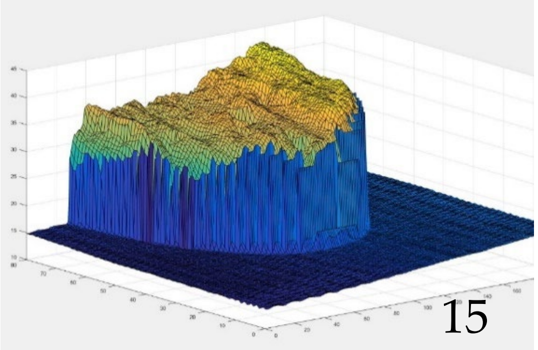
## *Field, Maynard Rd, Cary, NC*



## *Field core samples*

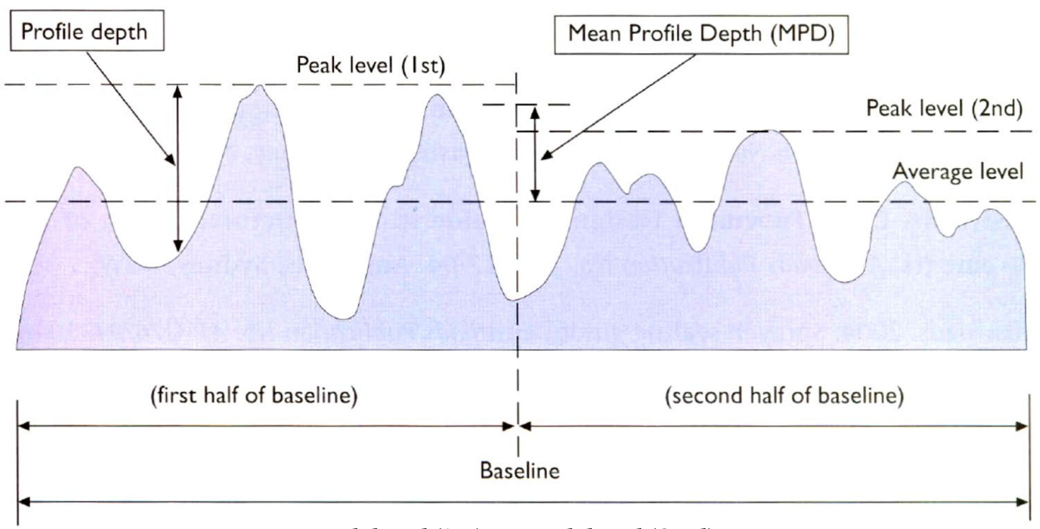
## *3D Laser Scanner*



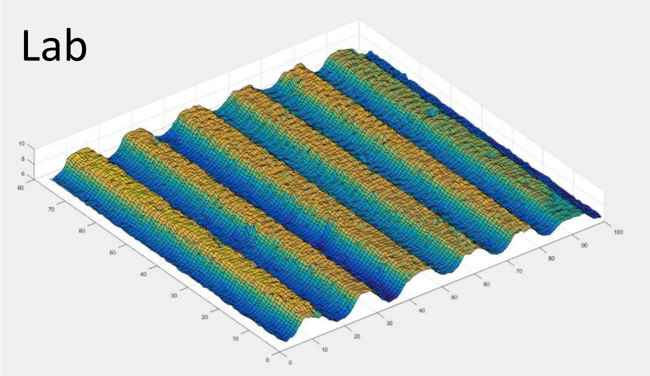


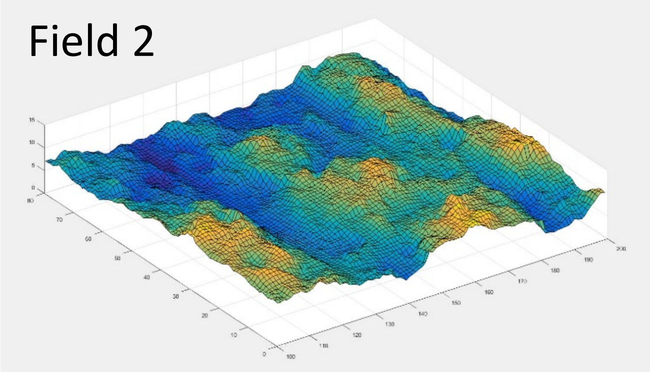
# Milled Surface

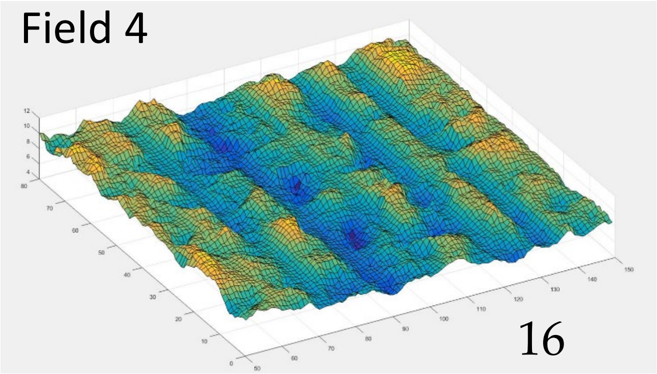
## *Mean Profile Depth (MPD)*

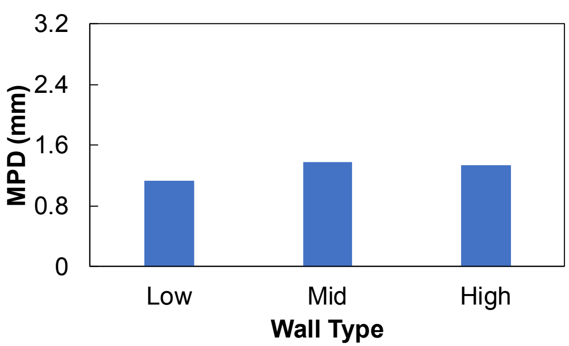


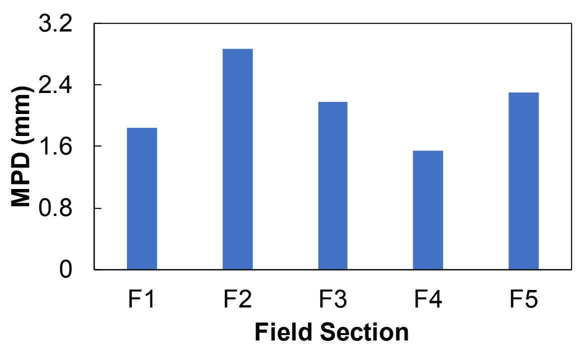

$$MPD = \frac{Peak\,level\,(1st) + Peak\,level\,(2nd)}{2} - Average\,level$$



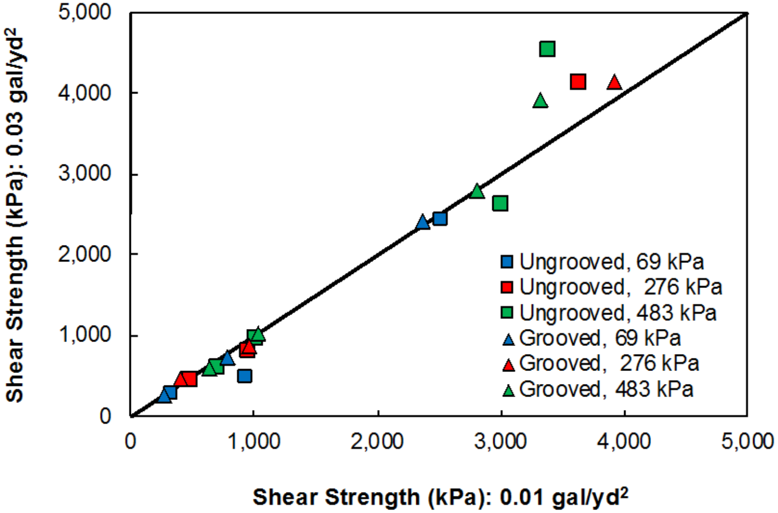



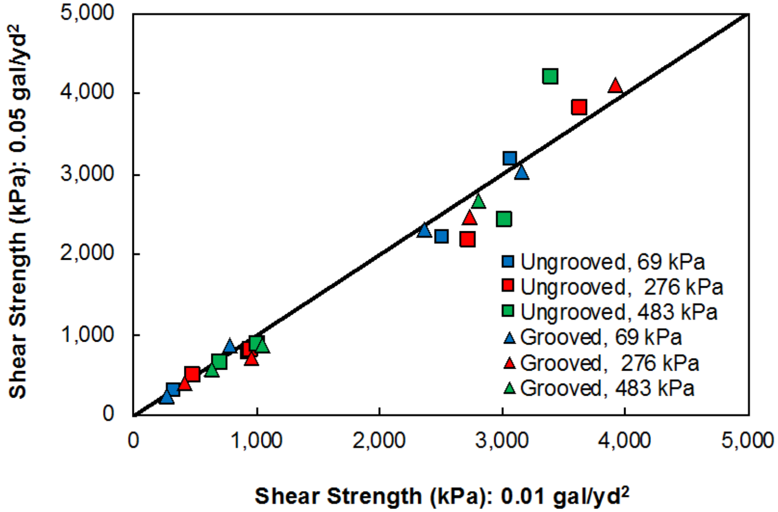



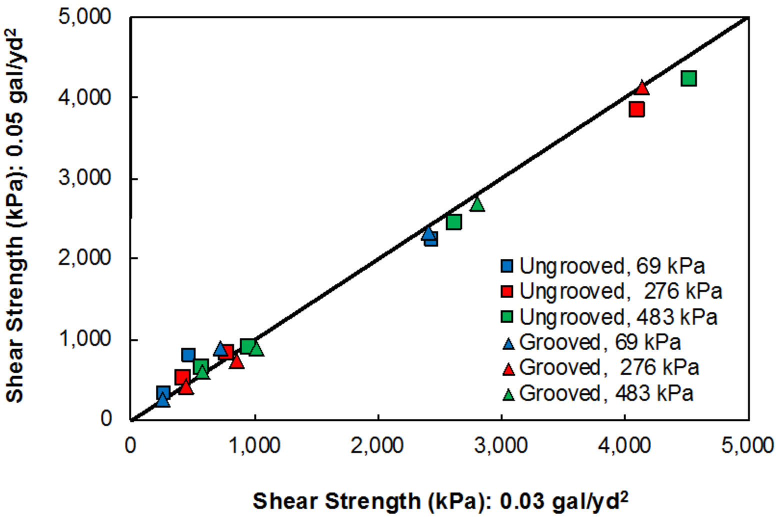



