Optimal Timing of Preventive Maintenance for Addressing Environmental Aging

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MnROAD Test Facility
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OUTLINE

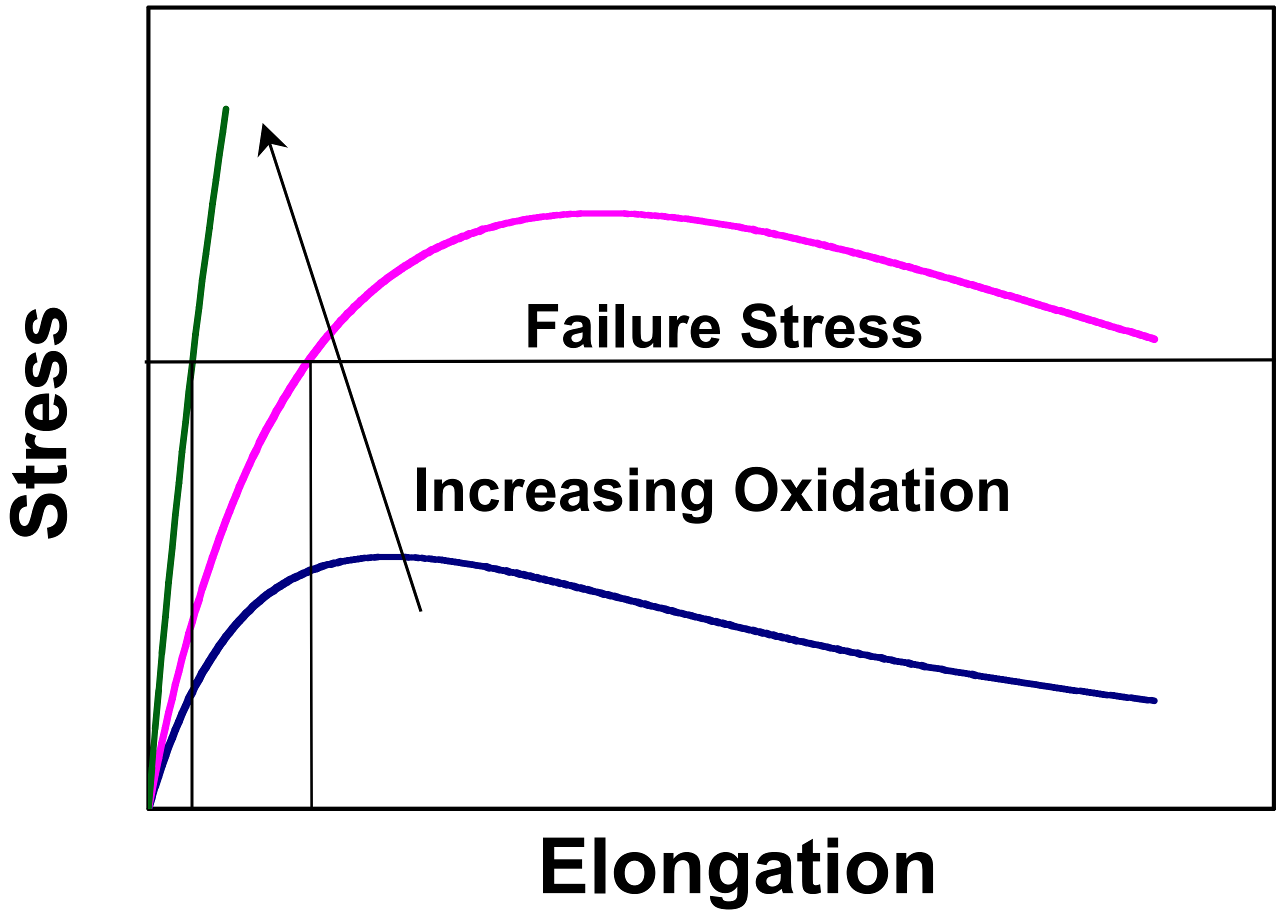
- ***Background***
- ***Needs***
- ***Needs being addressed***
- ***Needs - Not being addressed well enough***
- ***Combining efforts nationally***
- ***Suggested emphasis of this PFS***

THE PROBLEM

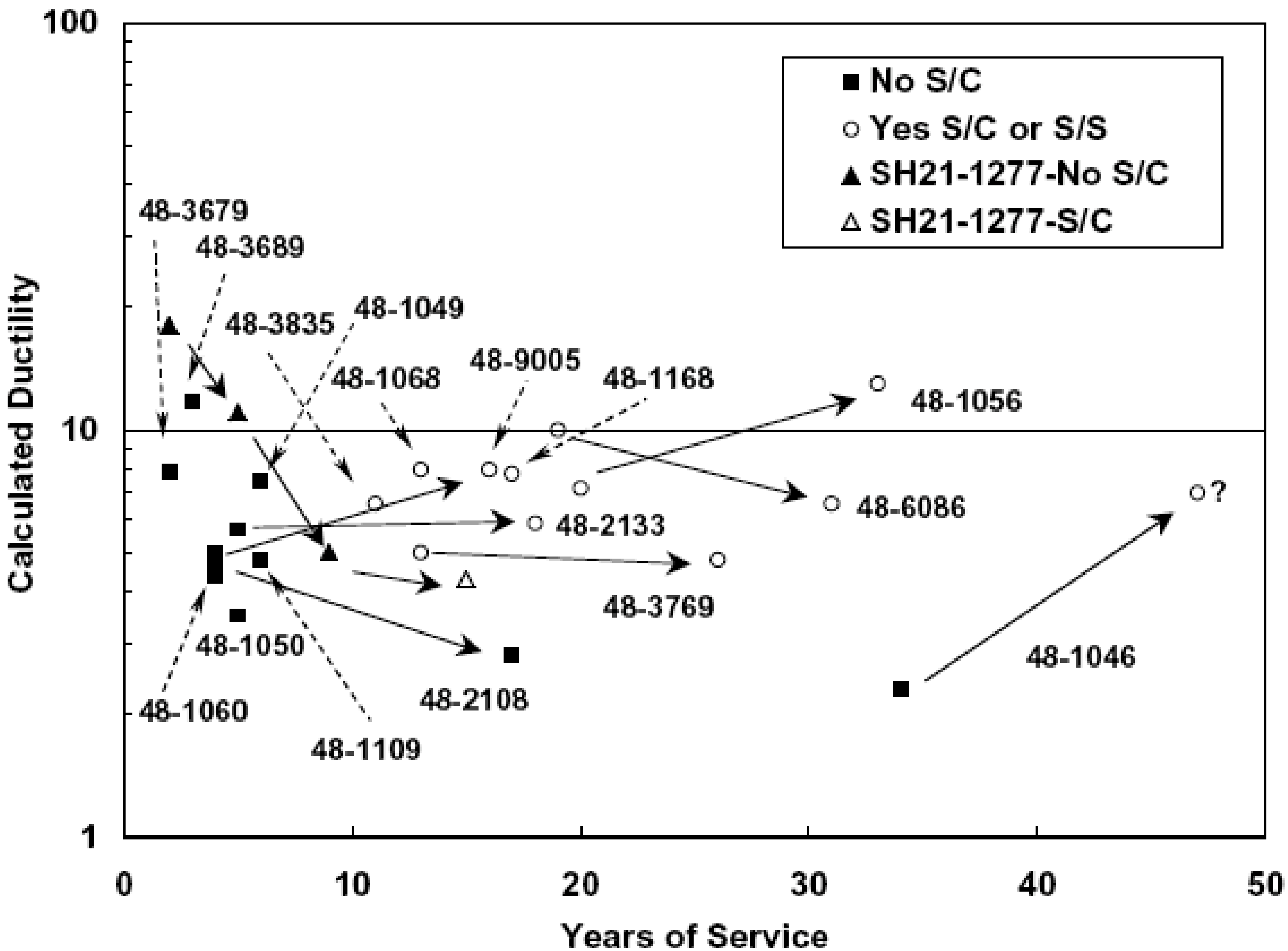
- Binder oxidation and hardening DO occur extensively beyond one inch down into the pavement
- Mixture performance declines significantly with binder oxidation
- Effective maintenance programs will inhibit binder oxidation in pavement or rejuvenate in-place binder - Is this possible?

