Effective Use of BMD for Well Performing, Cost Effective (and Safe) Asphalt Mixes

Thomas Bennert, Ph.D.
Center for Advanced Infrastructure and Transportation (CAIT)
Rutgers University

RUTGERS
Center for Advanced Infrastructure and Transportation

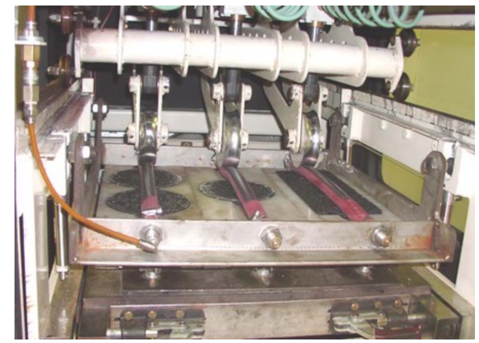
Northeast Asphalt User Producer Group
Springfield, MA
October 2024

DEPARTMENT OF TRANSPORTATION
THE STATE OF NEW JERSEY

NJDOT BMD Concept (Simplified)

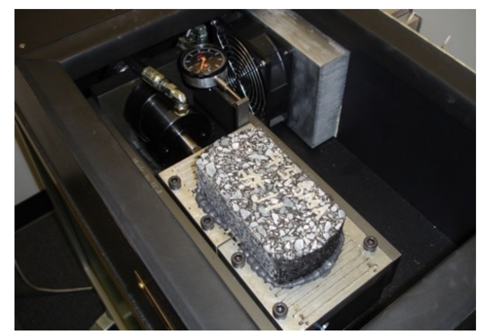
- Asphalt mixture design that utilizes asphalt mixture tests that relate to performance in the field
  - Criteria of tests should be a function of;
    - Distress type
    - Local climate conditions
    - Structural needs
      - Traffic level
      - Location in Pavement

=



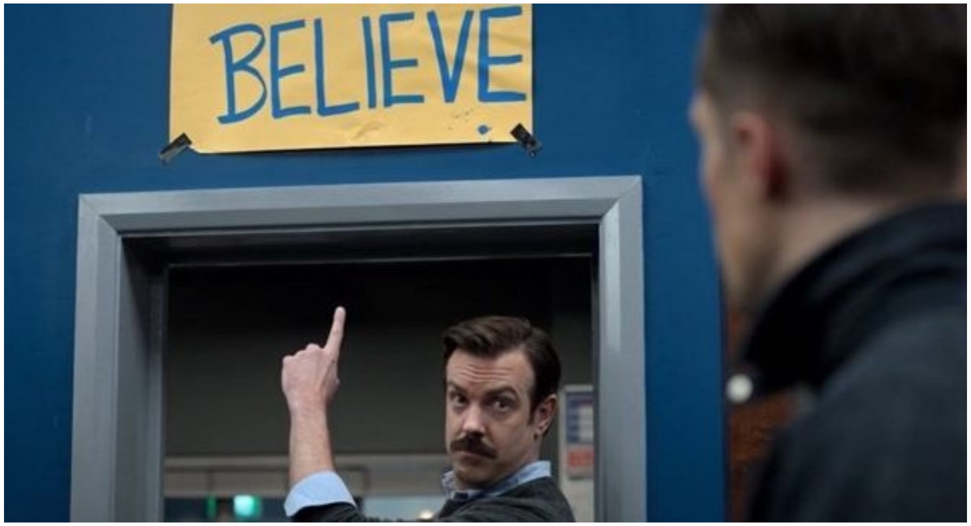
Mike Worden's foot

=



BMD for Cost Effective, Well Performing (and Safe) HMA Pavements

- Mixture selection for problematic pavements
- Improving/Modifying Specifications
  - Aggregate & asphalt binder properties/selection
  - Volumetrics
- "Opening" specifications for additives
- Safety? BMD 2.0



Mix Selection for Problematic Pavements

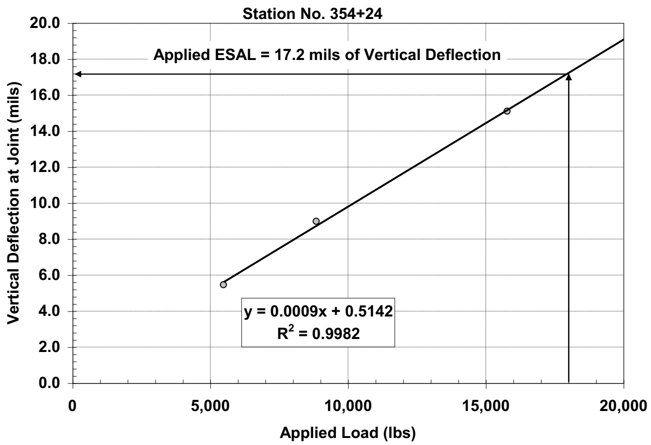
Importance of Including Mixture Performance Testing

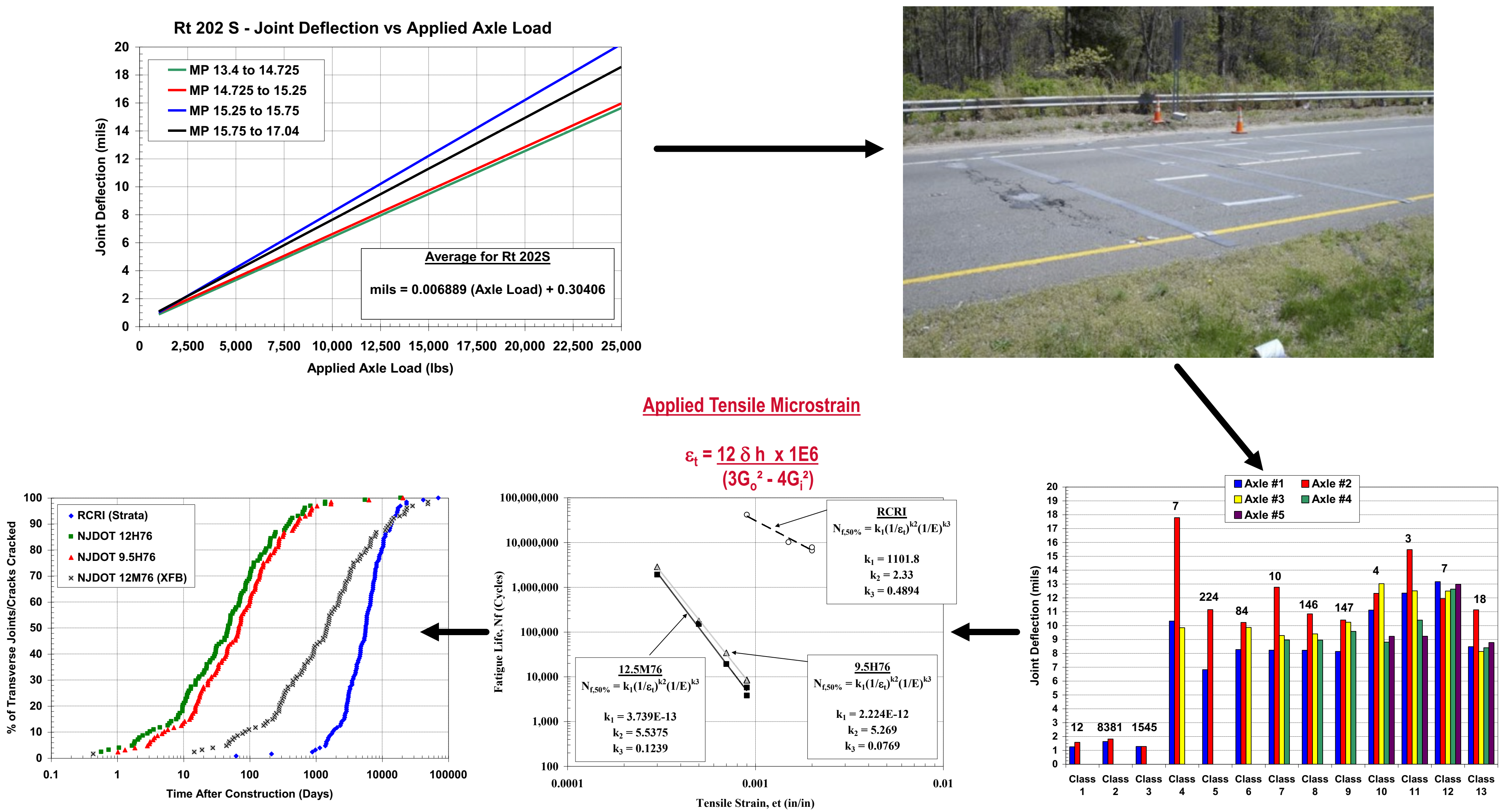
Reflective Cracking

- Reflective Cracking – the type of fatigue cracking generally witnessed when a crack in an asphalt overlay is generated immediately above the longitudinal joint and/or crack in the underlying PCC pavement
- Different loading mechanisms (or combination of) can cause reflective cracking
  - Mode 1 – Excessive Vertical Bending at PCC joint/crack (Pure Tensile Straining)
  - Mode 2 – Horizontal Deflections (PCC slab expansion and contraction) due to environmental cycling
  - Mode 3 – Poor Load Transfer at joint/crack results in independent movement of PCC slabs

Evaluating Material Properties for Composite Pavement Design - Mode 1

- The vertical deflection at the PCC joint/crack is a function of the applied axle load
- Magnitude of vertical deflection can be evaluated using Falling Weight Deflectometer (FWD) at different loads
- Combined with measured traffic/axle loading, a “Deflection Spectra” can be developed specifically for the pavement



