Effect of Bonding Quality of Tack Materials between Pavement Layers on Durability

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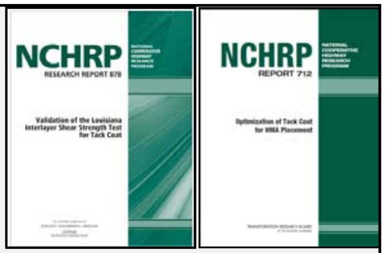
My Story

- **Background**
  - Durability
  - Bonding & Pavement Performance
- **Completed**
  - NCHRP Project 9-40
  - NCHRP Project 9-40A
    - » Deliverables
    - » Experiment/Results
    - » Summary and Conclusions



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Acknowledgement

- **NCHRP**
  - Technical Review Panel
  - State DOTs
- **Ramendra Das, Wei Cao**
- **State DOTs**
  - Missouri; Louisiana; Florida; Tennessee; Nevada; Oklahoma
- **Material Suppliers and Contractors**
  - Asphalt Products Unlimited
  - Ergon Asphalts
  - Blacklidge
  - Coastal Bridge

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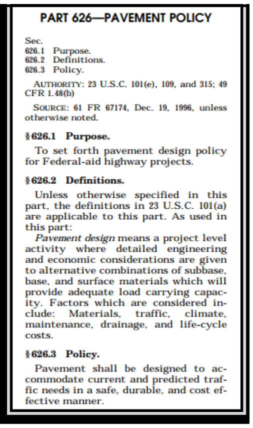
Durable Pavement

- Title 23 Code of Federal Regulations
  - Part 626.3 Policy.
- "Pavement shall be designed to accommodate current and predicted traffic needs in a safe, ***durable***, and cost effective manner."



PART 626—PAVEMENT POLICY

Sec.
626.1 Purpose.
626.2 Definitions.
626.3 Policy.

AUTHORITY: 23 U.S.C. 101(e), 109, and 315; 49 CFR 1.48(b)

SOURCE: 61 FR 67174, Dec. 19, 1996, unless otherwise noted.

§ 626.1 Purpose.

To set forth pavement design policy for Federal-aid highway projects.

§ 626.2 Definitions.

Unless otherwise specified in this part, the definitions in 23 U.S.C. 101(a) are applicable to this part. As used in this part:

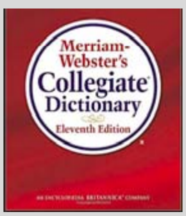
Pavement design means a project level activity where detailed engineering and economic considerations are given to alternative combinations of subbase, base, and surface materials which will provide adequate load carrying capacity. Factors which are considered include: Materials, traffic, climate, maintenance, drainage, and life-cycle costs.

§ 626.3 Policy.

Pavement shall be designed to accommodate current and predicted traffic needs in a safe, durable, and cost effective manner.

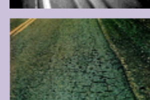
Durable

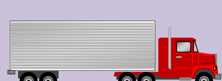
- *… able to exist for a long time without significant deterioration in quality or value.*"



Durable Flexible Pavement

- **Permanent deformation**
- **Fatigue cracking – repeated load**
- **Low temperature cracking**
- **Moisture induced damage**
- **Raveling**
- **etc …**





Design and Construction of Durable Flexible Pavements

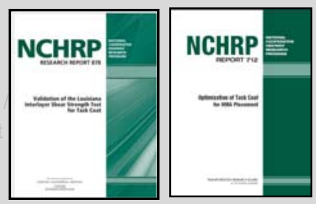
- **Mixture Design**
  - Components Materials
  - Engineered Performance / BMD
  - Sustainable Development
- **Construction**
  - Tack Coat Practices
  - Thermal segregation
  - Warm Mix Asphalt
  - Increased density