BACKGROUND

IN SERVICE: BINDERS OXIDIZE, BECOME STIFFER AND LESS DUCTILE…A RELENTLESS PROCESS!

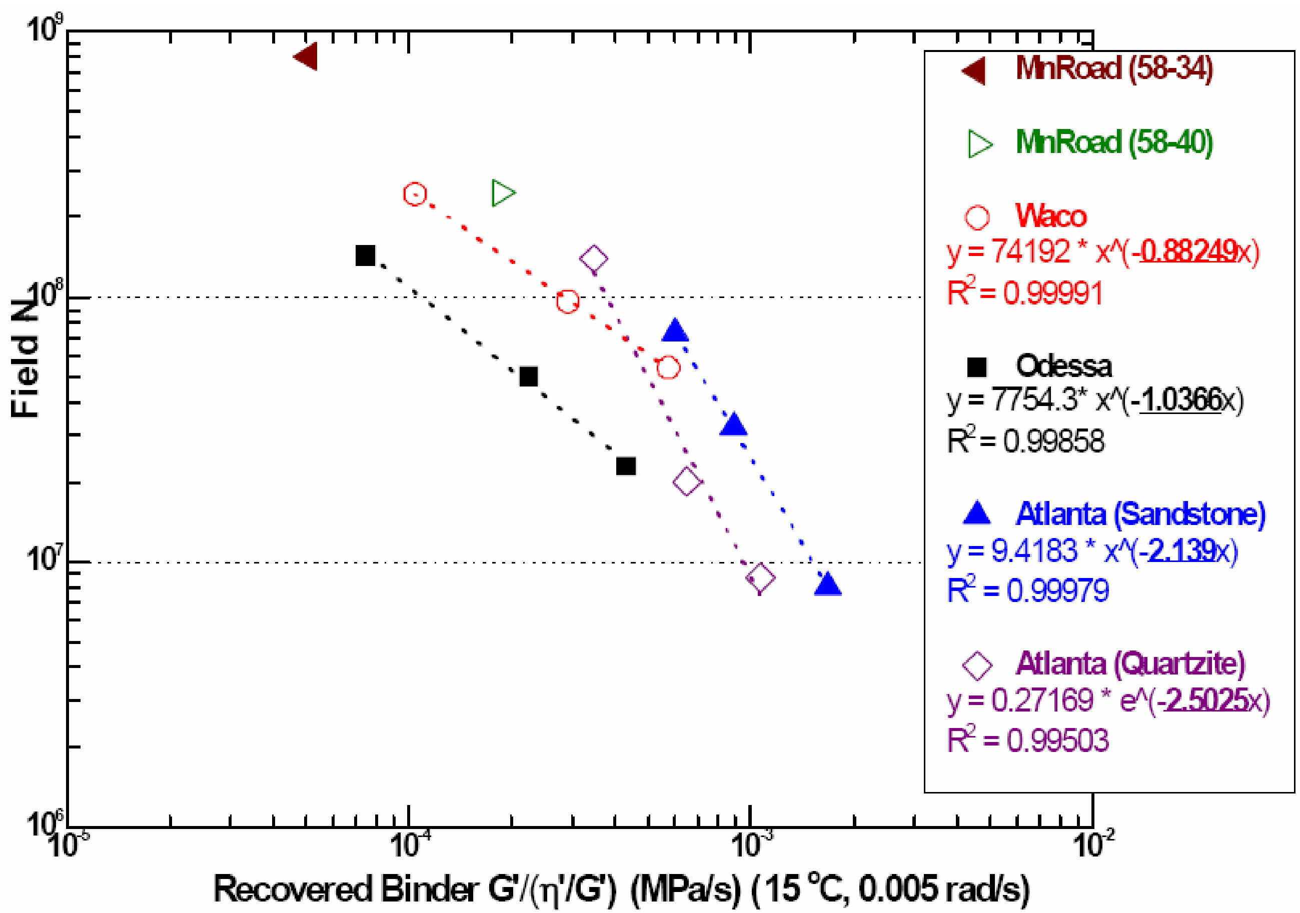


BACKGROUND
TxDOT 0-1872



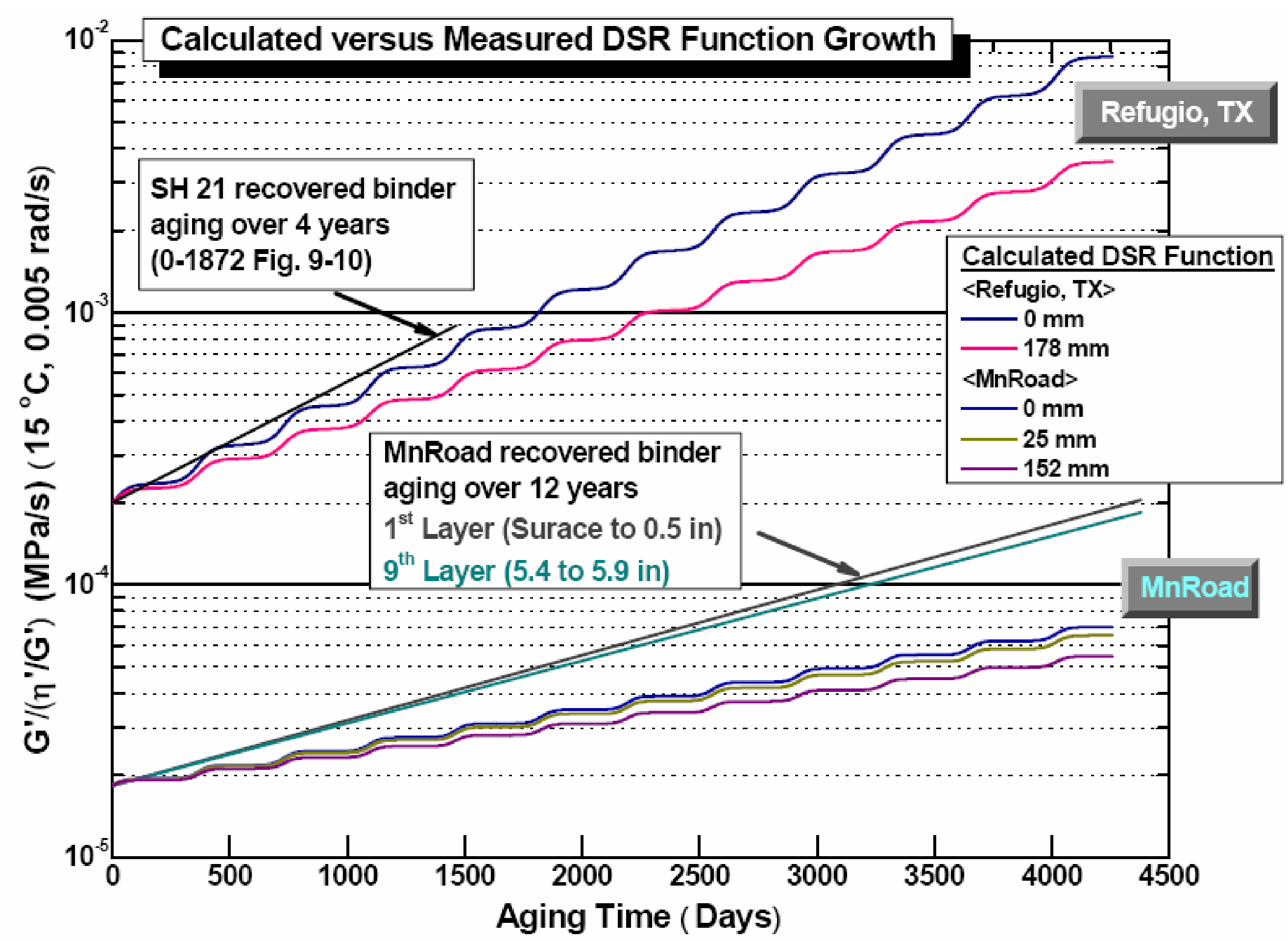
BACKGROUND
TxDOT 0-4688

