ICAO Seminar on Aerodrome Physical Characteristics and Pavements

By
Dr.M.W.Witczak
Invited Speaker

Held at
ICAO South American Regional Office
Lima, Peru
6 – 9 August 2013

An Overview of the New AASHTO MEPDG Pavement Design Guide

FEATURES OF THE AASHTO M-E PAVEMENT DESIGN GUIDE

- *Developed under the US NAS (National Academy of Sciences)– NCHRP (National Cooperative Highway Research program)*

- *$10,000,000 – 7 Year Effort (Largest Single US Transportation Research Project in the History of the US)*

- *Project Team Leaders*
  - *AC/Flexible Pavements: Dr. M.W.Witczak*
  - *Rigid Pavements: Dr.M.Darter*

Introduction

- ***Road and Highways are a very significant cost for agencies to construct, maintain and rehabilitate (US Infrastructure worth $1,000,000,000,000)***

- ***Pavement design is a very complex process that involves many variables as well as the variation of each variable. It is one of the most complex Civil Engineering structures to design because we demand a FS=1.0***

- ***Mechanistic concepts provide a more rational and realistic methodology for pavement design; however, pavement response models are mathematically very complex and do not have single closed form equation solution.***

- ***The M-E PDG provides a consistent and practical method to design a pavement for a desired level of reliability.***

INTRODUCTION- AC FLEXIBLE PAVEMENTS

- ***The MEPDG considers a wide range of AC Flexible pavement structural sections for :***
  - ***New pavement systems***
  - ***Overlay pavement systems***

NEW PAVEMENTS OPTIONS

- ***Conventional Flexible Pavements***
- ***Deep Strength HMA Pavements***
- ***Full-Depth HMA Pavements***
- ***"Semi-Rigid" Pavements***

REHABILITATION OPTIONS

- ***HMA Overlay over Existing HMA:***

  New   ***Existing***

  - ***AC***   ***Conventional AC***
  - ***AC***   ***Deep strength HMA pavements***
  - ***AC***   ***Full depth asphalt***
  - ***AC***   ***Semi-rigid pavements***
- ***HMA over JPCP***
- ***HMA over CRCP***

REHABILITATION OPTIONS (CONT'D)

- ***HMA over Fractured JPCP***
  - ***Crack and Seat***
  - ***Rubbilization***

- ***HMA over Fractured CRCP***
  - ***Rubbilization***

PAVEMENT DISTRESSES

- ***The primary distresses considered in the MEPDG for flexible pavements are:***
  - ***Permanent Deformation (rutting)***
    - ***AC Layers***
    - ***Unbound Base/Subbase/Subgrade Layers***
    - ***Total Rut Depth***
  - ***Fatigue Cracking***
    - ***Top Down-Longitudinal Cracking***
    - ***Bottom Up- Alligator Cracking***
  - ***Thermal Cracking***

- ***In addition, pavement smoothness (IRI) is predicted based on these primary distresses and other factors.***

Major Asphalt Pavement Distresses

- ***Major pavement distresses***
  - ***Permanent deformation***
  - ***Fatigue cracking***
  - ***Transverse (Thermal) cracking***

- ***How can we simulate these problems in the lab?***

Hierarchical Input Process

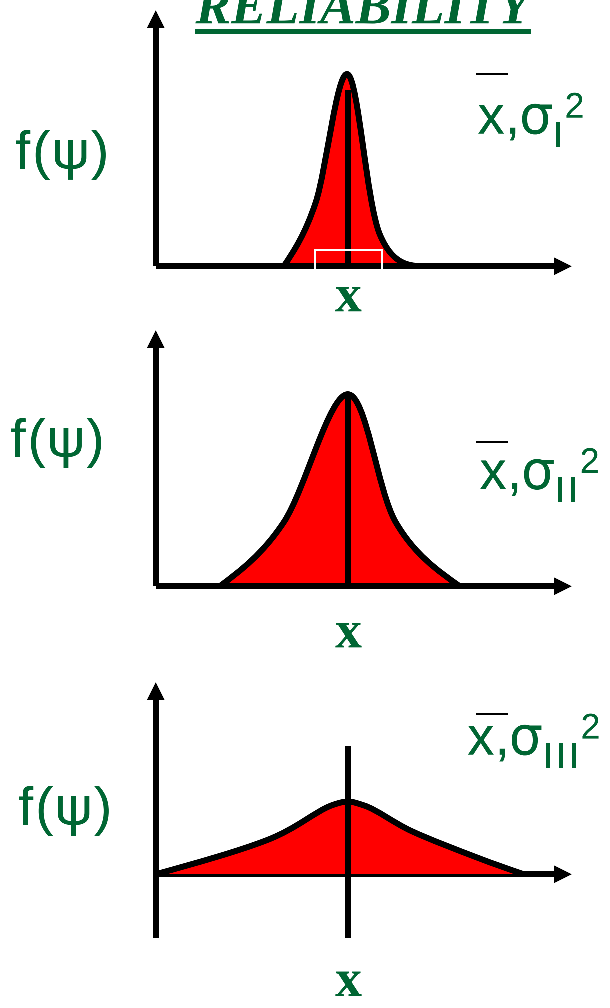
- ***Level 1 (High Reliability)***
  Analysis of special problems
  Usually will incorporate Testing
  High Visibility/Risk/Cost Projects

- ***Level 2 (Medium Reliability)***
  Standard Design - Most Cases
  (Rigorous but practical)

- ***Level 3 (Lower Reliability)***
  Lower impact/risk projects

HIERARCHIAL APPROACH (AC MODULUS)

LEVEL	***MIX***	***BINDER***	***RELIABILITY***
1	*E* Lab Test*	*G*,δ Lab Test*	
2	*E*Predictive equation*	*G*,δ Lab Test*	
3	*E*Predictive equation*	*AC Grade to properties*	



Hierarchical Approach in NCHRP 1-37A

- ***Major Reasons for Presence in M-E PDG***
  - ***Allows for a Quantifiable Decision to be Made, Based on Benefit / Costs Regarding the Utility of Using Detailed Engineering Tests and Data Collection / Analysis Techniques Relative to Simple, Empirical Correlations or Engineering Guesses***

Hierarchical Approach in MEPDG

- ***Major Reasons for Presence in M-E PDG***
  - ***Provide Quantifiable Methodology for Agency to Prove Certain High Profile, High Importance and High Cost Projects Justified***
    - ***"Most Advanced State of the Art Technology is Mandated to Save Significant Cost Benefits"***

Hierarchical Approach in MEPDG

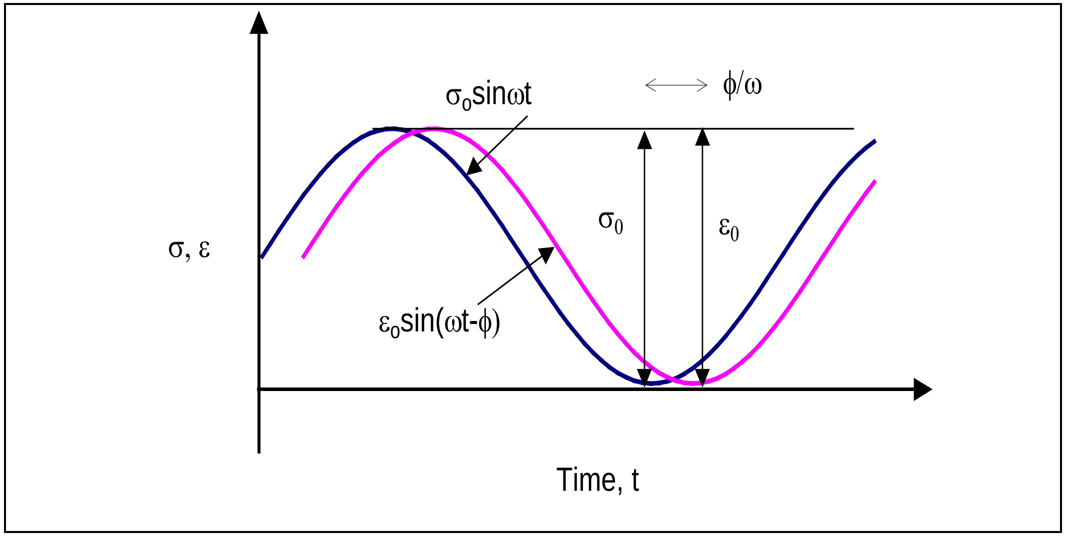
- ***Major Reasons for Presence in M-E PDG***
  - ***Collary is also True***
    - ***"Many Projects do not Require Sophisticated , Advanced Engineering Approaches"***

Dynamic Modulus Test Protocol

- ***Follow Latest AASHTO Protocols***
- ***Test Factorial***
  - ***5 Temperatures (14, 40, 70, 100, and 130 deg F)***
  - ***6 Frequencies (25, 10, 5, 1, 0.5, 0.1 Hz)***
- ***Recommend 3 Replicates per Mix***
- ***Recommend 3 LVDT's per Specimen***
- ***Critical Attention to Specimen Flatness/ Perpendicularity (Use Capping if Problem)***

Dynamic Modulus Test

Compressive Dynamic Modulus (|E*|) and Phase Angle (ϕ)



$$|E^*| = \frac{\sigma_0}{\varepsilon_0}$$

$$\phi = \omega t_i$$

Stress – Strain Relationship

$$\boxed{\sigma_t = \sigma_0 \sin(\omega t)}$$

$$\boxed{\varepsilon_t = \varepsilon_0 \sin(\omega t - \phi)}$$

$$\boxed{E^* = \frac{\sigma_0 \sin(\omega t)}{\varepsilon_0 \sin(\omega t - \phi)}}$$

$$\boxed{|E^*| = \frac{\sigma_0}{\varepsilon_0}}$$

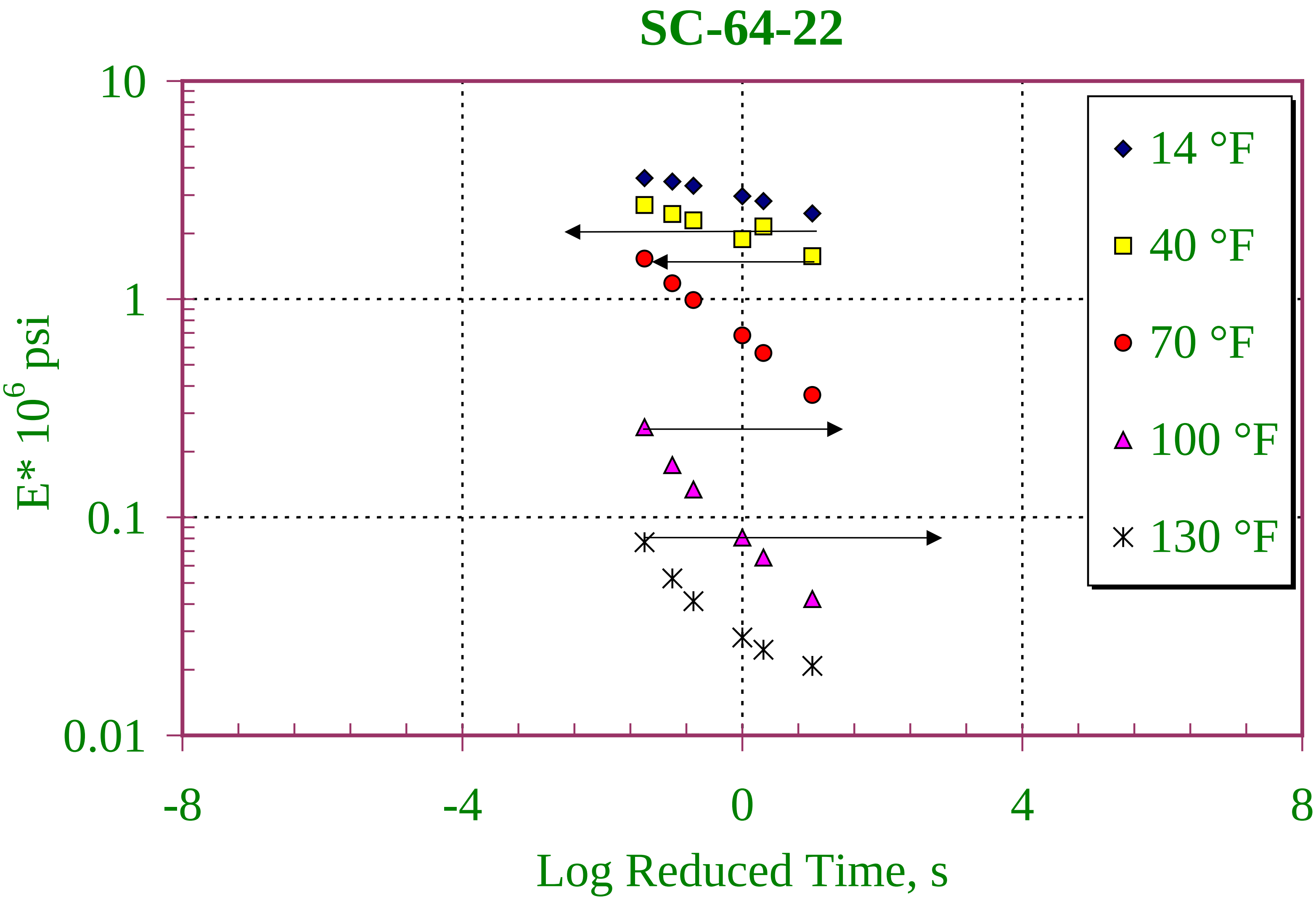
Construction of E* Master Curve

- **Dynamic Modulus Test (Level 1)**
  - ✓ AASHTO TP62-03
  - ✓ 5 Temperatures: 14, 40, 70, 100 and 130 °F
  - ✓ 6 Frequencies: 25, 10, 5, 1, 0.5 and 0.1 Hz

Spec ID	Temp. (°F)	Freq. (Hz)	E* (ksi)
Avg.	14	25	6469
Avg.	14	10	5665
Avg.	14	5	5103
Avg.	14	1	4289
Avg.	14	0.5	3747
Avg.	14	0.1	2684
Avg.	40	25	4453
Avg.	40	10	3623
Avg.	40	5	3113
Avg.	40	1	2378
Avg.	40	0.5	2016
Avg.	40	0.1	1347
Avg.	70	25	1465
Avg.	70	10	1194
Avg.	70	5	1013
Avg.	70	1	695
Avg.	70	0.5	560
Avg.	70	0.1	333

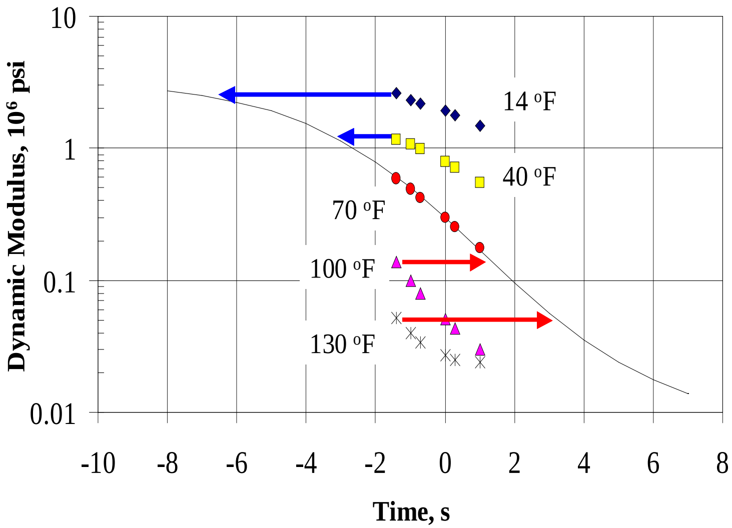
Spec ID	Temp. (°F)	Freq. (Hz)	E* (ksi)
Avg.	100	25	295
Avg.	100	10	207
Avg.	100	5	157
Avg.	100	1	92
Avg.	100	0.5	73
Avg.	100	0.1	48
Avg.	130	25	78
Avg.	130	10	59
Avg.	130	5	46
Avg.	130	1	34
Avg.	130	0.5	31
Avg.	130	0.1	28

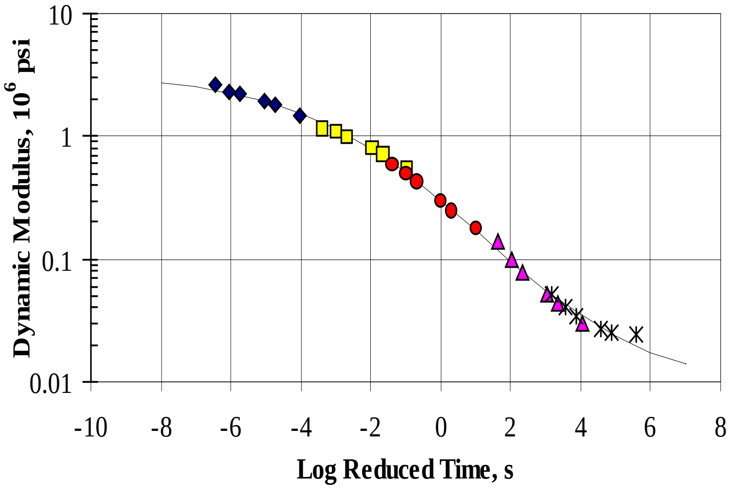
Manual Shifting



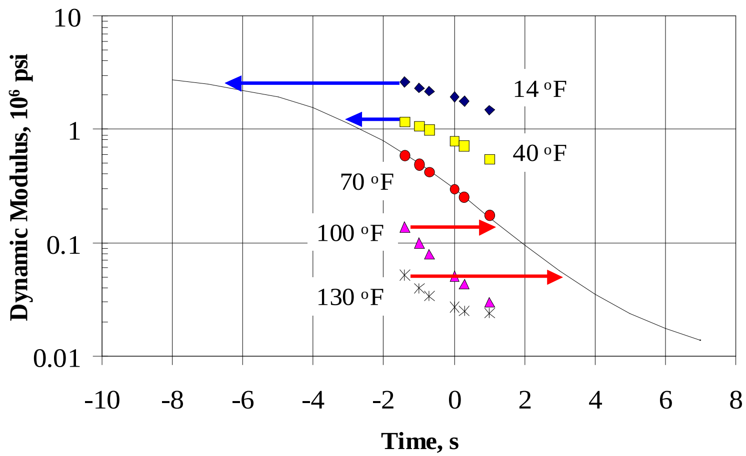
Construction of E* Master Curve

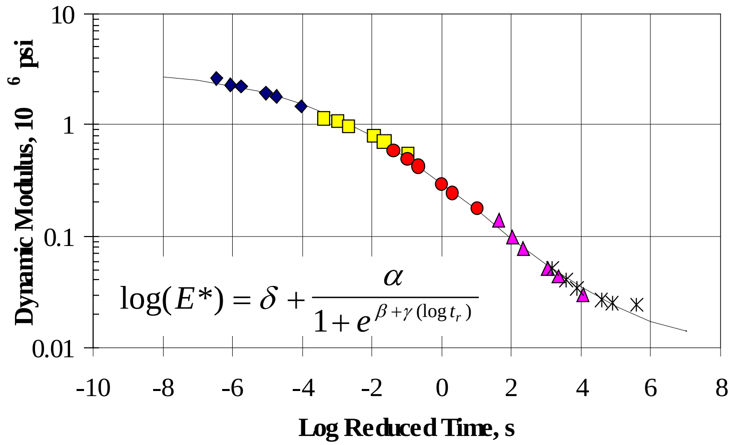
- ***Time-Temp. Superposition***
  - ***Use any arbitrary temperature value as a reference***
  - ***Normally this value is set to be at 70°F***
  - ***Shift E* test results at other temp. to reference temp. by time-temp superposition***
  - ***E* results are not changed***
  - ***Can calculate E* values at any temp. and freq. from master curve***