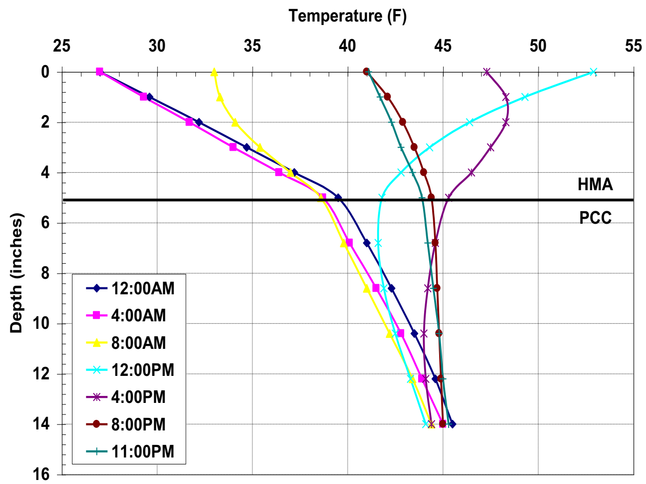

Rt 202 S - Joint Deflection vs Applied Axle Load
MP 13.4 to 14.725
MP 14.725 to 15.25
MP 15.25 to 15.75
MP 15.75 to 17.04
Average for Rt 202S
mils = 0.006889 (Axle Load) + 0.30406
Joint Deflection (mils)
Applied Axle Load (lbs)
Axle #1
Axle #2
Axle #3
Axle #4
Axle #5
Joint Deflection (mils)
Class 1
Class 2
Class 3
Class 4
Class 5
Class 6
Class 7
Class 8
Class 9
Class 10
Class 11
Class 12
Class 13
12
8381
1545
7
224
84
10
146
147
4
3
7
18
Applied Tensile Microstrain
ε_t = 12 δ h x 1E6
(3G_o² - 4G_i²)
RCRI
N_f,50% = k_1(1/ε_t)^k2(1/E)^k3
k_1 = 1101.8
k_2 = 2.33
k_3 = 0.4894
12.5M76
N_f,50% = k_1(1/ε_t)^k2(1/E)^k3
k_1 = 3.739E-13
k_2 = 5.5375
k_3 = 0.1239
9.5H76
N_f,50% = k_1(1/ε_t)^k2(1/E)^k3
k_1 = 2.224E-12
k_2 = 5.269
k_3 = 0.0769
Fatigue Life, Nf (Cycles)
Tensile Strain, et (in/in)
RCRI (Strata)
NJDOT 12H76
NJDOT 9.5H76
NJDOT 12M76 (XFB)
% of Transverse Joints/Cracks Cracked
Time After Construction (Days)

Evaluating Material Properties for Composite Pavement Design - Mode 2

- Expansion and contraction at PCC joint creates zone of tensile stress at bottom of asphalt overlay
- Horizontal deflection (ΔL) can be determined by:

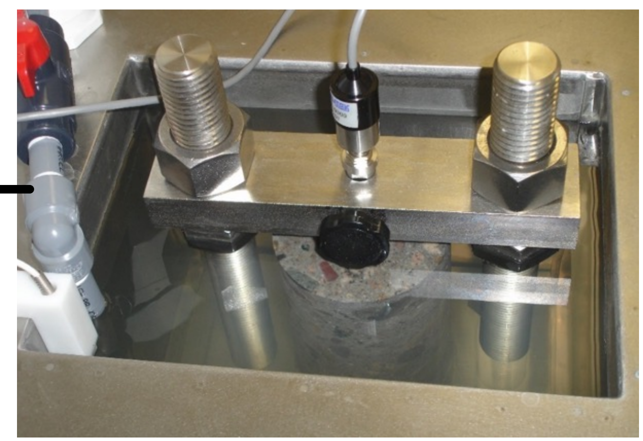
$$\Delta L = CTE(L)(\Delta T)(\beta)$$

ΔL = change in slab length; L = initial slab length
ΔT = rate of change in PCC temperature (24 hr);
β = slab/base friction coefficient

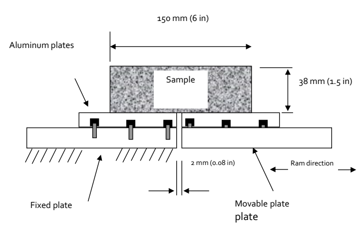


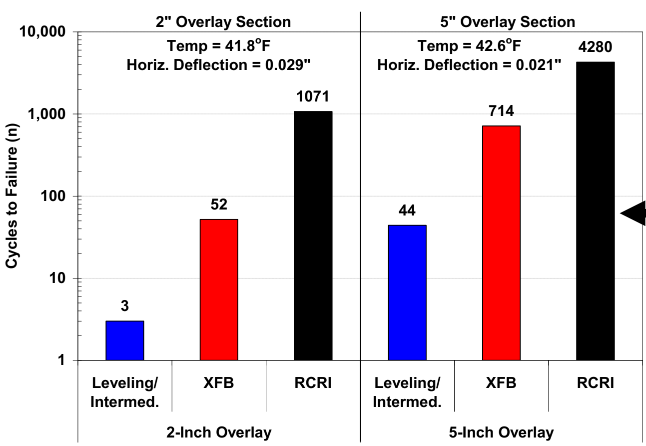
$$\Delta L = CTE(L)(\Delta T)(\beta)$$

ΔL = change in slab length; L = initial slab length
ΔT = rate of change in PCC temperature (24 hr);
β = slab/base friction coefficient



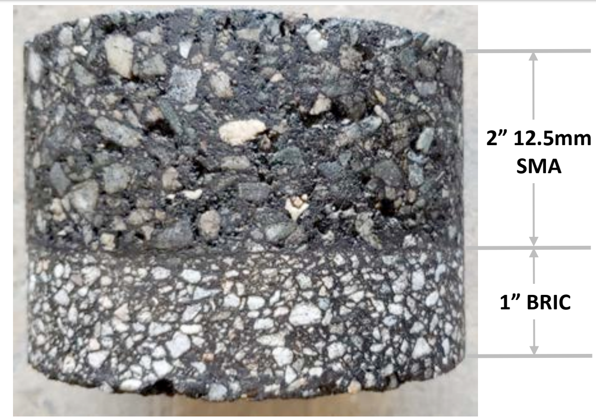
- Sample size: 6" long by 3" wide by 1.5" high
- Loading: Continuously triangular displacement 5 sec loading and 5 sec unloading
- Definition of failure
  - Discontinuity in Load vs Displacement curve
  - Visible crack on surface

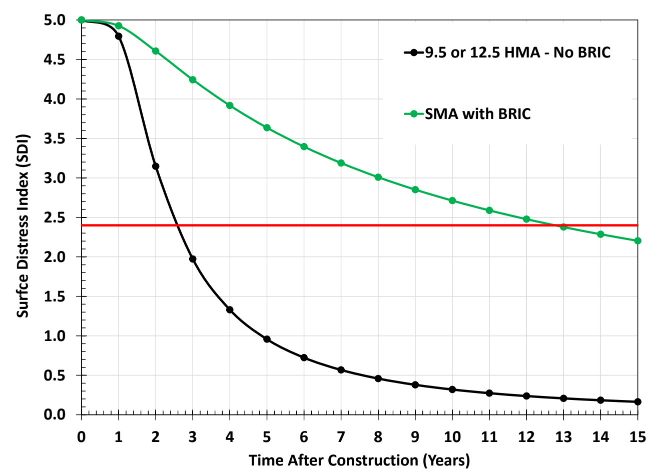




Design Approach for Composite Pavements

- Considered horizontal and vertical straining and performance required to withstand
- Rutting always included to ensure mix not too soft (APA Rutting)
  - 2″ SMA Surface
    - Good rutting & flexural fatigue resistance
      - Can withstand residual bending at the surface
    - Stiffness compatible with BRIC
  - 1″ BRIC
    - Excellent at withstanding horizontal and vertical deflections



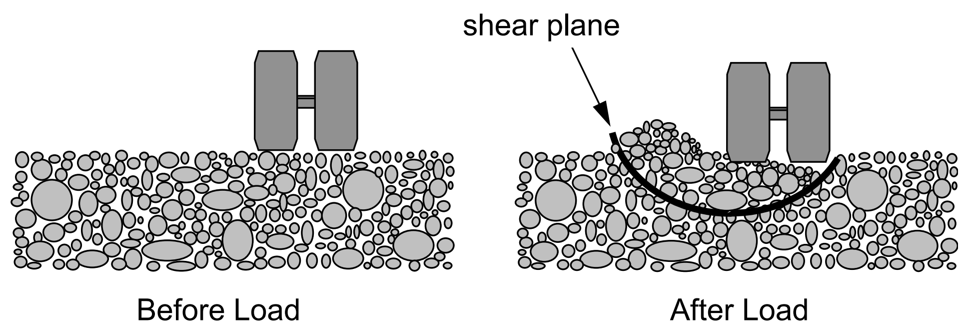


HMA Design Specifications

Material Specification Requirements

Review of Superpave – Consensus Properties

- Material Selection – Consensus Property Aggregates
  - Angularity – increased angularity & texture improve internal shear strength of mixture
  - Sand Equivalency – limit presence of clayey dust that can coat aggregates, reducing bonding of binder to stone
  - Flat & Elongated – minimize issues with aggregate breakage/breakdown during production & construction
- Added cost to improve angularity/ texture and reduce dust



Superpave to BMD

- Consensus properties were used to “guide” mix performance
  - With greater confidence in rutting tests, angularity/texture could be relaxed
  - Level of confidence should dictate level of specification relaxation

    For example: If lack of confidence for TSR, keep sand equivalency

    Good idea to maintain source properties

Table 2 - Additional Aggregate Criteria

Design ESALs (million)	Uncompacted Void Content (Percent), minimum				Sand Equivalent (Percent), minimum	Flat-and-Elongated (Percent), maximum
	Coarse Aggregate		Fine Aggregate			
	Depth from Surface[1]					
	≤ 4 inches (≤ 100 mm)	> 4 inches (> 100 mm)	≤ 4 inches (≤ 100 mm)	> 4 inches (> 100 mm)		
< 0.3	45	45	-	-	40	-
0.3 to < 30	45	45	43	40	45	10
≥ 30	47	47	43	43	50	

Note: 1. If at least 75% of a layer is deeper than 4 inches (100 mm) below the pavement surface, the greater than 4 inches (100 mm) aggregate consensus properties apply for mixture design of that layer. This eliminates the more stringent consensus properties for most 37.5 Base Courses.

