# Dynamic Modulus Testing of Iowa Asphalt Mixtures

Presented by

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# Introduction

- **Superpave mix design procedure**
  - **Product of SHRP**
- **Different design levels based on traffic levels**
  - **Volumetric mix design ( $<10^6$ ESALs)**
  - **Intermediate analysis (up to $10^7$ ESALs)**
  - **Complete analysis ( $>10^7$ ESALs)**

# Introduction (Cont'd)

- **Superpave volumetric mix design**
  - No mechanical test to check performance
  - Marshall method includes mechanical test
- **In the past years, comprehensive research efforts to develop**
  - Simple performance test (SPT)
  - To characterize material for the Mechanistic – Empirical pavement design guide (AASHTO 2002)
- **Recent research efforts (NCHRP 9-19, 1-37A)**
  - Complex dynamic modulus is a strong candidate for both pavement design and SPT
  - Recommended as a design parameter for rutting and fatigue cracking
  - Not a good indicator for thermal cracking

# Complex Dynamic Modulus

- **Not a new concept**
  - Papazian, 1962
- **Different research projects over decades**
  - Various combinations of frequencies and temperatures
  - Compression, tension-compression, tension
  - Laboratory compacted and field cored specimens
- **Most comprehensive in the past few years**
  - Professor Witzack and his research team (Arizona State Univ.)
  - Compression
  - Uniaxial loading and triaxial loading test

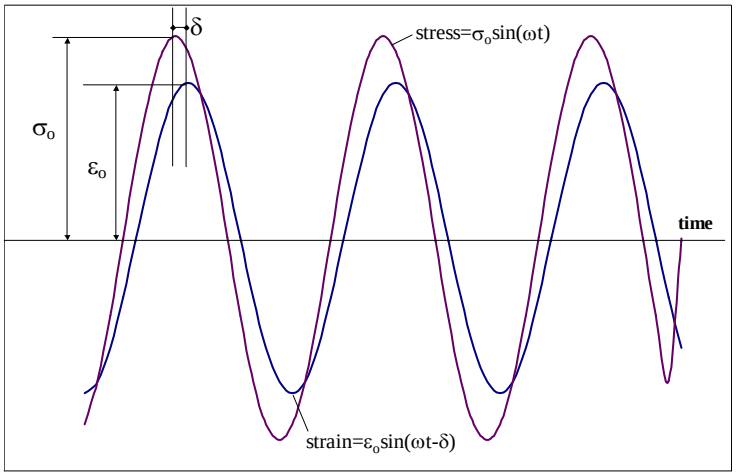
# Background of Dynamic Modulus

## (based on linear viscoelasticity concepts)

- Controlled sinusoidal load applied to cylindrical specimen
- Deformation measured at multiple locations on the sample
- Two fundamental parameters determined
  - Dynamic modulus, |E*|
  - Phase angle, δ
- Time-temperature superposition principle is assumed valid
- Master curve can be constructed using the factors from the dynamic modulus tests – explains the behavior of mixtures over a range of temperatures and rate of loading (fast vs. slow)

# Background of E* (cont'd)

## ➢ Determination of dynamic modulus

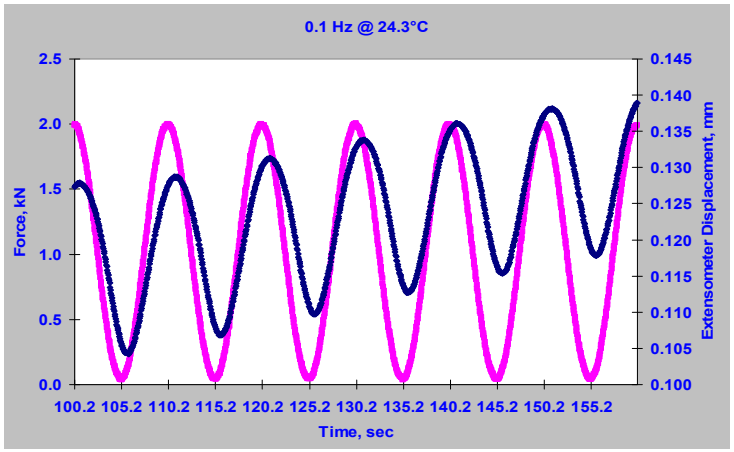



$$\sigma = \sigma_0 + \sigma_1 \cos(2 * pi * f * t + \phi_1)$$

$$\varepsilon = \varepsilon_0 + +\varepsilon_1 t + \varepsilon_2 \cos(2 * pi * f * t + \phi_2)$$