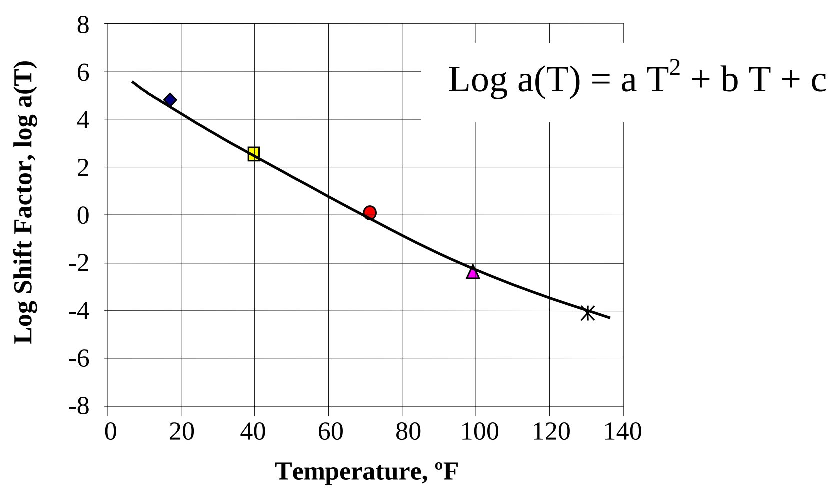




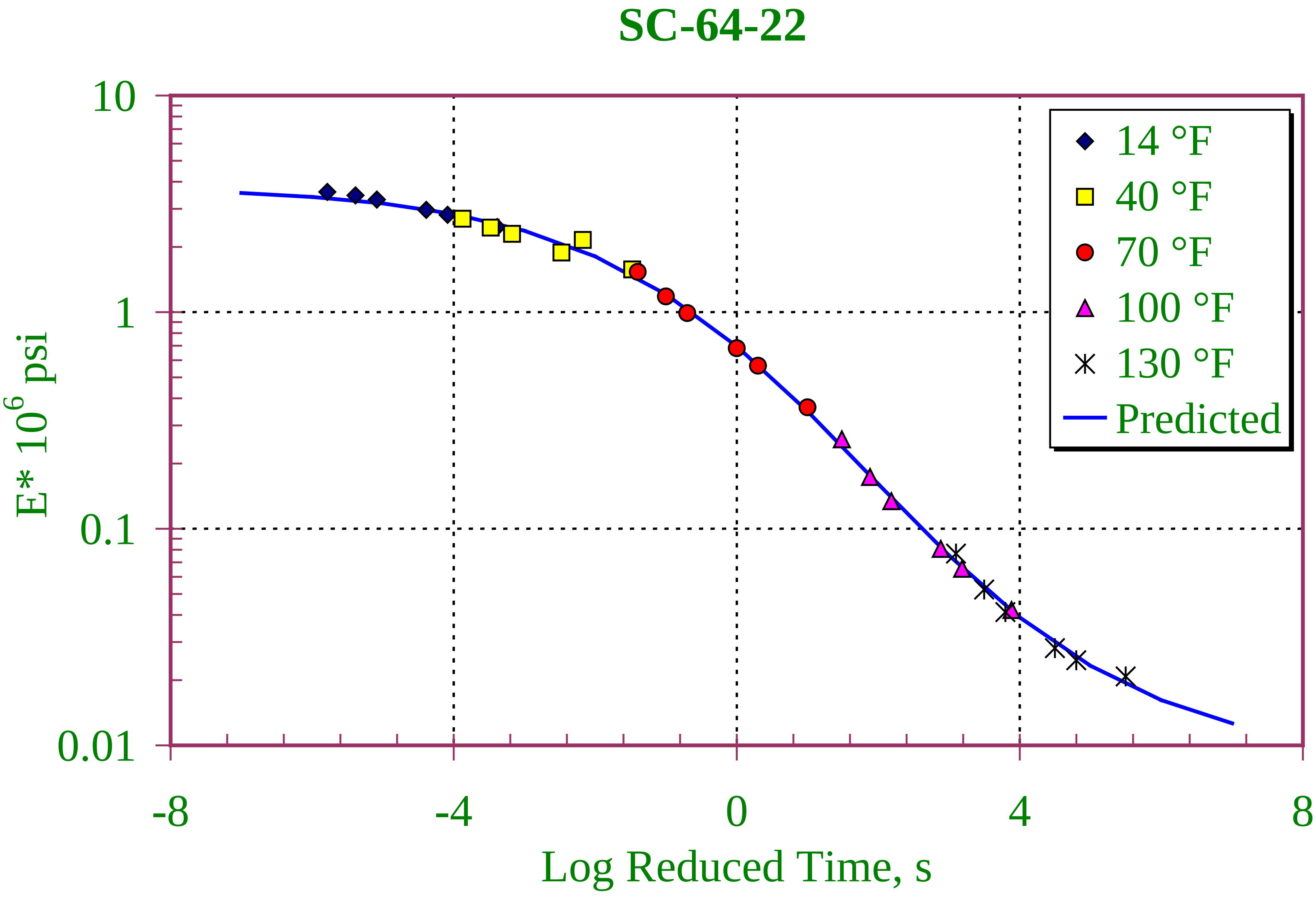
E* Master Curves Shifting Concept







Master Curve



Witczak Predictive Equation (WPE)

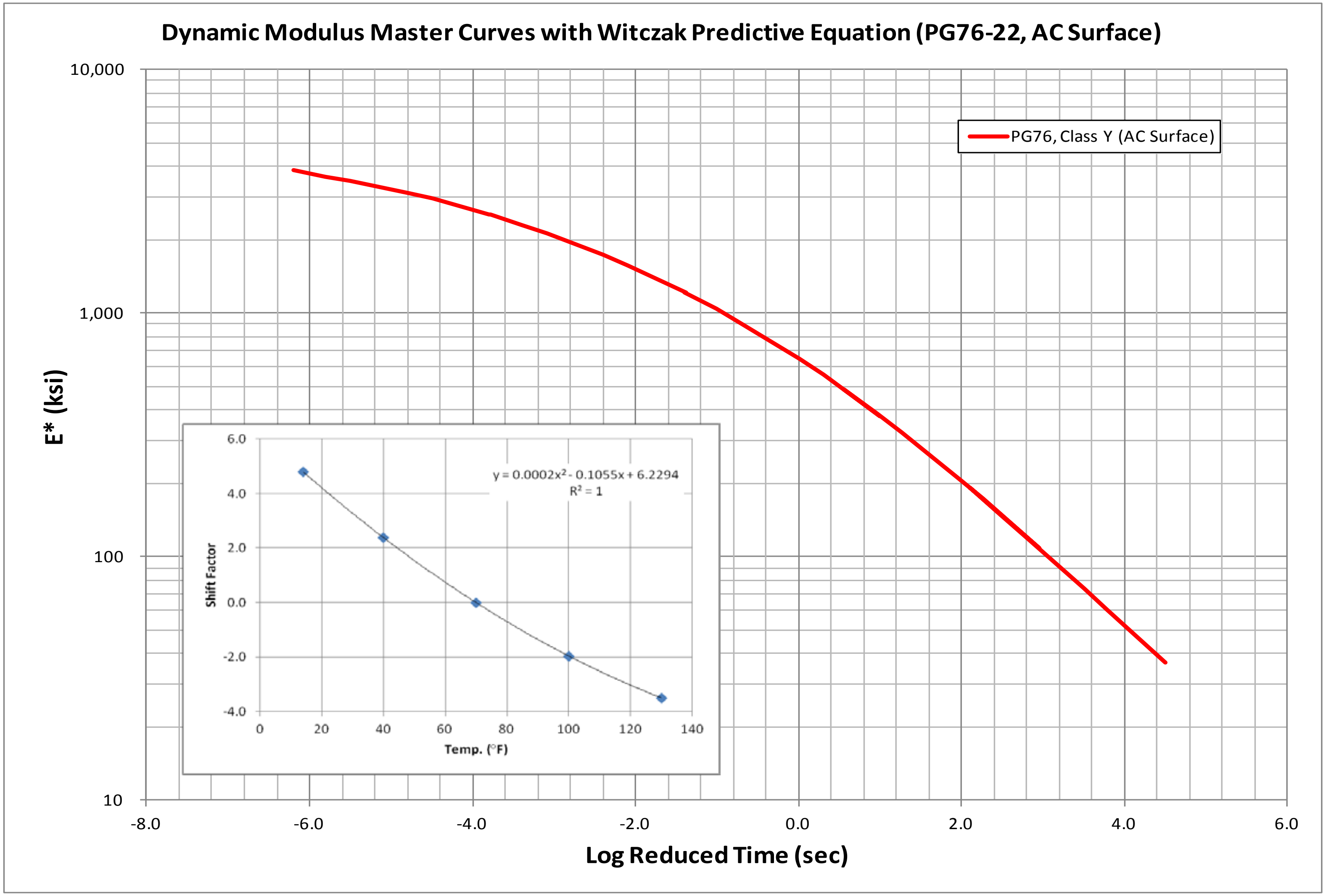
$$\log_{10} E^* = -1.24994 + 0.02923\rho_{200} - 0.00177(\rho_{200})^2 - 0.00284\rho_4 - 0.058097V_a - 0.82208\frac{V_{beff}}{V_{beff}+V_a} + \frac{3.872 - 0.0021\rho_4 + 0.00396\rho_{38} - 0.000017(\rho_{38})^2 + 0.0055\rho_{34}}{1+e^{(-0.603313-0.313351\log f - 0.393532\log\eta)}}$$

Where

- E^* = dynamic modulus (10^5 psi)
- η = binder viscosity (10^6 poise), $\log\log\eta = Ai + VTSi \log T$
- T = pavement temperature (Kalvin),
- Ai = Intercept of Viscosity-Temperature Regression Equation
- VTSi = Slope of Viscosity-Temperature Regression Equation
- V_a = Air voids (%)
- V_{beff} = Effective Binder Content by Volume (%)
- ρ_{34}, ρ_{38}, ρ_4 = Cumulative Retained on 3/4“, 3/8“, and #4 Sieves, respectively (%)
- ρ_{200} = Passing on #200 Sieve (%)

Dynamic Modulus Master Curve

AC Surface with PG76-22



MC Sigmoidal Predictive Equation

$$\log|E^*| = \delta + \frac{\alpha}{1 + e^{\beta + \gamma(\log t_r)}}$$

t_r	=	***Time of loading at reference temperature***
δ	=	***Minimum value of E****
$\delta+\alpha$	=	***Maximum value of E****
β, γ	=	***Parameters describing the shape of the sigmoidal function***

Time-Temperature Superposition: Shifting

$$\mathrm{t_r} = \frac{t}{a(T)} \quad \Rightarrow \quad a(T) = \frac{t}{\mathrm{t_r}}$$

***t_r* = Time of loading at reference temperature**

***t* = Time of loading**

***a(T)* = Shift factor as a function of temperature**

***T* = Temperature**

E* Master Curve Mathematical Formulation

$$\log(E^*) = \delta + \frac{\alpha}{1 + e^{\beta + \gamma(\log t_r)}}$$

And

$$\log(t_r) = \log(t) - \log[a(T)]$$

SOURCE OF VARIATION OF METHODS

Where:

E* = Dynamic Modulus (psi)

δ, α, β, and γ = Sigmoidal Parameters

t_r = Reduced Time

t = Time (sec)

a(T) = shift factor dependent on temperature, T (in ^{o}F)

Final Master Curve Equation

$$\log(E^*) = \delta + \frac{\alpha}{1 + e^{\beta + \gamma\left[\log(t) - \log(aT^2 + bT + c)\right]}}$$

Optimized simultaneously to get the 7 parameters (δ, α , β, γ, a, b, and c)

Master Curve Equations

$$\text{Log}\left|E^*\right| = \delta + \frac{\alpha}{1 + e^{\beta + \gamma(\log t_r)}}$$

$$\log(a(T)) = \log(t) - \log(t_r)$$

$$\log a(T) = a\text{Temp}^2 + b\text{Temp} + c$$

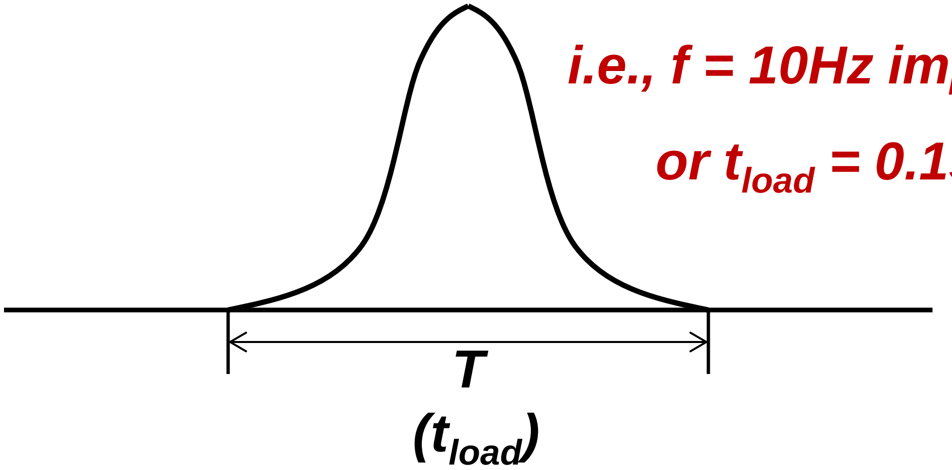
$$t_r = 1/f_r$$

$$f_{eff} = \frac{17.6\nu}{2(a + h_{eq})}$$

Definition of Time (Period)

- ***T: Called "Period" but it is actually the time required for the response to begin repeating itself***
- ***The fundamentally accepted definition (exclusive of rheologists) is that:***

$$T = t_{load} = 1 / f$$



i.e., f = 10Hz implies 10cycles/sec

or t_{load} = 0.1sec

Typical Calculated Frequency Values as Function of Speed

Type Road Facility	Design Speed (mph)	Location	Frequency (Hz)		
			Representative AC Layer (4”-12”)	Thin AC Layers Wearing Surface (1”-3”)	Thick AC Layers Binder/Base (3”-12”)
Interstate	**60**	**Mid**	**15 - 40**	**45 - 95**	**12 - 25**
		Bottom	**5 - 20**	**28 - 55**	**5 - 15**
State Primary	**45**	**Mid**	**10 - 30**	**35 - 70**	**15 - 20**
		Bottom	**5 - 15**	**21 - 42**	**5 - 10**
Urban Street	**15**	**Mid**	**5 - 10**	**10 - 25**	**5 - 10**
		Bottom	**1 - 4**	**7 - 14**	**1.5 - 5**
Intersection	**0.5**	**Mid**	**0.1 – 0.5**	**0.5 – 1.0**	**0.1 – 0.25**
		Bottom	**0.05 – 0.25**	**0.25 – 0.5**	**0.05 – 0.15**

Introduction to the Ai-VTSi Analysis

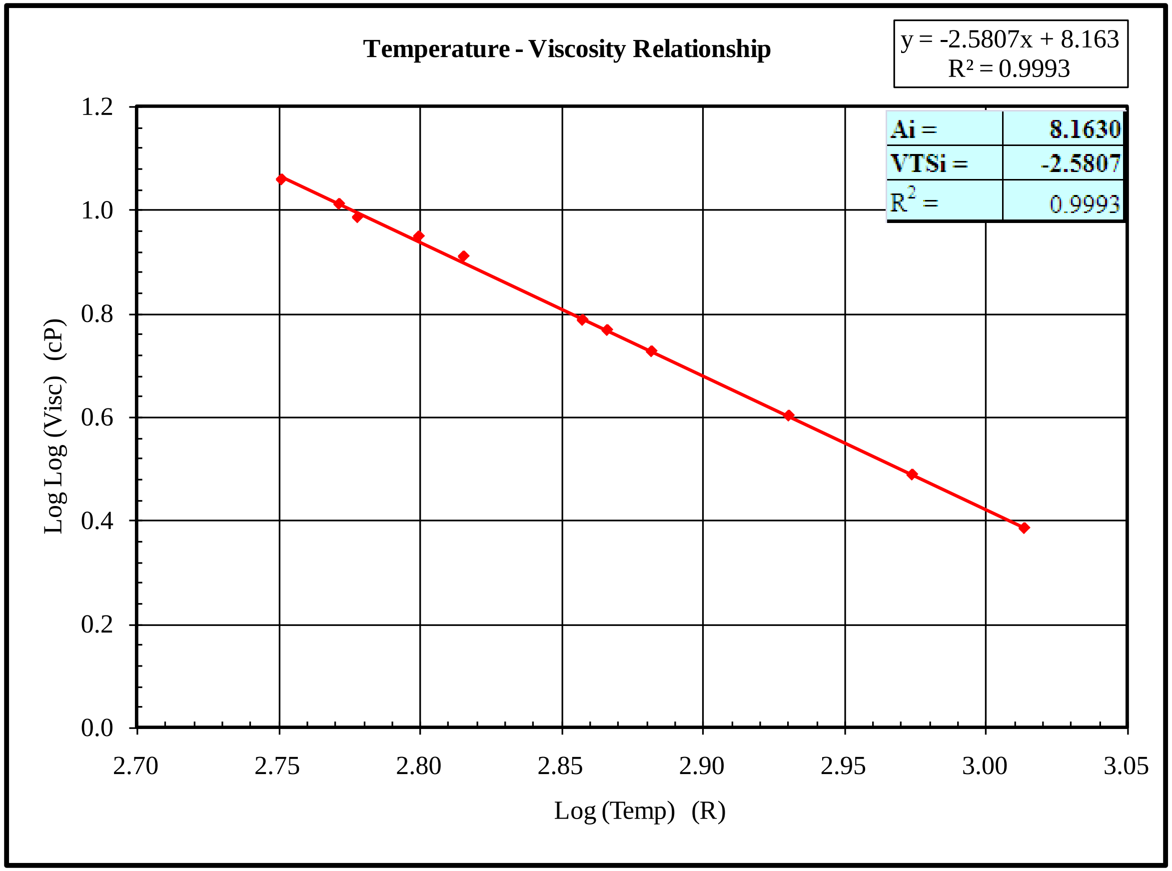
Relationships Used in the Ai-VTSi Analysis

- ***Loglog ή(cp) = Ai + VTSi* Log Tr***
  - ***ή(cp) – in units of centipoise***
  - ***Tr – Rankine Temperature (Tr=Tf+459.7)***

Viscosity in Witczak E* Model (Part of Level 2)