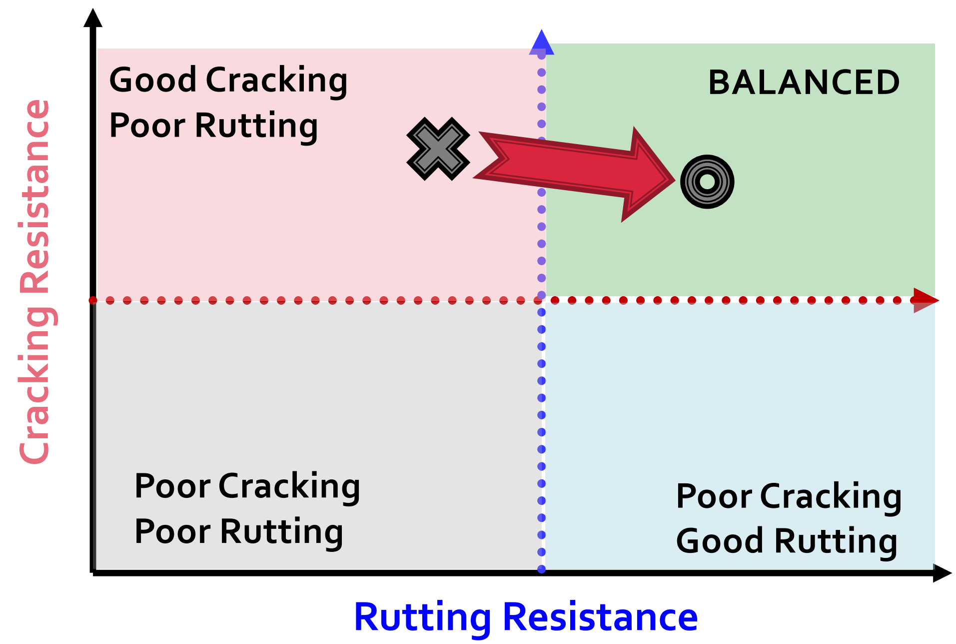
Table M3.06.2-1: Aggregate Consensus Property Requirements

Traffic Level	Design ESALs (Millions) (See Note 1)	Fractured Faces, Coarse Aggregate % Minimum (See Note 2)		Uncompacted Content of Fine Aggregate % Minimum		Sand Equivalent % Minimum	Flat and Elongated % Maximum (See Note 2)
		All Courses (except Base Course)	Base Course	All Courses (except Base Course)	Base Course		
1	<0.3	55/--	--/--	-- (See Note 4)	--	40	--
2	0.3 to <10	85/80 (See Note 3)	60/--	45	40	45	10
3	≥10	95/90	80/75	45	40	45	10

1. The anticipated project traffic level expected on the design lane over a 20-year period. Regardless of the actual design life of the roadway, determine the design ESALs for 20 years.
2. This criterion does not apply to #4 nominal maximum size mixtures.
3. 85/80 denotes that 85% of the coarse aggregate has one fractured face and 80% has two or more fractured faces.
4. For #4 nominal maximum size mixtures designed for traffic levels below 0.3 million ESALs, the minimum Uncompacted Void Content is 40.

BMD In Practice

- Example is typical BMD issue
  - Agency has criteria established for rutting and cracking
  - Initial design shows good cracking performance but poor rutting
  - Actions?
    - Stiffer asphalt binder?
    - More angular/texture stone?
    - Reduce effective asphalt content?
    - Increase recycled asphalt content?
    - Modify gradation/redesign?



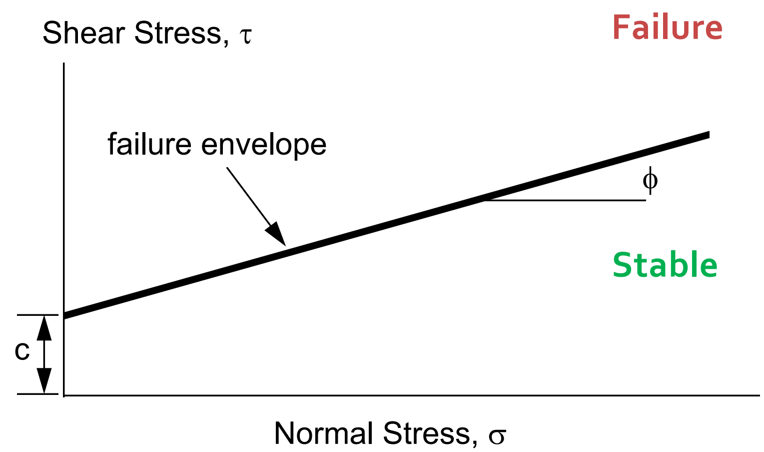
BMD In Practice

- Developing rutting resistance
  - Using Mohr-Coulomb theory as simple example
  - Failure envelope can be improved by improving cohesion component (binder contribution) or friction angle (aggregate contribution) or a combination of both

  Final approach would be a function of costs and availability

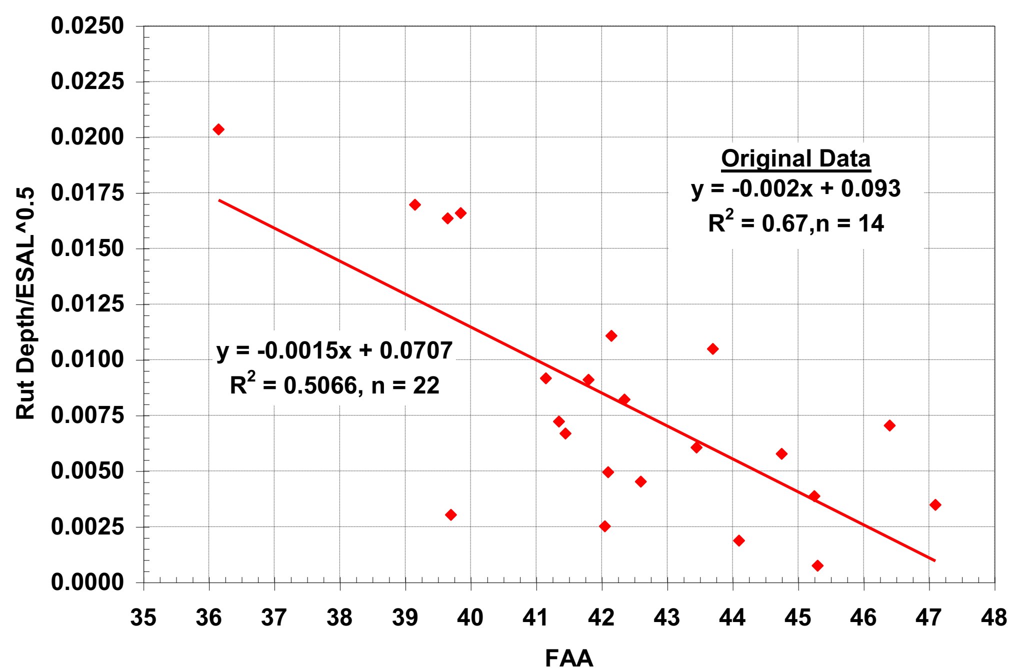
$$\tau = C + \sigma \times \tan \phi$$

τ = shear strength
C = cohesion (asphalt binder)
ϕ = friction angle (aggregate)
σ = normal stress applied to material



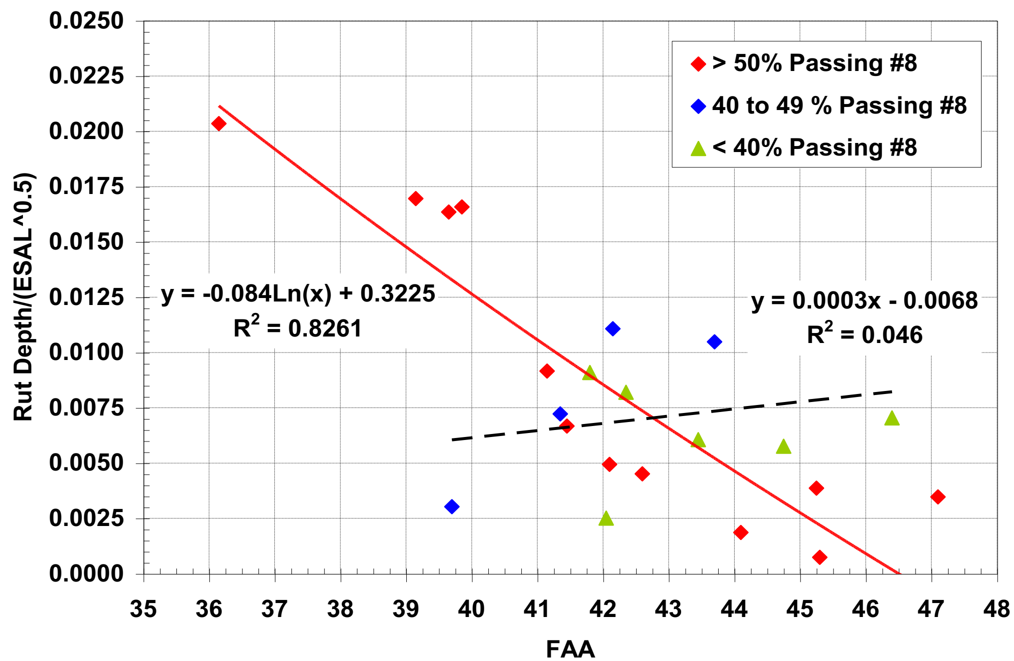
Example #1: Impact of Fine Aggregate Angularity

- Original work by Cross and Brown (1991) showed impact of FAA on HMA rutting



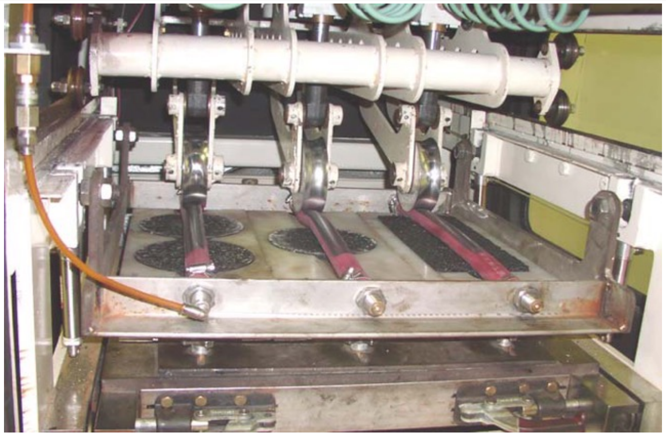
Example #1: Impact of Fine Aggregate Angularity

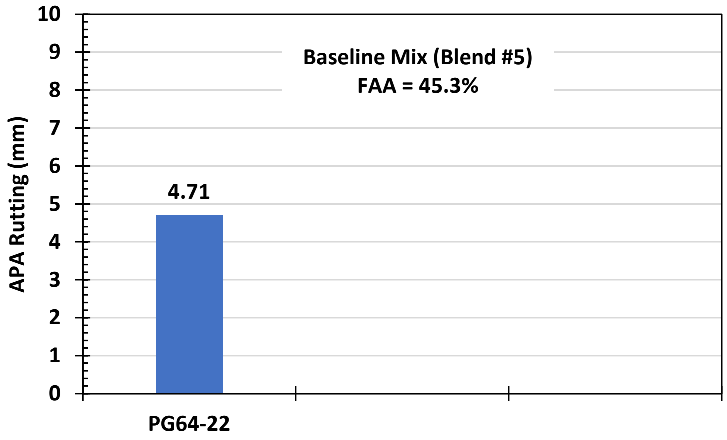
- Original work by Cross and Brown (1991) showed impact of FAA on HMA rutting
- Filtering of data shows that greatest impact on finer nominal maximum aggregate size
  - Thin lift, surface course asphalt mixtures are of greatest concern



Example #1: Impact of Fine Aggregate Angularity

- Reconstructed an approved NJDOT 12.5mm mix, PG64-22
  - Held gradation +/- 3%
  - Asphalt content maintained +/- 0.3%
  - Specimen AV Target 6 to 7%
- NJDOT utilizes the Asphalt Pavement Analyzer (AASHTO T340) as a rutting test < 4.0 mm