$$|E^*| = \frac{\sigma_1}{\varepsilon_2}$$

$$\phi = \phi_2 - \phi_1$$




σ, ε: stress and strain respectively,
t, f: time and frequency respectively,
$\sigma_0,\sigma_1,\varepsilon_0,\varepsilon_1,\varepsilon_2,\Phi_1, \Phi_2$: regression constants
$\varepsilon_1$: slope of the drift curve of the displacement
|E*|, Φ: dynamic modulus and phase angle

# Background of E* (cont'd)

## ➢ Master curve and shift factors (Williams-Landel-Ferry model)

$$\log \alpha_T = \frac{C_1 (T - T_S)}{C_2 + T - T_S}$$

T: temperature
$T_s$: reference temperature
$C_1$,$C_2$: constants

## ➢ Pellinen model

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

δ: minimum modulus value
$F_r$: reduced frequency
α: span of modulus values
β, γ: shape parameters

# Objectives

- **Established test protocol through shake down evaluation**
  - The effect of temperature
  - The effect of frequency
  - The effect of strain level
  - Damage assessment
- **Performed dynamic modulus testing on typical Iowa mixtures**
  - 21 Iowa asphalt mixtures
  - Construct master curves for the MEPDG

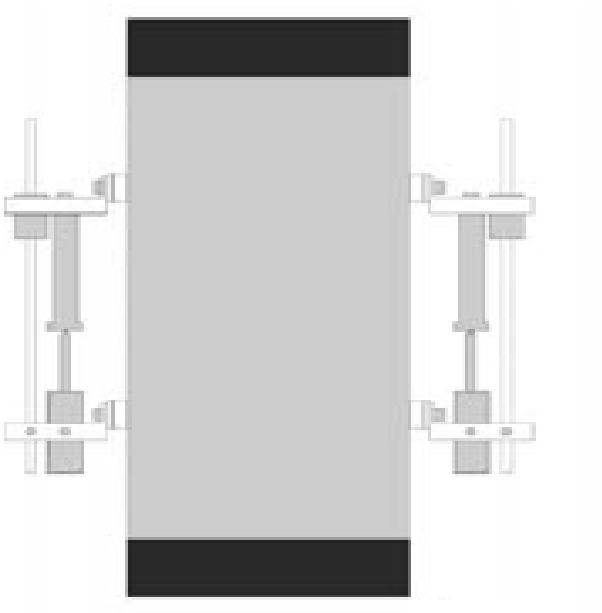
# Sample Preparation

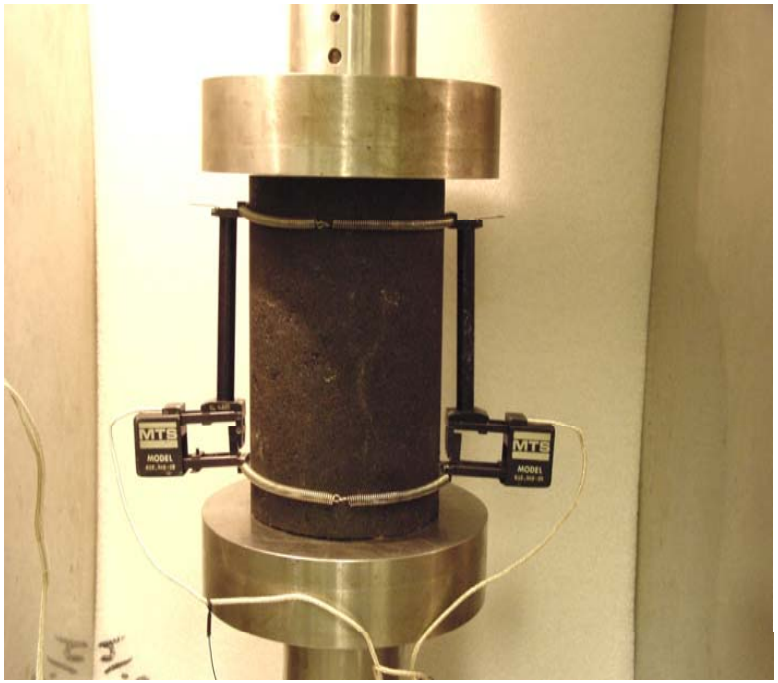
- Sample preparation under comprehensive investigation (NCHRP 9-29)