ASTM A_i-VTS_i Viscosity Model

$$\log \log \eta = A + VTS \log T_R$$



Relationships Used in the Ai-VTSi Analysis

- ***Conversion of Pen (5 sec; 100 gm) to ή***

ή (in Poise) = 10.5012-2.2601 * log Pen + 0.00389* (log Pen)^2

Relationships Used in the Ai-VTSi Analysis

- ***ή at Trb (Softening Point) = 13,000 Poise (Shell Oil)***
- ***ή (cp) = ή (cs) * (1 / Gb)***
- ***1 Pa-s = 10 Poise***

Determination of Ai-VTSi

Latest Revision	10/24/2012

Project:	Example						
Binder Type (Grade):	Koch AC-20						
Aged Condition:	Neat:		RTFO:		RTFO+PAV:	Field Extracted:	
Bitumen Spec Grav (Gb):		1.028			Date:	10/24/2012	
Sample ID:	ASU Lab				Technician:	MWW	
Remarks:							

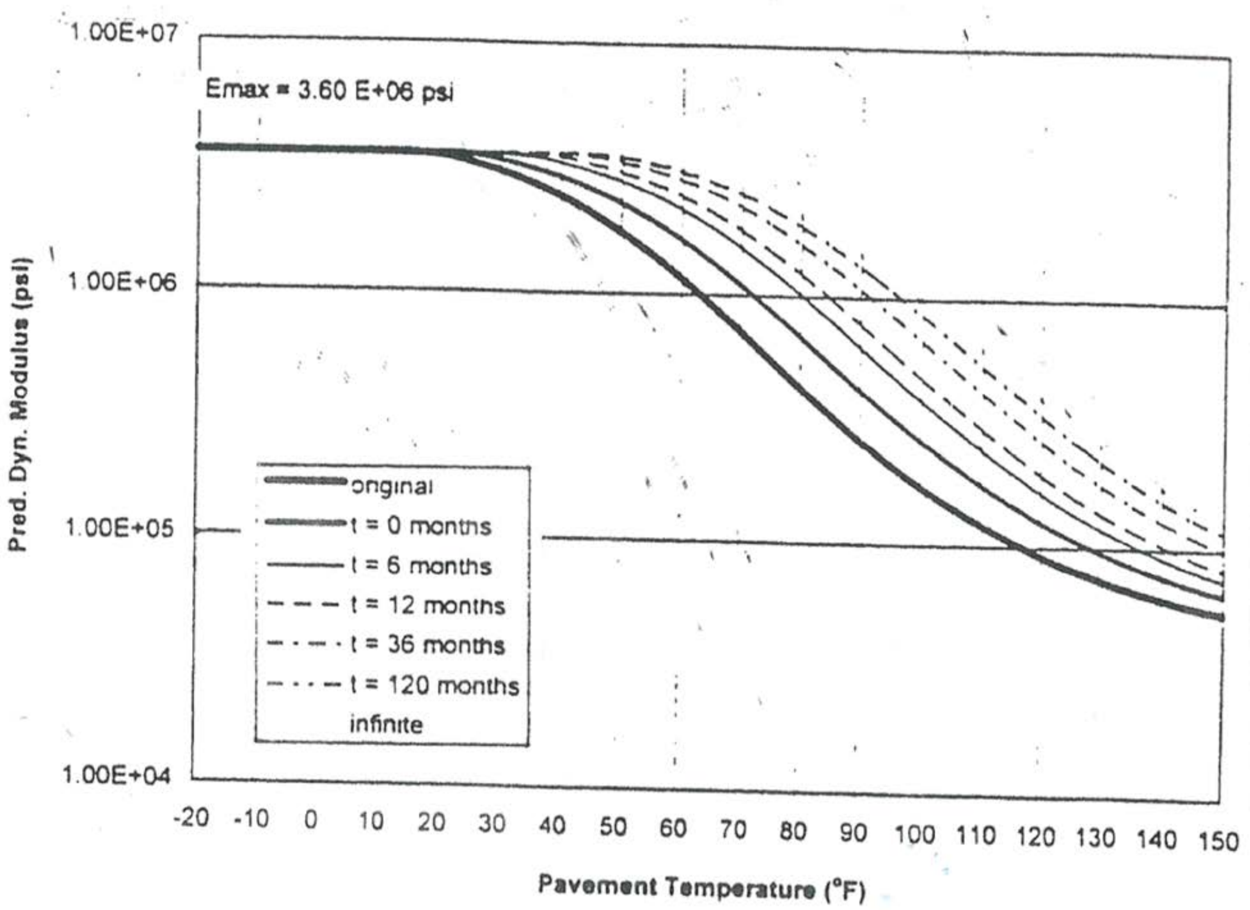
Test	Temp (C)	Temp (F)	Temp (R)	Log Temp (R)	Penetration (.1mm)	Viscosity (Poise)	Viscosity (cP)	LogLog Visc
Penetration	4.0	39.2	498.9	2.698	3.00	2.65E+09	2.65E+11	1.058
Penetration	15.0	59.0	518.7	2.715	10.00	1.76E+08	1.76E+10	1.011
Penetration	25.0	77.0	536.7	2.730	25.00	2.24E+07	2.24E+09	0.971
Penetration	32.0	89.6	549.3	2.740	56.00	3.65E+06	3.65E+08	0.933
Softening Point, F	51.5	124.7	584.4	2.767		13,000	1.30E+06	0.786
Absolute Visc, P	60.0	140.0	599.7	2.778		8225	8.23E+05	0.772
Kinematic Visc, cst	125.0	257.0	716.7	2.855		451.00	4.64E+02	0.426
Brookfield Visc, P	93.3	200.0	659.7	2.819		66.30	6.63E+03	0.582
Brookfield Visc, P	148.9	300.0	759.7	2.881		2.46	2.46E+02	0.379
Brookfield Visc, P	162.8	325.0	784.7	2.895		1.40	1.40E+02	0.332
Brookfield Visc, P	176.7	350.0	809.7	2.908		0.88	8.80E+01	0.289

Summary of Ai-VTSi Values for Example (With Mix / Compaction Temperatures)

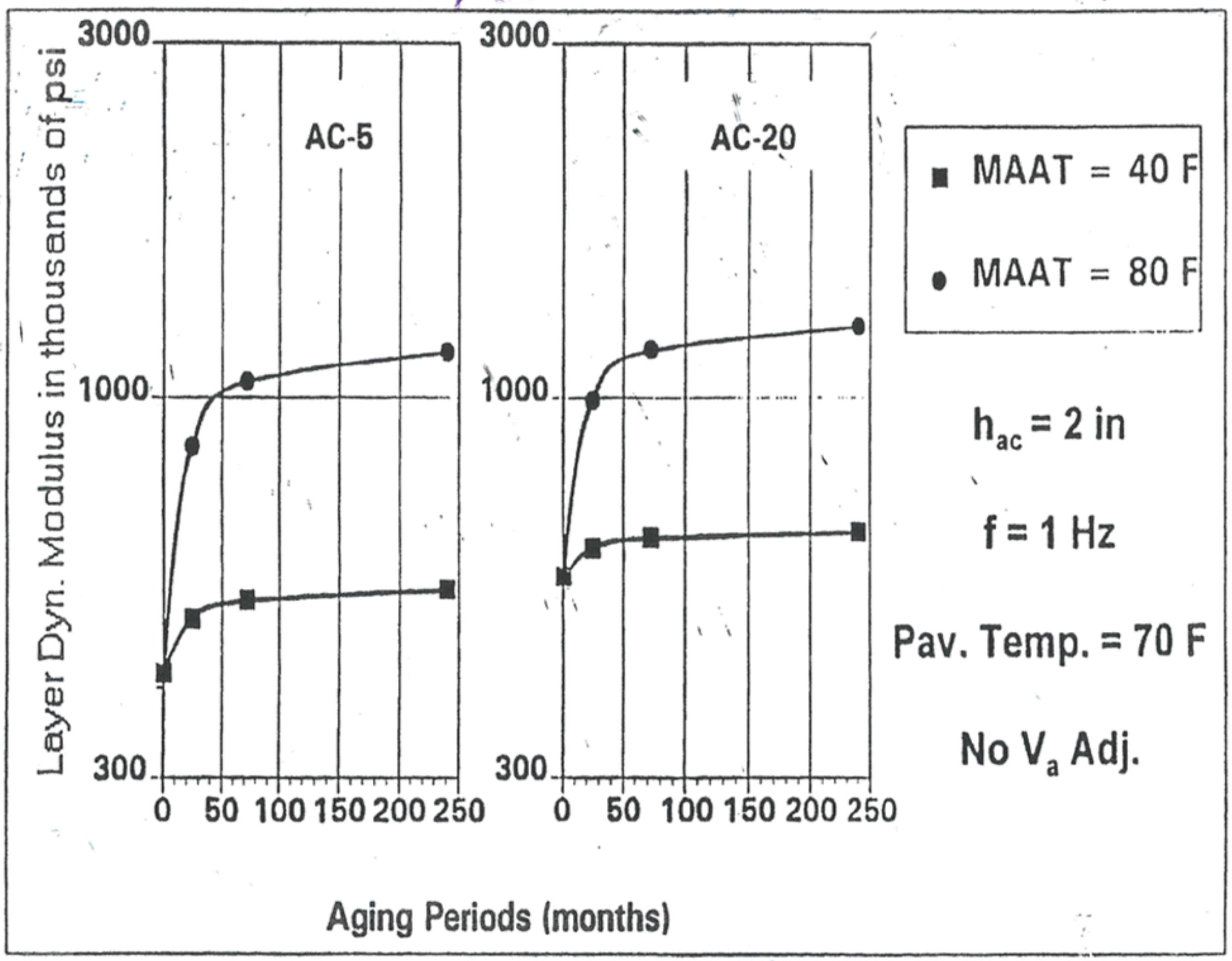
Ai-VTSi Regression Values	
Ai :	10.499
VTSi :	-3.5134
R^2 :	0.9994

Mixing and Compaction Temperatures				
Parameter	Level	Target ή (cp)	T (deg F)	T (deg C)
Mixing Temp	Min	150	320	160
	Avg	170	315	157
	Max	190	310	155
Compaction Temp	Min	250	299	148
	Avg	280	295	146
	Max	310	291	144

Impact of Aging Upon E* Master Curves



Change of E* Due to Field Aging Time for 2 Differing Environmental Locations

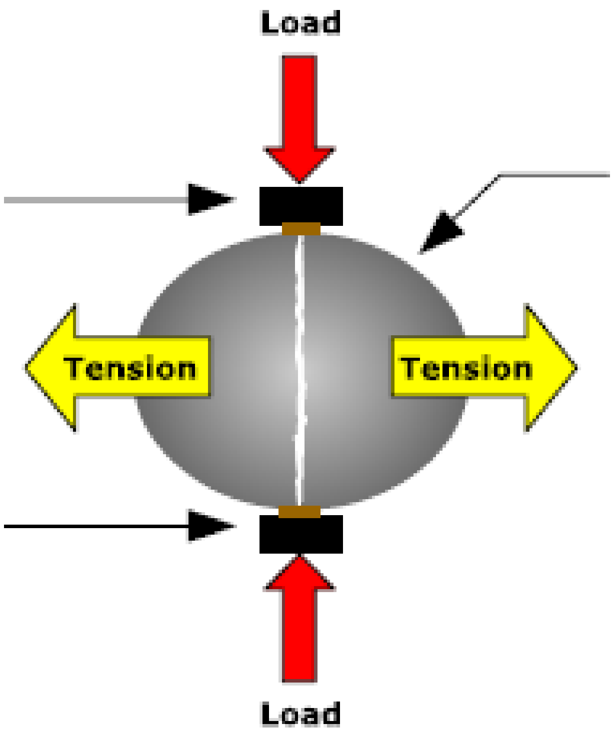


Dynamic Modulus (E)*

Advantages:

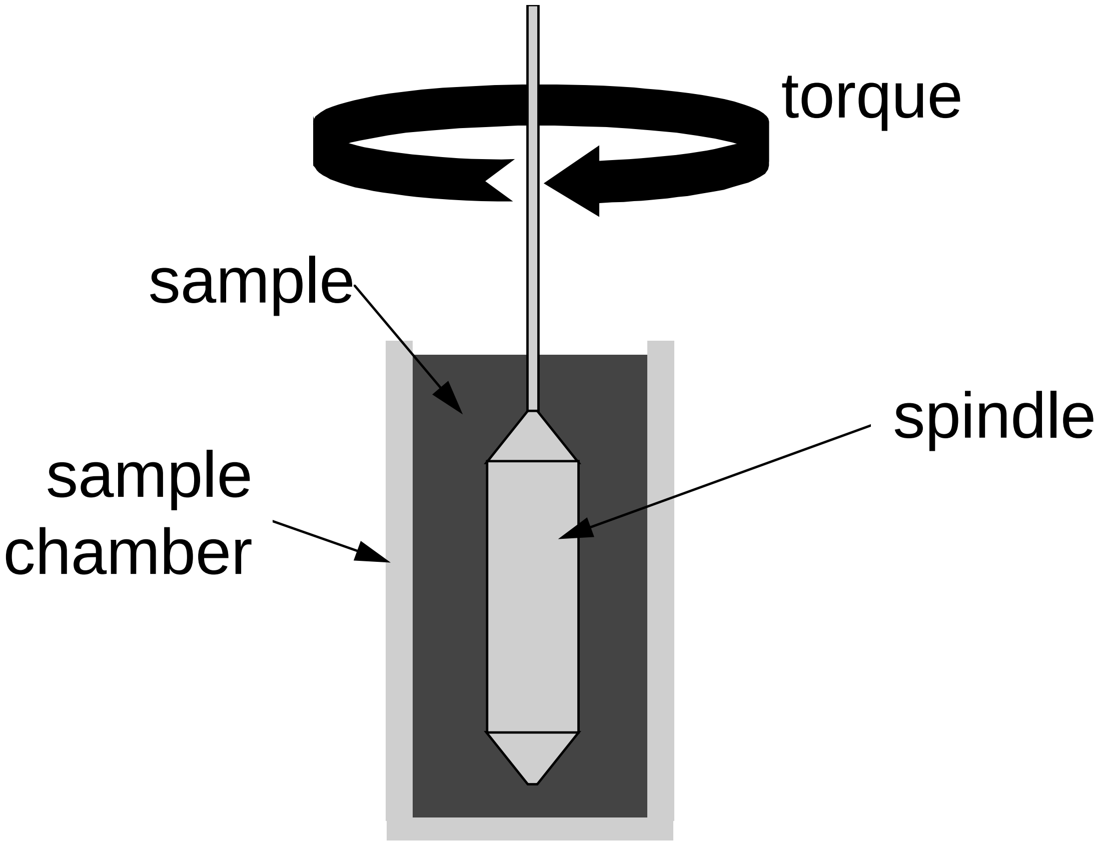
- ***E* allows hierarchical characterization***
- ***takes care of aging***
- ***takes care of vehicle speed***
- ***can be linked to PG Binder***
- ***E* approximates FWD back-calculated modulus***
- ***provides rational mechanistic material property for distress prediction***
- ***FHWA – AASHTO test protocols available***
- ***Distress predictive models available***