Laboratory Design

Field Construction

Design and Construction of Durable Flexible Pavements

- Mixture Design
  - Components Materials
  - Engineered Performance /
  - Sustainable Development
- **Construction**
  - Tack Coat Practices
  - Thermal
  - Warm Mi
  - Increase

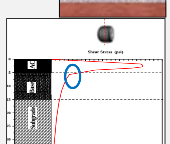


Field Construction

Durable Pavement – Construction Tack Coat

- **Purpose of tack coat application**
  - To ensure adequate bond between pavement layers
  - To transmit traffic loads down through the whole pavement structure
- **Not properly bonded, increase tendency for**
  - Cracking,
  - Debonding (delamination/slippage/sliding), and/or
  - Fatigue cracking

  …and thus failure in the new overlay
- **Tack coat material is relatively inexpensive portion compared to overall pavement construction cost**
  - Bonding failure is extremely $$$!!!



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Improper Tack Coat Application

Courtesy of James A. Scherocman

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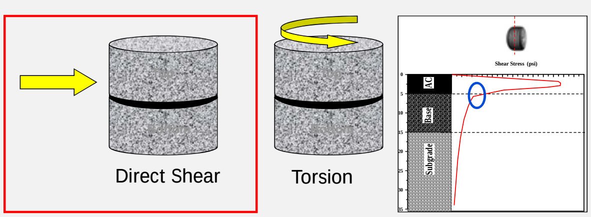
Durable Pavement – Construction
Proper Tack Coat Application
100% Coverage

0.031 gsy	0.062 gsy	0.155 gsy
Low	Medium	High

Ascertain Bonding Qualitry/Performance



Supply **>** **Demand**

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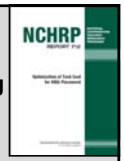
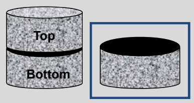
Objectives – NCHRP Project 9-40

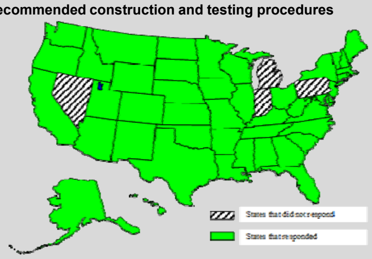


- Evaluate factors that affect interlayer bonding
  - Tack coat material type and application rate
  - Pavement surface type
  - Temperature
  - Construction condition
- Develop AASHTO test methods and practices related to tack coats
  - Tack Coat Quality
    - spray application
  - Interlayer Bond Strength



Outcome – NCHRP Project 9-40

- Worldwide Survey on Tack Coat Practices
  - 92% return
  - Canada, Denmark, Finland, South Africa, and the Netherlands.
- Best Practices and Training Manual
  - recommended construction and testing procedures

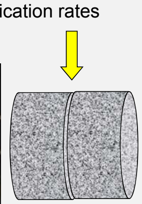


Outcomes of NCHRP Project 9-40

- AASHTO TP 114 and AASHTO TP 115 test method was developed to characterize quality and Bond Strength of tack coats
- Recommended threshold Interface Shear Strength criterion
  - Minimum 40 psi
- Recommended optimum tack coat residual application rates

Surface Type	Residual Application rate, gsy
New HMA	0.035
Existing HMA	0.055
Milled HMA	0.055
PCC	0.045

AASHTO TP 114



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Objective – NCHRP Project 9-40A

- **Validate AASHTO TP 114 test method and minimum recommended ISS threshold (40 psi) criterion**
- **Evaluate factors that affects interface bonding**
  - Pavement Surface Type
  - Tack Coat Material Type
  - Residual Application Rate
  - Service Time
- **Investigate the effect of bonding on short-term pavement performance**