AS BINDERS OXIDIZED, MIXTURE FATIGUE RESISTANCE DECLINES…



BACKGROUND
TxDOT 0-4688

BINDER OXIDATION MODEL CAN BE USED TO ESTIMATE HARDENING RATE IN PAVEMENT

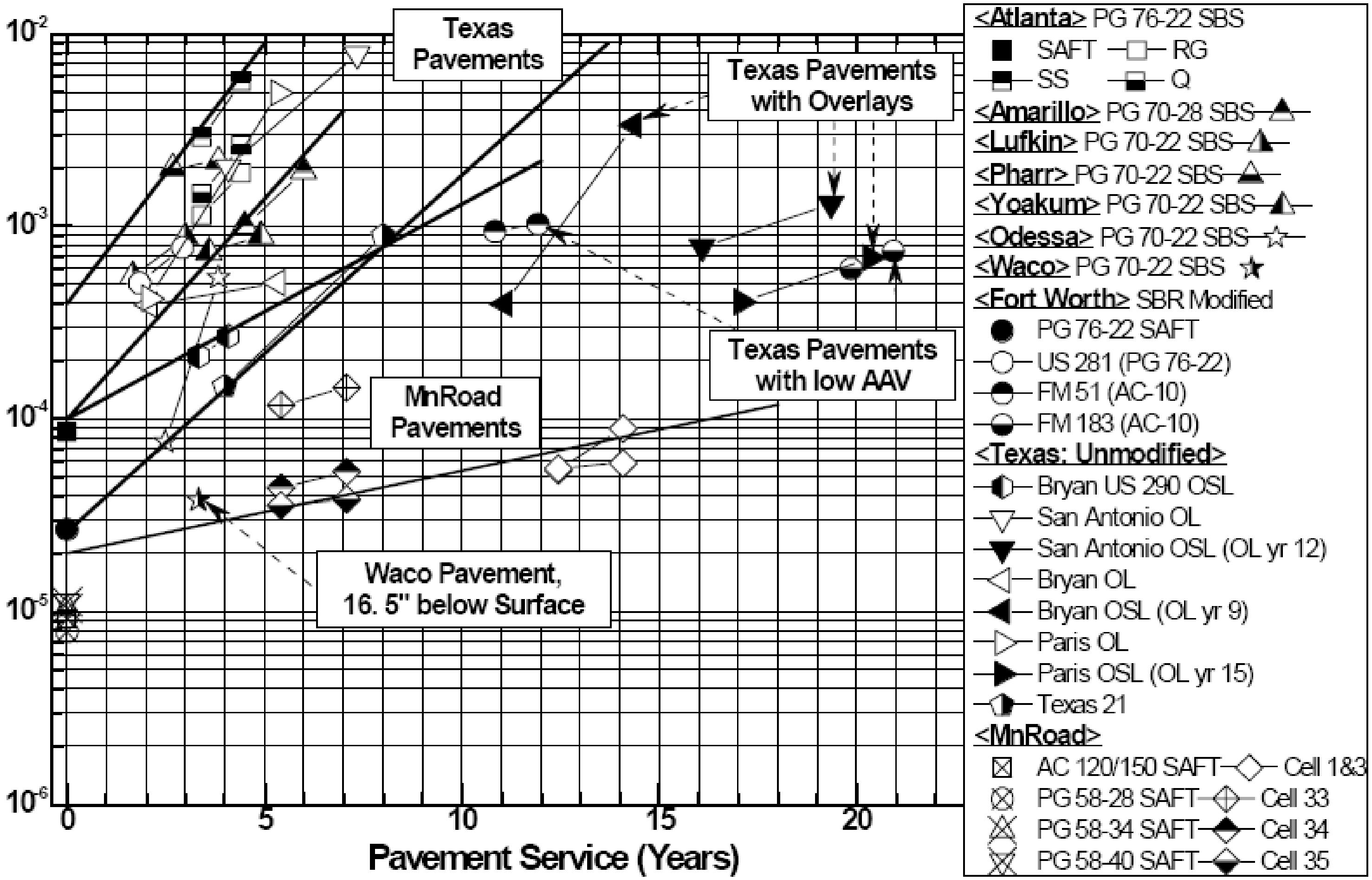


BACKGROUND
TxDOT 0-4688