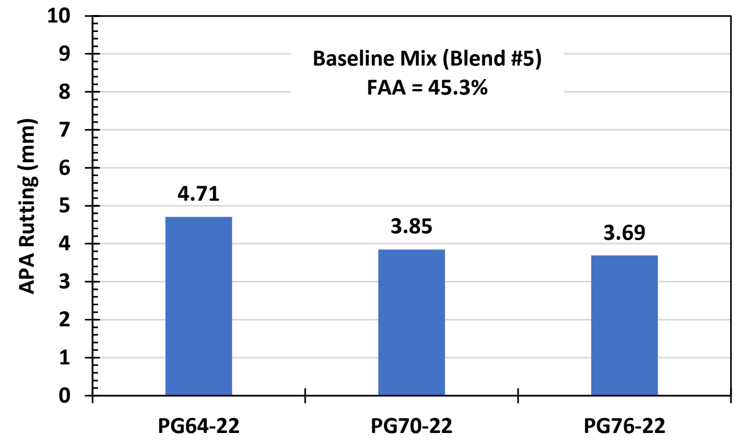




Example #1: Impact of Fine Aggregate Angularity

- Reconstructed an approved NJDOT 12.5mm mix, PG64-22
  - Held gradation +/- 3%
  - Asphalt content maintained +/- 0.3%
  - Specimen AV Target 6 to 7%
- NJDOT utilizes the Asphalt Pavement Analyzer (AASHTO T340) as a rutting test < 4.0 mm

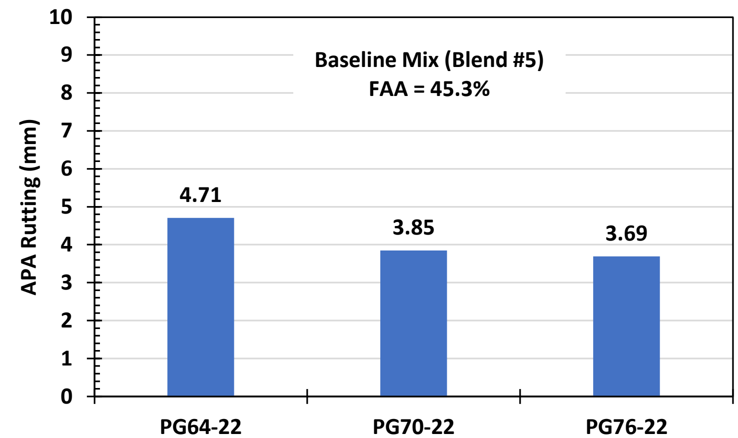
Cohesion (C)



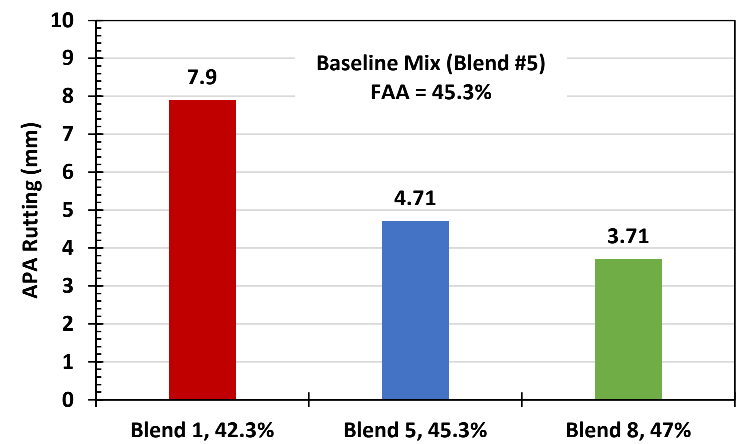
Example #1: Impact of Fine Aggregate Angularity

- Reconstructed an approved NJDOT 12.5mm mix, PG64-22
  - Held gradation +/- 3%
  - Asphalt content maintained +/- 0.3%
  - Specimen AV Target 6 to 7%
- NJDOT utilizes the Asphalt Pavement Analyzer (AASHTO T340) as a rutting test < 4.0 mm

Cohesion (C)

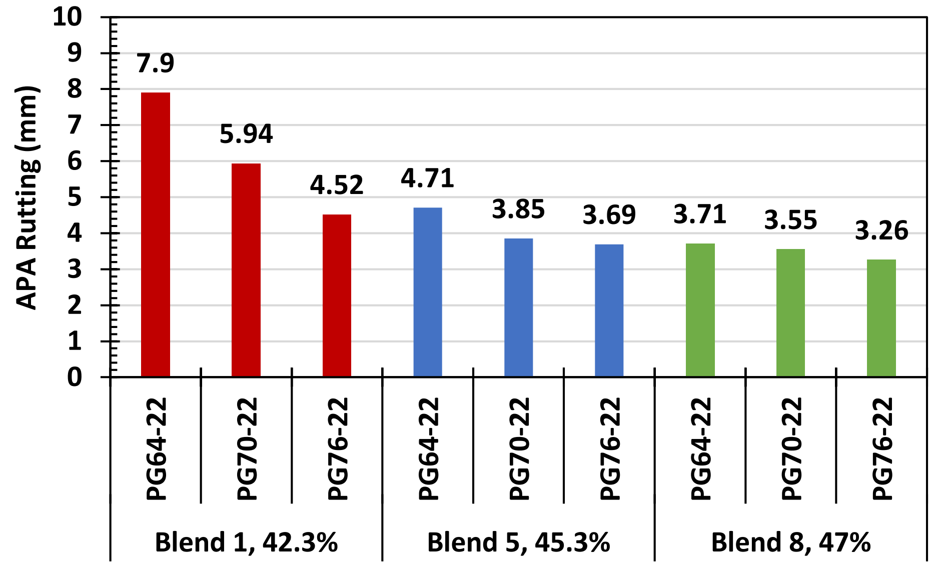


Friction Angle (ϕ)



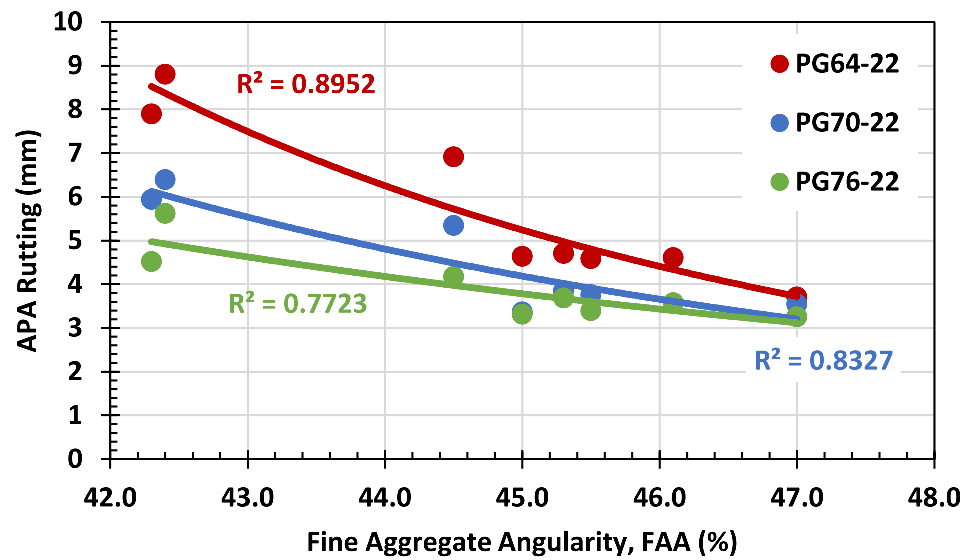
Example #1: Impact of Fine Aggregate Angularity

- Reconstructed an approved NJDOT 12.5mm mix, PG64-22
  - Held gradation +/- 3%
  - Asphalt content maintained +/- 0.3%
  - Specimen AV Target 6 to 7%
- NJDOT utilizes the Asphalt Pavement Analyzer (AASHTO T340) as a rutting test < 4.0 mm



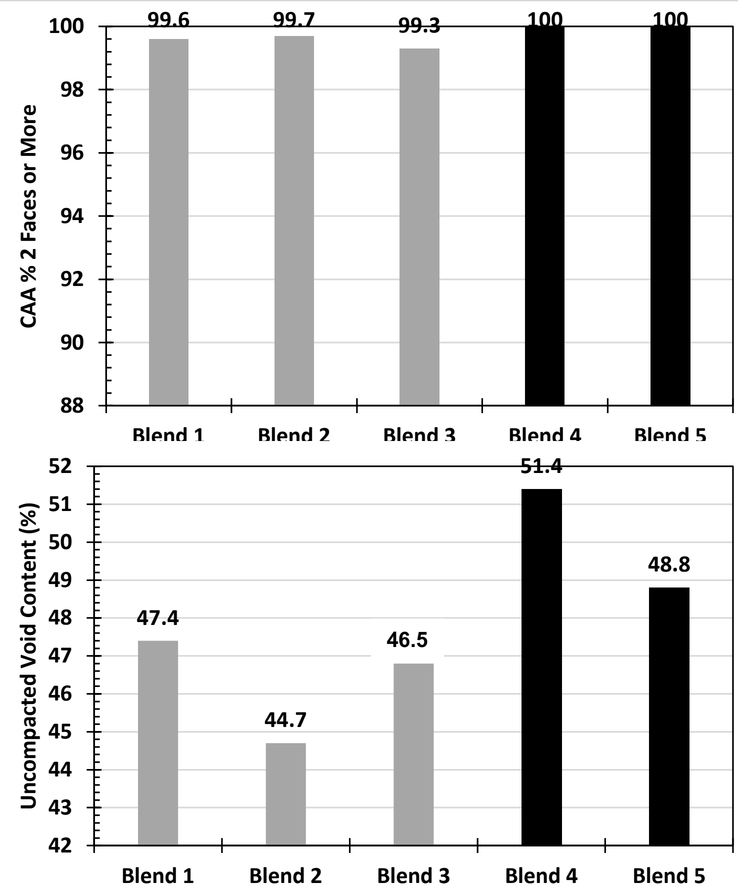
Example #1: Impact of Fine Aggregate Angularity

- Reconstructed an approved NJDOT 12.5mm mix, PG64-22
  - Held gradation +/- 3%
  - Asphalt content maintained +/- 0.3%
  - Specimen AV Target 6 to 7%
- NJDOT utilizes the Asphalt Pavement Analyzer (AASHTO T340) as a rutting test < 4.0 mm