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Scope

- **Six field projects**
  - Missouri; Louisiana; Florida; Tennessee; Nevada; Oklahoma
- **Four Pavement surface types:**
  - New HMA; Existing HMA; Milled HMA; PCC
- **Tack coat material types:**
  - Slow setting (SS-1H, CSS-1H, SS-1)
  - Non-tracking rapid setting (NTSS-1HM, CBC-1H, CRS-1 HBC)
- **Tack coat residual application rates:**
  - One specified by state DOTs
  - Other one as recommended by NCHRP 9-40 study

Surface Type	Residual Application rate, gsy
New HMA	0.035
Existing HMA	0.055
Milled HMA	0.055
PCC	0.045

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Methodology

- **Pre-construction**
  - Identify test sections
  - Distress survey
  - Distributor Truck Calibration
  - Pavement surface texture depth measurement
  - Falling weight deflectometer test
- **During-construction**
  - Application rate measurement
  - Tack coat sample collection
  - Construction related information collection
- **Post-construction**
  - Field cores collection
  - Falling weight deflectometer test
  - Distress survey

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Project Location

- **Projects were selected based on**
  - different climatic conditions
  - relatively high traffic volume

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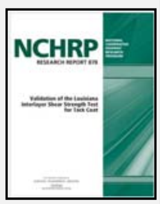
Project Description

- **Missouri Project**
  - Four Pavement surface types (New, Existing, Milled HMA and PCC)
  - Two tack coat types (SS-1H, NTSS-1HM)
  - One residual application rate (0.05 gsy)
- **Louisiana Projects**
  - **LA 30 Route**
  - Milled HMA pavement surface
  - Two tack coat types (SS-1H, NTSS-1HM)
  - One residual application rate (0.06 gsy)
  - **LA 1053 Route**
  - New HMA pavement surface
  - Four tack coat types (two NTSS-1HM, CBC-1H, SS-1H)
  - Two residual application rates for each tack coat type



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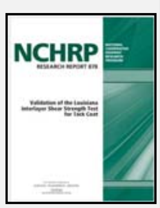
Project Description

- **Tennessee Project**
  - Milled HMA pavement surface
  - Three tack coat types (CBC-1H, NTSS-1HM, CSS-1H)
  - One residual application rate for each tack coat type
- **Florida Project**
  - Existing HMA pavement surface
  - Two tack coat types (CRS-1HBC, SS-1H)
  - Two residual application rates for each tack coat type
- **Nevada Project**
  - Milled HMA pavement surface
  - Two tack coat types (CBC-1H, CSS-1H)
  - Two residual application rates for each tack coat type
- **Oklahoma Project**
  - PCC pavement surface
  - Two tack coat types (CBC-1H, CSS-1H)
  - Two residual application rates for each tack coat type



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Experimental Program

- Tack coat distributor truck calibration
- Pavement surface texture measurement
- Falling weight deflectometer test
- Field tack coat application rate measurements
- Characterization of interface bond strength
- Characterization of tack coat materials
- Distress survey

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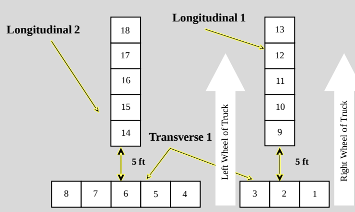
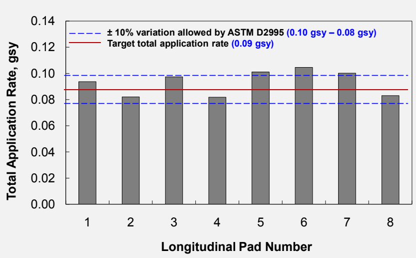
Tack Coat Distributor Truck Calibration

- Geotextile Pad layout
  - ASTM D 2995
  - One transverse
  - Two longitudinal



Typical Tack Coat Calibration Test Result

- **Target Application rate = Residual Rate/Percent Residue**
  - Target Residual Rate for Milled HMA = 0.055 gsy
  - Percent Residue = 60%
  - Target Total Application Rate = 0.055 gsy/0.60 = 0.09 gsy