- Typical gyratory sample not homogenous
  - Density gradation
  - Across diameter (surface vs. interior)
  - Top and bottom vs. interior
- Coring procedure recommended
  - Prepare tall 6" gyratory specimen
  - Obtain 4" by 6" tall specimen

# Sample Preparation (Cont'd)

- **Coring procedure**
  - Difficult to perform
- **Possible solution**
  - Using slender 4" mold

# Test Setup






Dynamic modulus test
(NCHRP Report 547)

# Shake Down Test

- Five temperatures (from low to high)
  - 4.4, 15, 21, 26 and 37°C
- Eleven frequencies (from high to low)
  - 25, 15, 10, 7, 5, 2, 1, 0.7, 0.5, 0.3, and 0.1Hz
- Five replicates
- Two strain levels
  - 80 and 120 micro-strains
- One mixture
  - Jewell

# Shake Down Test (cont'd)

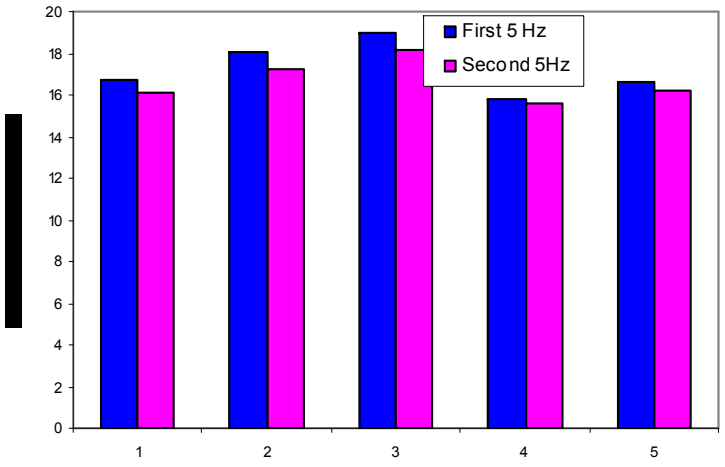
- Using various frequency combinations to check possible damage during testing

| Samples | 25 | 15 | 10 | 7 | 5 | 2 | 1 | 0.7 | 0.5 | 0.3 | 0.1 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | X | X | X | X | X | X | X | X | X | X | X |
| 5 | | | | X | X | X | X | X | X | X | X |
| 5 | | | | | | | X | X | X | X | X |
| 5 | | | | | | | | | X | X | X |

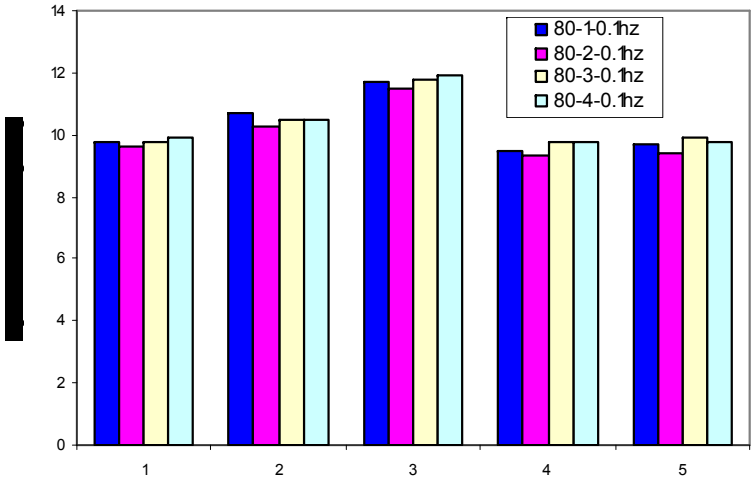
- Conditioned in the temperature chamber
- Capture the last seven cycles