Texas Department of Transportation

Texas Transportation Institute

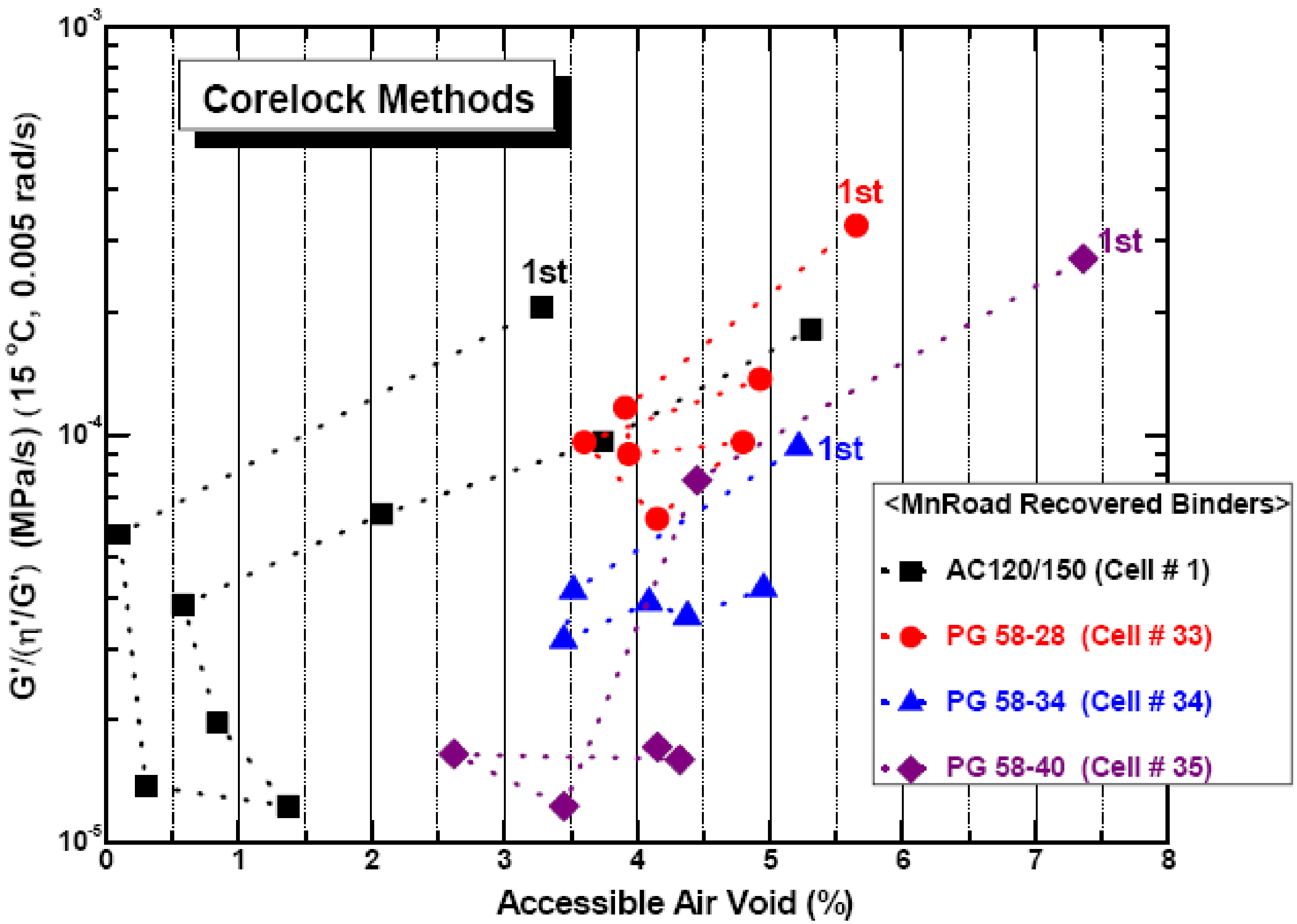
THROUGHOUT SERVICE, BINDER HARDENING PROCEEDS IN A WAY THAT DEPENDS DEPENDS ON CLIMATE AND THE PHYSICAL STRUCTURE OF THE MIXTURE