Example #2: Impact of Coarse Aggregate Angularity

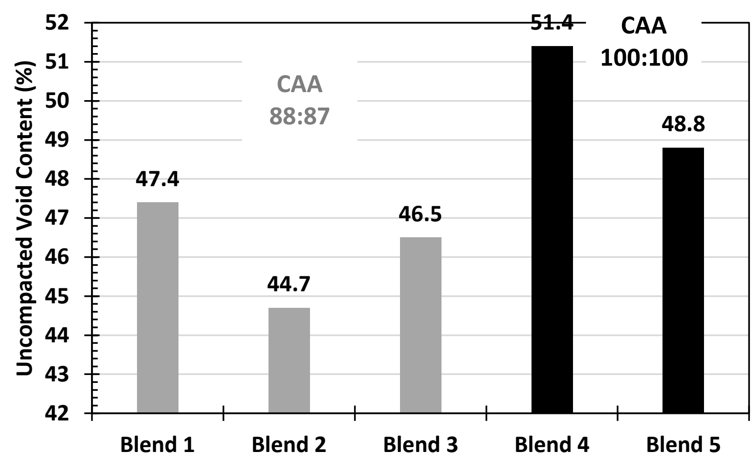
- Current Superpave specifications utilizes fractured face count to quantify coarse aggregate angularity
  - Fractured faces not an indication of angularity or texture – just a means of quantifying efficiency of crushing
  - AASHTO T326 a better means of assessing angularity/texture
    - Consistent with T304



Example #2: Impact of Coarse Aggregate Angularity

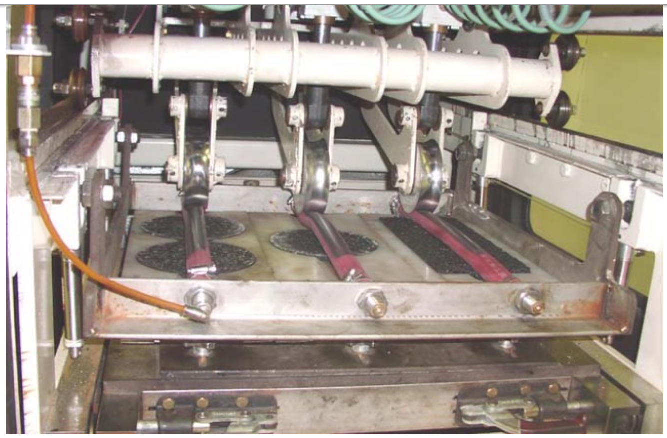
- 12.5 mm mix design
- Different levels of CAA developed by blending fractured with unfractured gravel
  - Held gradation +/- 3%
  - Asphalt content maintained +/- 0.3%
  - Specimen AV Target 6 to 7%
- Same fine aggregate used for all mixes
- Can I get CAA 88:87 to meet high ESAL's?
- APA as a rutting test
  - > 10 MESAL's: < 4.0 mm

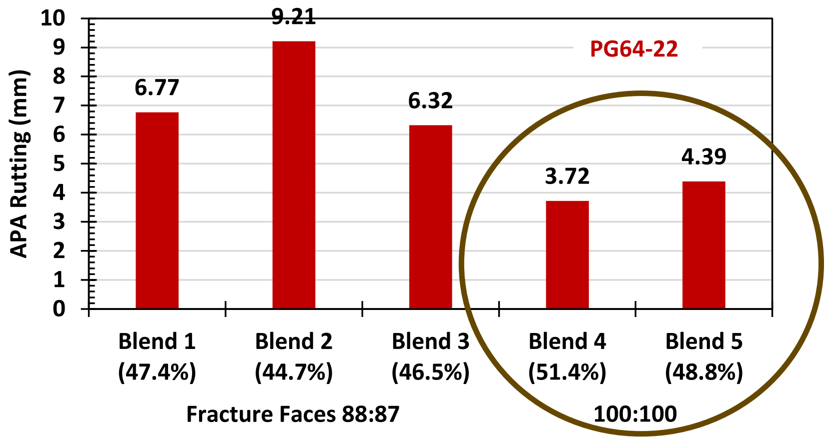
Design ESALs[a] (Million)	Fractured Faces, Coarse Aggregate,[c] % Minimum — Depth from Surface ≤100 mm	Fractured Faces, Coarse Aggregate,[c] % Minimum — Depth from Surface >100 mm
<0.3	55/—	—/—
0.3 to <3	75/—	50/—
3 to <10	85/80[b]	60/—
10 to <30	95/90	80/75
≥30	100/100	100/100



Example #2: Impact of Coarse Aggregate Angularity

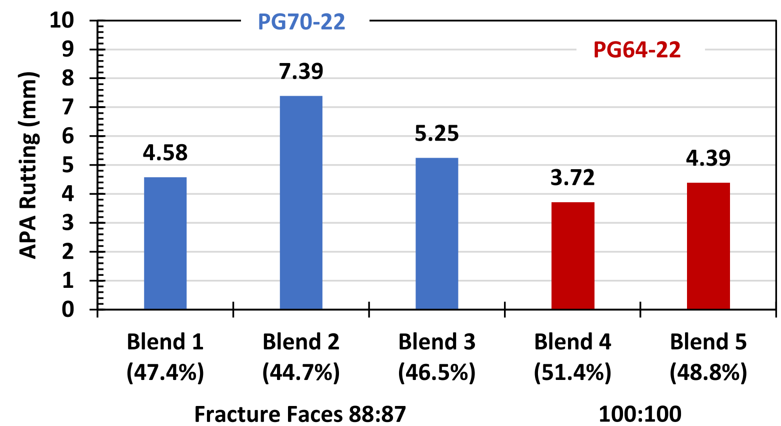
- 12.5 mm mix design
- Different levels of CAA developed by blending fractured with unfractured gravel
  - Held gradation +/- 3%
  - Asphalt content maintained +/- 0.3%
  - Specimen AV Target 6 to 7%
- Same fine aggregate used for all mixes
- <u>Can I get CAA 88:87 to meet high ESAL's?</u>
- APA as a rutting test
  - > 10 MESAL's: < 4.0 mm





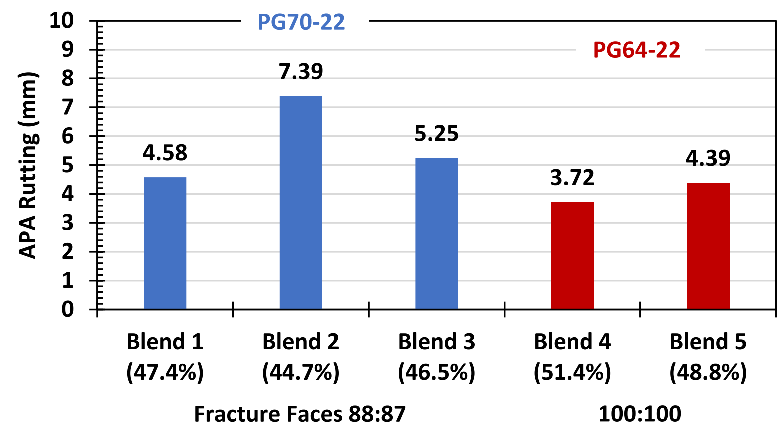
Example #2: Impact of Coarse Aggregate Angularity

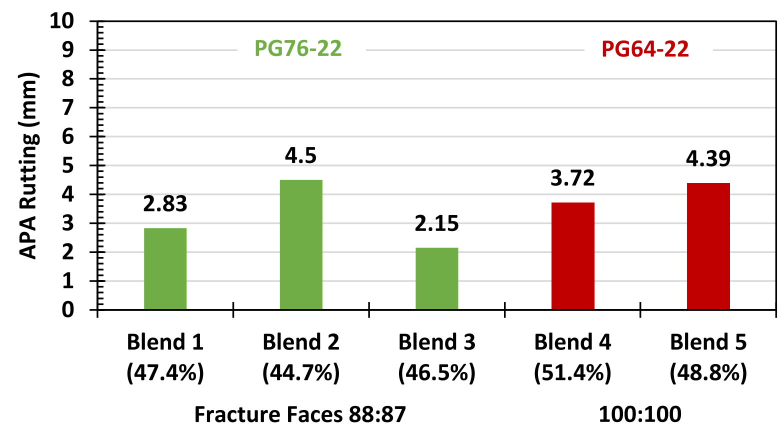
- 12.5 mm mix design
- Different levels of CAA developed by blending fractured with unfractured gravel
  - Held gradation +/- 3%
  - Asphalt content maintained +/- 0.3%
  - Specimen AV Target 6 to 7%
- Same fine aggregate used for all mixes
- <u>Can I get CAA 88:87 to meet high ESAL's?</u>
- APA as a rutting test
  - > 10 MESAL's: < 4.0 mm



Example #2: Impact of Coarse Aggregate Angularity

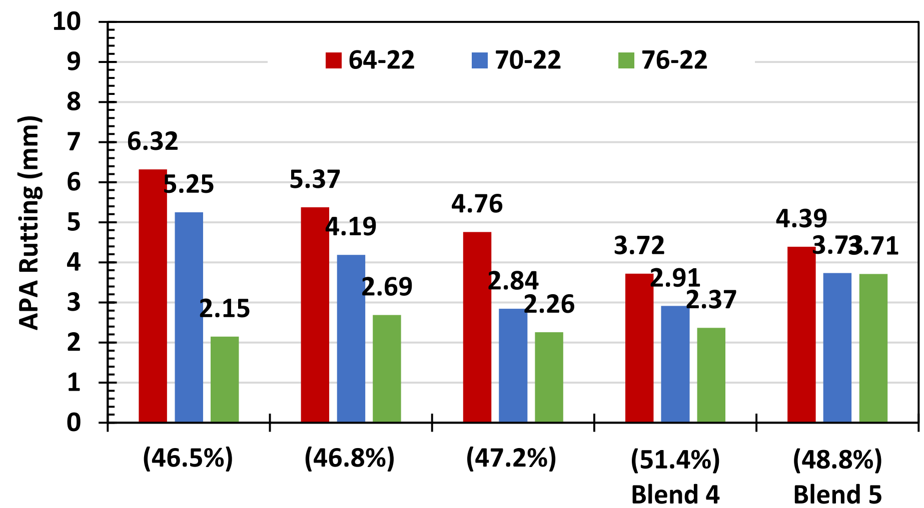
- 12.5 mm mix design
- Different levels of CAA developed by blending fractured with unfractured gravel
  - Held gradation +/- 3%
  - Asphalt content maintained +/- 0.3%
  - Specimen AV Target 6 to 7%
- Same fine aggregate used for all mixes
- <u>Can I get CAA 88:87 to meet high ESAL's?</u>
- APA as a rutting test
  - > 10 MESAL's: < 4.0 mm