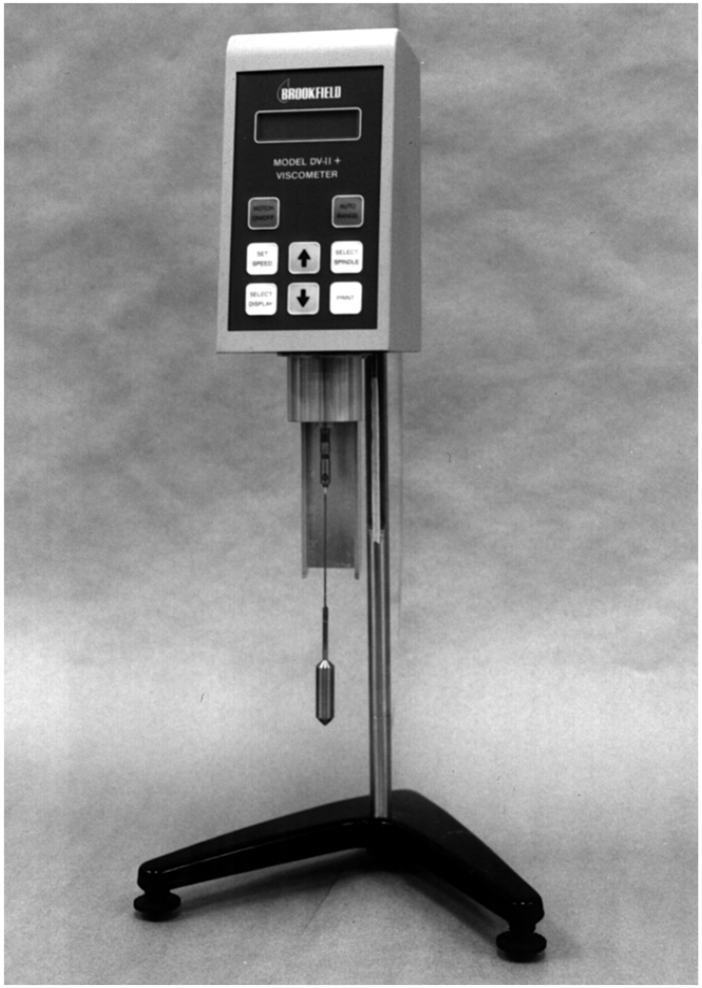
Indirect Tension Creep Test



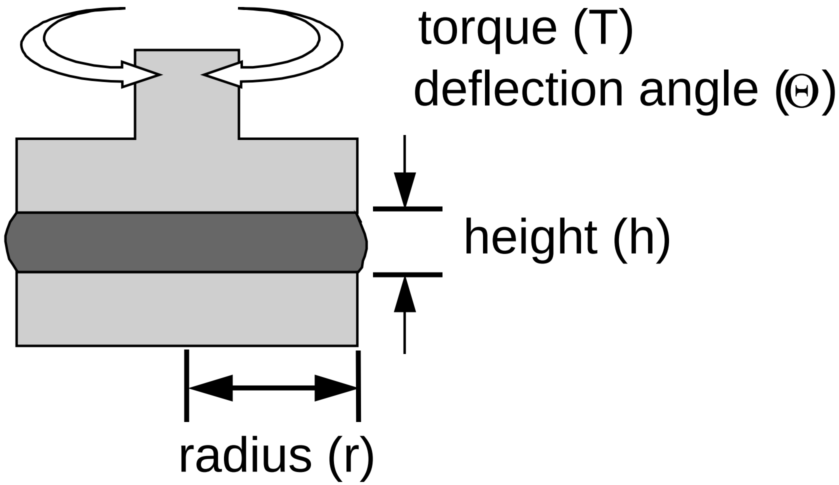
Beam Fatigue Test

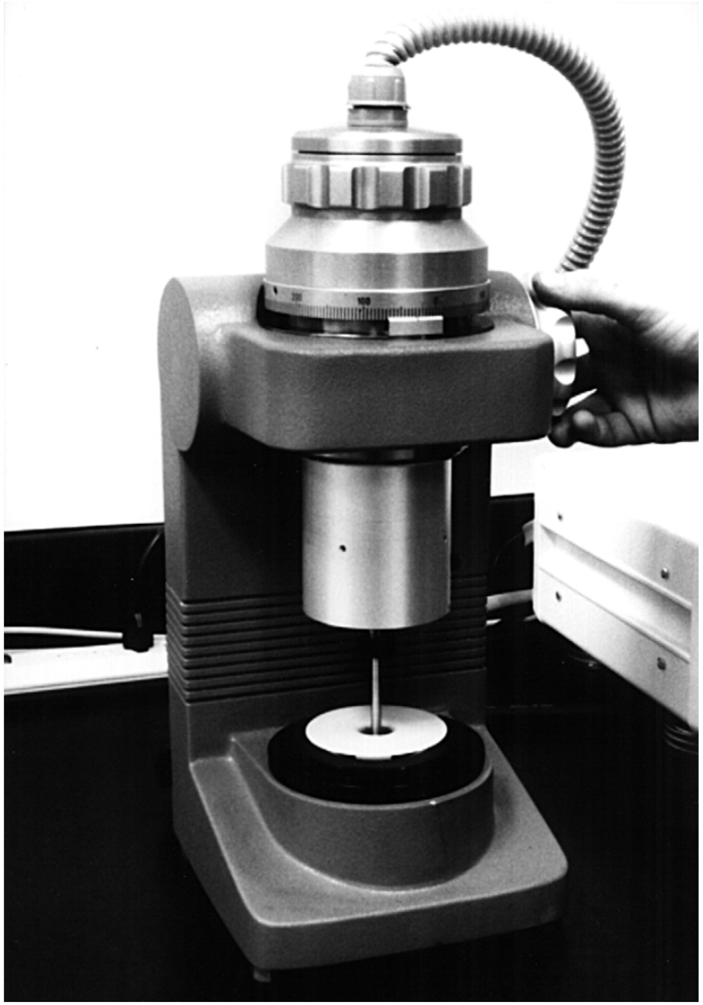
Rotational Viscometer





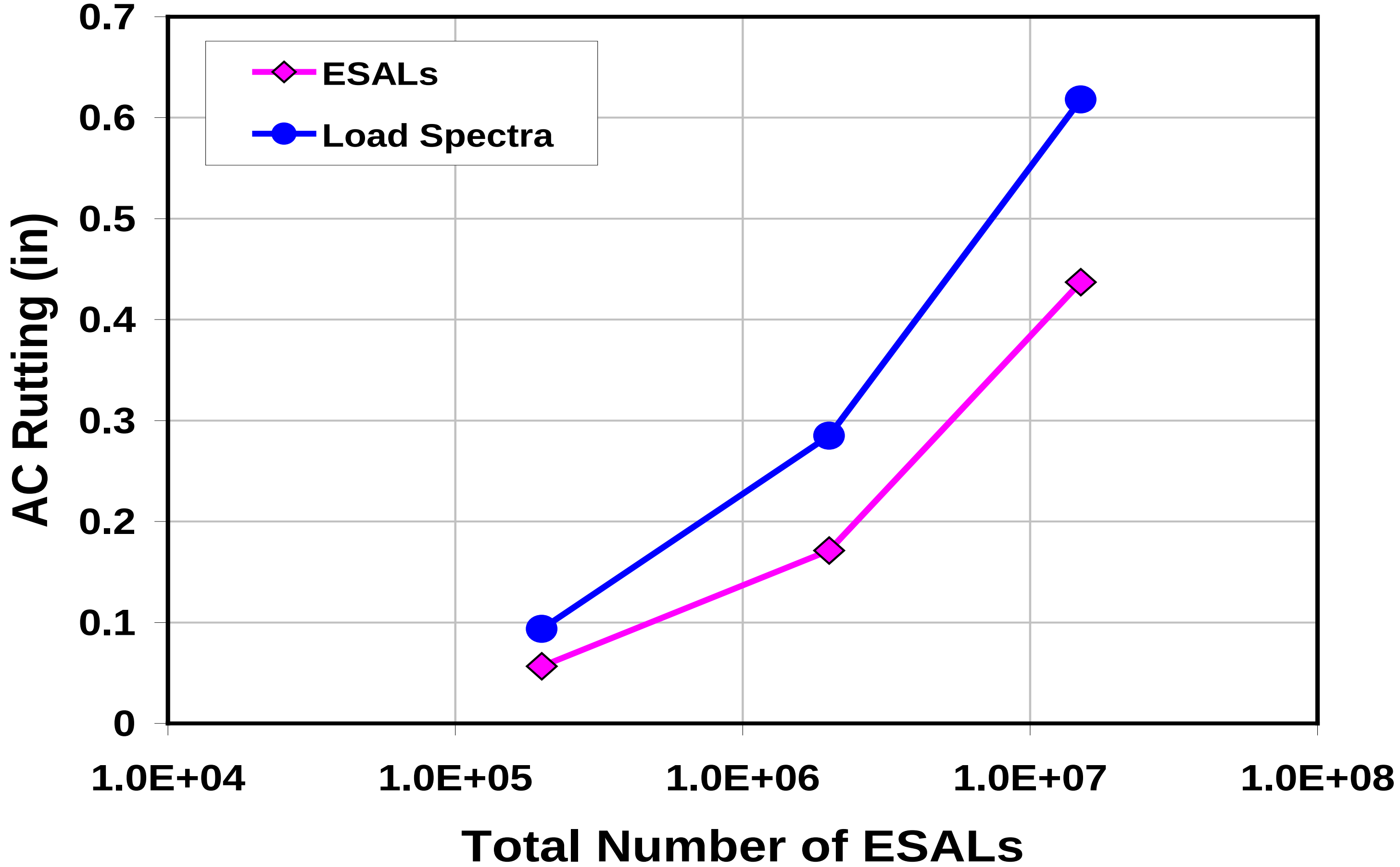
Dynamic Shear Rheometer





EXAMPLES OF THE FLEXIBLE PAVEMENT DESIGN PROCESS

INFLUENCE OF TRAFFIC ANALYSIS METHOD UPON AC RUTTING

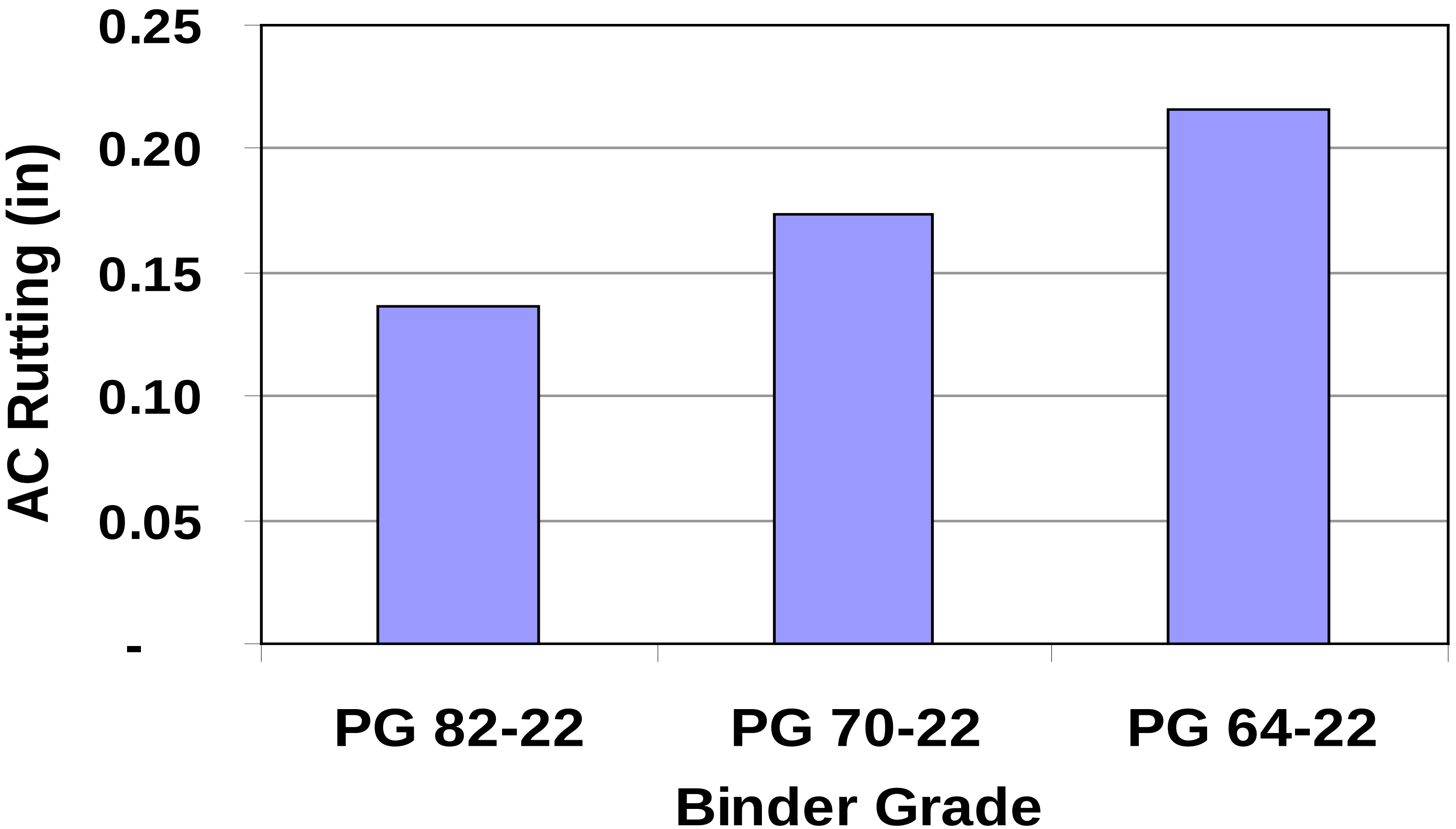


INFLUENCE OF TRAFFIC ANALYSIS METHOD UPON AC RUTTING AND CRACKING (SUMMARY)

- ***Actual Traffic load spectra yields higher levels of rutting and cracking compared to the classical E18KSAL's.***

- ***Traffic repetitions is a significant parameter influencing pavement distress.***

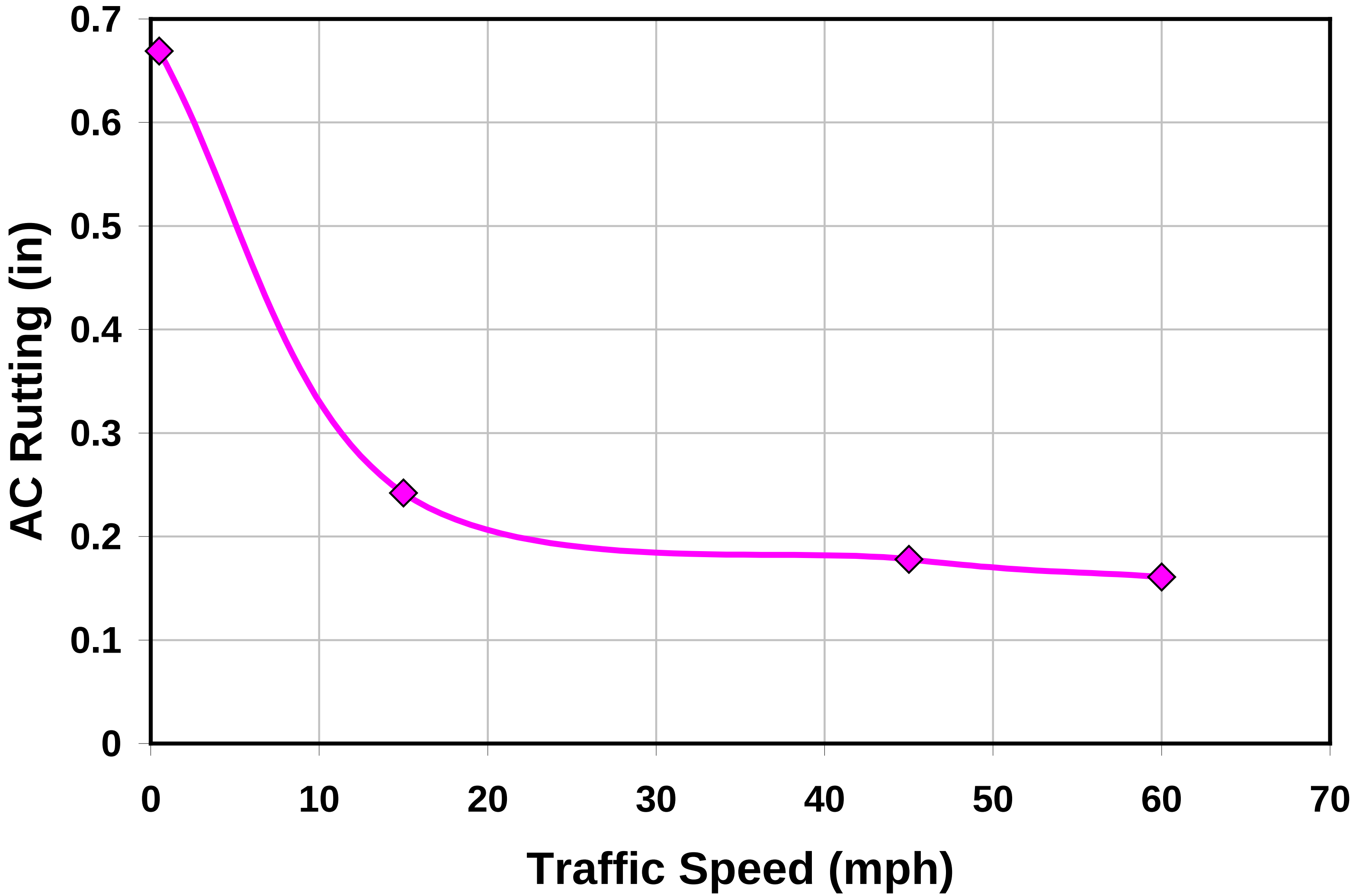
INFLUENCE OF BINDER GRADE UPON AC RUTTING



INFLUENCE OF BINDER GRADE UPON AC RUTTING (SUMMARY)

- ***Binder stiffness has a significant influence upon AC rutting.***
- ***As the binder stiffness increases, AC rutting decreases.***
- ***In fact, as the entire HMA mix stiffness increases, AC rutting decreases.***

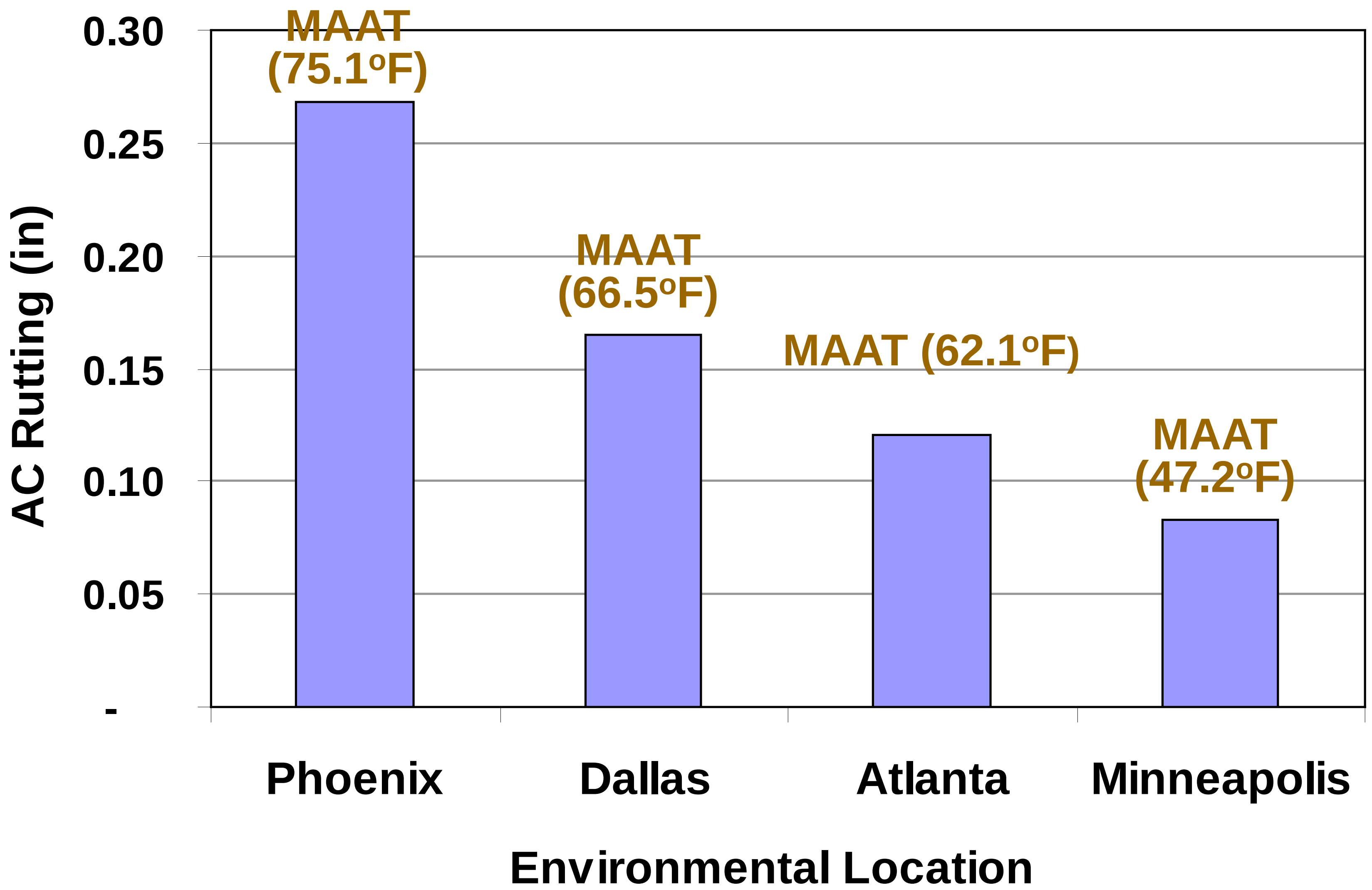
INFLUENCE OF TRAFFIC SPEED UPON AC RUTTING



INFLUENCE OF TRAFFIC SPEED UPON AC RUTTING (SUMMARY)

- ***Traffic Speed Influences The AC Rutting.***
- ***Creep Speed (Parking Lot, Intersection Analysis) Causes Much More Damage To The Pavement Compared To Faster Highway Speeds.***