Uniformity of application

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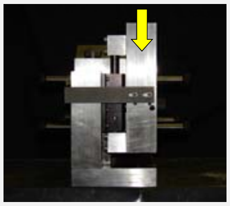
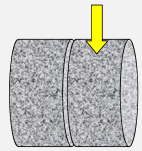
Characterization of Interface Bond Strength

- AASHTO TP 114 test method
  - Loading rate
    - 2.54 mm (0.1 in.) per minute
  - Interface Shear Strength





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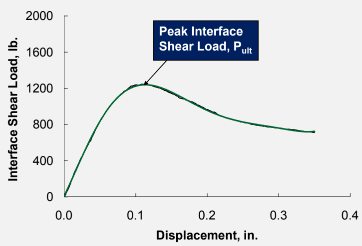
Material Response Parameter - Bond Quality



$$ISS = \frac{P_{ult}}{\frac{\pi D^2}{4}}$$

- Interface Shear Strength (ISS, psi) : COV < 15%

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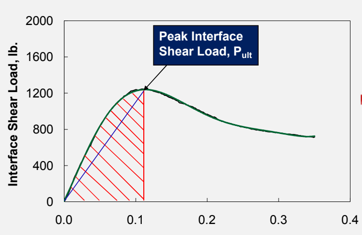
Material Response Parameter - Bond Quality



$$ISS = \frac{P_{ult}}{\frac{\pi D^2}{4}}$$

$$IBE = \frac{\text{Area Under the Curve upto } P_{ult}}{\frac{\pi D^2}{4}}$$

$$K-modulus = \frac{ISS}{\text{Displacement at } P_{ult}}$$

- Interface Shear Strength (ISS, psi) : COV < 15%
- Interface Bond Energy (IBE, lb.-in/in²)
- Interface Shear Stiffness (k-modulus, psi/in)

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Pavement Surface Texture

- **Sand Patch Test**
  - ASTM E 965
  - Mean Texture Depth (MTD)

$$MTD = \frac{4V}{\pi D^2}$$

Surface Type	AVG. Mean Texture Depth, mm
New HMA	0.91
Existing HMA	0.97
Milled HMA	1.77
PCC	1.49

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Application Rate Measurement

- **ASTM D 2995 (Method A)**
  - Residual Application Rate = Percent Residue × Total Application Rate

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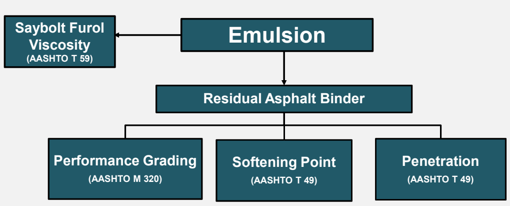
Tack Coat Characterization



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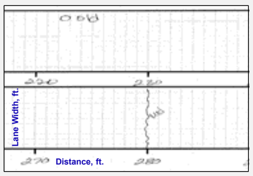
Distress Survey

- **Distress Identification Manual for the Long-Term Pavement Performance Program**
- **Cracking classification:**
  - low (mean crack width ≤ 0.24-in.)
  - moderate (mean crack width > 0.24-in. and ≤ 0.75-in.)
  - high (mean crack width ≥ 0.75-in.)
- **Rutting classification:**
  - low (mean rut depth ≤ 0.47-in.)
  - moderate (mean rut depth > 0.47-in. and ≤ 0.98-in.)
  - high (mean rut depth ≥ 0.98-in.)