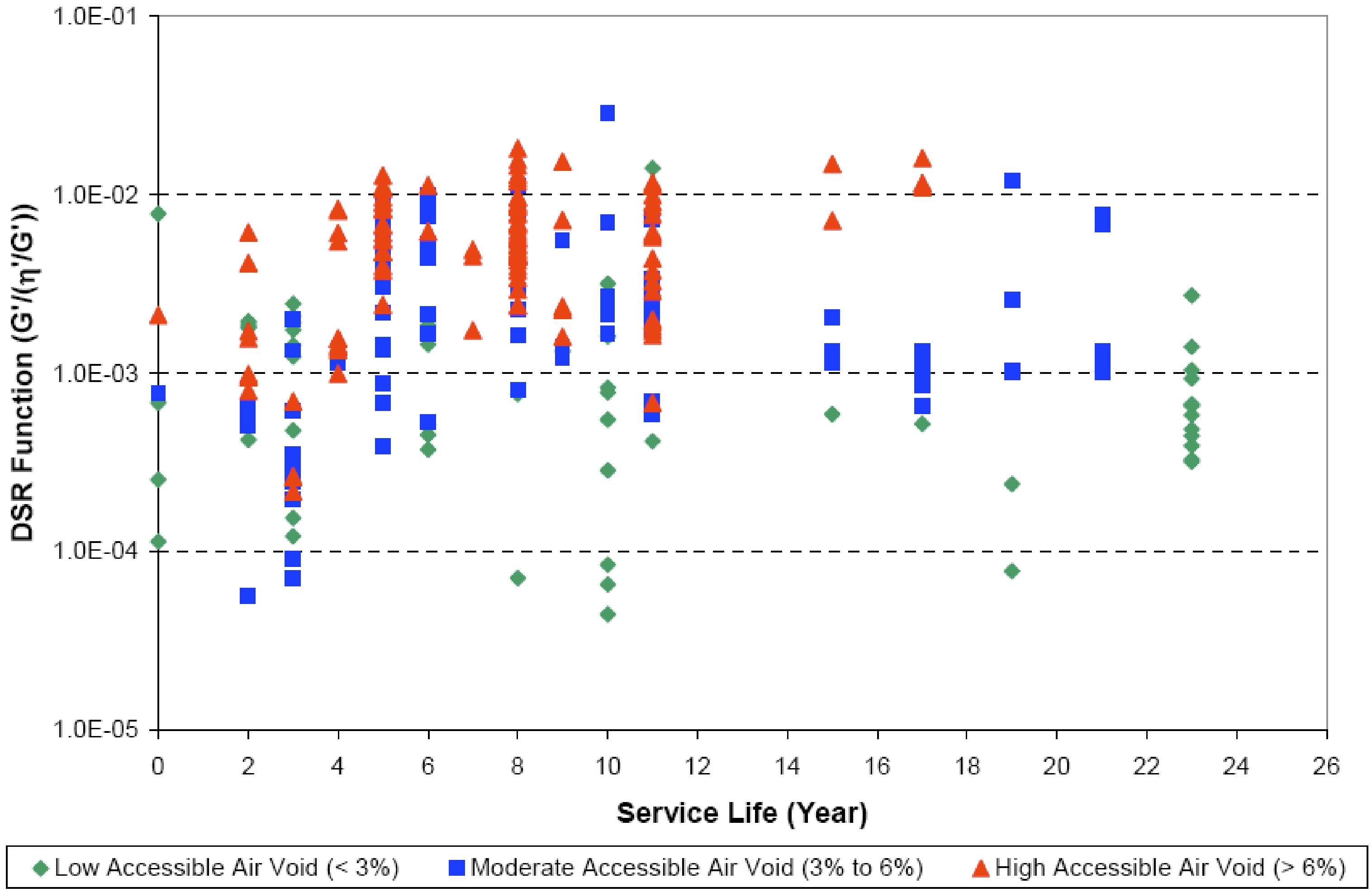
A&M

BACKGROUND
TxDOT 0-4688

ACCESSIBLE AIR VOIDS IS ONE OF THE KEY MIXTURE PARAMETERS THAT SIGNIFICANTLY AFFECTS BINDER OXIDATION



BACKGROUND
TxDOT 0-5091



TxDOT 0-5091
- SUMMARY -

- Effects of fog seals on pavement durability appear to be minimal, with respect to sealing or rejuvenation
- Fog seals did not appear to penetrate below the pavement surface
- The aging rates of asphalt binders are decreased by very low accessible air voids

BACKGROUND
- SUMMARY -

- Binder oxidation and hardening DO occur extensively beyond one inch down into the pavement
- Mixture performance declines significantly with binder oxidation
- Effective maintenance program would inhibit binder oxidation in pavement and/or rejuvenate in-place binder
- Evidence suggests that sealants may affect binders…or may not

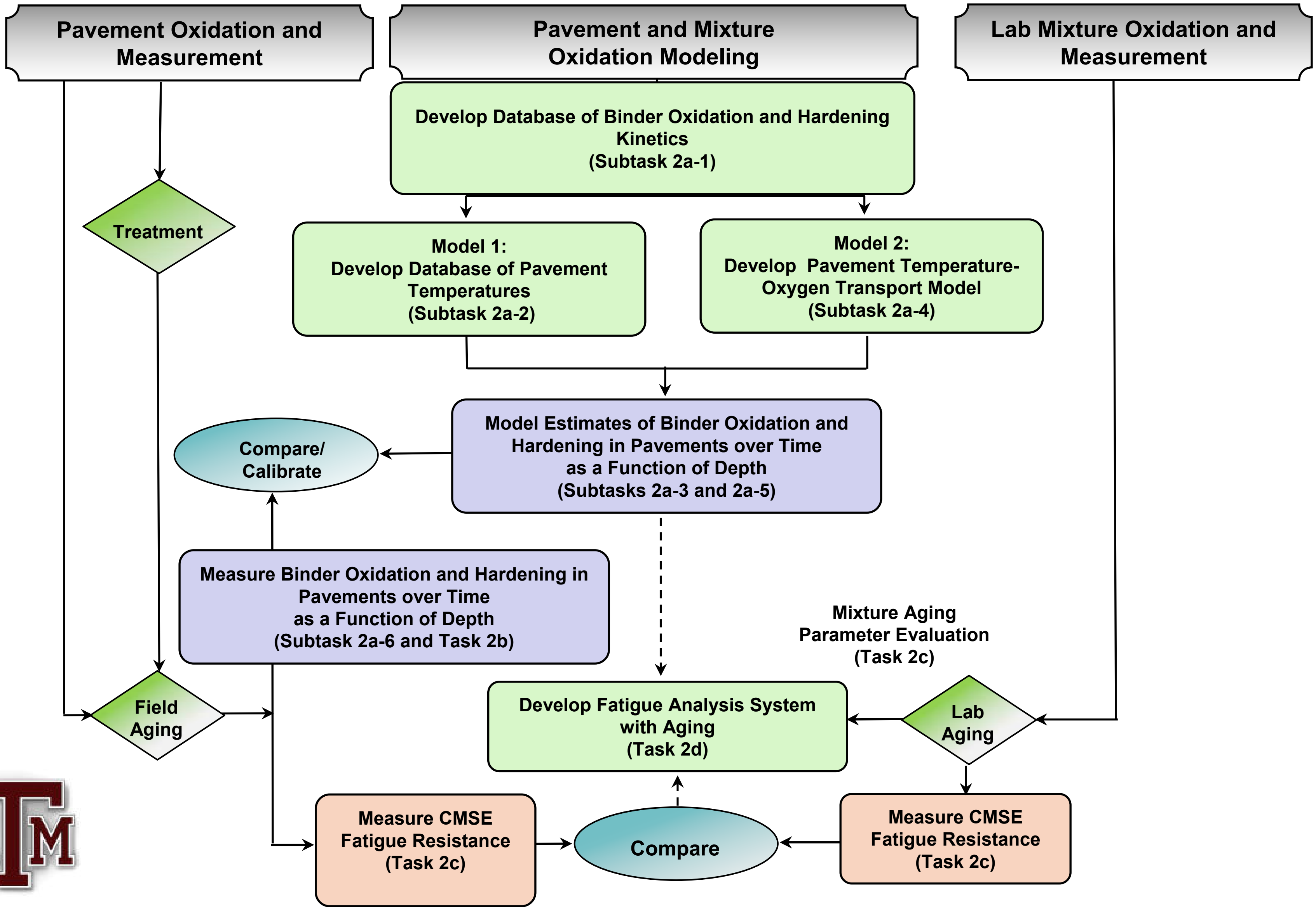
RESEARCH NEEDS

- Improved Understanding of binder oxidation and hardening rates in pavements (model)
  - Improved measurements of mixture air voids morphology: pore size, spacing, AAV
  - Improved understanding of air permeation through pavements
- Improved understanding of the impact of binder hardening on mixture performance (e.g. fatigue)
- Field measurements of binder oxidation in pavements and maintenance treatment effectiveness