# Shake Down Test Results

- **Replicates**
  - Consistent, no significant difference (t – test)
- **Damage assessment**
  - No significant damage found



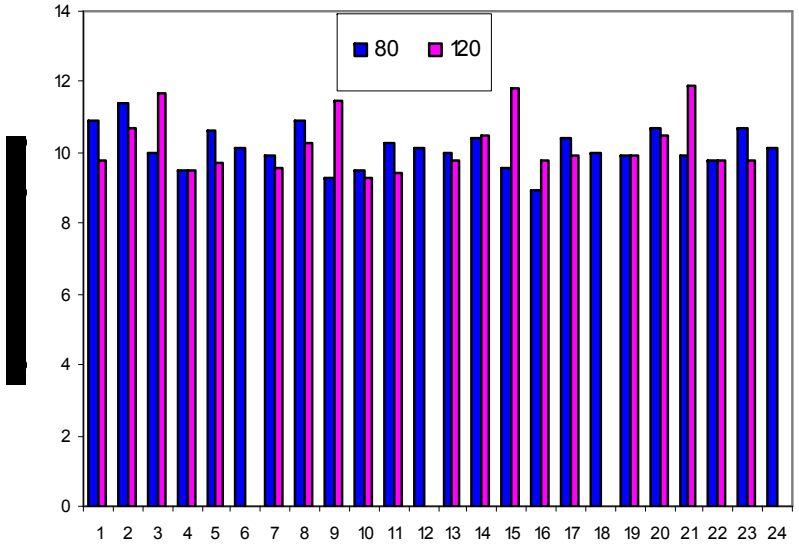

Five Replicates



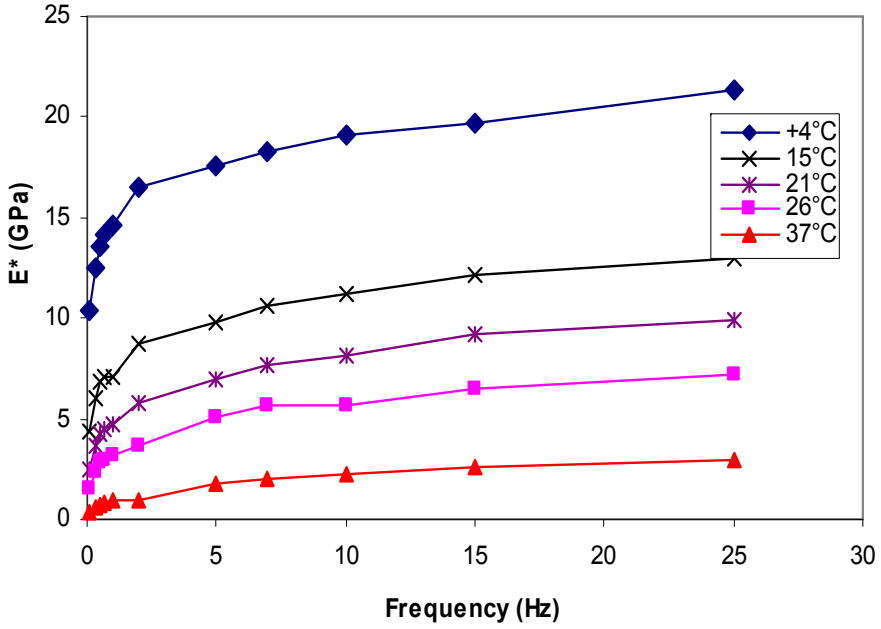

Damage assessment

# Shake Down Test Results (cont'd)

- **Strain level effect**
  - **No significant difference (t – test)**
- **Temperature and frequency effect**