# Effect of Application Rate

## *CRS-2: Grooved and Ungrooved*

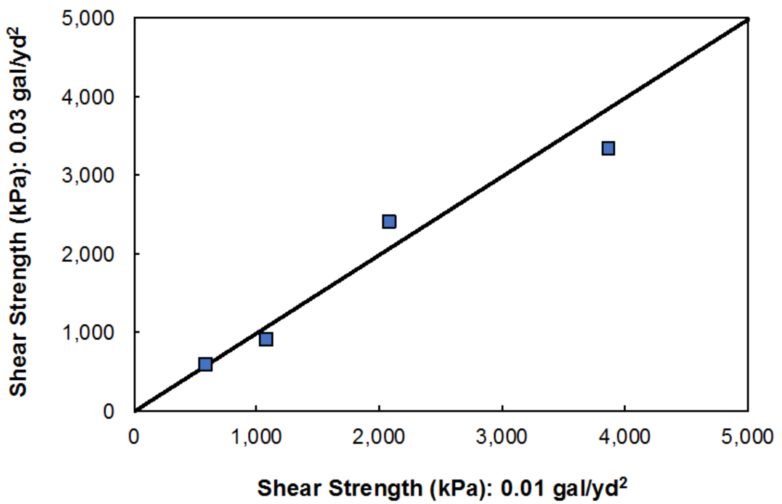


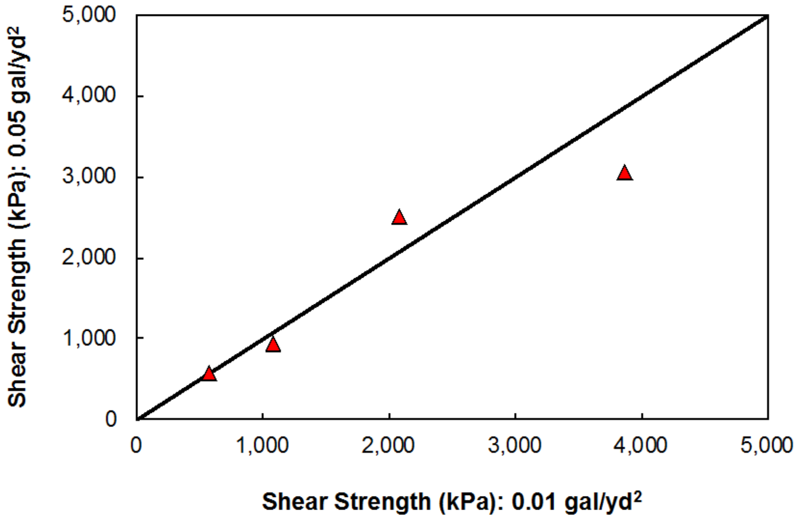



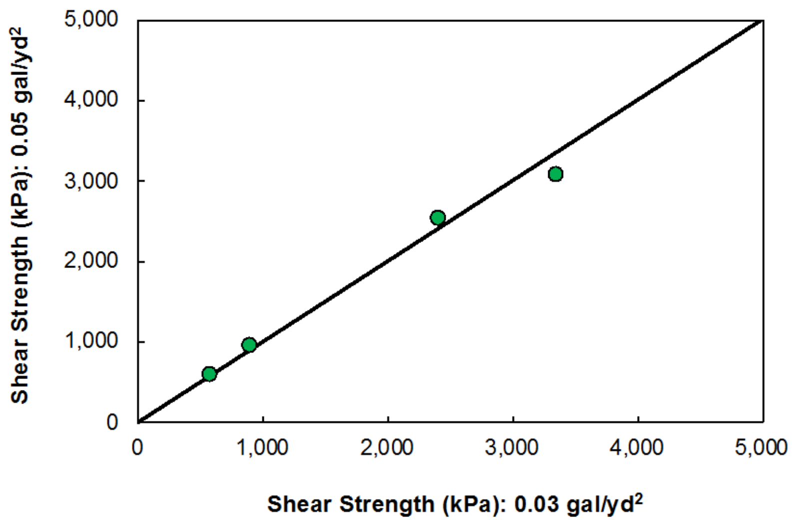



# Effect of Application Rate

## *CRS-1h, Grooved*

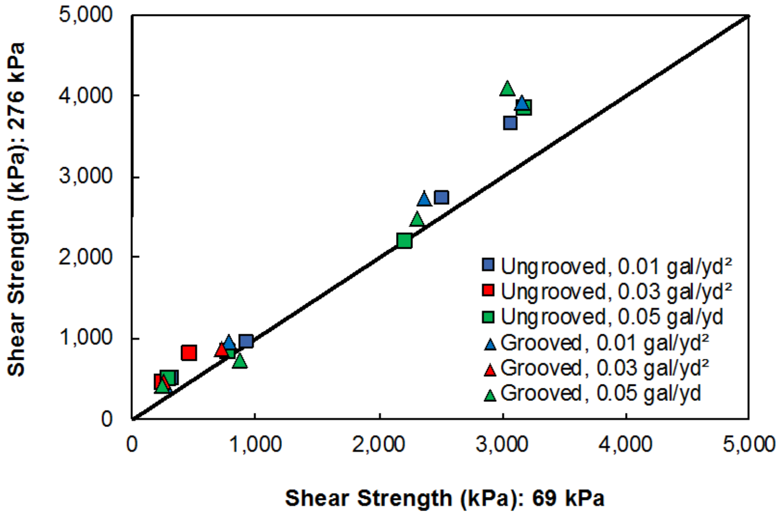


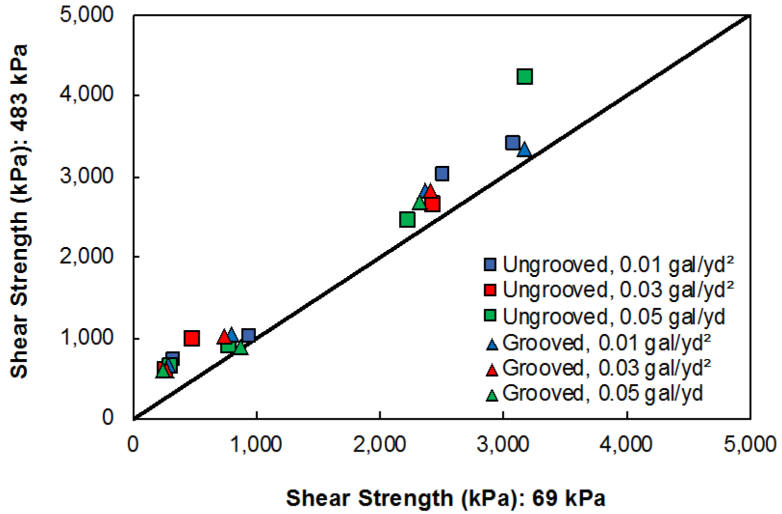



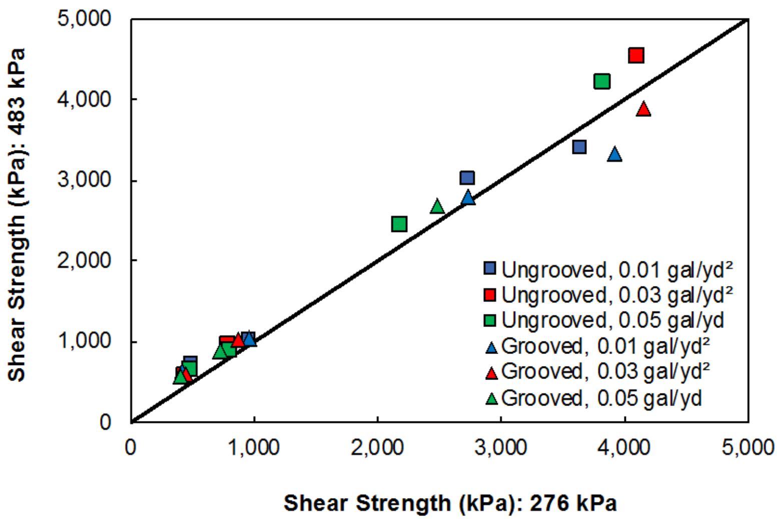



# Effect of Confining Pressure

## *CRS-2: Grooved and Ungrooved*

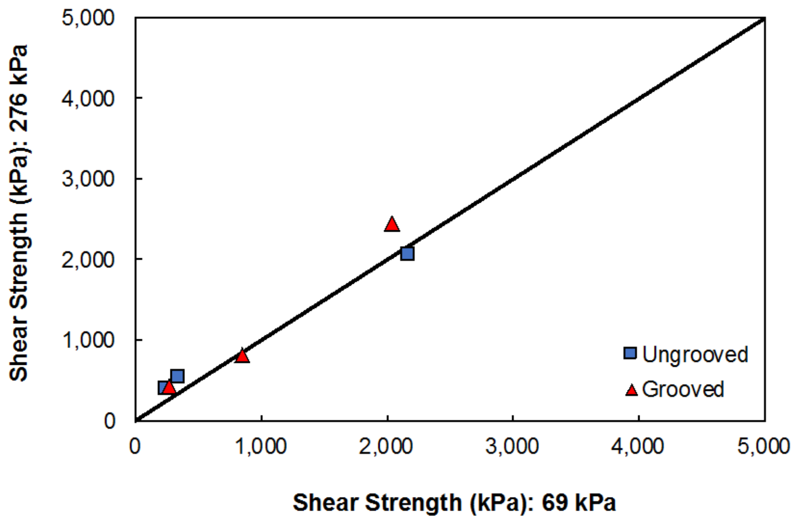


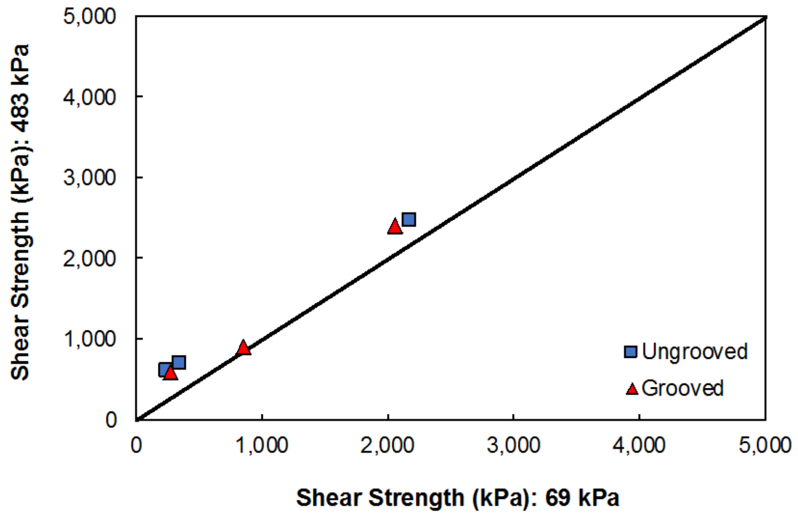



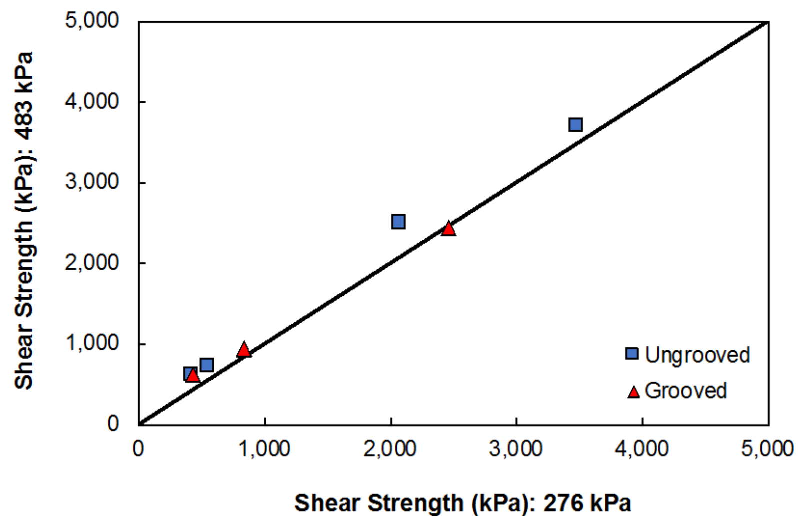



# Effect of Confining Pressure

## *CRS-1h: Grooved and Ungrooved*



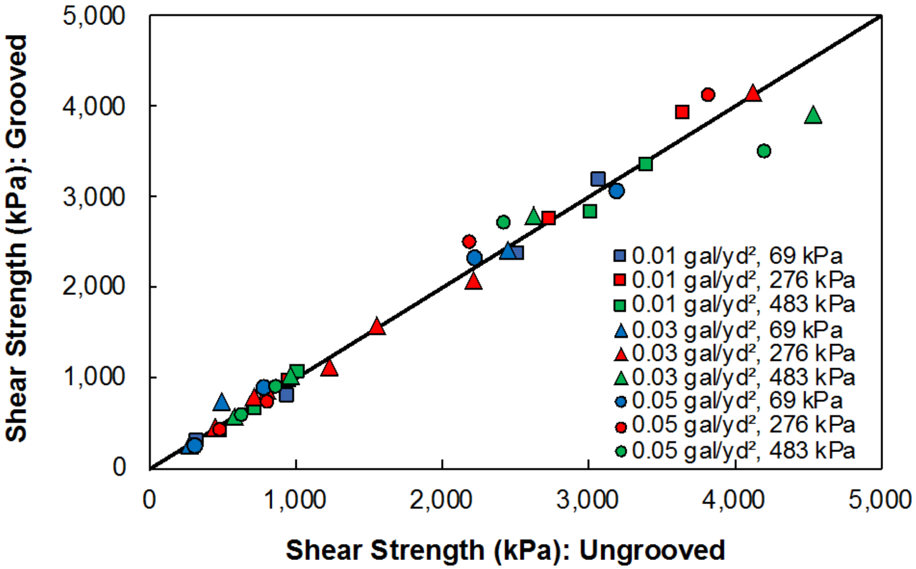



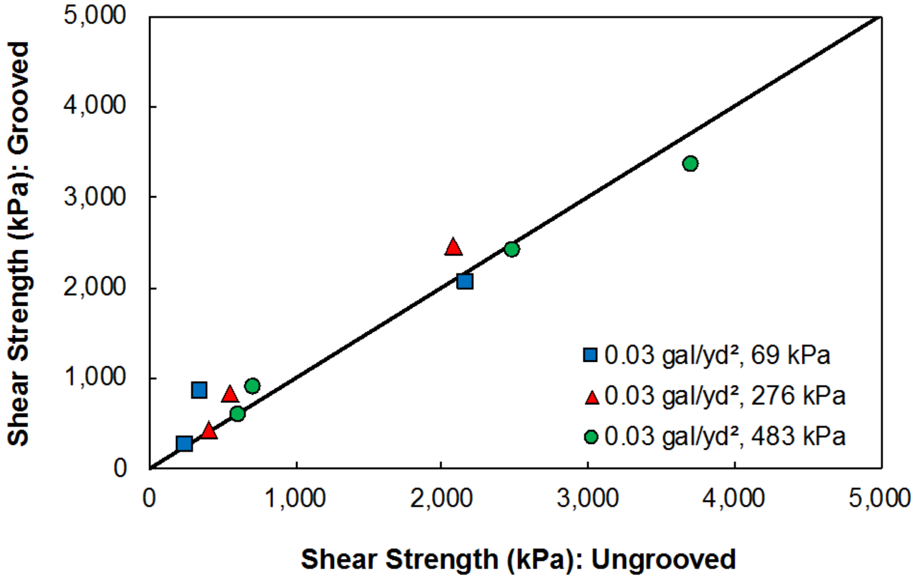