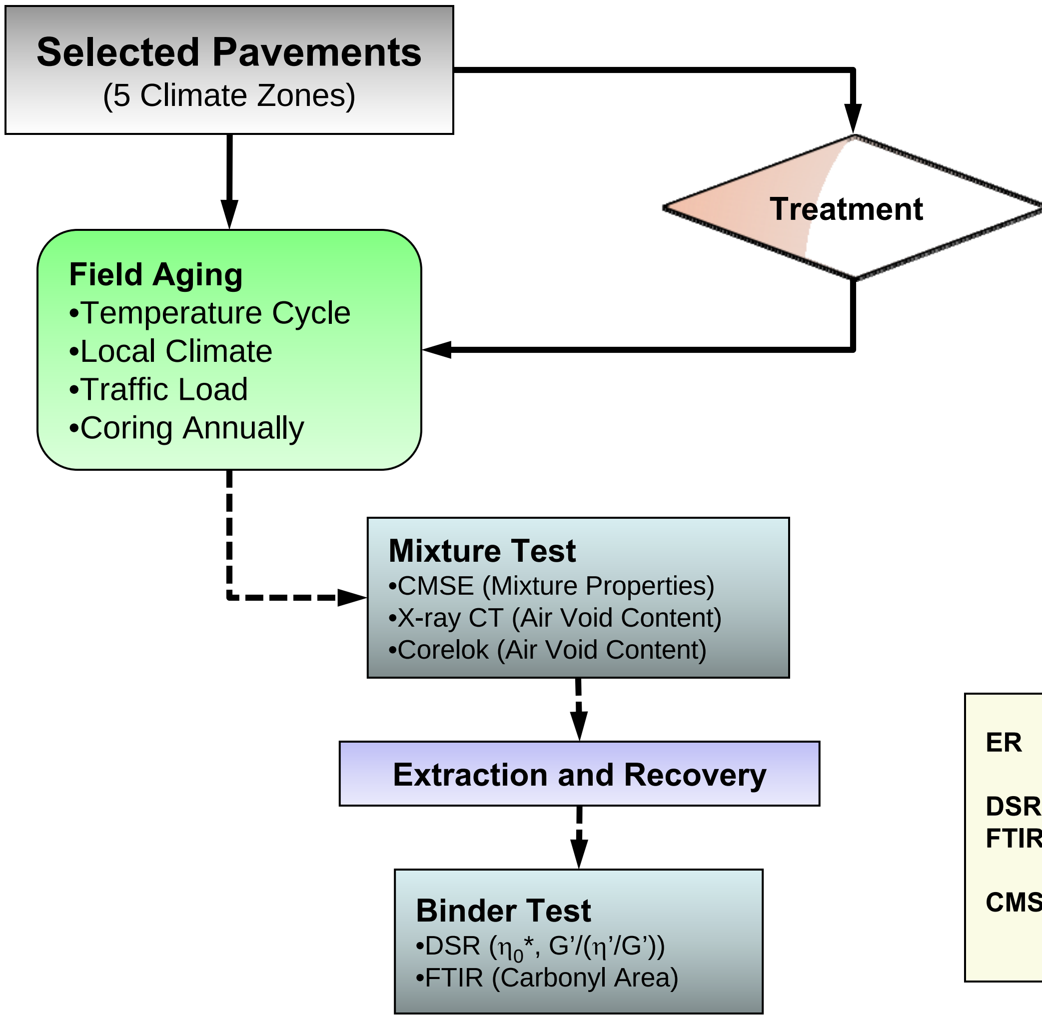
CURRENT EFFORTS

- Improved Understanding of binder oxidation and hardening rates in pavements (model)
  - Thermal/Oxygen transport model - ARC, 0-6009
  - Improved measurements of mixture air voids morphology: pore size, spacing, AAV - ARC
  - Improved understanding of air permeation through pavements - ??
- Improved understanding of the impact of binder hardening on mixture performance (e.g. fatigue) - 0-6009 (laboratory, field data, Texas mixtures); ARC (modeling, laboratory, field data, non-Texas)
- Field measurements of binder oxidation in pavements and maintenance treatment effectiveness - 0-6009 (Texas)

WORK PLAN – TxDOT 0-6009



TxDOT 0-6009: Evaluate Maintenance Treatments to Reduce Aging



ER	(Environmental Room)
DSR	(Dynamic Shear Rheometer)
FTIR	(Fourier Transform Infrared)
CMSE	(Calibrated Mechanistic Approach with Surface Energy)

NEEDS - NOT BEING MET

- Improved Understanding of binder oxidation and hardening rates in pavements (model)
  - Improved understanding of air permeation through pavements - Pavement breathing? Permeation from below? Flow out the edges?
  - Do treatments restrict access to oxygen? Compete with moisture drainage?
- Field measurements: binder oxidation; maintenance treatment effectiveness - more data are needed in many climates to give better confidence in models

SUGGESTED EMPHASIS OF PFS

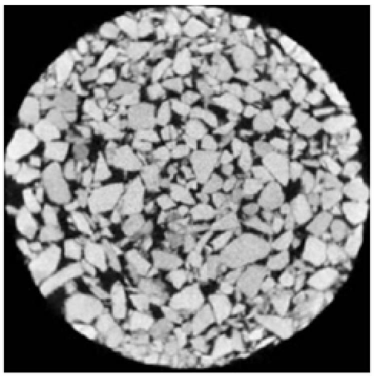
- **Additional measurements of field aging and maintenance treatment effectiveness - flow into and through pavements; ability to retard oxidation and/or rejuvenate binders**
  - **Hot-applied treatments**
  - **Emulsion Treatments**
- **A better understanding of fundamentals will allow determining optimal timing - link to fundamentals of binder oxidation in 0-6009 and ARC**

…Discussion…

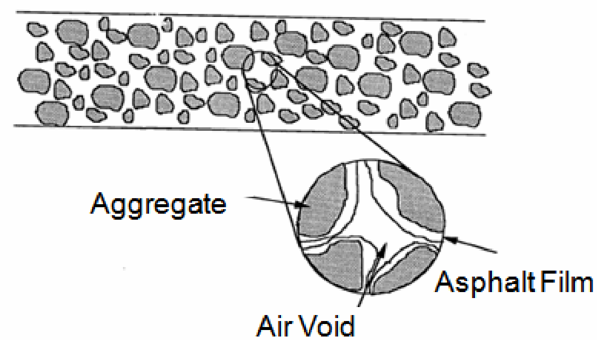
…Backup Slides…

TEST PLAN

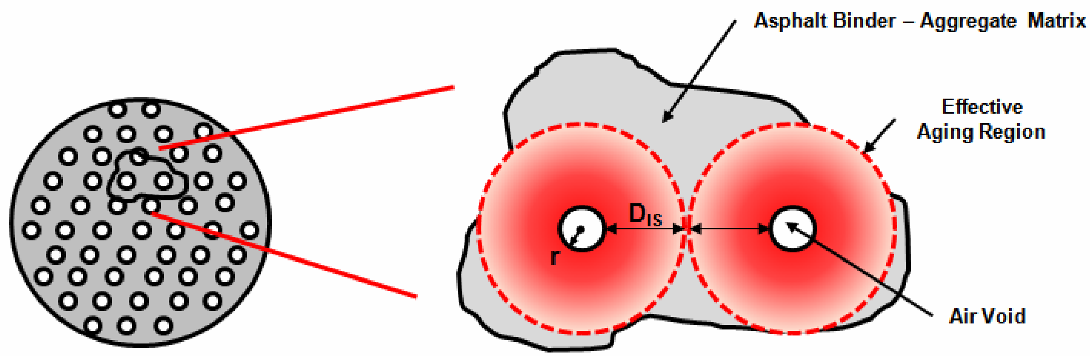
Model Development Approach



X-ray CT Image



Schematic – Pavement Layer



r = Air Void Pore Radius
D_{IS} = Distance to Impermeable Surface

"Two Adjacent Pores"