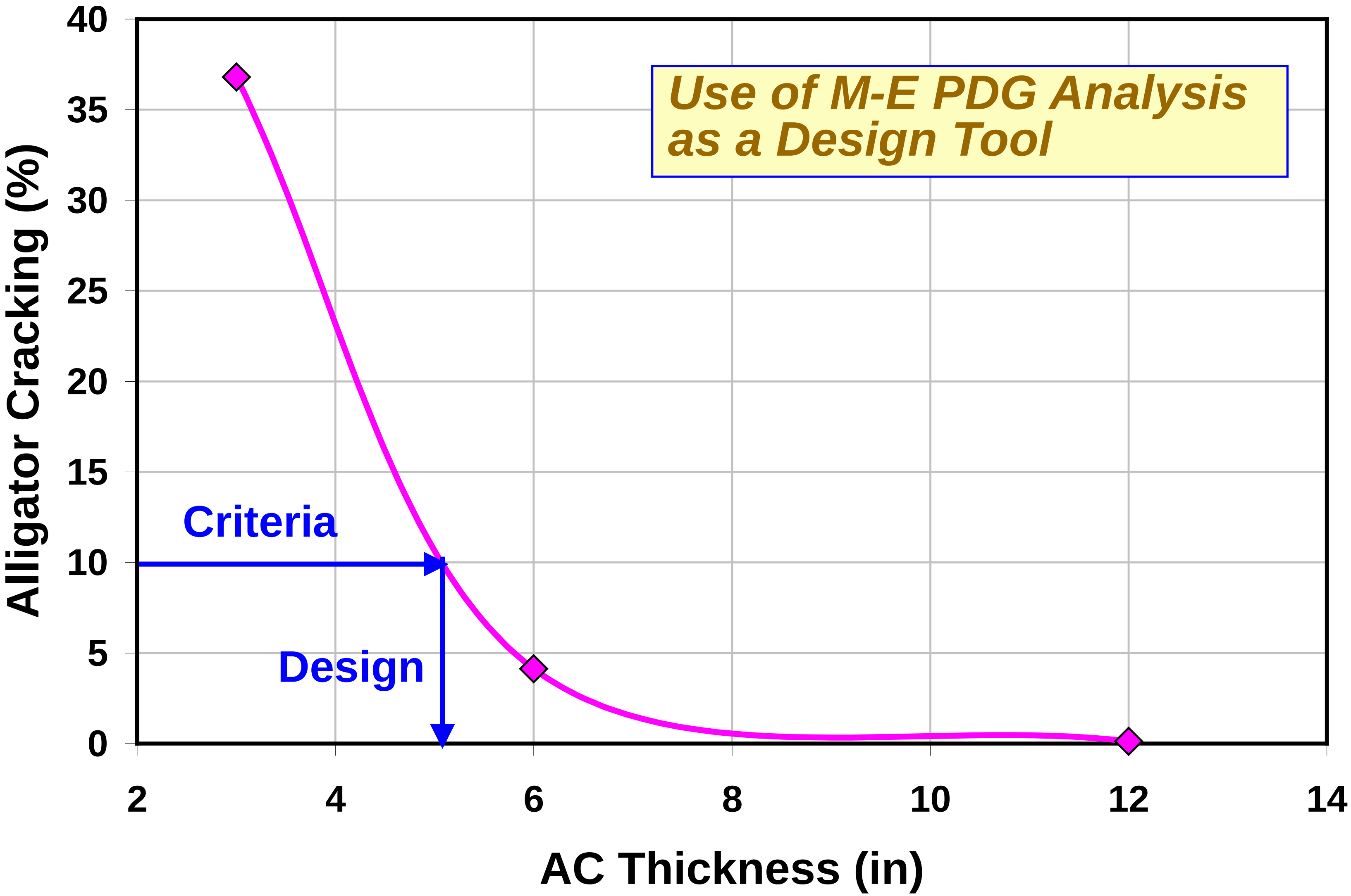
INFLUENCE OF ENVIRONMENTAL LOCATION UPON AC RUTTING



INFLUENCE OF ENVIRONMENTAL LOCATION UPON AC RUTTING (SUMMARY)

- ***For all variables being the same, the higher the temperature of an environmental location, the higher the AC rutting becomes.***

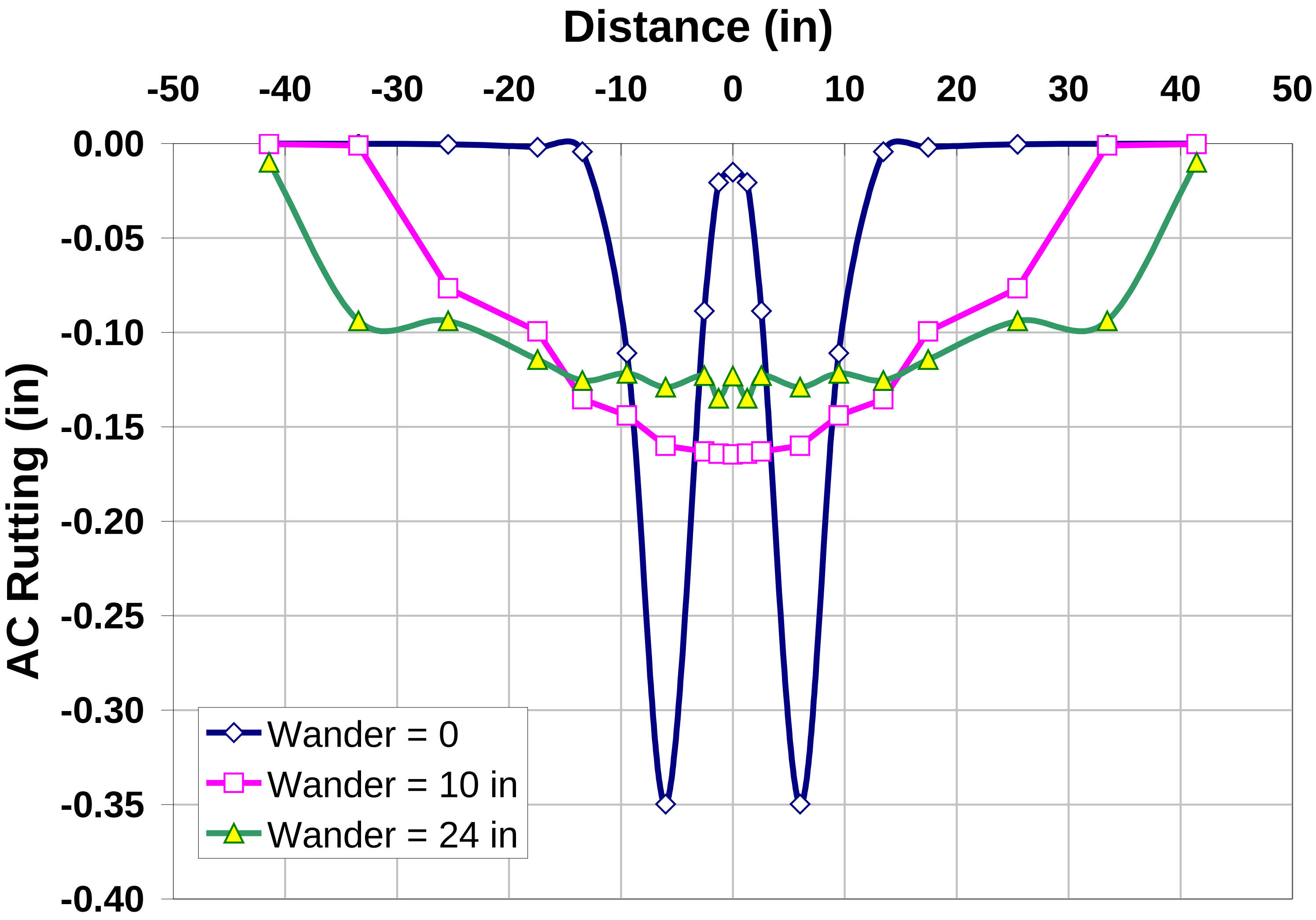
INFLUENCE OF AC THICKNESS UPON AC ALLIGATOR FATIGUE CRACKING



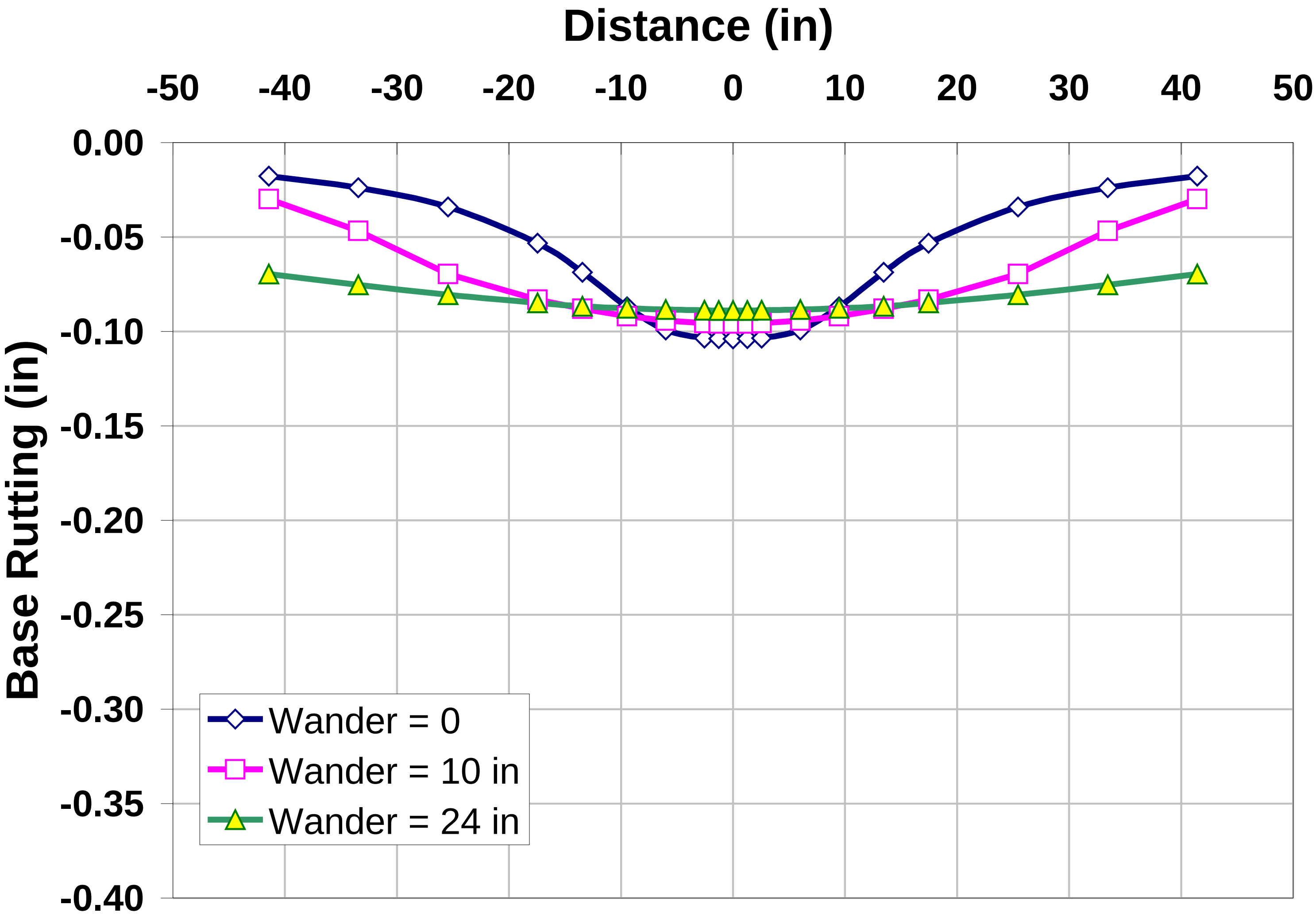
INFLUENCE OF AC THICKNESS UPON AC ALLIGATOR FATIGUE CRACKING (SUMMARY)

- ***AC thickness has a significant influence upon Alligator fatigue cracking. As the AC thickness increases, the amount of alligator (bottom-up) fatigue cracking decreases.***

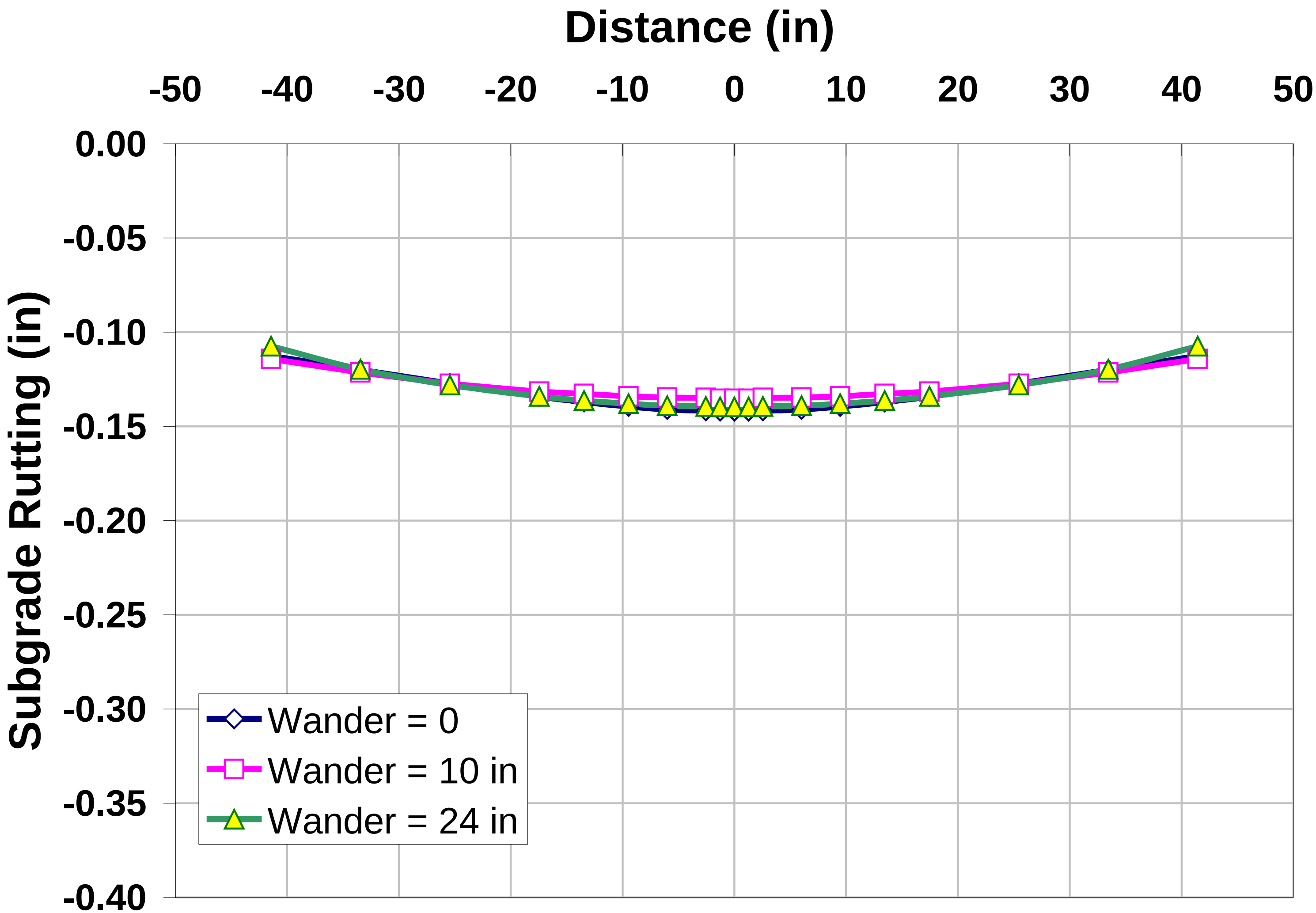
INFLUENCE OF TRAFFIC WANDER UPON AC RUTTING



INFLUENCE OF TRAFFIC WANDER UPON BASE LAYER RUTTING



INFLUENCE OF TRAFFIC WANDER UPON SUBGRADE LAYER RUTTING

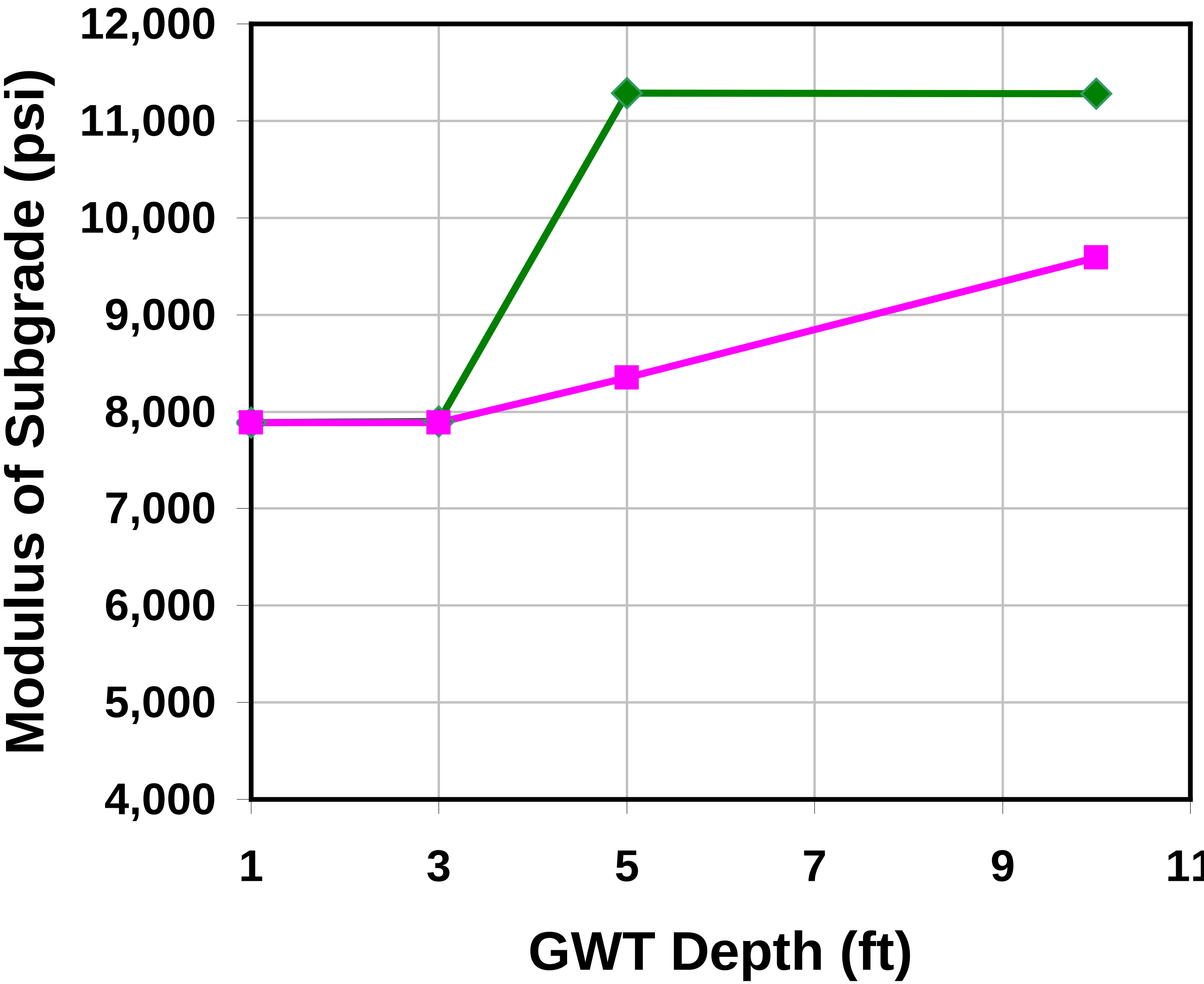


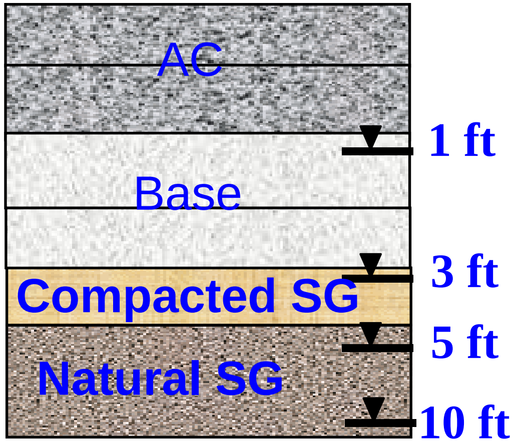
INFLUENCE OF TRAFFIC WANDER UPON AC RUTTING (SUMMARY)