# Effect of Surface Type

## *Grooved vs. Ungrooved*

### *CRS-2*

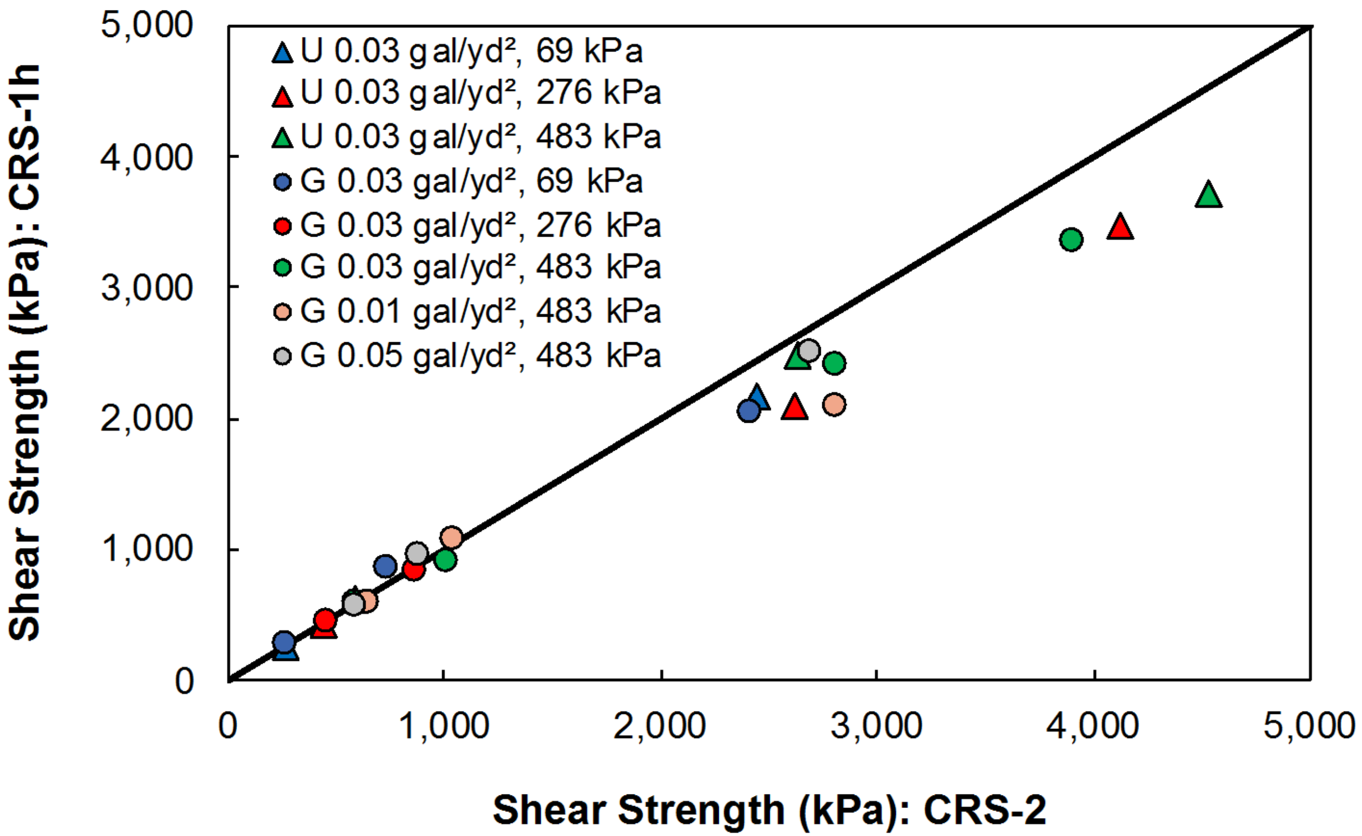



### *CRS-1h*



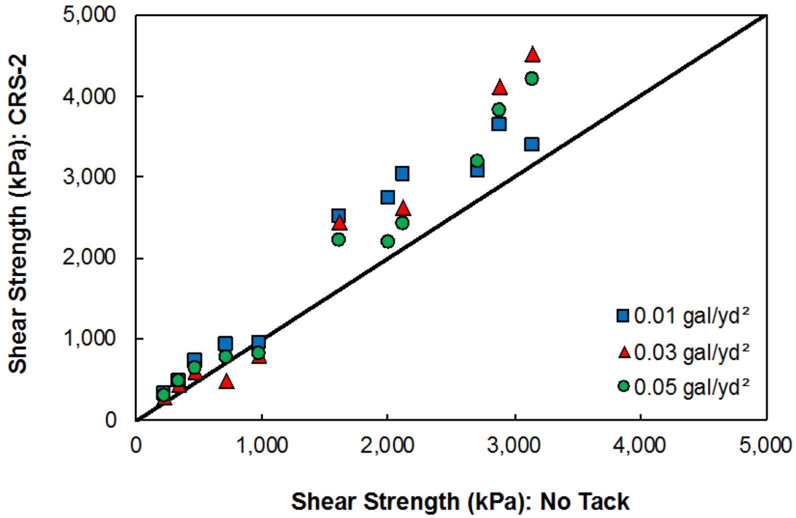
# Effect of Tack Coat Material

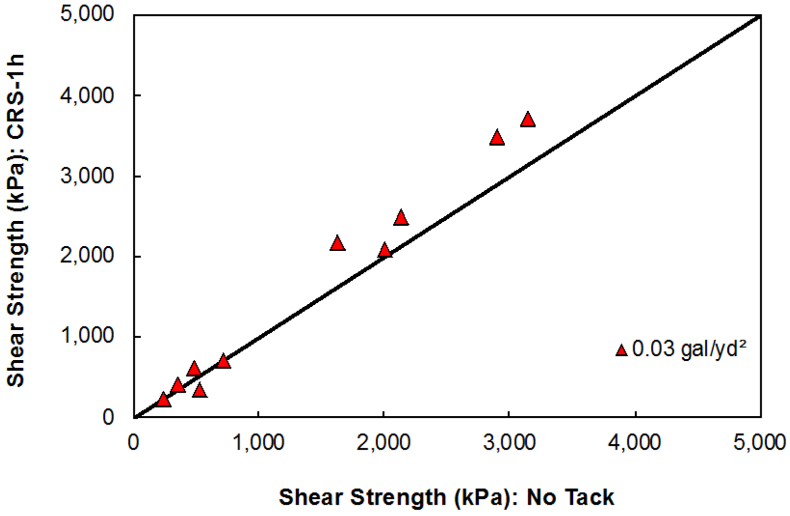
## *CRS-2 vs. CRS-1h*

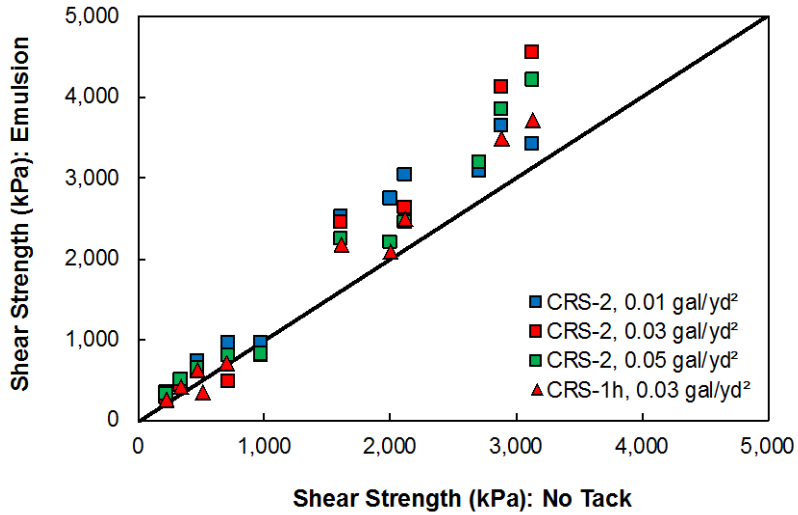


# Effect of Tack Coat Material

## *CRS-2 & CRS-1h vs. No Tack*

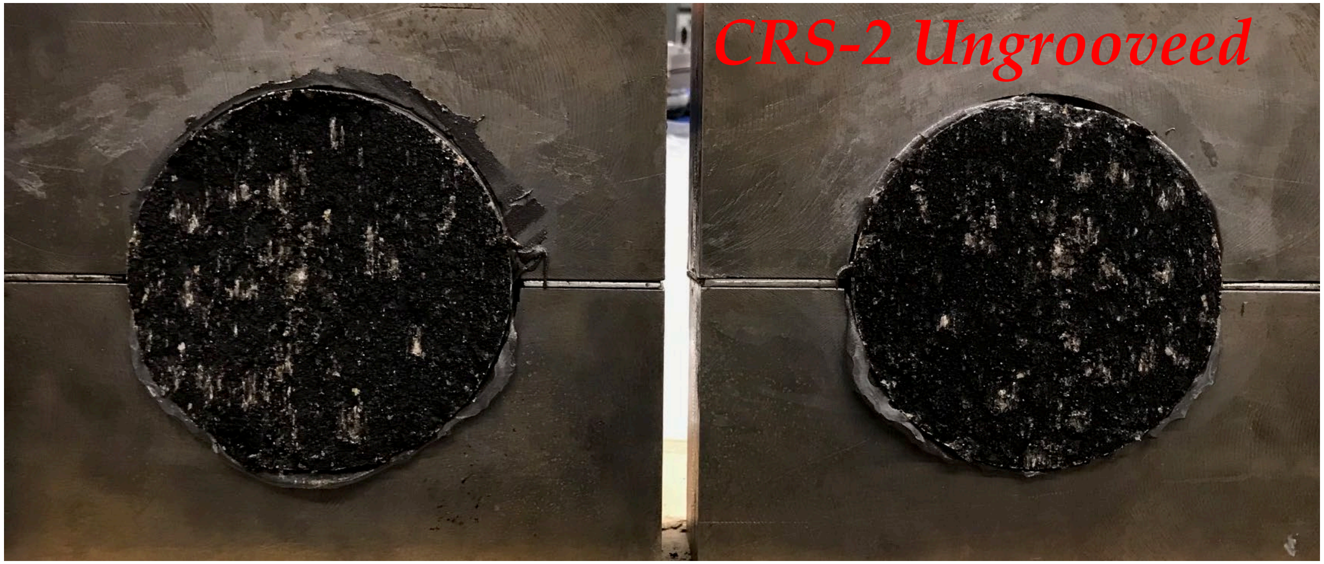


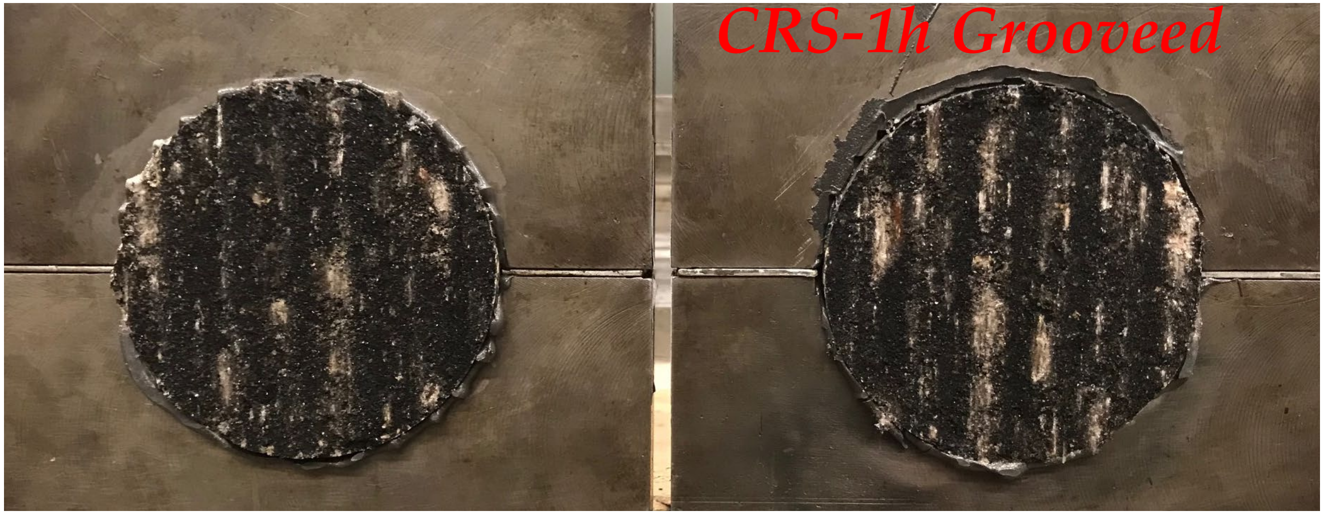



# Specimens after MAST test

***Confining Pr = 40 psi, Temp. = 19 ℃, Strain rate= 50 mm/min***




# Conclusions

- A mechanistic framework for the evaluation of tack coat quality has been established using BBS of binder, ISS of mixture, and FlexPAVETM for pavement analysis.
- Time-temperature superposition of BBS and ISS has been verified.
- Effects of tack coat application rate in ISS are found insignificant.
- Effects of confining pressure on ISS are found to be significant.
- CRS-2 tack coat demonstrated higher ISS than CRS-1h tack coat.
- Milled surface condition did not change the ISS from the unmilled surface condition. However, this conclusion is based on laboratory-fabricated milled surface condition where the shear loading direction was aligned to the groove direction. The results from milled surface with random groove pattern in the field are expected to be different.