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Results and Discussion

- Rheological properties of tack coats
- Surface texture depths
- Effect of tack coat type on ISS
- Effect of pavement surface type on ISS
- Effect of residual application rate on ISS
- Effect of service time on ISS
- Analysis of FWD test results
- Density test results
- Relationship between ISS and FWD center deflections
- Short-term performance of test sections

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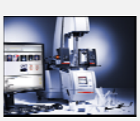
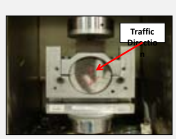
Results





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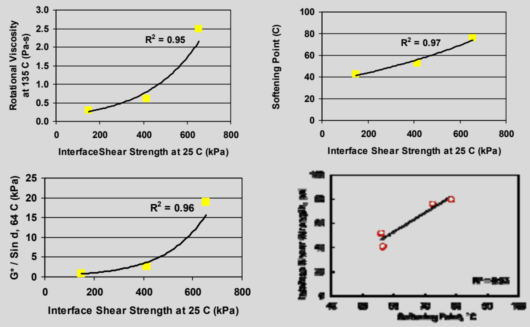
Relationship between ISS vs. Rheology Test Results



Rheological Properties of Tack Coats

Project	Tack Coat Type	Percent Residue, %	Saybolt Furol Viscosity, s	Penetration, dmm	Softening Point, °C	Performance Grade
Missouri	SS-1H	61.0	29.2	71.0	51.4	64-22
	NTSS-1HM	63.0	41.5	9.0	82.0	94-10
Louisiana (LA 30)	SS-1	64.1	32.7	102.0	43.5	46-28
	NTSS-1HM	54.3	34.2	9.0	78.1	82-10
Louisiana (LA 1053)	NTSS-1HM	43.6	16.0	8.0	78.3	94-4
	CBC-1H	51.7	15.2	40.3	56.4	70-16
	NTSS-1HM	57.1	16.2	8.7	72.5	88-10
	SS-1H	57.8	25.1	45.3	55.8	70-22
Florida	SS-1H	60.0	23.5	50.3	52.5	64-22
	CRS-1HBC	59.3	19.5	68.4	50.2	64-22
Tennessee	NTSS-1HM	52.3	16.7	8.0	79.2	100-10
	CBC-1H	52.5	15.2	48.3	55.1	70-22
	CSS-1H	61.5	23.3	66.3	52.6	64-22
Nevada	CBC-1H	59.1	18.0	58.3	52.0	70-28
	CSS-1H	48.1	16.4	53.0	52.2	70-22
Oklahoma	CBC-1H	51.2	17.8	52.7	55.0	64-22
	CSS-1H	61.7	38.2	53.0	51.0	64-22

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Surface Mean Texture Depths

Pavement Surface Type	Field Project	Surface MTD, mm	Average MTD, mm	Measured Range, mm
Milled HMA	Missouri	1.62	1.77	2.14-1.38
	Louisiana	1.56		
	Tennessee	1.92		
	Nevada	1.83		
New HMA	Missouri	0.87	0.91	0.95-0.84
	Louisiana	0.93		
Existing HMA	Missouri	0.99	0.97	0.99-0.95
	Florida	0.96		
PCC	Missouri	1.26	1.49	1.67-1.25
	Oklahoma	1.61		

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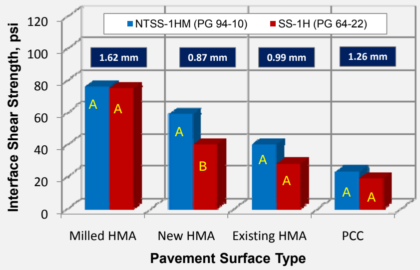
Effect of Tack Coat Type on ISS

MISSOURI PROJECT



- All tack coat material were compared at 0.05 gsy residual application rate

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Effect of Tack Coat Type on ISS

MISSOURI PROJECT

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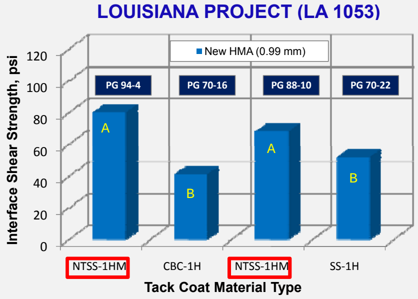
Effect of Tack Coat Type on ISS