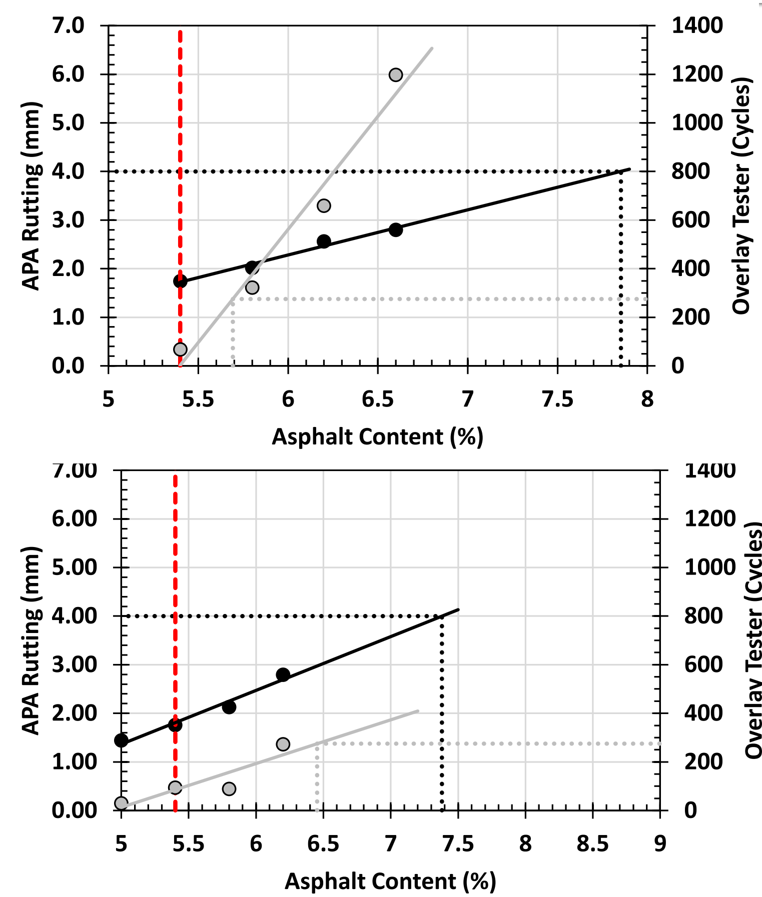
Example #2: Impact of Coarse Aggregate Angularity

- 12.5 mm mix design
- Different levels of CAA developed by blending fractured with unfractured gravel
  - Held gradation +/- 3%
  - Asphalt content maintained +/- 0.3%
  - Specimen AV Target 6 to 7%
- Same fine aggregate used for all mixes
- Can I get CAA 88:87 to meet high ESAL's?
- NJDOT utilizes the Asphalt Pavement Analyzer (AASHTO T340) as a rutting test
  - > 10 MESAL's: < 4.0 mm



Cost Effective BMD – Aggregate vs PG

- Current Superpave requirements for aggregates included to "guide" performance
- Confidence in performance criteria can allow asphalt mix suppliers the flexibility to use improved aggregate or improved asphalt binder properties to meet performance
  - Provides cost and production flexibility!

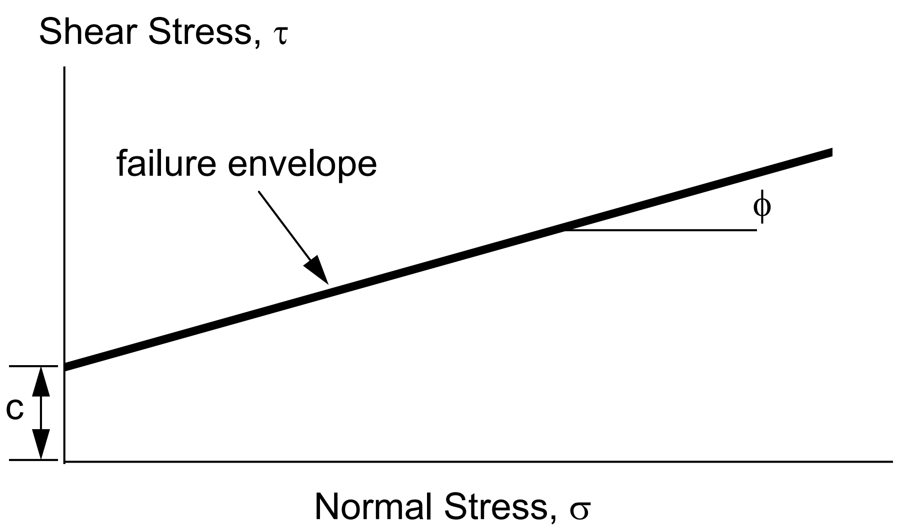


Use of Additives to Improve Performance

Including Performance Testing for Comparative Performance

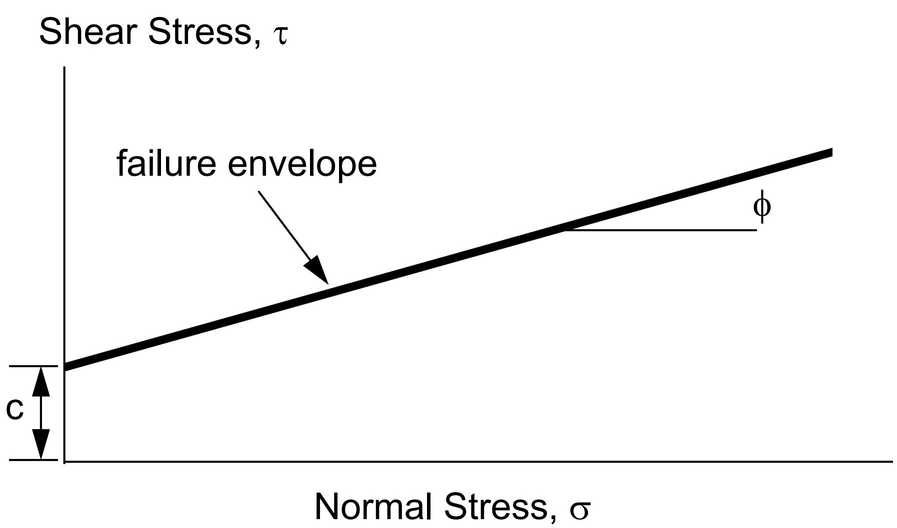
Use of Additives - Fibers

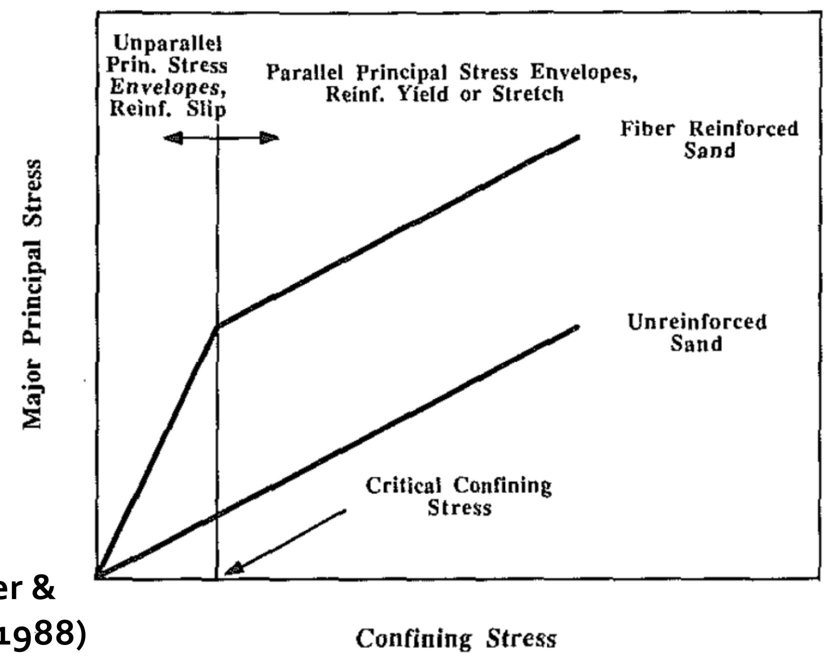
- Confidence in BMD should allow for use additives to meet performance
  - Example: How can fibers improve asphalt mixture performance?



Use of Additives - Fibers

- Confidence in BMD should allow for use additives to meet performance
  - Example: How can fibers improve asphalt mixture performance?

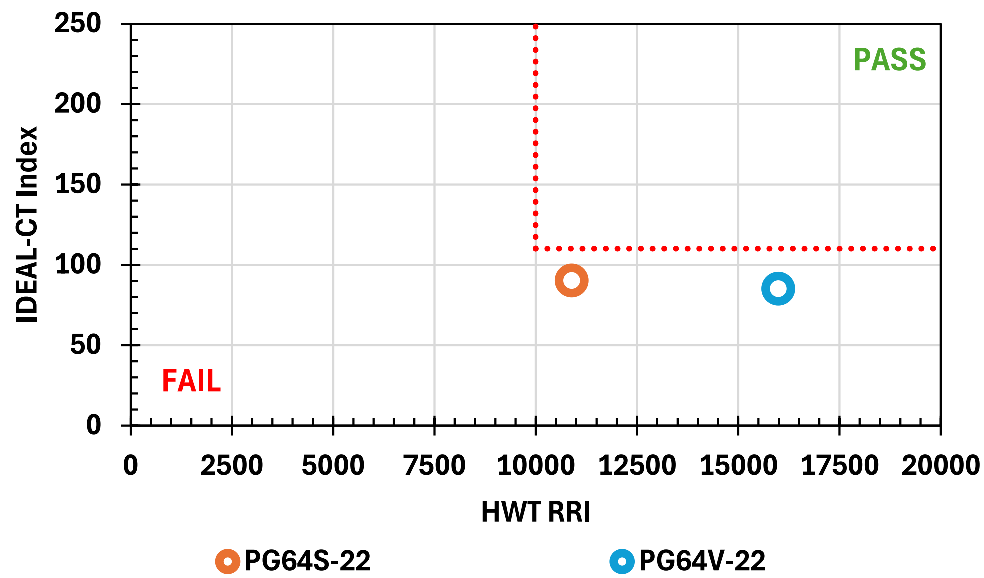




Maher & Gray (1988)