- ***The more channelized that the vehicular traffic becomes, the more severe the pavement rutting becomes.***

- ***The severity of the rutting is magnified for layers near the surface.***

INFLUENCE OF GWT DEPTH UPON SUBGRADE LAYER MODULUS

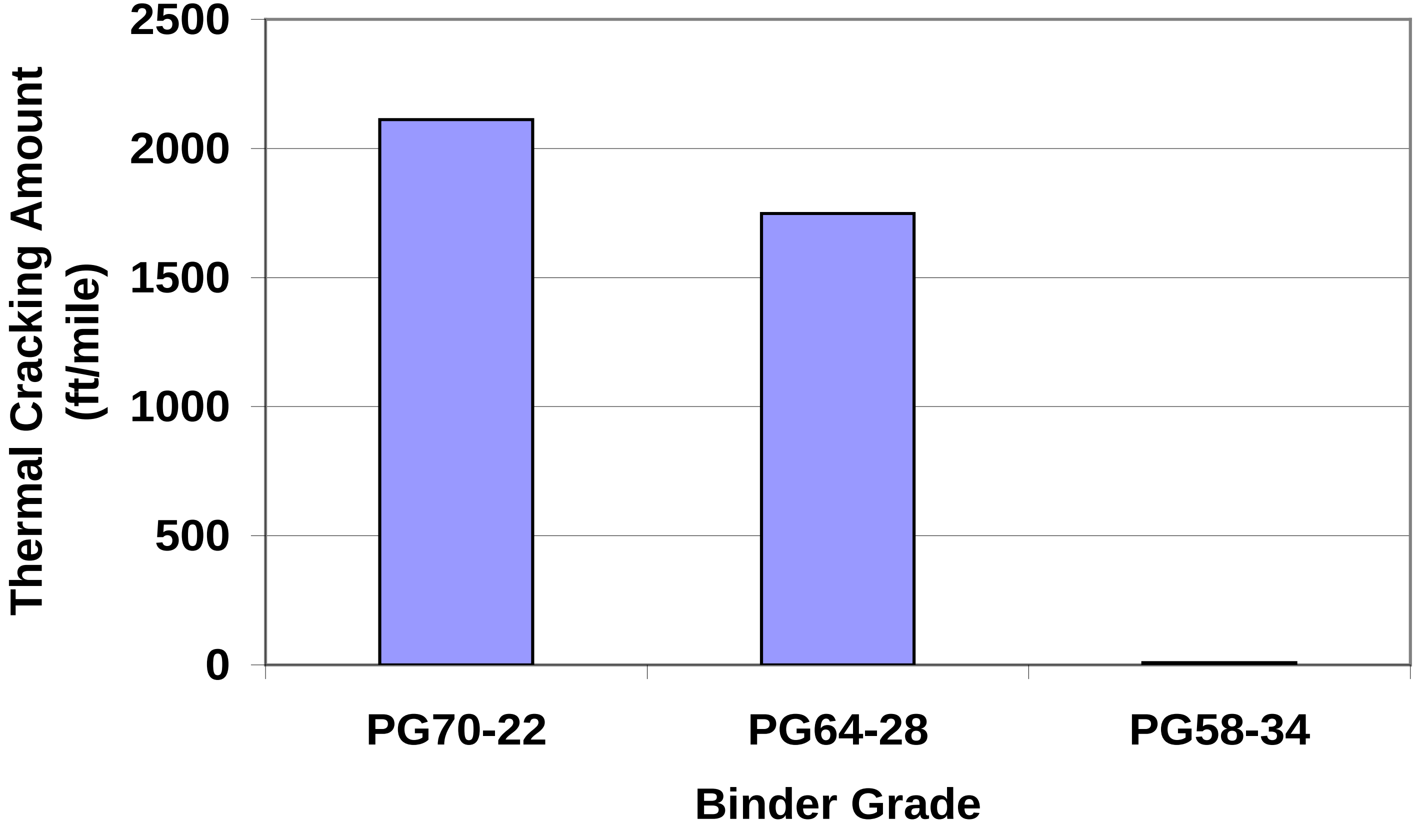




INFLUENCE OF GWT DEPTH UPON UNBOUND MATERIALS MODULI (SUMMARY)

- ***Presence of GWT near / within unbound material layers can significantly alter the material moduli and hence increase pavement damage.***

INFLUENCE OF BINDER GRADE UPON AC THERMAL FRACTURE (FARGO, ND)

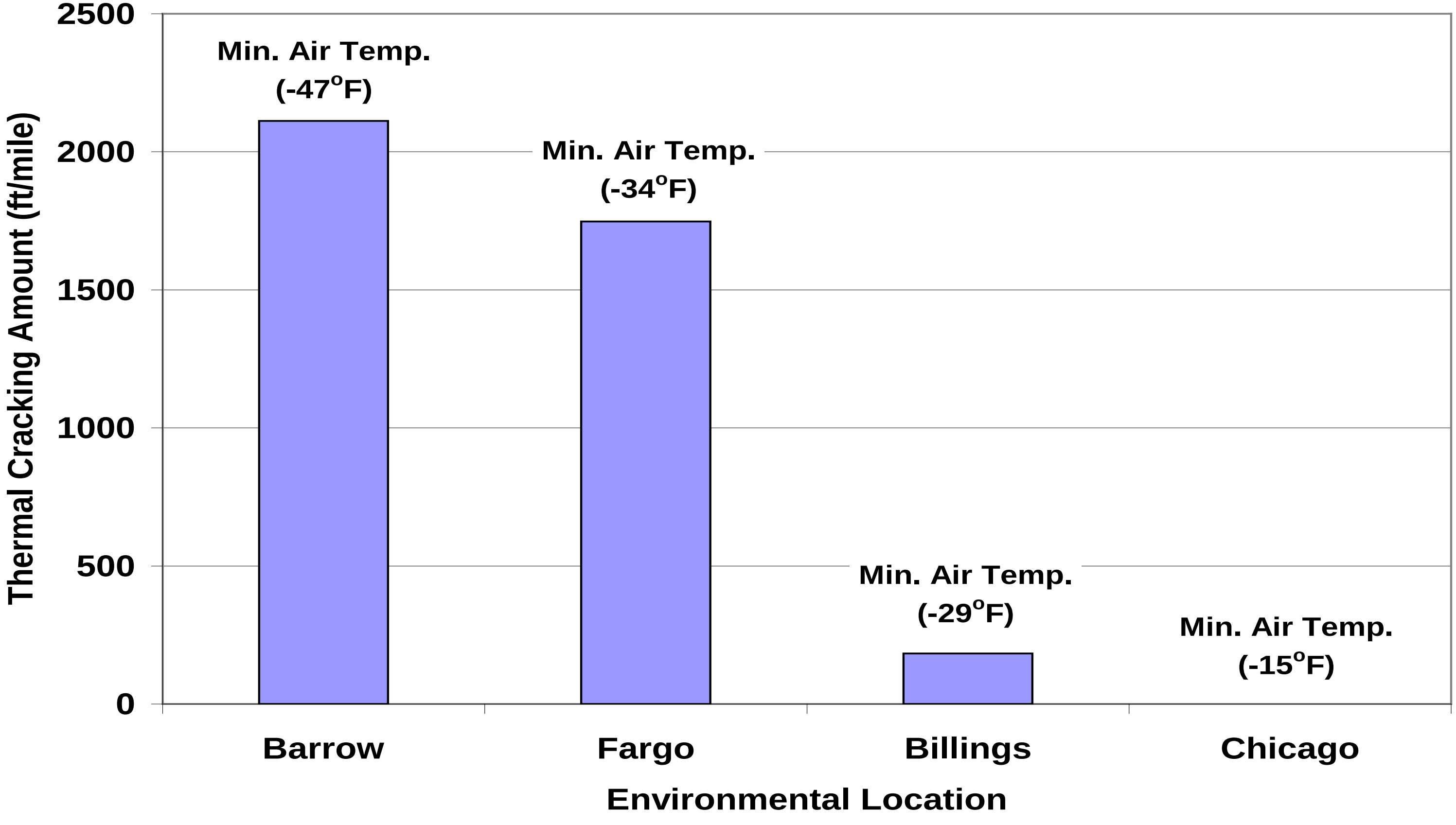


INFLUENCE OF BINDER GRADE UPON AC THERMAL FRACTURE (SUMMARY)

- ***Binder stiffness has the greatest influence upon Thermal Fracture within a cold environment.***

- ***As the binder stiffness (or surface layer stiffness) increases, the AC Thermal Fracture increases.***

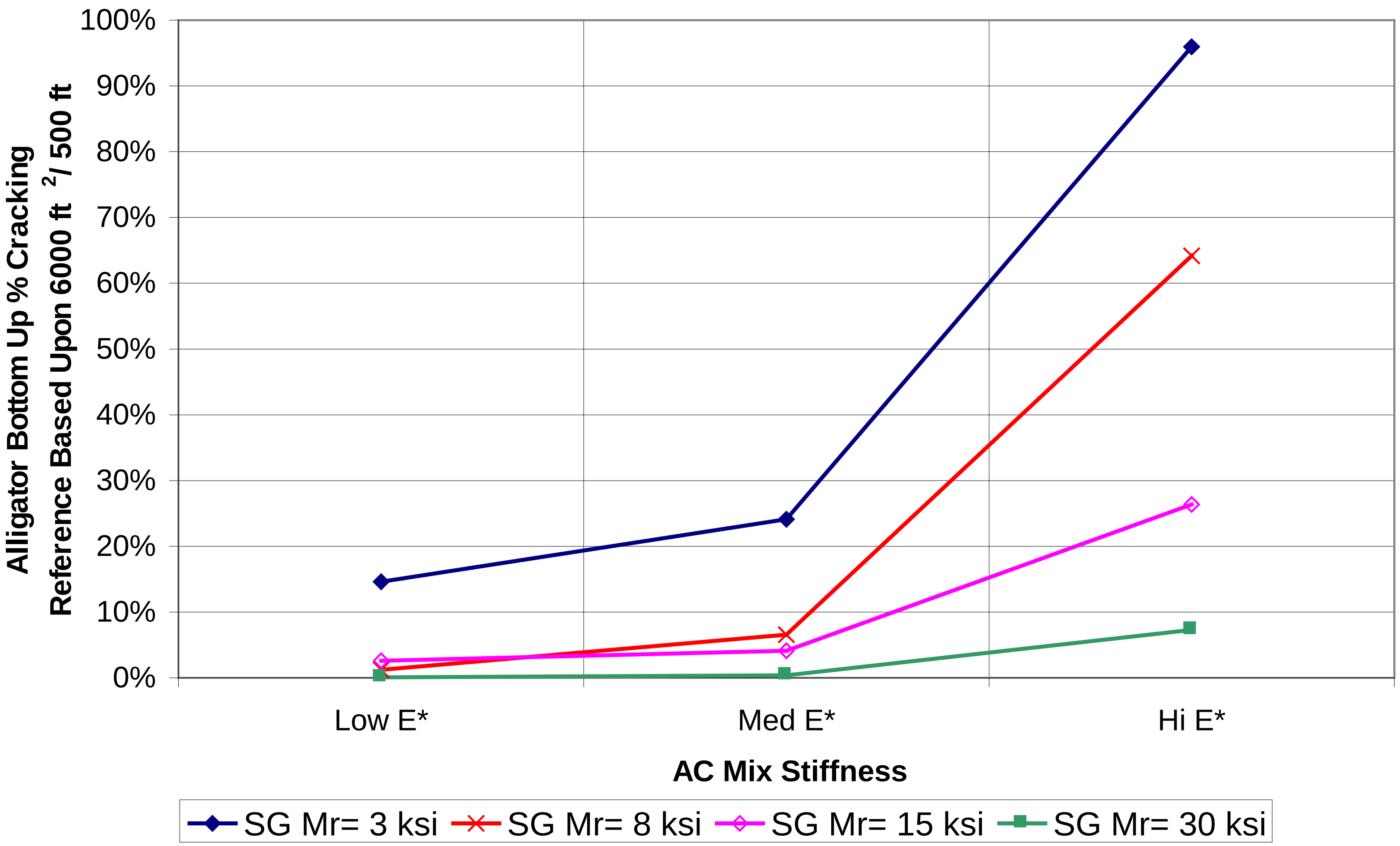
INFLUENCE OF ENVIRONMENTAL LOCATION UPON AC THERMAL FRACTURE



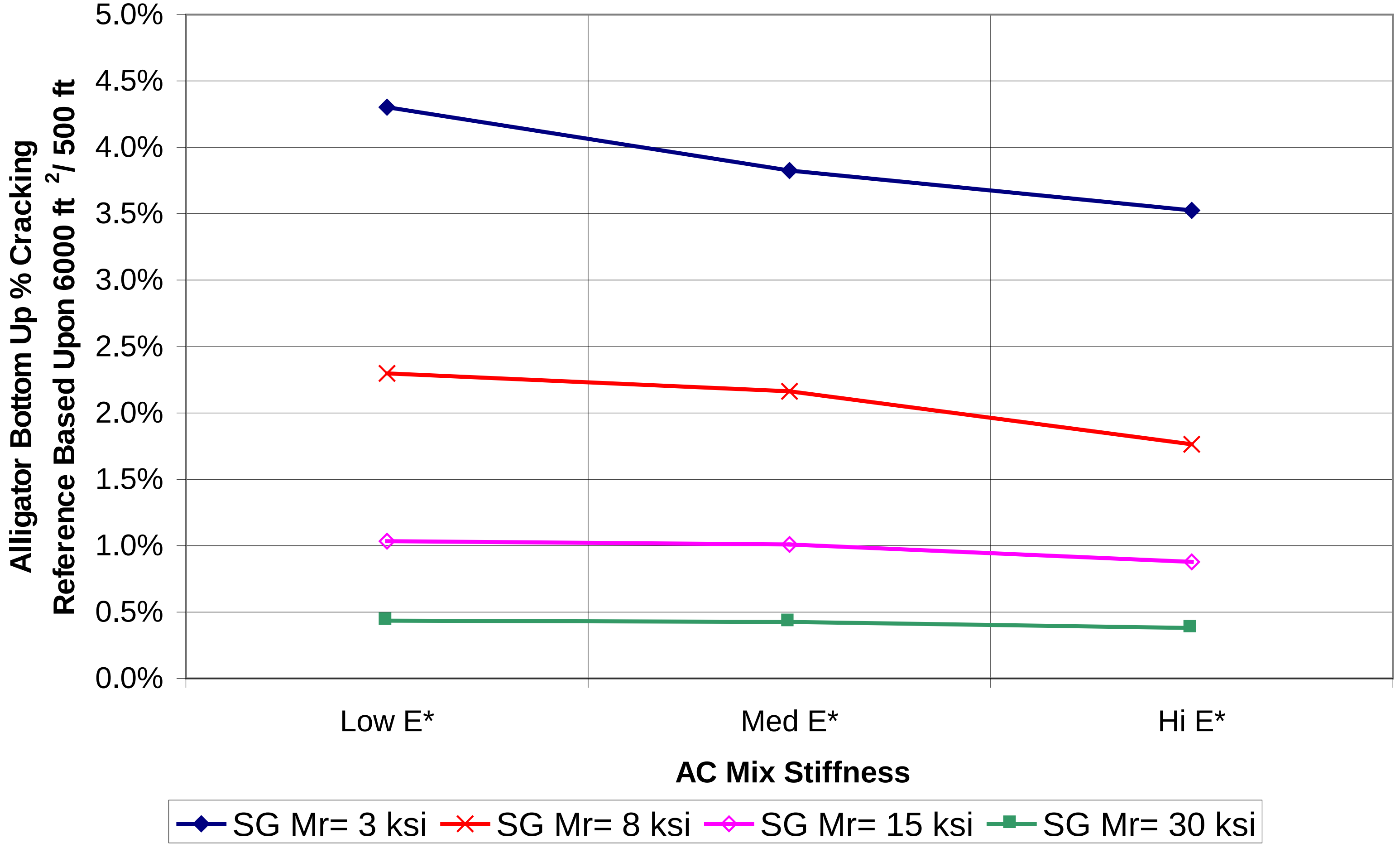
INFLUENCE OF TIME AND VARIOUS AC VOLUMETRIC PROPERTIES UPON AC THERMAL FRACTURE (SUMMARY)

- ***Thermal Cracking cumulatively increases over time.***
- ***Combined property of binder content and air void has an influence upon the Thermal Fracture.***
- ***In general, AC Thermal Fracture decreases with an increase of binder content and a decrease in air void.***