LOUISIANA PROJECT (LA 1053)



- All tack coat material were compared at 0.02 gsy residual application rate

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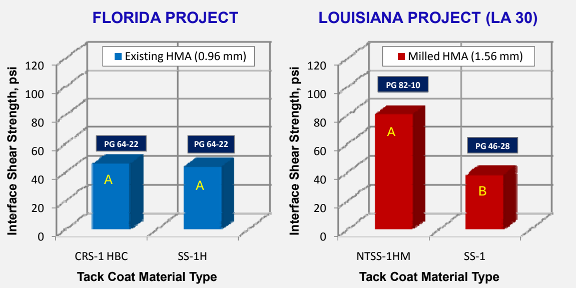
Effect of Tack Coat Type on ISS



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Effect of Tack Coat Type on ISS

Summary:

- All test sections met 40 psi threshold except
  - PCC surface in Missouri project
  - SS-1 tack coat on LA 30 project
- NTSS-1HM tack coat exhibited higher ISS than SS-1H
- CBC-1H showed similar ISS when compared with SS-1H

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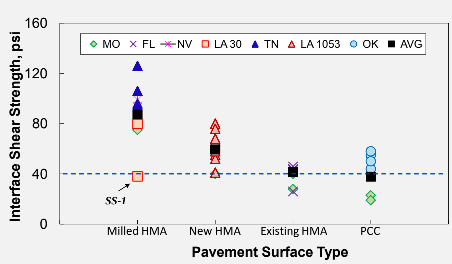
Effect of Surface Type on ISS



- **ISS was largely dependent on**
  - Type of pavement surface (HMA versus PCC)
  - Pavement surface texture (milled versus non-milled)

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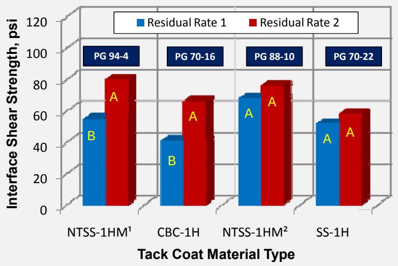
Effect of Residual Application Rate on ISS

LOUISIANA PROJECT (LA 1053)
New HMA



Tack Coat Material	Residual Rate, gsy	
	1	2
NTSS-1HM[1]	0.01	0.02
CBC-1H	0.02	0.04
NTSS-1HM[2]	0.02	0.03
SS-1H	0.02	0.03

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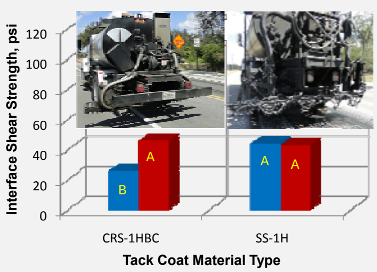
Effect of Residual Application Rate on ISS

FLORIDA PROJECT
Existing HMA



Tack Coat Material	Residual Rate, gsy	
	1	2
CRS-1HBC	0.02	0.04
SS-1H	0.04	0.04

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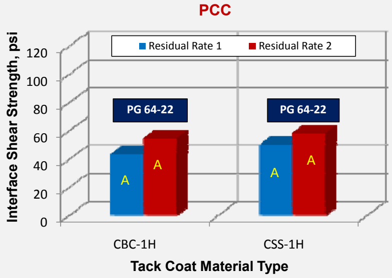
Effect of Residual Application Rate on ISS

OKLAHOMA PROJECT
PCC



Tack Coat Material	Residual Rate, gsy	
	1	2
CBC-1H	0.03	0.04
CSS-1H	0.07	0.08

- **ISS improved with the increase in**
  - residual application rate for all tack coat and pavement surface types