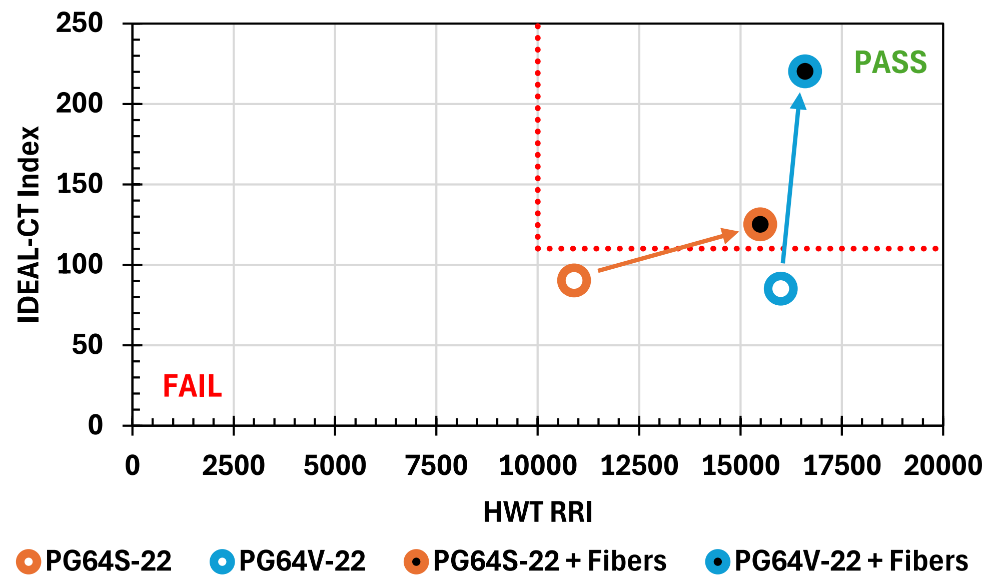
Use of Additives to Enhance Performance (Data from BATT, 2024)

- Utilizing Hamburg Wheel Tracking for rutting & IDEAL-CT Index for cracking
- Initial testing shows both PG64S-22 and PG64V-22 binders meet rutting but not cracking



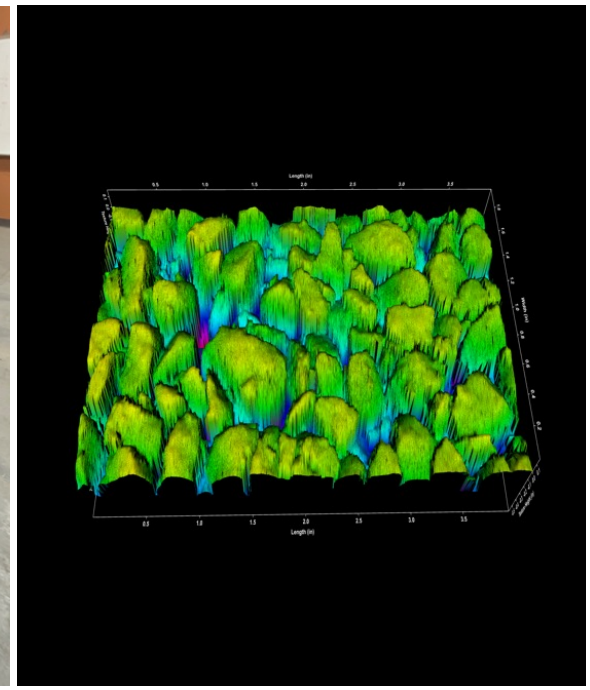
Use of Additives to Enhance Performance (Data from BATT, 2024)

- Inclusion of fibers improved the cohesive properties of the mixtures
  - Resulted in improved rutting resistance and cracking resistance
  - Evidence to show "fibers" can mirror improvement observed with binder modification



But What about Safety? BMD 2.0

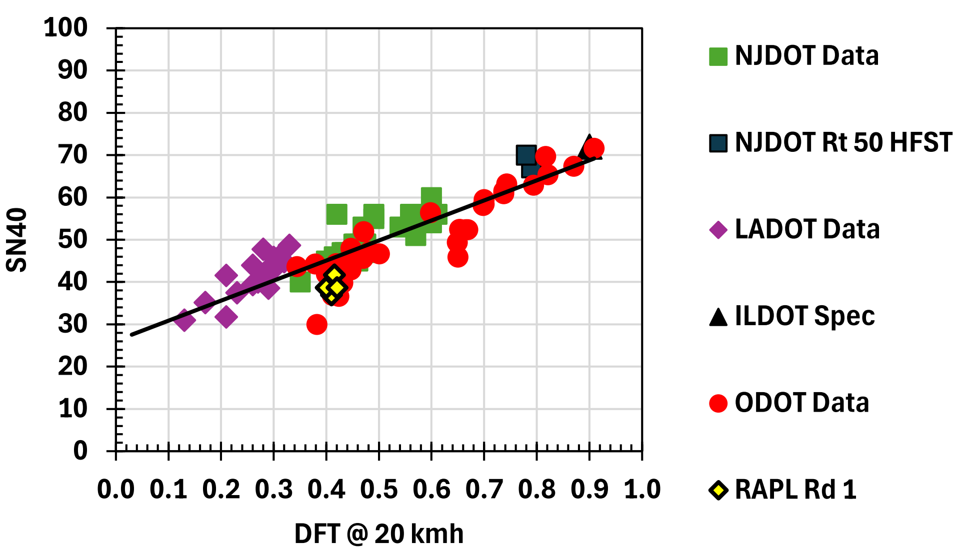
Laboratory Evaluation of Friction and Texture

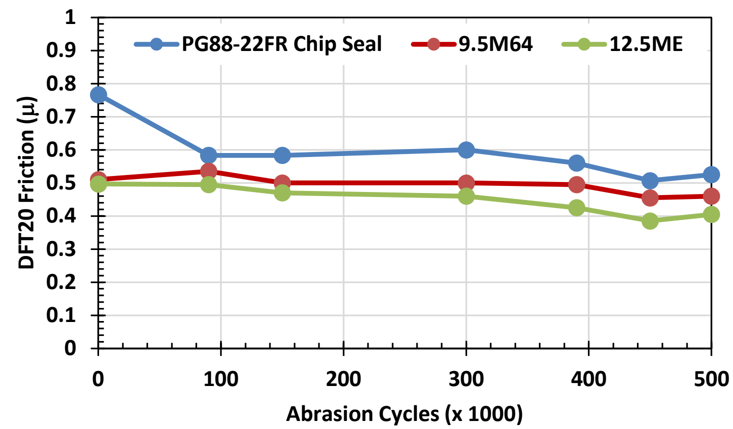


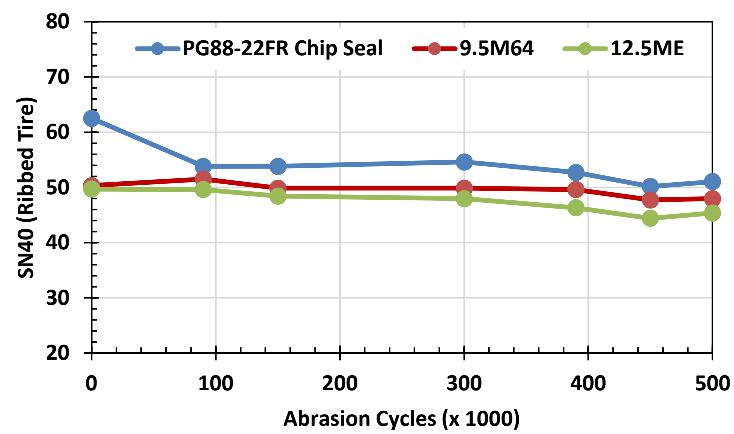
Developing Field Data for Performance Criteria

- Field sections being evaluated for friction using Dynamic Friction Tester (DFT) as well as surface texture with AMES Laser Texture Device
  - Being used to develop criteria that can be brought back into laboratory
  - Same type of methodology as BMD rutting and cracking performance

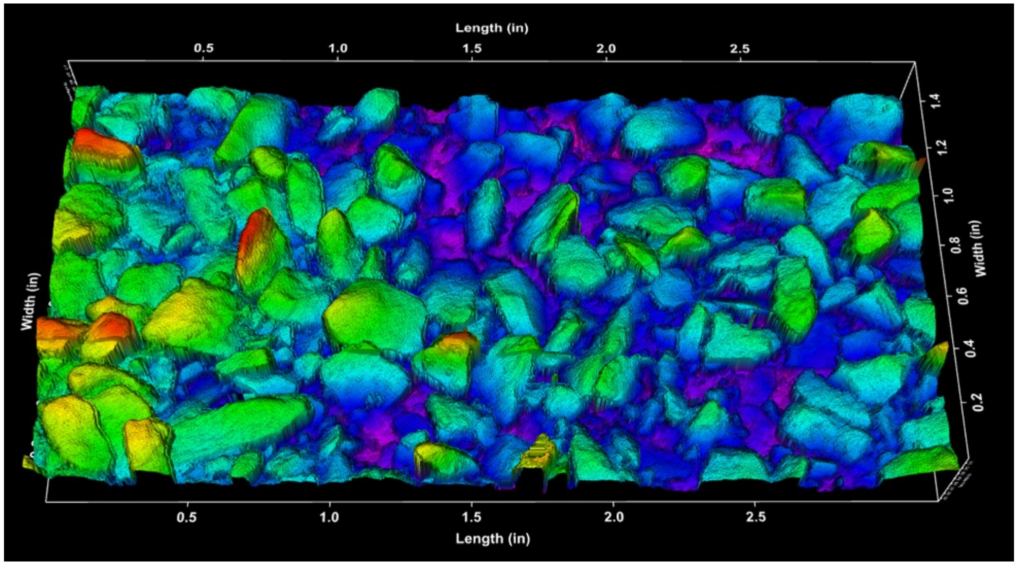
Ex. Friction Properties of Different Mixtures





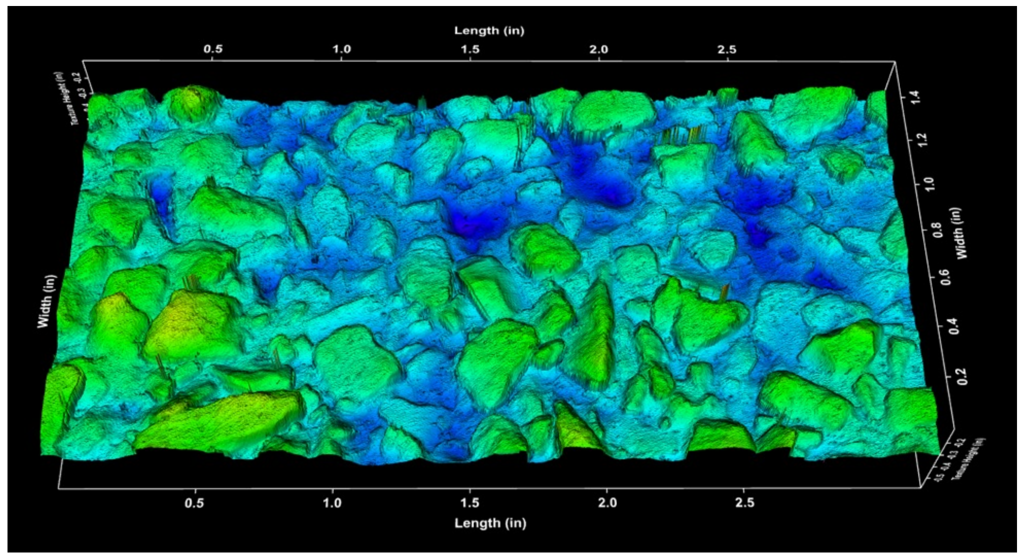


Lab Testing of PG88-22FR Chip Seals



0 Cycles

300,000 Cycles



BMD 2.0 – High Friction Aggregate?