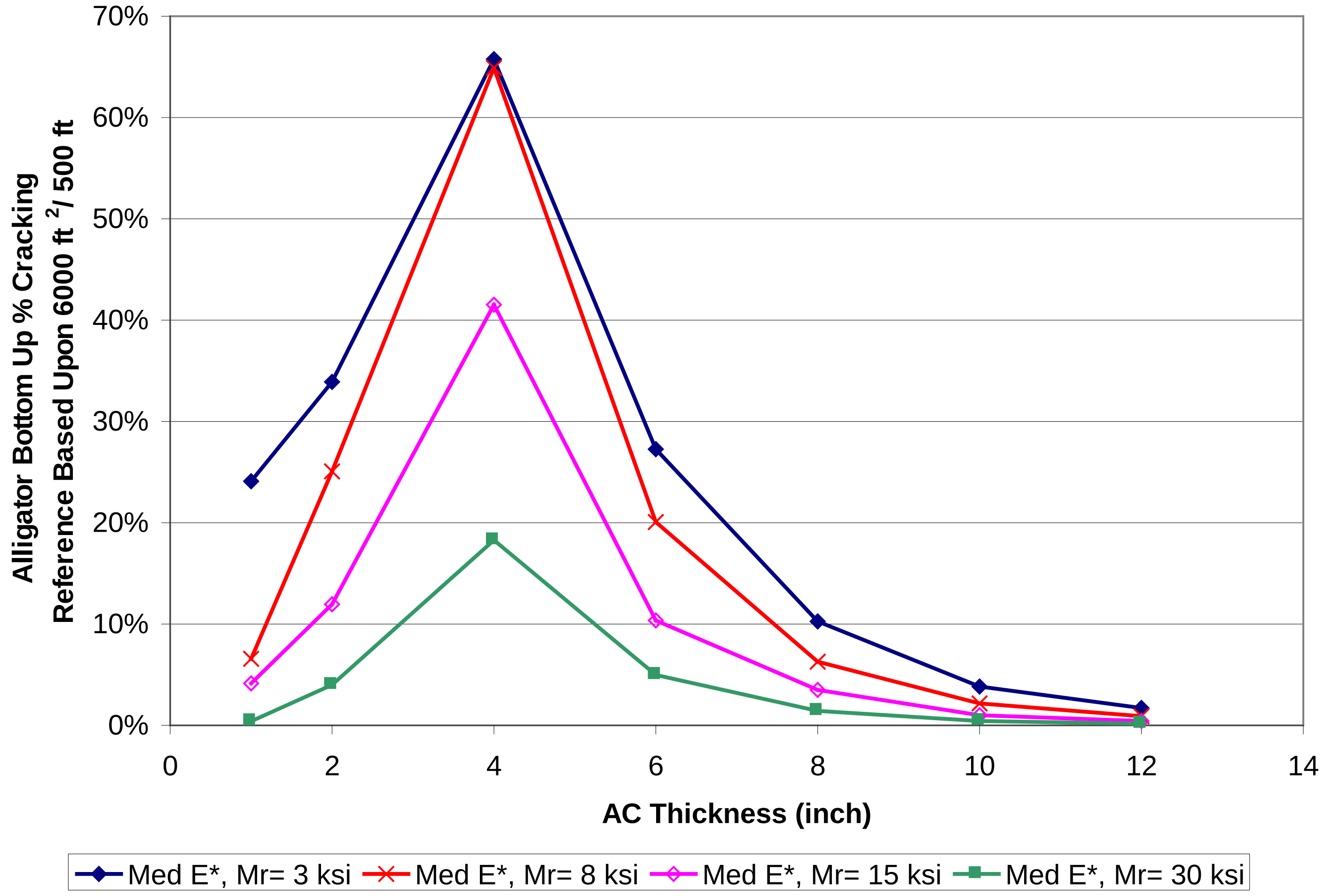
Influence of AC Mix Stiffness on Alligator Cracking, (H_{AC} = 1 in)



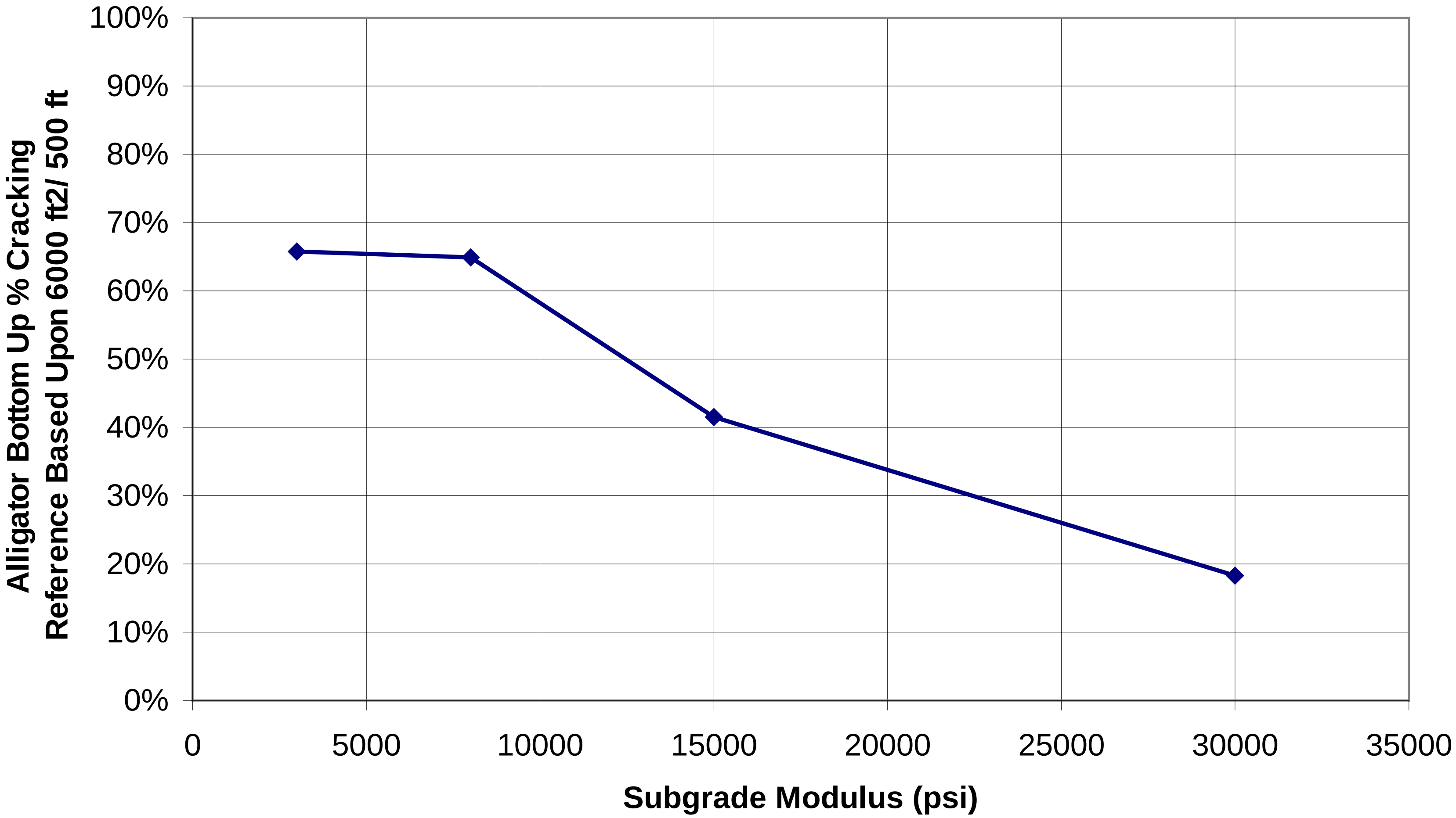
Influence of AC Mix Stiffness on Alligator Cracking, (H_{AC} = 10 in)



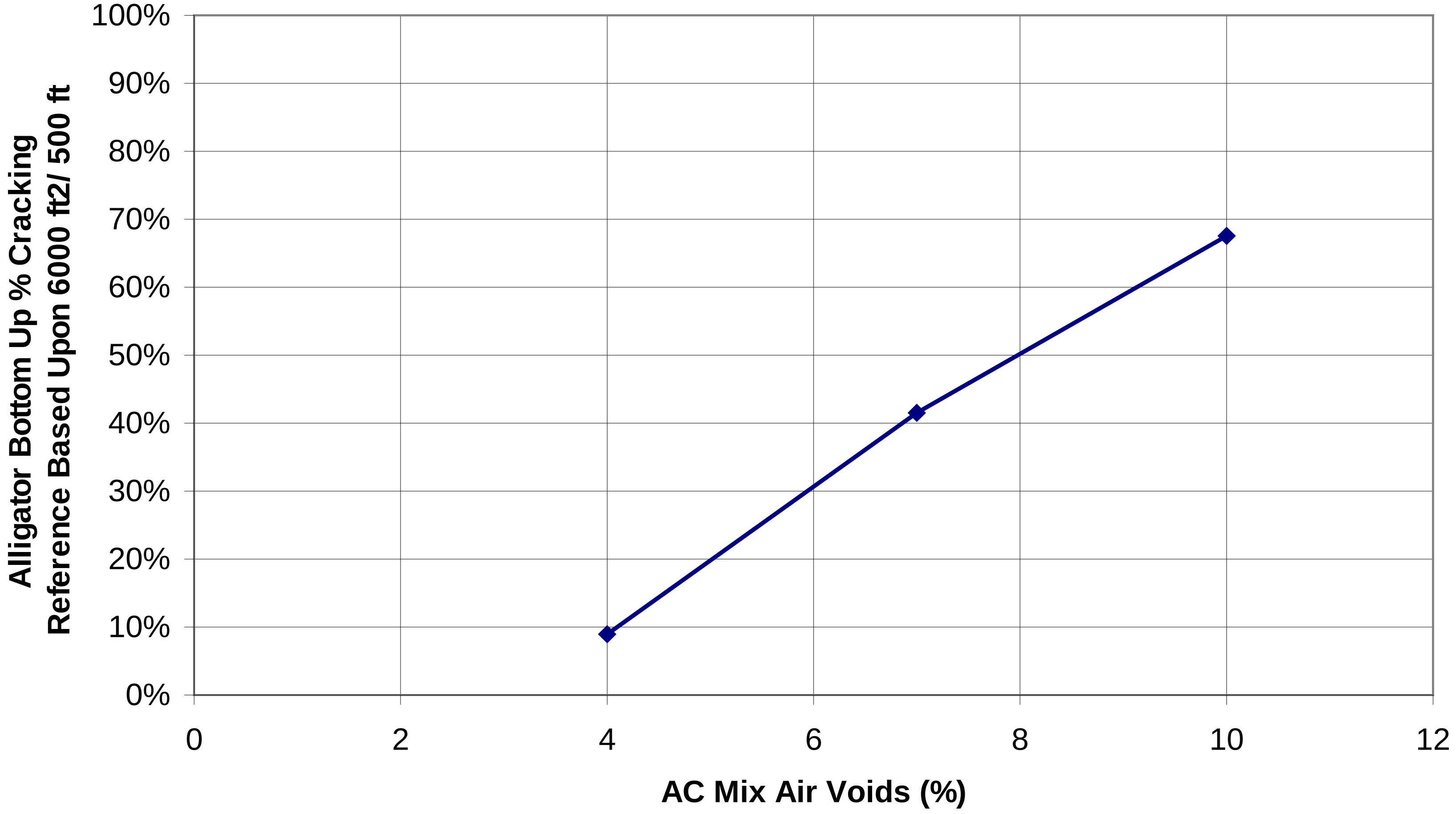
Influence of AC Thickness upon Alligator Cracking



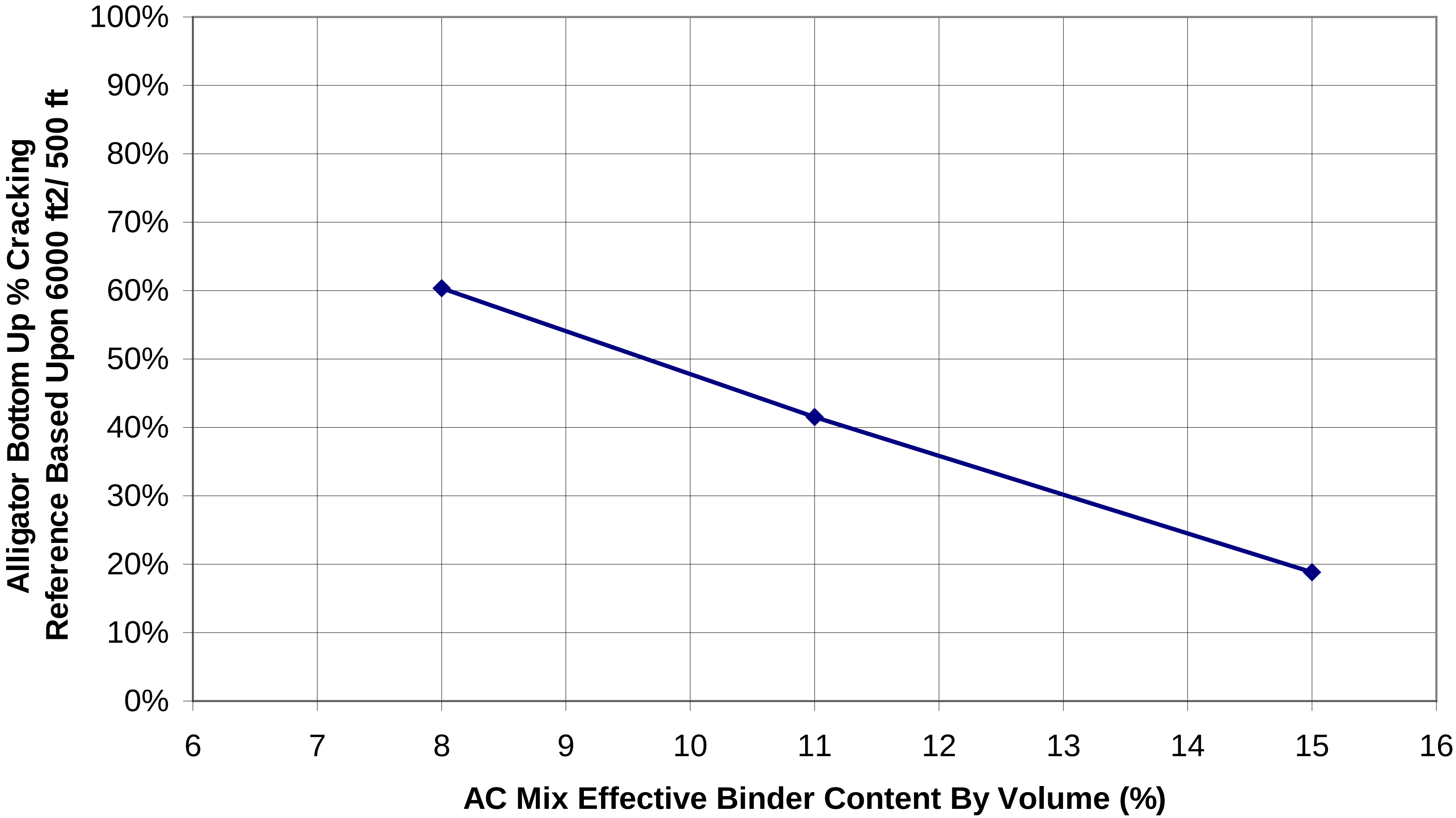
Influence of Subgrade Modulus upon Alligator Cracking

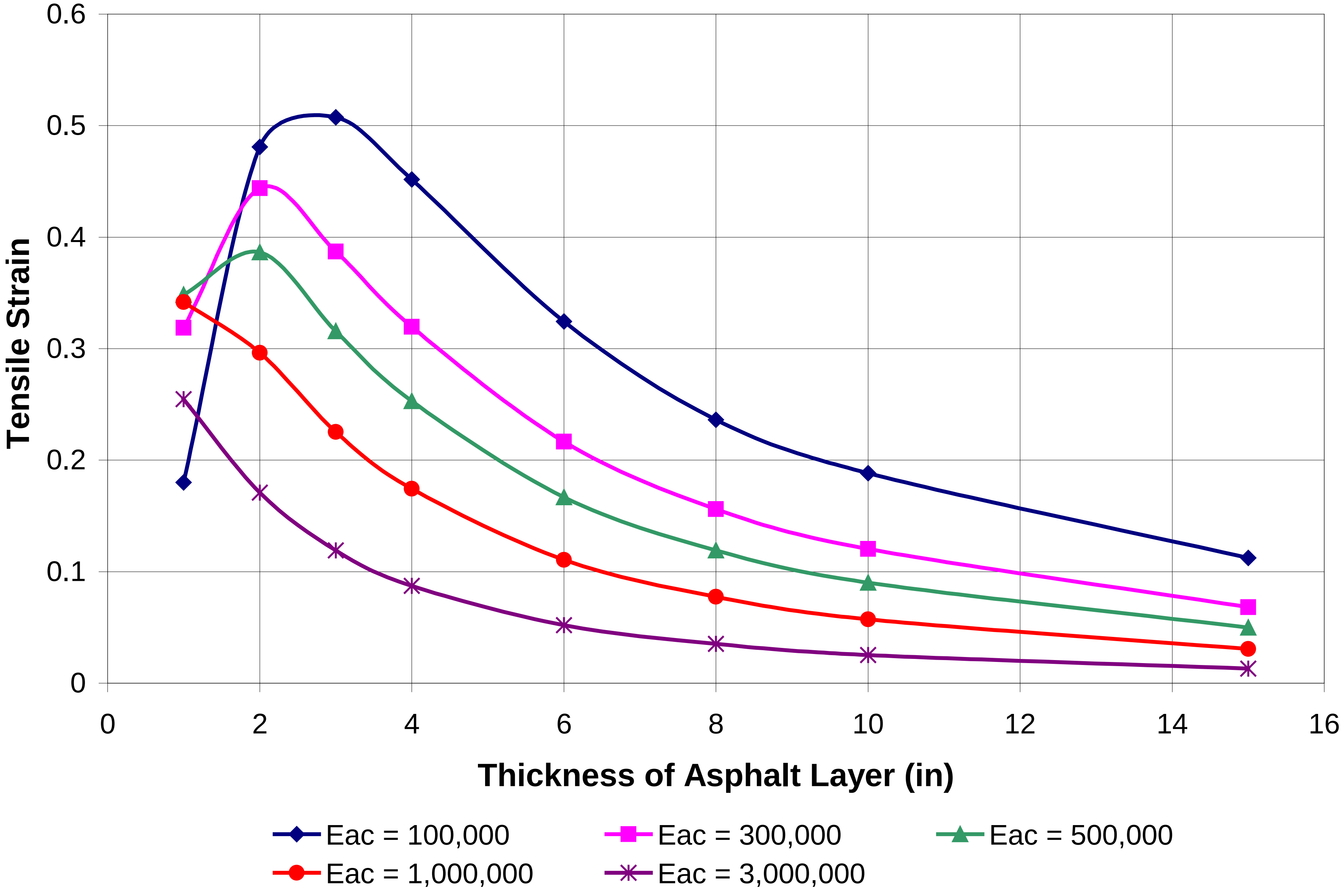


Influence of AC Mix Air Voids upon Alligator Cracking



Influence of Percent AC Binder by volume upon Alligator Cracking





0.6
0.5
0.4
0.3
0.2
0.1
0
Tensile Strain
0
2
4
6
8
10
12
14
16
Thickness of Asphalt Layer (in)
Eac = 100,000
Eac = 300,000
Eac = 500,000
Eac = 1,000,000
Eac = 3,000,000

AC Rut Depth Prediction (M-E PDG)

$$R_d = \sum_{z_1}^{z_2} \varepsilon_p dz$$

$$\frac{\varepsilon_p}{\varepsilon_r} = \hat{\beta}_{r_1} T^{\hat{\beta}_2} N^{\hat{\beta}_{r3}}$$

$$\varepsilon_p = \varepsilon_r \left(\hat{\beta}_{r_1} T^{\hat{\beta}_2} N^{\hat{\beta}_{r3}} \right)$$

Lab Relationship

Basic Model:

$$\varepsilon_{p_z} = \left[\frac{1}{E_z} \right] \left[\sigma_z - \mu(\sigma_x + \sigma_y) \right] \left[(C_1 + C_2 Z) \beta_o^{\ z} \right] \left[\beta_{r_1} T^{\beta_{r2}} N^{\beta_{r3}} \right]$$

Unbound Base / Subbase / Subgrade Rut Depth Prediction (M-E PDG)

$$R_d = \sum_{z_1}^{z_2} \varepsilon_p dz$$

Basic Model:

$$\frac{\varepsilon_p}{\varepsilon_r} = \hat{\beta}\left(\frac{\varepsilon_o}{\varepsilon_r}\right) e^{-\left(\frac{\rho}{N}\right)^{\beta}}$$