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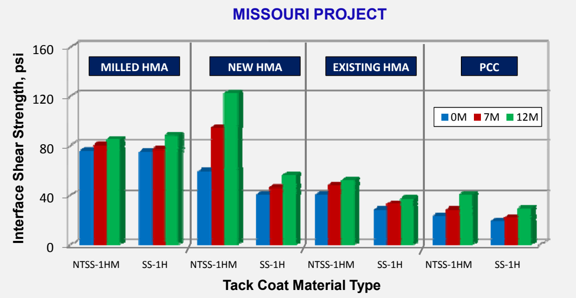
Effect of Service Time on ISS



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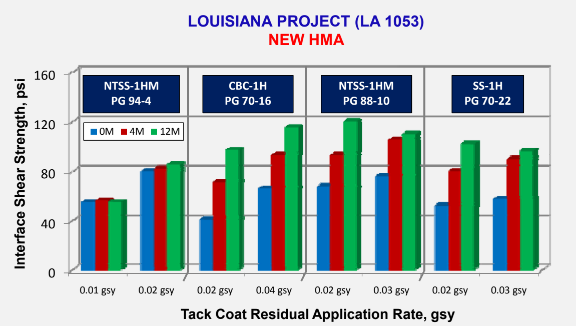
Effect of Service Time on ISS



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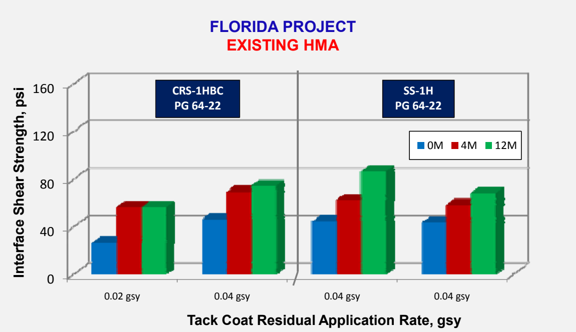
Effect of Service Time on ISS



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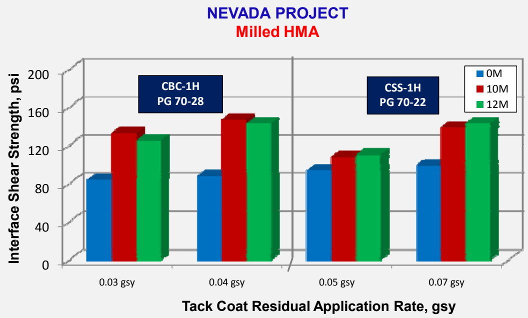
Effect of Service Time on ISS



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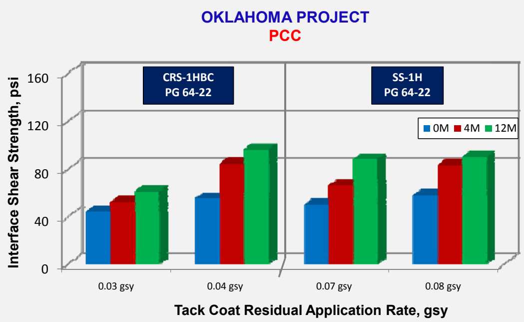
Effect of Service Time on ISS



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Effect of Service Time on ISS

Summary:

- All test sections met 40 psi threshold except PCC surface in Missouri project
- ISS increased with service time due to tack coat curing
- Curing effect is more pronounced with
  - non-tracking rapid setting tack coat materials on new HMA surfaces
  - increase in the residual application rate

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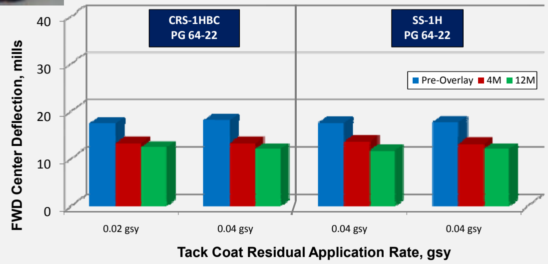
Analysis of FWD Test Results