Modeling Concept

Equation for Oxidation Model

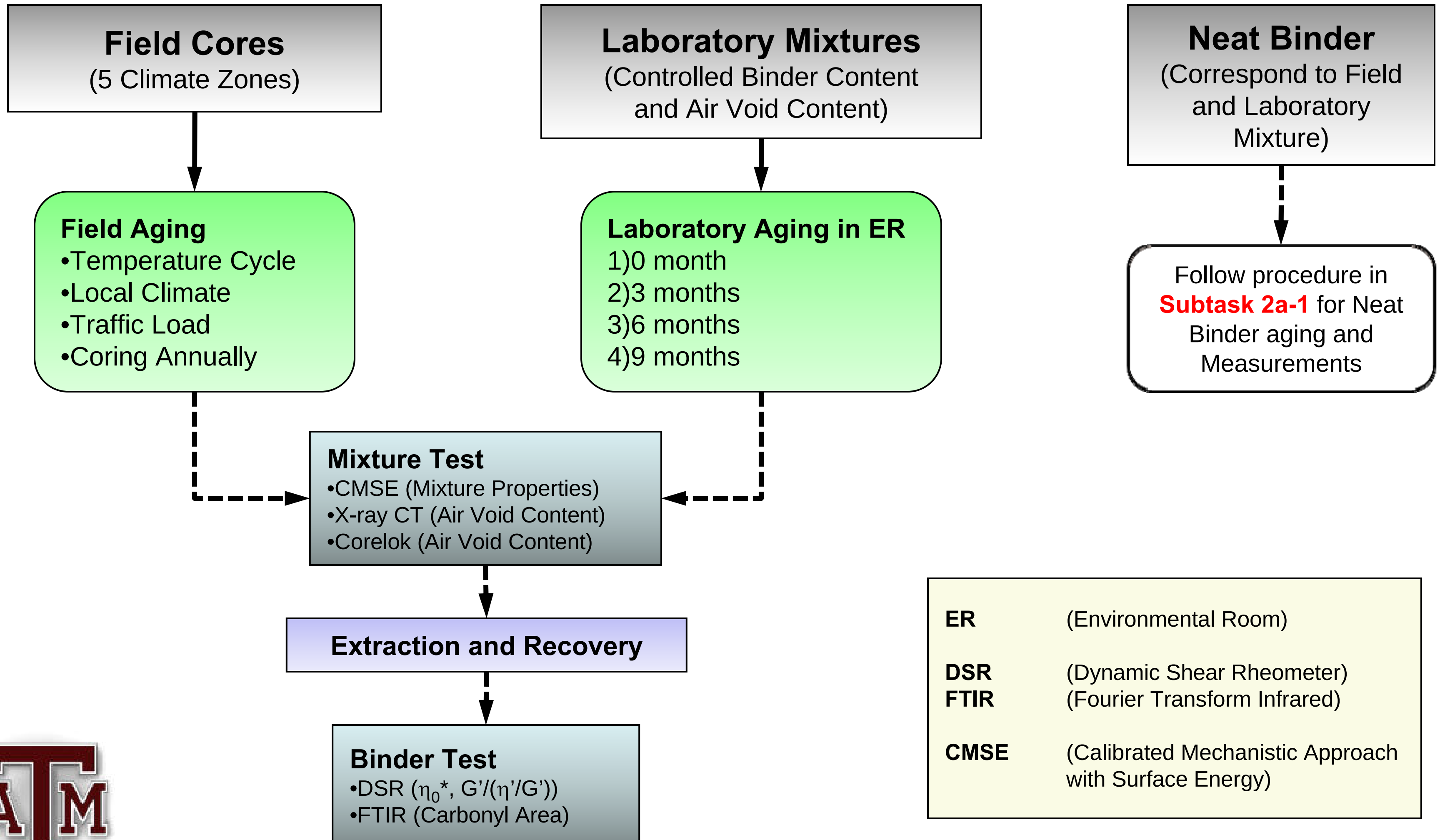
$$\frac{\partial P}{\partial t} = \left(\frac{\partial D_{O_2}}{\partial P}\right)\left(\frac{\partial P}{\partial r}\right)^2 + D_{O_2}\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial P}{\partial r}\right)\right] - \left(\frac{cRT}{h}\right) r_{CA}$$

$$\frac{d\mathrm{CA}}{dt} = r_{\mathrm{CA}} = AP^{\alpha} e^{-E/RT}$$

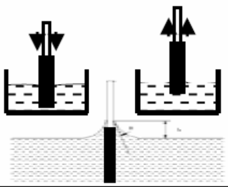
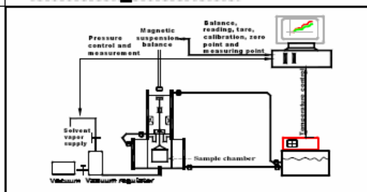
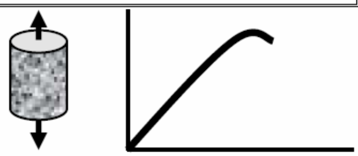
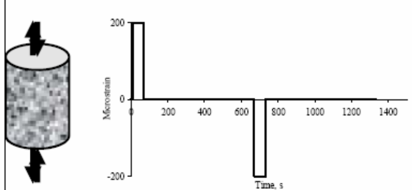
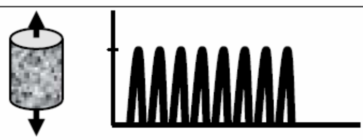
Where
- P = Oxygen partial pressure in asphalt binder film
- α = Order of reaction
- E = Activation energy
- D_{O_2} = Oxygen diffusivity in asphalt film
- c = Experimental constant
- R = Gas Constant
- T = Absolute temperature of asphalt film
- h = Henry's law constant