- As BMD currently addresses structural needs, can we incorporate functional needs?
  - Electric Arc Furnace (EAF) slag crushed to #10 size aggregate
  - Substituted at 10% of a washed stone sand for 10% of EAF slag

    9.5M64 with 0% RAP

    Rutting: APA Rutting

    Cracking: Overlay Tester

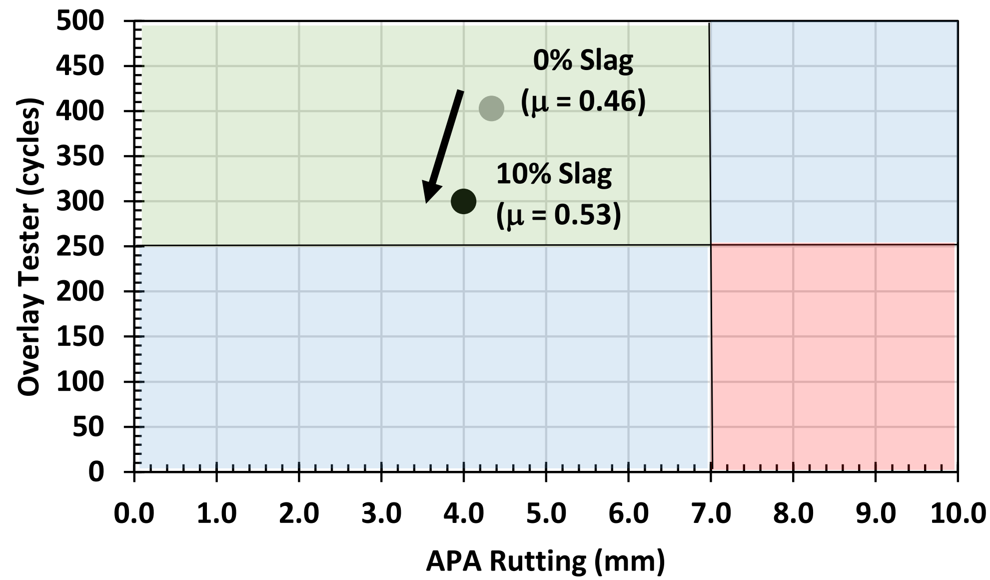
    Friction: Dynamic Friction Tester (DFT)

EAF Slag

Washed Stone Sand

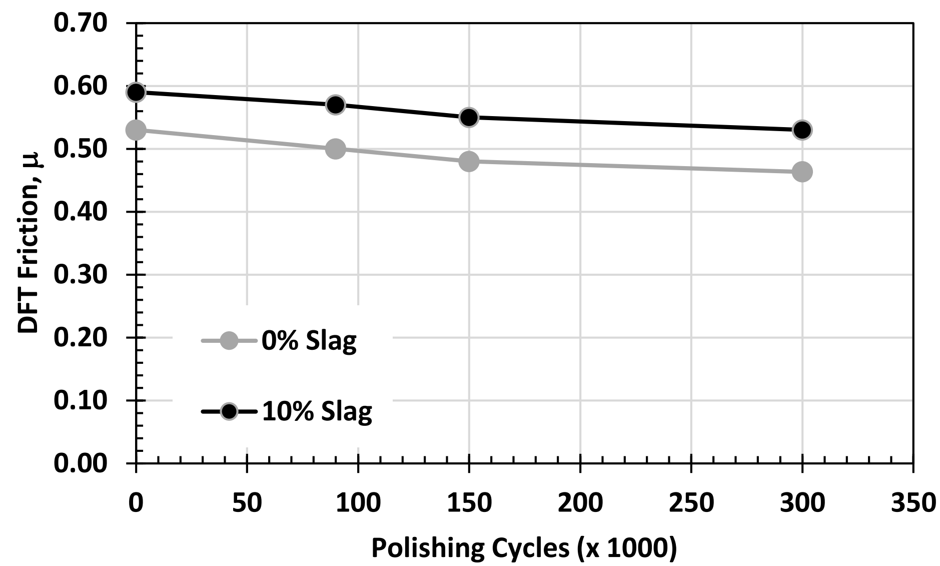
BMD 2.0 – High Friction Aggregate?

- Even though reduction in cracking, improvement in rutting and surface
- Within BMD (Approach C & D), relaxation to reduction of volumetrics
  - Confidence in performance tests & criteria should allow for volumetric and constituent freedom during design and production



Laboratory Friction Measurements

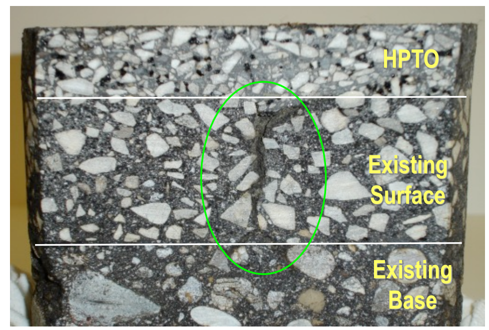


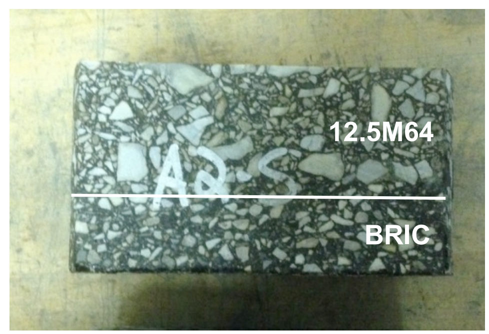



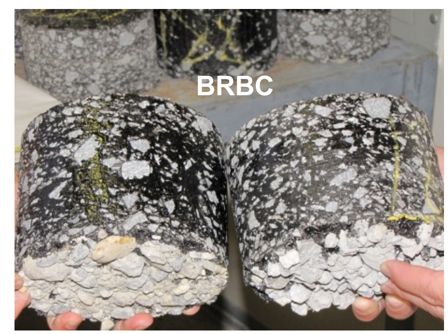
0% EAF Slag: SN40 = 48.0
10% EAF Slag: SN40 = 51.3

Summary

- The use and benefit of BMD is a function of the confidence in the criteria
- The more confident of the mixture test to field performance, the more open agencies should be to modifications to specifications and incorporation of additives
  - Allows for cost effective and innovative asphalt materials
  - Same methodology can also be applied to functional pavement properties





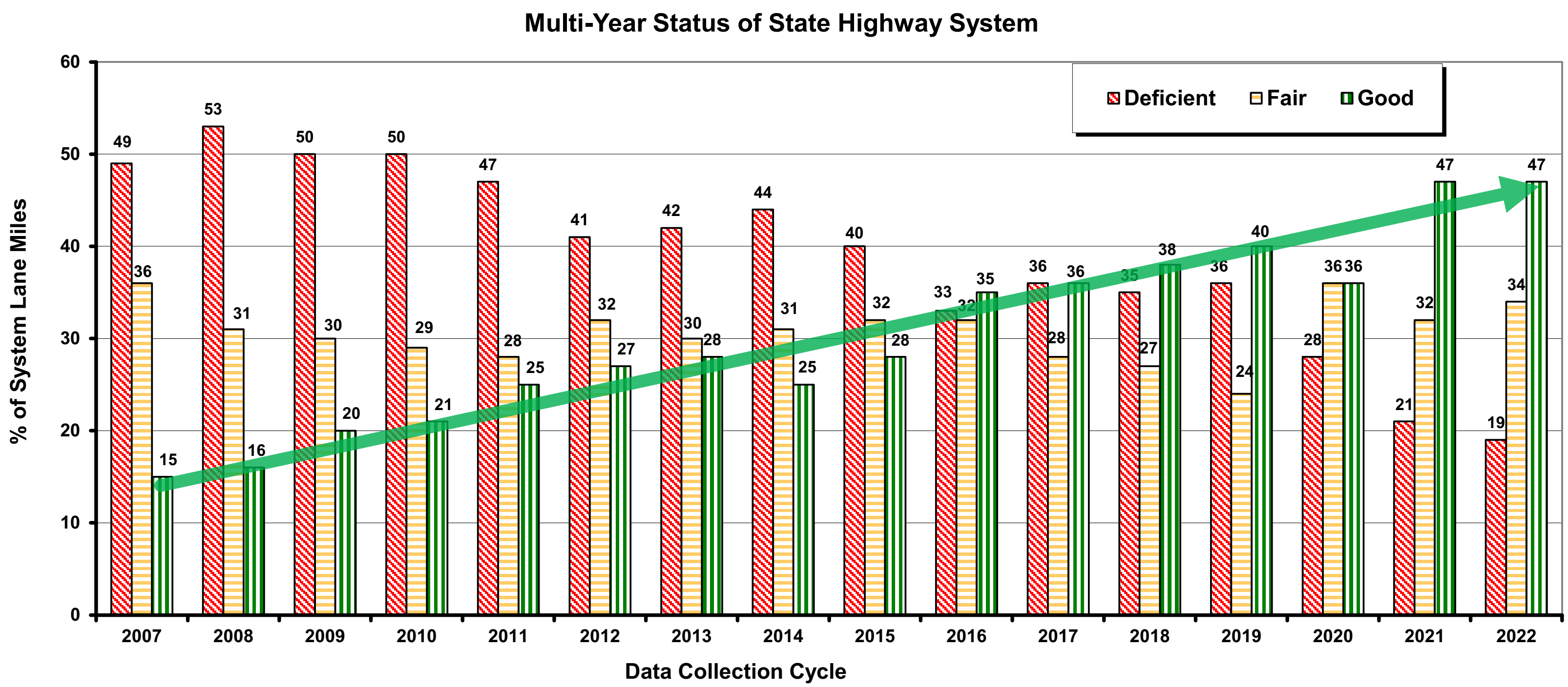


As Ted Lasso reminded us..
"Be curious, not judgmental…"

Thank you for your time!

Thomas Bennert, Ph.D.
Center for Advanced Infrastructure and Transportation (CAIT)
Rutgers University
bennert@soe.rutgers.edu
609-213-3312

NJDOT Network Since Implementing Performance Tests



Source: NJDOT Pavement Management System