Not Linear Log-Log; Linear Semi log

$$\varepsilon_p = \varepsilon_r \left[\hat{\beta}\left(\frac{\varepsilon_o}{\varepsilon_r}\right) e^{-\left(\frac{\rho}{N}\right)^{\beta}} \right]$$

$$\varepsilon_p = \left[\frac{1}{E_z}\right]\left[\sigma_z - \mu(\sigma_x + \sigma_y)\right]\left[\hat{\beta}\left(\frac{\varepsilon_o}{\varepsilon_r}\right) e^{-\left(\frac{\rho}{N}\right)^{\beta}} \right]$$

Unbound Base / Subbase / Subgrade Rut Depth Prediction (M-E PDG) (Cont'd)

Lytton Coefficients

$$\left(\frac{\varepsilon_o}{\varepsilon_r}\right) = f\left(\rho, \beta, E_r\right)$$

$\beta = f\,(w_c)$

$\rho = f\,(\beta)$

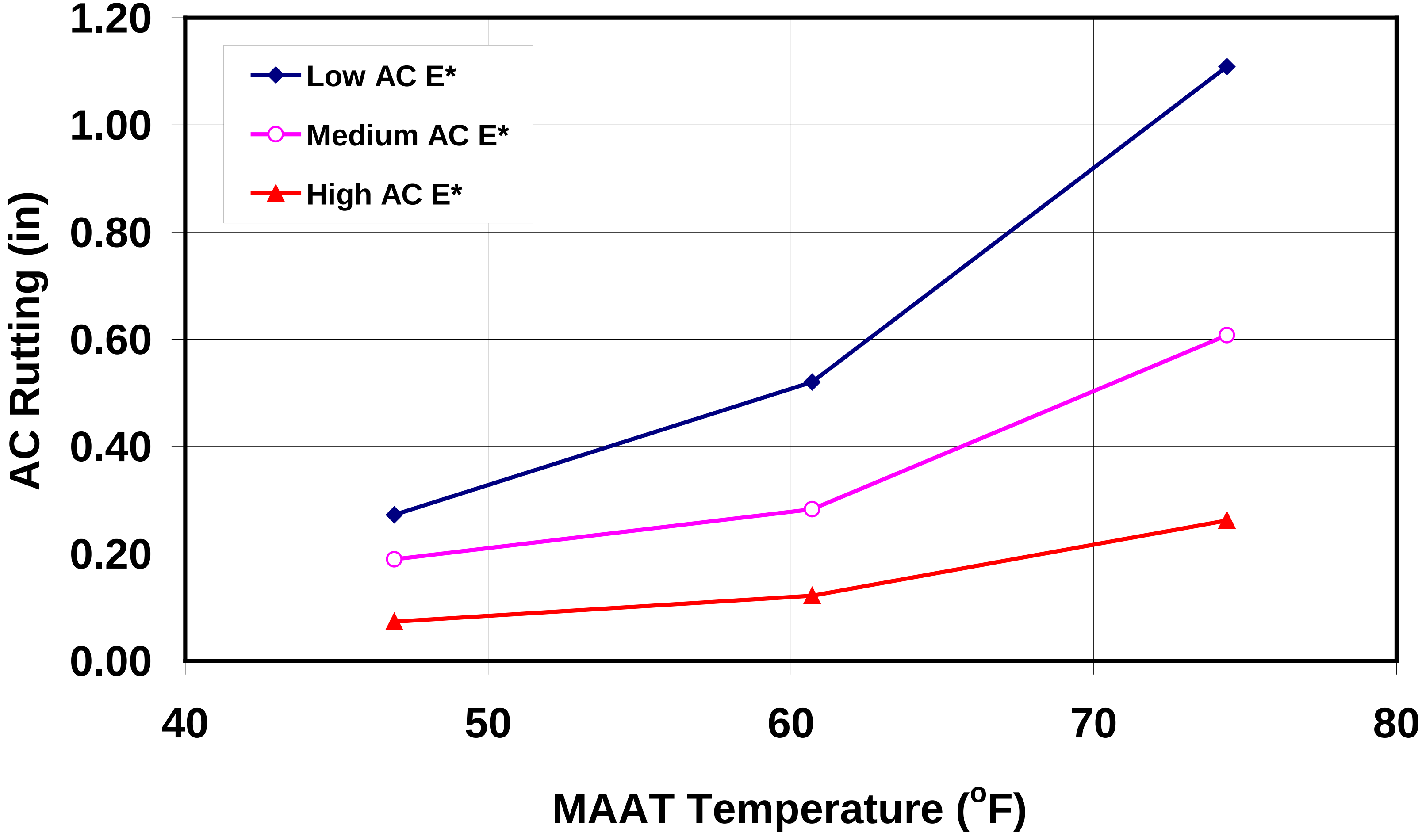
$C_o = f\,(E_r)$

EICM / 1-37A Moduli – Moisture Interaction Critical here

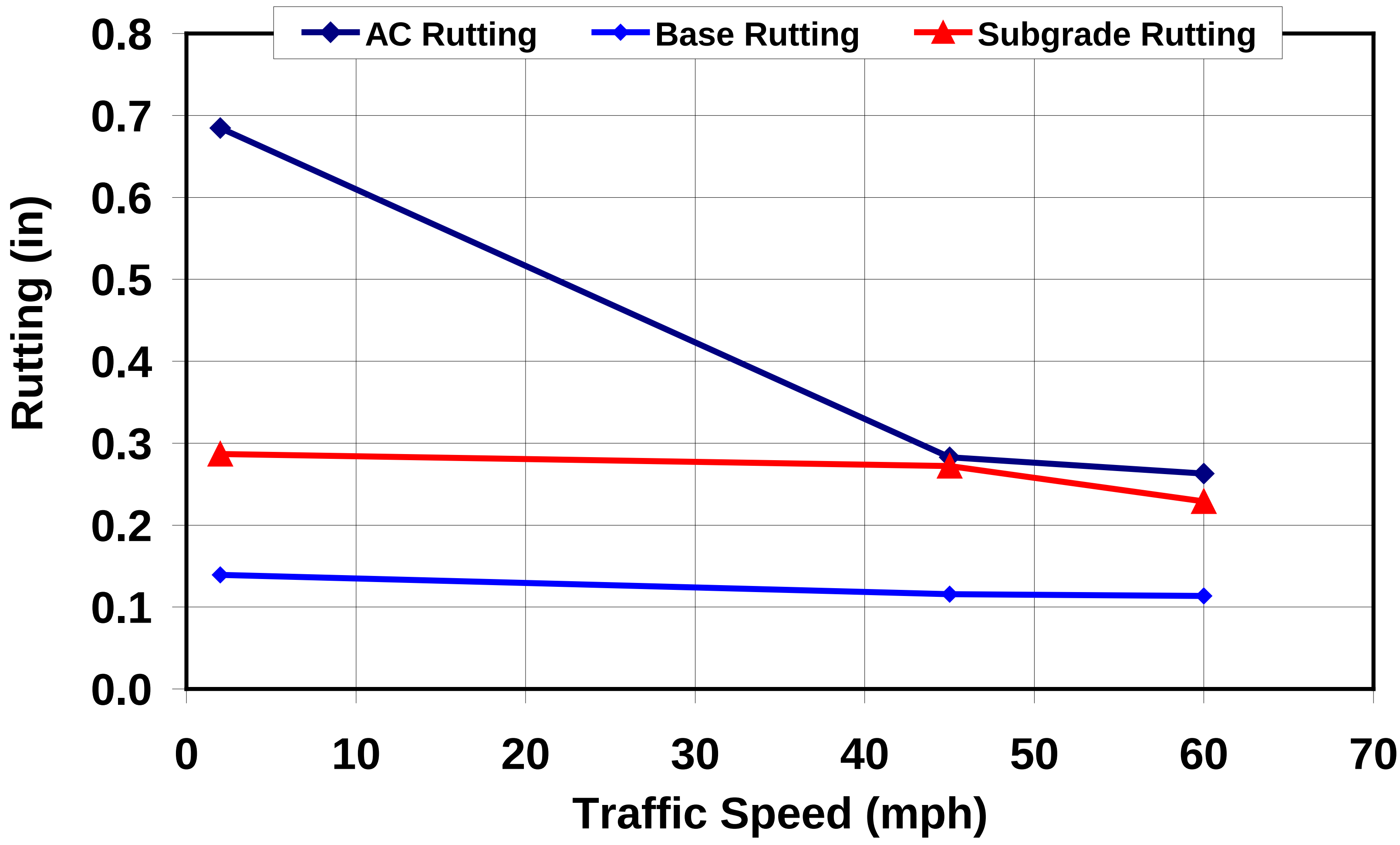
$\Delta w \rightarrow \Delta E_r$

$$\varepsilon_p = \left[\frac{1}{E_z}\right]\left[\sigma_z - \mu(\sigma_x + \sigma_y)\right]\underbrace{\left[\beta_{fc}\right]\left[f\left(w_c, E_z\right)\right]}_{\text{Calibrated Model}}\left[N\right]$$

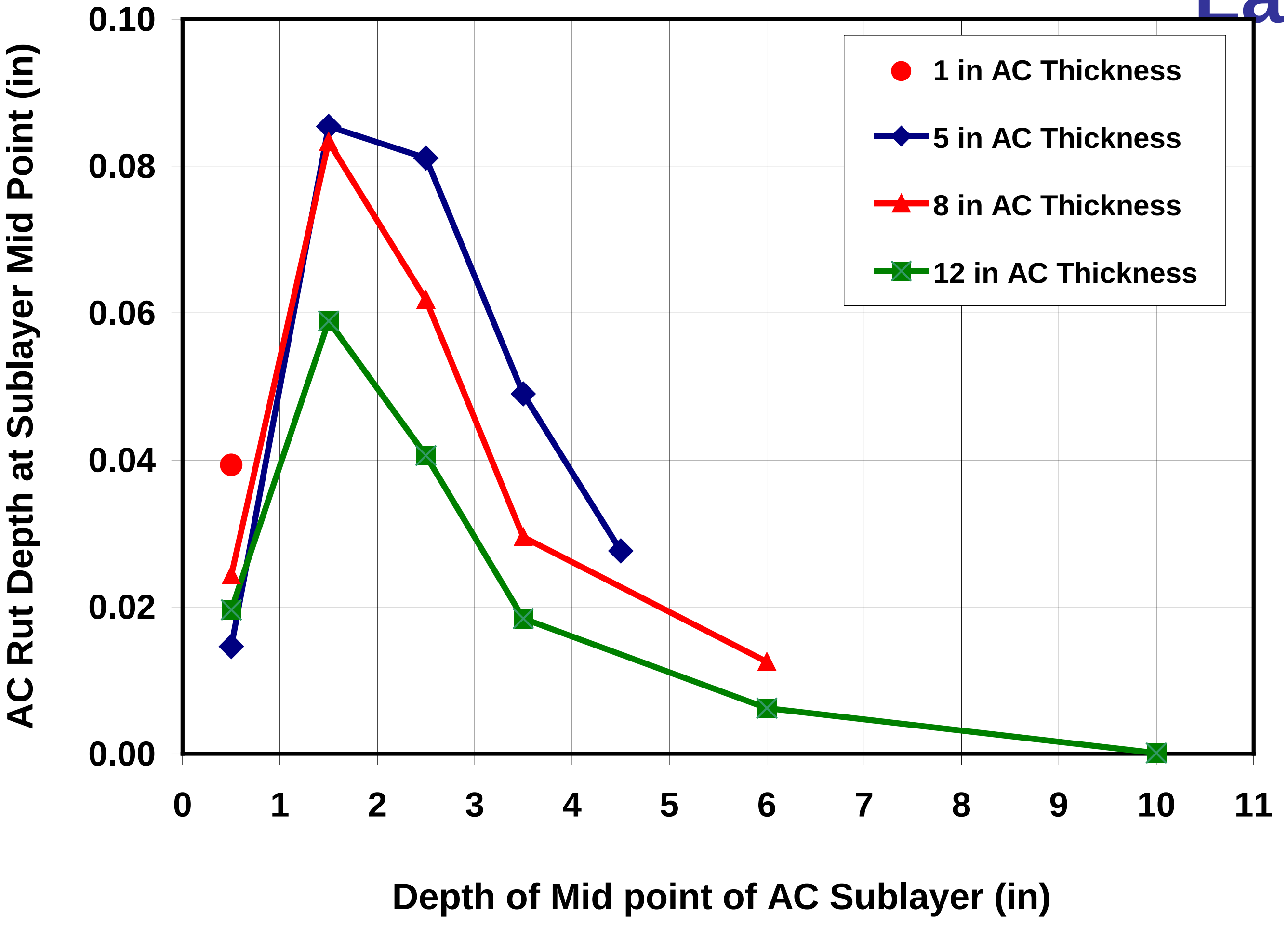
Influence of MAAT upon Permanent Deformation



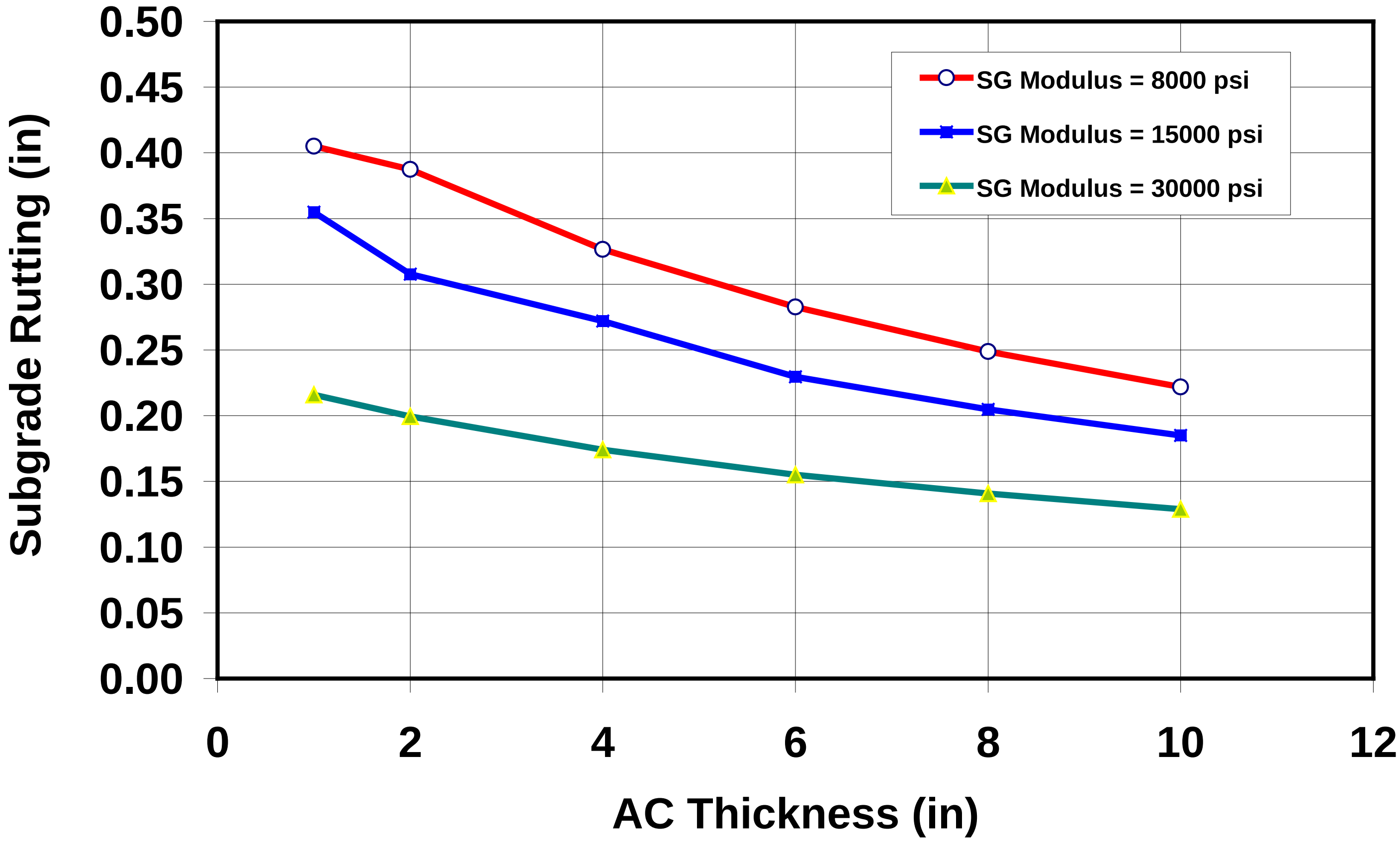
Effect of Traffic Speed upon Permanent Deformation



Influence of AC Thickness upon AC Rutting as Function of Depth Within AC Layer



Effect of AC Thickness on Subgrade Rutting at Different Subgrade Modulus (Medium AC Mix Stiffness)



General $\varepsilon_p/\varepsilon_r$ Relationship Used in the 2002 Design Guide

HMA Layer

$$\frac{\varepsilon_p}{\varepsilon_r} = k_1 * \beta_{r1} * 10^{-3.1552} T^{1.734*\beta_{r2}} N^{0.3993*\beta_{r3}}$$

ε_p = plastic strain

ε_r = resilient strain

T = layer temperature (deg F)

N = no of load repetition

k_1 **=** Confining Pressure, Depth Function.

β_{r1}, β_{r2}, β_{r3} = Calibration Factors

Field Calibration Factors AC-Fatigue

$$N_f = \beta_{f_1} F'' K_{1\sigma} \left[\frac{1}{\varepsilon_t} \right]^{5\beta_{f2}} E^{-1.4\beta_{f3}}$$

N_f = number of repetitions to fatigue cracking

ε_t = tensile strain at the critical location

E = material stiffness

K_1 = laboratory calibration parameter

$\beta_{f_1}, \beta_{f_2}, \beta_{f_3}$ = calibration factors

OVERALL M-E PDG SUMMARY

- ***M-E PDG is the most powerful Pavement-Material Analysis-Design Tool ever developed.***
- ***M-E PDG will lead to a more fundamental analysis of the consequences associated with the material-structure - environmental interaction.***
- ***M-E PDG has the potential for increasing pavement performance and life while decreasing life cycle costs associated with new and rehab scenarios.***

Implementation Considerations

- ***Be careful of blind application of Modified asphalts in MEPDG.***

- ***E* value may be okay***
  - ***Distress performance prediction models (ac rutting, fatigue cracking and thermal fracture) generally calibrated with conventional asphalt mixtures***
  - ***Performance prediction of Modified AC Mixtures questionable***
  - ***Suggest local calibration***

Implementation Considerations

- ***MEPDG is an excellent product and major enhancement to current technology; however the technology is still evolving:***
  - ***Do not expect perfect predictions***
    - ***Need to locally calibrate to actual field performance***
      - ***Must be prepared to Conduct Trench Sections!!!!!!***
    - ***Need to have a well defined nationally coordinated approach to develop planned model enhancements***
      - ***Reflective cracking***
      - ***Rutting and fatigue cracking model enhancements***
      - ***Chemically Stabilized Materials Calibration***
      - ***Performance of modified mixtures***
      - ***Refinement of level standard deviations for use in reliability models***