FLORIDA PROJECT
EXISTING HMA



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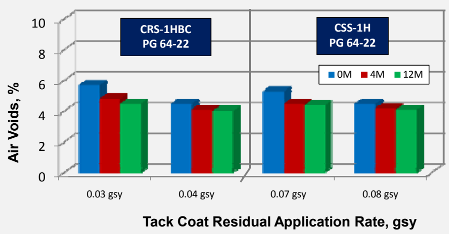
Density Test Results

OKLAHOMA PROJECT
PCC



- **Densification of overlays was primarily attributed to the**
  - densification effect of HMA overlays due to in-service trafficking
  - improved interface bonding with service time

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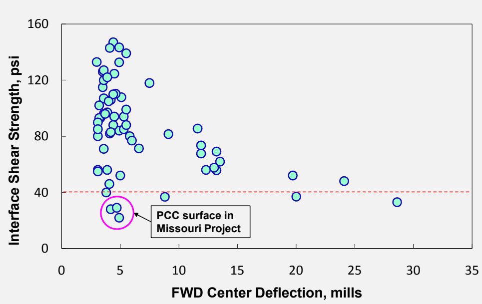
Relationship between ISS and FWD Deflection



- **Indicates surface deflection depends on**
  - the interface bonding between pavement layers

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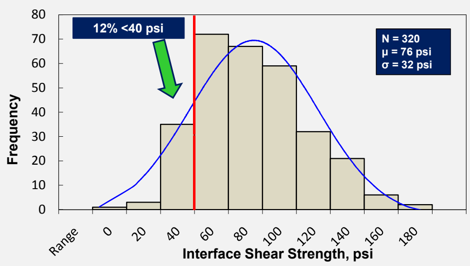
Short-Term Pavement Performance



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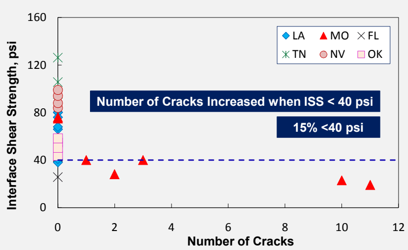
Short-Term Pavement Performance



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Conclusions

- **Effect of tack coat type on ISS**
  - Non-tracking rapid setting tack coats with stiff base asphalt (NTSS-1HM) exhibited the highest ISS, and slow setting resulted in the lowest
- **Effect of pavement surface type on ISS**
  - ISS was largely dependent on
    - Type of pavement surface (HMA versus PCC)
    - Type of pavement surface texture (milled versus non-milled)
  - Milled surface yielded the highest ISS, followed by new HMA, existing HMA, and PCC surface types
    - Higher surface roughness provided greater shear resistance
- **Effect of residual application rate on ISS**
  - ISS improved with the increase in residual application rate for all tack coat types and pavement surface types

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Conclusions

- **Effect of service time on ISS**
  - ISS increased with service time due to tack coat curing
  - Curing effect is more pronounced with
    - non-tracking rapid setting tack coat materials on new HMA surfaces
    - increase in the residual application rate
- **Falling weight deflectometer test results**
  - Mean center deflection decreased with service time
  - Densification of overlays was attributed to
    - in-service trafficking
    - improved ISS
- **Short-term pavement performance**
  - ISS values correlated well with short-term performance
  - No rutting and surface cracking
  - Few test sections with ISS < 40 psi showed low to moderate cracking

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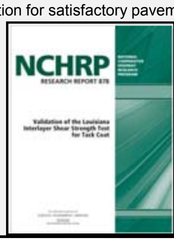
Recommendations

- **AASHTO TP 114 test**
  - Quality control and quality assurance testing of tack coat construction
  - Evaluation of interface-bonding condition of in-service pavements
- **Use of minimum ISS threshold criterion (40 psi)**
  - As the specification for satisfactory pavement performance



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