# Thank you!

# Questions?

# Impact of Local M-EPDG Calibration Using Sustainable Materials

Tara Cavalline, PhD, PE
Brett Tempest, PhD, PE
Edward Blanchard
Clay Medlin
Rohit Chimmula

NCDOT Research and Innovation Summit
May 7, 2019

# Background

- NCDOT has used Pavement ME Design software program for design of pavements (based on M-EPDG)
- Best results are obtained using locally calibrated input values
- Local inputs for concrete pavements needed
- Thermal inputs are of particular interest

- Portland Limestone Cements (PLC) have been shown to reduce the carbon footprint of concrete
- PLCs are commonly used in concrete produced in Europe and Canada
- Increasing number of states are allowing use of PLCs.
- North Carolina has recently made provisions to allow PLCs, but do not have experience with PLCs in concrete mixtures with local materials

UNC CHARLOTTE

# Project Objectives

1. Develop and batch concrete mixtures for concrete pavements
   – Utilize aggregates from Mountain, Piedmont, and Coastal regions
   – Utilize manufactured sand (2MS) and natural sand
   – Utilize both Type I/II OPC as well as PLC
   – PLC produced from same clinker as Type I/II OPC
   – Two types of fly ash

2. Perform laboratory testing to determine:
   - Determine mechanical properties
   - Determine thermal characteristics
   - Evaluate durability performance

3. Prepare a catalog of concrete characteristics for use by NCDOT as inputs in Pavement ME Design

UNC CHARLOTTE

# Analysis Focus Areas

1. Sensitivity analysis and implications of new inputs on concrete pavement design

2. Durability performance of mixtures used for concrete pavements

3. Quantifying sustainability benefits of PLC use

- Project report: NCDOT RP 2015-03, “Improved Data for Mechanistic-Empirical Pavement Design for Concrete Pavements.”

- Cavalline, T.L, Tempest, B.Q., Blanchard, E.H., Medlin, C.D., Chimmula, R.R., and Morrison, C.S. (2018), “Impact of Local Calibration Using Sustainable Materials for Rigid Pavement Analysis and Design.” ASCE Journal of Transportation Engineering, Part B: Pavements, 144(4).

UNC CHARLOTTE

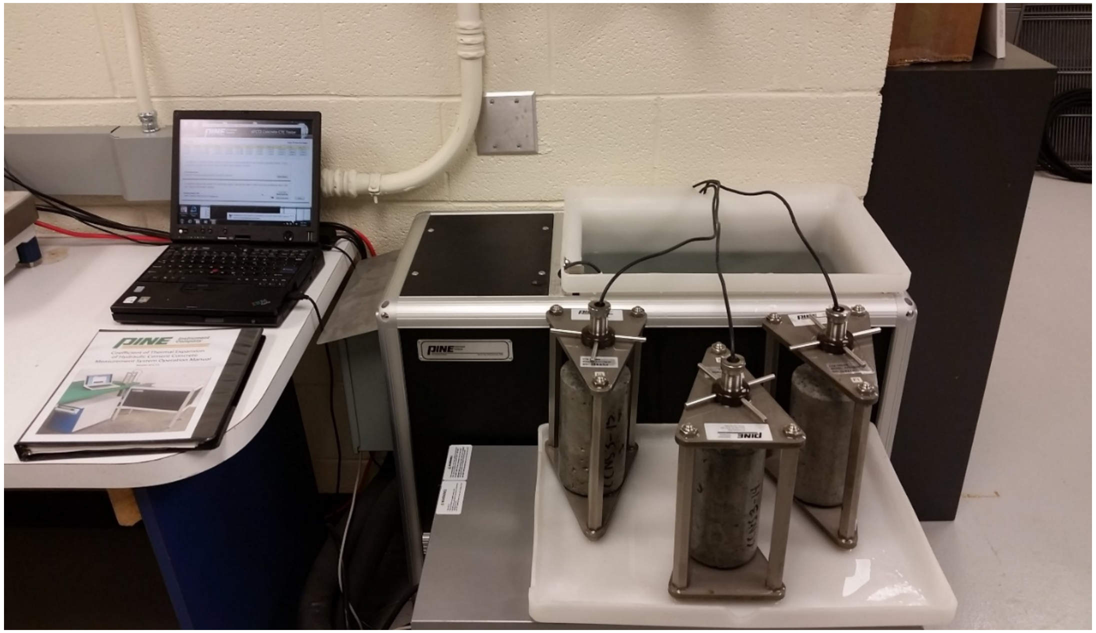
| Mixture ID* | Material Types | | | | Selected Proportions, pcy | |
|---|---|---|---|---|---|---|
| | Cement | Fly Ash | Coarse Aggregate | Fine Aggregate | Cement | Fly Ash |
| C.A.N.M | OPC Source A | None | Coastal | Manuf. Sand | 573 | 0 |
| M.A.N.M | | None | Mountain | Manuf. Sand | 573 | 0 |
| P.A.N.M | | None | Piedmont | Manuf. Sand | 573 | 0 |
| P.A.N.N | | None | | Natural Sand | 573 | 0 |
| P.A.A.M | | Source A | | Manuf. Sand | 460 | 137 |
| P.A.B.M | | Source B | | Manuf. Sand | 460 | 137 |
| C.B.N.M | OPC Source B | None | Coastal | Manuf. Sand | 573 | 0 |
| M.B.N.M | | None | Mountain | Manuf. Sand | 573 | 0 |
| P.B.N.M | | None | Piedmont | Manuf. Sand | 573 | 0 |
| P.B.N.N | | None | | Natural Sand | 573 | 0 |
| P.B.A.M | | Source A | | Manuf. Sand | 460 | 137 |
| P.B.B.M | | Source B | | Manuf. Sand | 460 | 137 |
| C.BL.N.M | PLC (produced from OPC Source B) | None | Coastal | Manuf. Sand | 573 | 0 |
| M.BL.N.M | | None | Mountain | Manuf. Sand | 573 | 0 |
| P.BL.N.M | | None | Piedmont | Manuf. Sand | 573 | 0 |
| P.BL.N.N | | None | | Natural Sand | 573 | 0 |
| P.BL.A.M | | Source A | | Manuf. Sand | 460 | 137 |
| P.BL.B.M | | Source B | | Manuf. Sand | 460 | 137 |

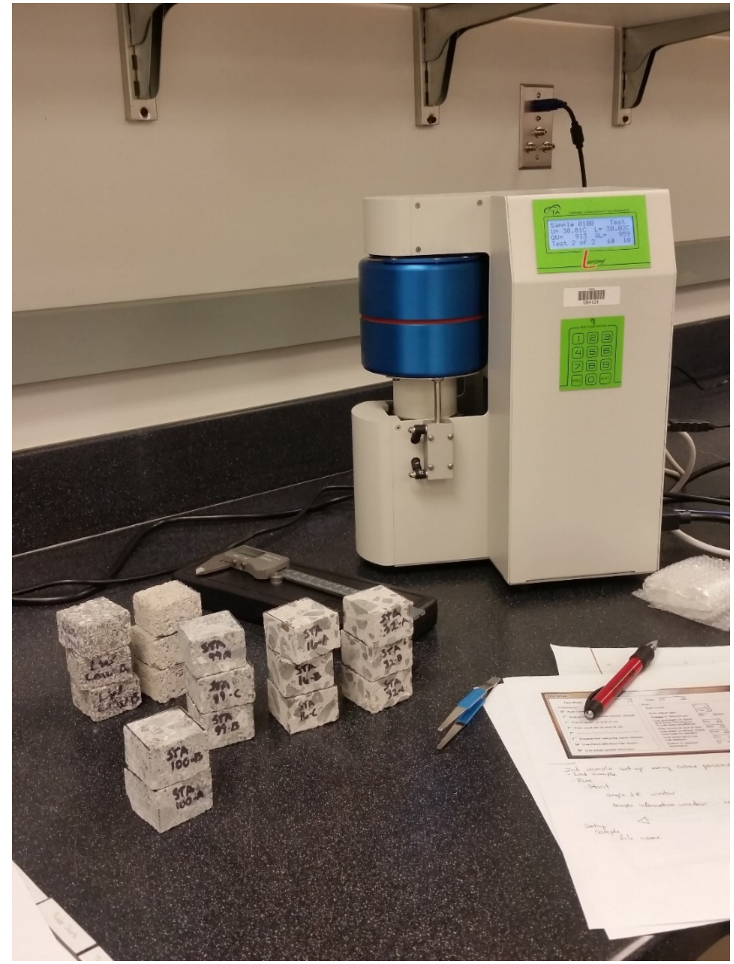
*Note: Explanation of Mixture ID coding: First letter, coarse aggregate type (C = Coastal, P = Piedmont, M = Mountain), Second letter, cement type (A = OPC source A, B = OPC source B, BL = PLC), Third letter, fly ash type (N = None, A = fly ash source A, B = fly ash source B), Fourth letter, fine aggregate type: M = manufactured sand, N = natural sand

# Laboratory Testing Program

| | Test | Protocol | Age(s) in days | Replicates |
|---|---|---|---|---|
| Fresh | Air content | ASTM C231 and Super air meter | Fresh | 1 each type of test, each batch |
| | Slump | ASTM C143 | Fresh | 1 |
| | Fresh density (unit weight) | ASTM C138 | Fresh | 1 |
| | Temperature | AASHTO T309 | Fresh | 1 |
| Hardened | Compressive strength | ASTM C39 | 3, 7, 28, 90 | 3 each age |
| | Resistivity | AASHTO TP95-11 | 3, 7, 28, 90 | 3 each age |
| | Modulus of rupture | ASTM C78 | 28 | 2 |
| | Modulus of elasticity and Poisson's ratio | ASTM C469 | 28 | 2 |
| | Coefficient of thermal expansion | AASHTO T336 | 28 | 3 |
| | Heat capacity | ASTM C2766 | 56 | 3 |
| | Thermal conductivity | ASTM E1952 | 56 | 3 |
| | Shrinkage | ASTM C157 | per standard | 3 |
| | Cracking potential | ASTM C1581 | per standard | 3 |
| | Rapid chloride permeability | ASTM C1202 | 28 | 2 |
| | Freezing and thawing resistance | ASTM C666, procedure A | per standard | 3 |
| | Thaumasite attack ** | CSA A3004-C8 | per standard | 6 |

# Thermal Property Test Equipment





UNC CHARLOTTE

# Summary of Findings - Mechanical Properties

- PLC performed similarly to OPC in mechanical property test results, providing incentive to use this sustainable alternative to OPC.