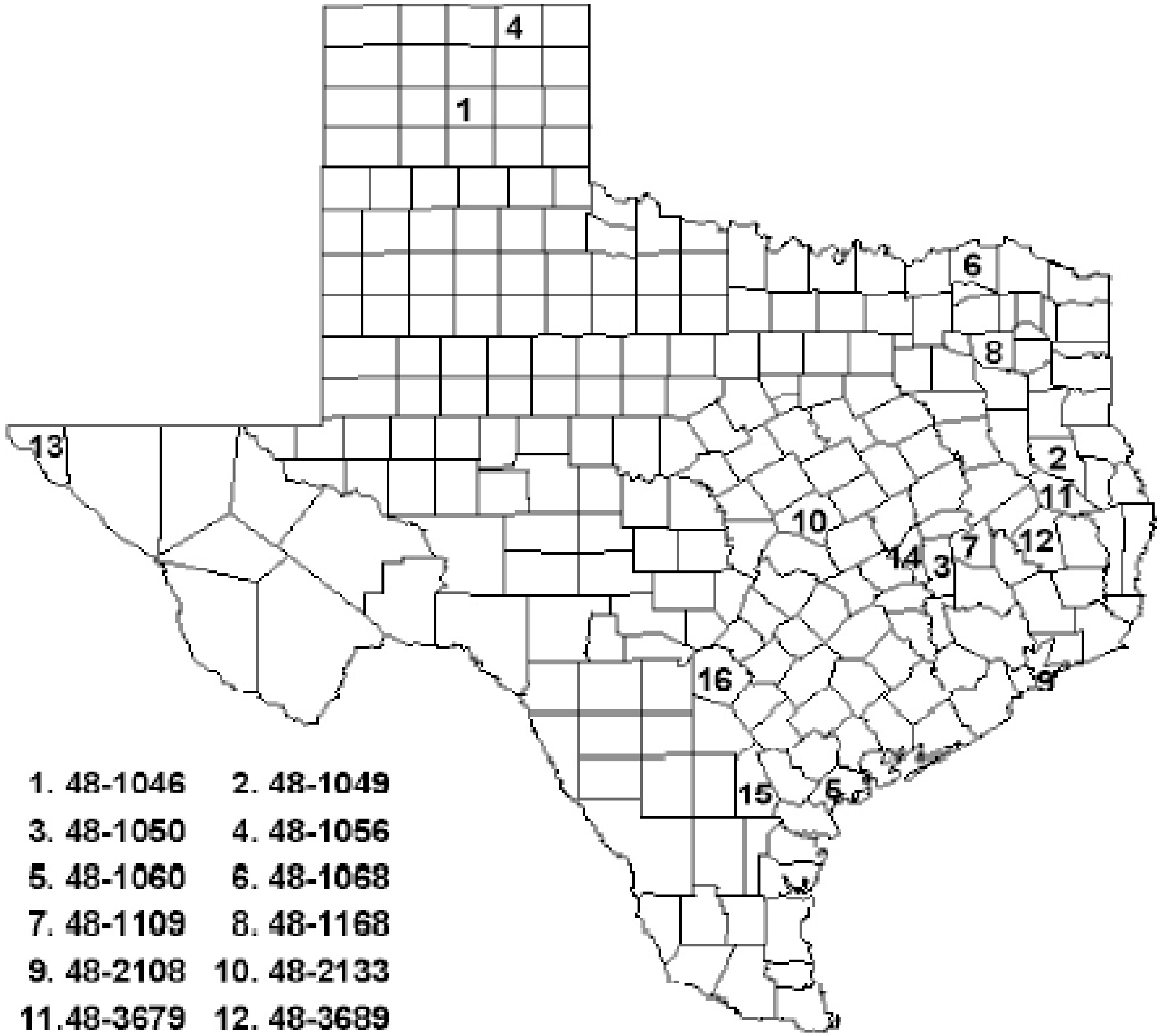
TEST PLAN

Measure Field & Lab Binder Aging Rates to Calibrate the Transport Model



CMSE Test Procedures

Test	Loading Configuration, Test Parameters, and Output Data
Wilhelmy Plate-CMSE	 Automatic immersion and withdrawal of binder-coated glass plates into/from liquid solvents up to approx. 5 mm (0.2 in) depth @ 20±2 °C (68±4 °F). Test time: ≅45 minutes. Measurable & output data are dynamic contact angle (θ) and surface energy (SE) components for the binder ($\Gamma_{i\text{-}binder}$)
Universal Sorption Device-CMSE	 Clean oven dried 50 g (0.1 lb) aggregate of fraction size (4.75 mm (No. 4) < aggregate size < 2.63 mm (No. 8)). Measurable parameters are vapor pressure & adsorbed gas mass of liquid solvents @ 25±2 °C (77±4 °F). Test time: 60 to 70 hrs. Output data is SE components for the aggregates ($\Gamma_{j\text{-}aggregate}$).
Tensile Strength (TS)- CMSE	 Tensile loading until break @ 0.05 mm/min (0.002 in/min) @ 20 °C (68 °F). Test time: ≅5 minutes. Output data are HMA mixture tensile strength (σ_t) and failure strain (ε_f).
Uniaxial Relaxation Modulus (RM)- CMSE	 Trapezoidal shaped strain-controlled @ 200 microstrain (tension & compression), 60 s loading & 600 s rest period @ 10 °C (50 °F), 20 °C (68 °F), and 30 °C (86 °F). Test time: ≅ 25 minutes. Output data are HMA mixture elastic relaxation modulus (E_i), stress relaxation rate (m), and temperature correction factors (a_T).
Uniaxial Repeated Direct-Tension (RDT)-CMSE	 Haversine strain-controlled @ 1 Hz, 30 °C (86 °F), & 350 microstrain level for 1,000 load cycles. Test time: ≅20 minutes. Output data are dissipated pseudo strain energy and rate of fracture damage accumulation (b).



1. 48-1046
2. 48-1049
3. 48-1050
4. 48-1056
5. 48-1060
6. 48-1068
7. 48-1109
8. 48-1168
9. 48-2108
10. 48-2133
11. 48-3679
12. 48-3689
13. 48-3769
14. 48-3835
15. 48-6086
16. 48-9006

BACKUP SLIDE 2

Texas Transportation Institute

Improvement over EICM and recent advanced models

Improvements Over EICM and existing Models

	Our Model
Surface B.C	$\rho C \frac{\Delta x}{2}\frac{\partial T_s}{\partial t} = (1-\alpha)q_s + \varepsilon_a \sigma T_a^4 - \varepsilon \sigma T_s^4 - h_c (T_s - T_a) + k\frac{\partial T_s}{\partial x}$ * q_s [shortwave solar radiation] $\varepsilon_a \sigma T_a^4$ [incoming longwave radiation] $\varepsilon \sigma T_s^4$ [outgoing longwave radiation] $h_c (T_a - T_s)$ [convection heat loss]
Heat conduction inside pavement	$\frac{\partial T}{\partial t} = \frac{k}{\rho C}\frac{\partial^2 T}{\partial x^2}$
Bottom B.C	Depth independent heat flux **
Input data	
Ta	Interpolated hourly air temperature with max. and min. temperature recorded **
Qs	Hourly solar radiation predicted using SUNY or METSTAT model (available at NSRDB) **
Wind speed	Hourly wind speed
Model Parameters	Optimized model parameters (Based on temp. measured in the middle depth of Pav.) **

* Improvement over EICM * over recent advanced models