- Coarse aggregate type did not significantly influence laboratory tests used to determine MEPDG inputs.

- Including fly ash in in pavement mixtures improves durability and sustainability, but makes 28-day compressive strength an unsuitable M-EPDG input.

- Modulus of elasticity values (at 28-days) for all mixtures ranged from of 2,400,000 psi to 3,700,000 psi. This is lower than the suggested range of 3,000,000 psi to 4,000,000 psi suggested in the MEPDG literature.

- Many of the mixtures exhibited Poisson's ratio test results that were higher than the suggested range provided in the MEPDG literature (0.15 to 0.18).

UNC CHARLOTTE

# Summary of Findings - Thermal Properties

## Coefficient of Thermal Expansion

- Measured CTE values are consistently lower than the CTE values currently used by NCDOT.
- Measured CTE values were significantly lower than the recommended values suggested in the MEPDG literature for granitic gneiss and limestone.
- Mixtures containing the natural sand had a notably higher coefficient of thermal expansion than those containing the manufactured sand.
    - Movement towards use of 2MS associated with lower CTE and potentially improved thermal performance
    - Implications on CTE for concrete mixtures that are blends of manufactured and natural sand?

UNC CHARLOTTE

# Summary of Findings - Thermal Properties

## Thermal Conductivity

- For mixtures with the manufactured sand an MEPDG input for thermal conductivity of 0.80 to 0.90 BTU/(ft·hr·°F) appears to be reasonable.
  - Significantly lower than the default input value is 1.25 BTU/(ft·hr·°F).

- Mixtures with the natural sand had a higher thermal conductivity, closer to the default value of 1.25 BTU/(ft·hr·°F).

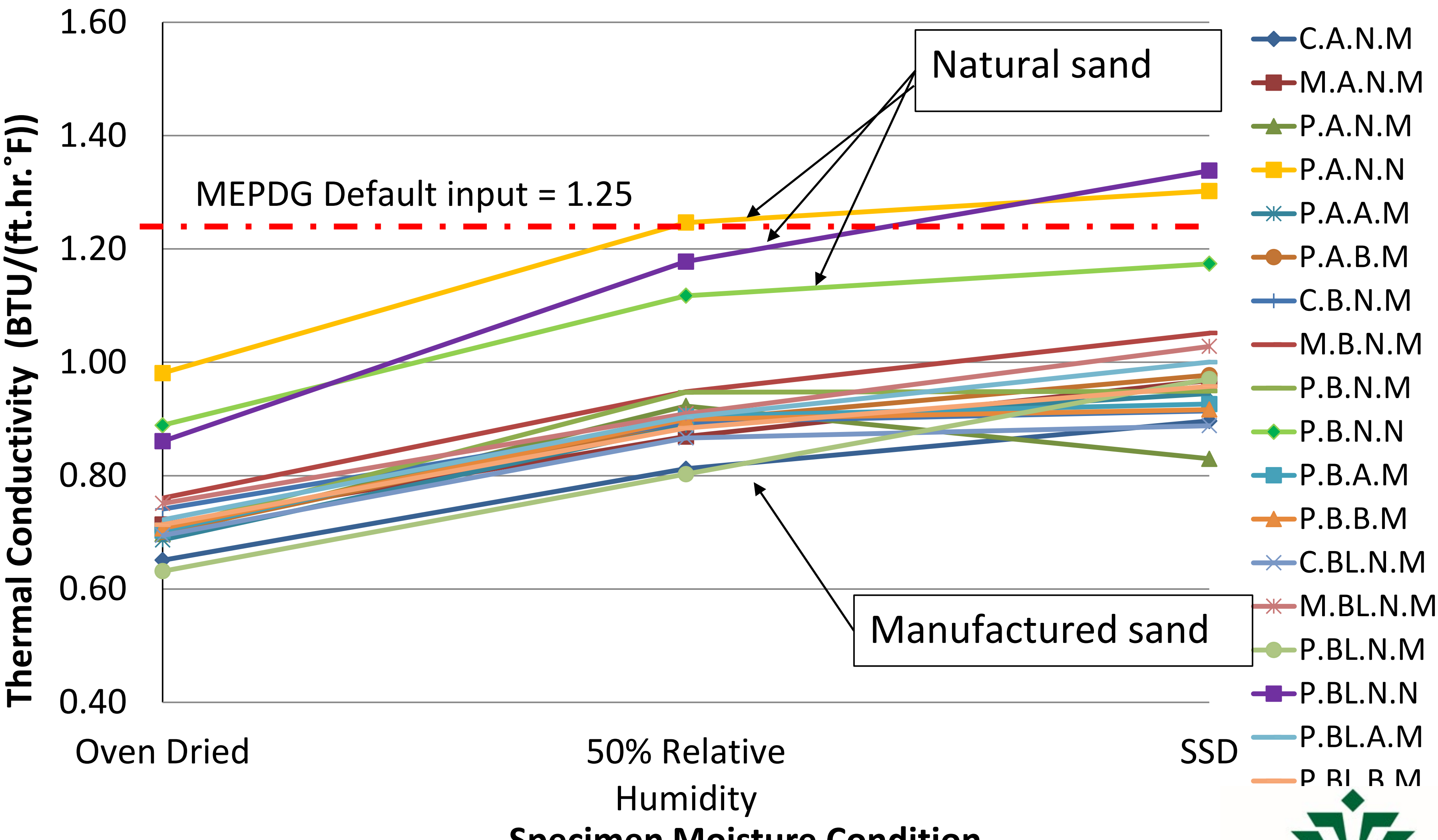
## Heat Capacity

- All measured values for heat capacity were notably lower than the default values suggested in the MEPDG literature.
- Regardless of materials utilized, an MEPDG input for heat capacity of 0.20 BTU/lb·ft appears to be reasonable.  The default value is 0.28 BTU/lb·ft.
- The effect of sand type on heat capacity is not readily evident.

***Role of moisture content of concrete specimen was investigated. ***

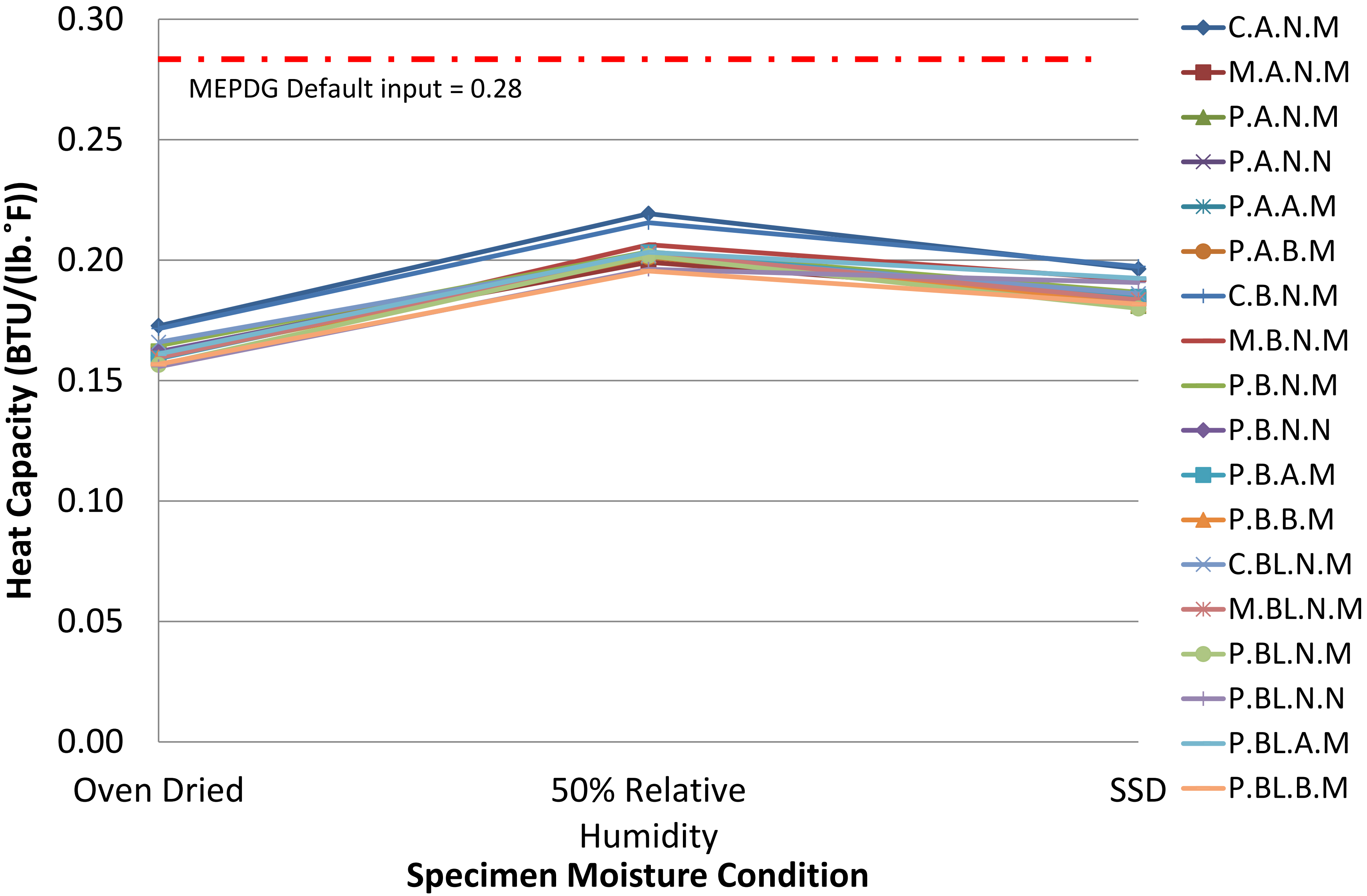
UNC CHARLOTTE

# Influence of Specimen Moisture Condition on Thermal Conductivity




UNC CHARLOTTE

# Impact of Specimen Moisture Condition
# Heat Capacity



# Proposed Catalog of Inputs

<table>
<tr><th colspan="3">Materials</th><th colspan="8">M-EPDG Input</th></tr>
<tr><th>Coarse Aggr.</th><th>Fine Aggr.</th><th>Fly Ash</th><th>Unit Wt (pcf)</th><th>MOE (psi)</th><th>Pois. Ratio</th><th>MOR (psi)</th><th>CTE, (in/in/°F)</th><th>Heat Cap. BTU/(lb·°F)</th><th>Thermal Cond. (BTU/(ft·hr ·°F)</th></tr>
<tr><td>Piedmont</td><td>Man. Sand</td><td>No</td><td>145</td><td>3,000,000</td><td rowspan="2">0.19</td><td rowspan="2">660</td><td>$4.63\times10^{-6}$</td><td rowspan="5">0.22</td><td>0.95</td></tr>
<tr><td>Piedmont</td><td>Man. Sand</td><td>Yes</td><td>142</td><td>2,500,000</td><td>$4.57\times10^{-6}$</td><td>0.90</td></tr>
<tr><td>Piedmont</td><td>Natural Sand</td><td>No</td><td>142</td><td>3,400,000</td><td>0.16</td><td>740</td><td>$5.40\times10^{-6}$</td><td>1.20</td></tr>
<tr><td>Mountain</td><td>Man. Sand</td><td>No</td><td>146</td><td>2,700,000</td><td rowspan="2">0.19</td><td rowspan="2">660</td><td>$4.56\times10^{-6}$</td><td>0.95</td></tr>
<tr><td>Coastal</td><td>Man. Sand</td><td>No</td><td>139</td><td>3,500,000</td><td>$4.30\times10^{-6}$</td><td>0.90</td></tr>
</table>

<table>
<tr><td>NCDOT often utilized</td><td>150</td><td>4,200,000</td><td>0.17<br>0.20</td><td>650<br>690</td><td>$6.0\times10^{-6}$</td><td>0.28</td><td>1.25</td></tr>
<tr><td>MEPDG suggested</td><td>150</td><td>4,200,000</td><td>0.20</td><td>690</td><td>$5.5\times10^{-6}$</td><td>0.28</td><td>1.25</td></tr>
</table>

# Sensitivity Analysis Results
## Effect of Increase of Each Input on Predicted Distress

| Input | Terminal IRI (in/mile) | Mean Joint Faulting (in) | Transverse Cracking (% slabs cracked) |
|---|---|---|---|
| Unit weight ↑ | Decrease (VS) | Decrease (S) | Decrease (N) |
| Modulus of rupture ↑ | Decrease (VS) | Neutral (N) | Decrease (VS) |
| Modulus of elasticity ↑ | Increase (S) | Increase (S) | Increase (S) |
| Poisson's ratio ↑ | Increase (S) | Increase (S) | Increase (S) |
| CTE ↑ | Increase (VS) | Increase (VS) | Increase (S) |
| Thermal conductivity ↑ | Increase, then decrease (N) | Increase (S) | Decrease (VS) |
| Heat Capacity ↑ | Decrease (N) | Neutral (N) | Decrease (S) |

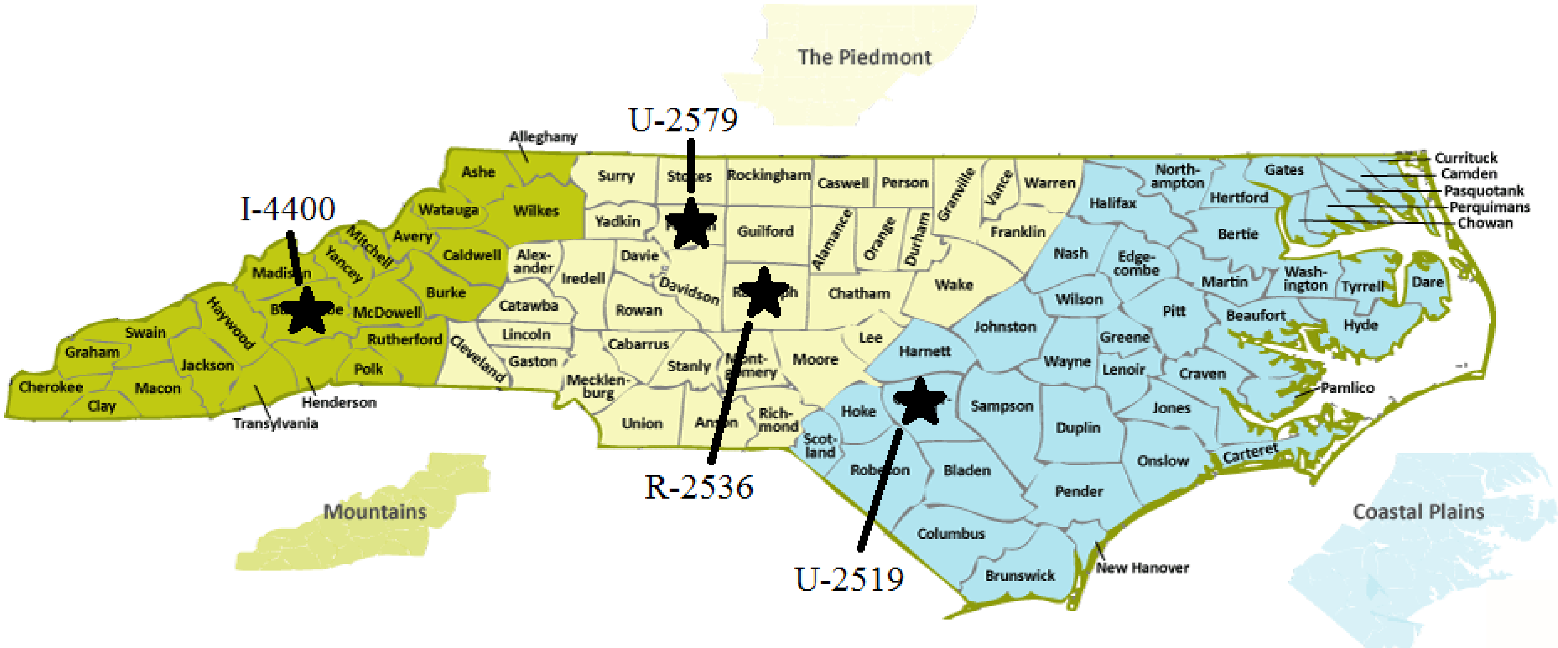
VS = Very Sensitive, S = Sensitive, N = Neutral

UNC CHARLOTTE

# Implications of New Inputs on Concrete Pavement Design

## NCDOT Selected Projects of Interest

- Project: I-4400 – I-26 in Buncombe Co.
- Project: U-2579 – W-S Northern Beltway, Forsyth Co.
- Project: R-2536 – Asheboro Bypass, Randolph Co.
- Project: U-2519 – Fayetteville Outer Loop, Cumberland Co.




UNC CHARLOTTE

# Minimal Influence of Cement Type

| Piedmont - Forsyth Co. | | | | | | | |
|---|---|---|---|---|---|---|---|
| NCDOT Project U-2579C Versus Piedmont Aggregate | | | | | | | |
| | | | NCDOT Project U-2579C Forsyth Co. | NCDOT 2MS Manufactured Sand with B Cement | NCDOT 2MS Manufactured Sand with BL Cement | C-33 Natural Sand with B Cement | C-33 Natural Sand with BL Cement |
| Layer 1: PCC | Pavement Thickness (in) | | 11 | 11 | 11 | 11 | 11 |
| | Cementitious Material Content (lb/yd$^3$) | | 600 | 550 | 550 | 550 | 550 |
| | Water to cement ratio | | 0.42 | 0.48 | 0.48 | 0.48 | 0.48 |
| | Unit Weight (PCF) | | 150 | 143 | 144 | 142 | 141 |
| | 28 Day Compressive Strength (psi) | | | 4,850 | 5,020 | 4,390 | 5,190 |
| | 28 Day Modulus of Rupture (psi) | | 690 | 670 | 655 | 715 | 753 |
| | 28 Day Modulus of Elasticity (psi) | | 4,200,000 | 3,340,000 | 2,430,000 | 3,510,000 | 3,040,000 |
| | Poisson's Ratio | | 0.20 | 0.20 | 0.18 | 0.19 | 0.15 |
| | Coefficient of Thermal Expansion (x $10^{-6}$ in/in°F) | | 6.00 | 4.63 | 4.54 | 5.31 | 5.32 |
| | Heat Capacity (Btu/lb-°F) | | 0.28 | 0.20 | 0.20 | 0.20 | 0.20 |
| | Thermal Conductivity (Btu/(ft)(hr)(°F)) | | 1.25 | 0.95 | 0.80 | 1.12 | 1.18 |
| Layer 2: | | | 4.25 inches of Flexible Pavement | | | | |
| Layer 3: | | | 8 inches of Lime Stabilized | | | | |
| Layer 4: | | | 12 inches of A-2-5 Subgrade | | | | |
| Layer 5: | | | Semi-infinite layer of A-2-5 Subgrade | | | | |
| Climate Data | | | Winston Salem, NC | | | | |
| Distress | Terminal IRI (in/mile) | 185.00 (Target) | 131.90 | 117.80 | 112.06 | 126.66 | 121.81 |
| | Mean Joint Faulting (in) | 0.12 (Target) | 0.08 | 0.06 | 0.05 | 0.07 | 0.07 |
| | JPCP Transverse Cracking (percent slabs) | 10.00 (Target) | 4.39 | 3.83 | 3.83 | 3.83 | 3.83 |
| Reliability | Terminal IRI (in/mile) | | 99.83 | 99.99 | 100.00 | 99.93 | 99.97 |
| | Mean Joint Faulting (in) | | 99.34 | 99.98 | 100.00 | 99.76 | 99.92 |
| | JPCP Transverse Cracking (percent slabs) | | 99.83 | 99.96 | 99.96 | 99.96 | 99.96 |

UNC CHARLOTTE

# Improved Performance with Local Inputs

| | | | NCDOT Project U-2579C Forsyth Co. | NCDOT 2MS Manufactured Sand 11 inch | NCDOT 2MS Manufactured Sand 10.5 inch | NCDOT 2MS Manufactured Sand 10 inch |
|---|---|---|---|---|---|---|
| Piedmont - Forsyth Co. | | | | | | |
| NCDOT Project U-2579C Versus Piedmont Aggregate | | | | | | |
| Layer 1: PCC | Pavement Thickness (in) | | 11 | 11 | 10.5 | 10 |
| | Dowel Diameter (in) | | 1.5 | 1.5 | 1.25 | 1.25 |
| | Cementitious Material Content (lb/yd$^3$) | | 600 | 550 | 550 | 550 |
| | Water to cement ratio | | 0.42 | 0.48 | 0.48 | 0.48 |
| | Unit Weight (PCF) | | 150 | 145 | 145 | 145 |
| | 28 Day Modulus of Rupture (psi) | | 690 | 660 | 660 | 660 |
| | 28 Day Modulus of Elasticity (psi) | | 4,200,000 | 3,000,000 | 3,000,000 | 3,000,000 |
| | Poisson's Ratio | | 0.20 | 0.20 | 0.20 | 0.20 |
| | Coefficient of Thermal Expansion (x $10^{-6}$ in/in°F) | | 6.00 | 4.63 | 4.63 | 4.63 |
| | Heat Capacity (Btu/lb-°F) | | 0.28 | 0.20 | 0.20 | 0.20 |
| | Thermal Conductivity (Btu/(ft)(hr)(°F)) | | 1.25 | 0.95 | 0.95 | 0.95 |
| Layer 2: | | | 4.25 inches of Flexible Pavement | | | |
| Layer 3: | | | 8 inches of Lime Stabilized | | | |
| Layer 4: | | | 12 inches of A-2-5 Subgrade | | | |
| Layer 5: | | | Semi-infinite layer of A-2-5 Subgrade | | | |
| Climate Data | | | Winston Salem, NC | | | |
| Distress | Terminal IRI (in/mile) | 185.00 (Target) | 131.90 | 115.58 | 144.70 | 143.94 |
| | Mean Joint Faulting (in) | 0.12 (Target) | 0.08 | 0.05 | 0.10 | 0.10 |
| | JPCP Transverse Cracking (percent slabs) | 10.00 (Target) | 4.39 | 3.83 | 3.83 | 3.83 |
| Reliability | Terminal IRI (in/mile) | | 99.83 | 99.99 | 99.24 | 99.30 |
| | Mean Joint Faulting (in) | | 99.34 | 99.99 | 96.55 | 96.95 |
| | JPCP Transverse Cracking (percent slabs) | | 99.83 | 99.96 | 99.96 | 99.96 |

UNC CHARLOTTE

# Implications on Concrete Pavement Design

- Recommended catalog of PCC inputs for M-EPDG is presented for use in local calibration efforts.
- Some recommended inputs differ significantly from MEPDG default/recommended values

- Coarse aggregate type not highly influential in MEPDG inputs
- Shift in use from natural to manufactured sands may have performance implications on PCC pavements
  - predicted to be mostly favorable if workability challenges are not an issue

- Fly ash mixtures – encourage for durability benefits
  - use of 28-day compressive strength likely an unsuitable input for MEPDG

UNC CHARLOTTE

# Implications on Concrete Pavement Design

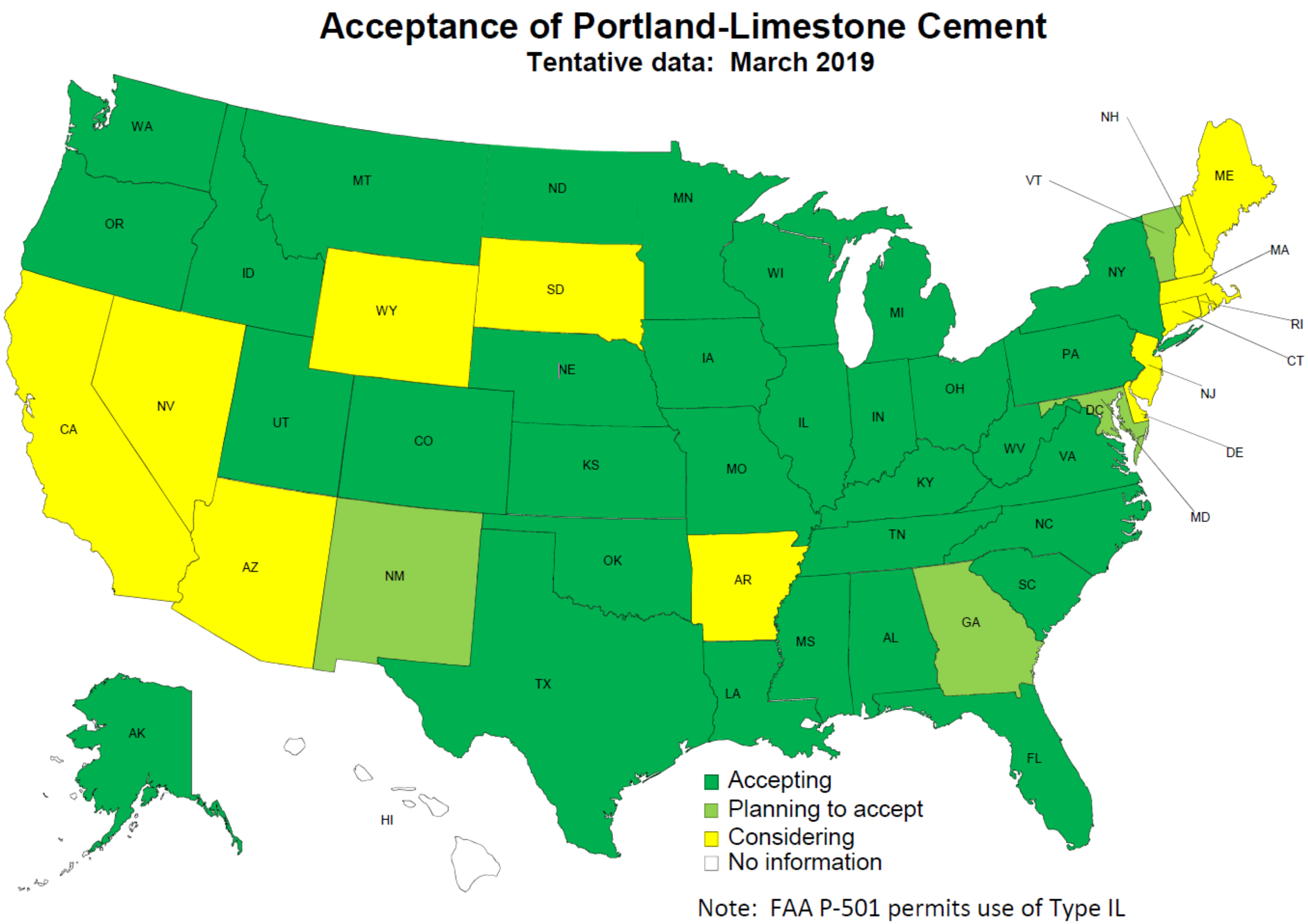
- Improved pavement performance was predicted using new locally calibrated inputs
  - Offers insight into potentially longer service life of existing pavements
  - Use of new inputs may result in design of thinner pavements (up to 1”)
    - Cost savings
    - Sustainability benefits
  - Decision to use thinner pavement section should be weighed against
    - Risks of under-prediction of traffic
    - Section loss associated with diamond grinding

- Reducing dowel size for thinner sections significantly impacts predicted performance

UNC CHARLOTTE

# Industry Forecast for PLC

- PLC provided equivalent performance to OPC Type I/II
- Decision to allow PLC is supported by test data and MEPDG analysis
- Sustainability benefits!
  - Reduced carbon emissions, durability performance benefits




Seven cement plants in southeast produced PLC at least one time between 2012 and 2016

from Paul Tennis, PCA May 2019

# Thank you!

- Clark Morrison, Brian Hunter, Chris Peoples, Nilesh Surti, NCDOT StIC
- We appreciate the opportunity to continue to be of assistance to NCDOT!


49ERS
CHARLOTTE STRONG

UNC CHARLOTTE