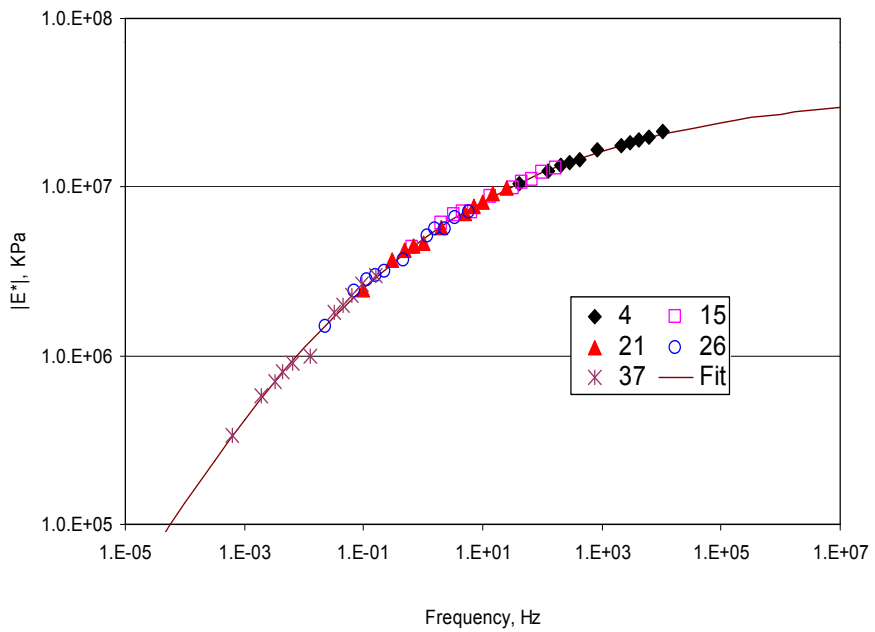



Two strain levels: 80 and 120με

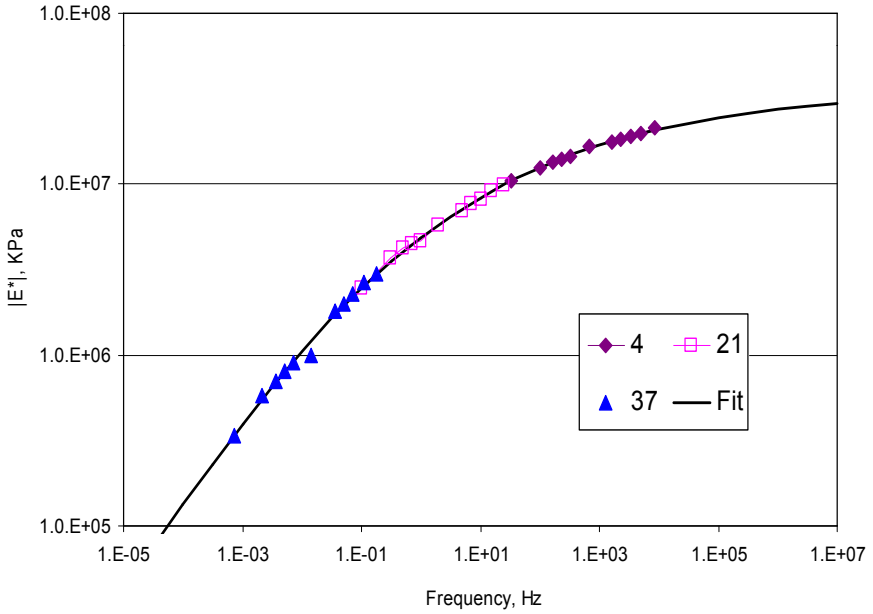


# Shake Down Test Results (Cont'd)

- **Master curves**

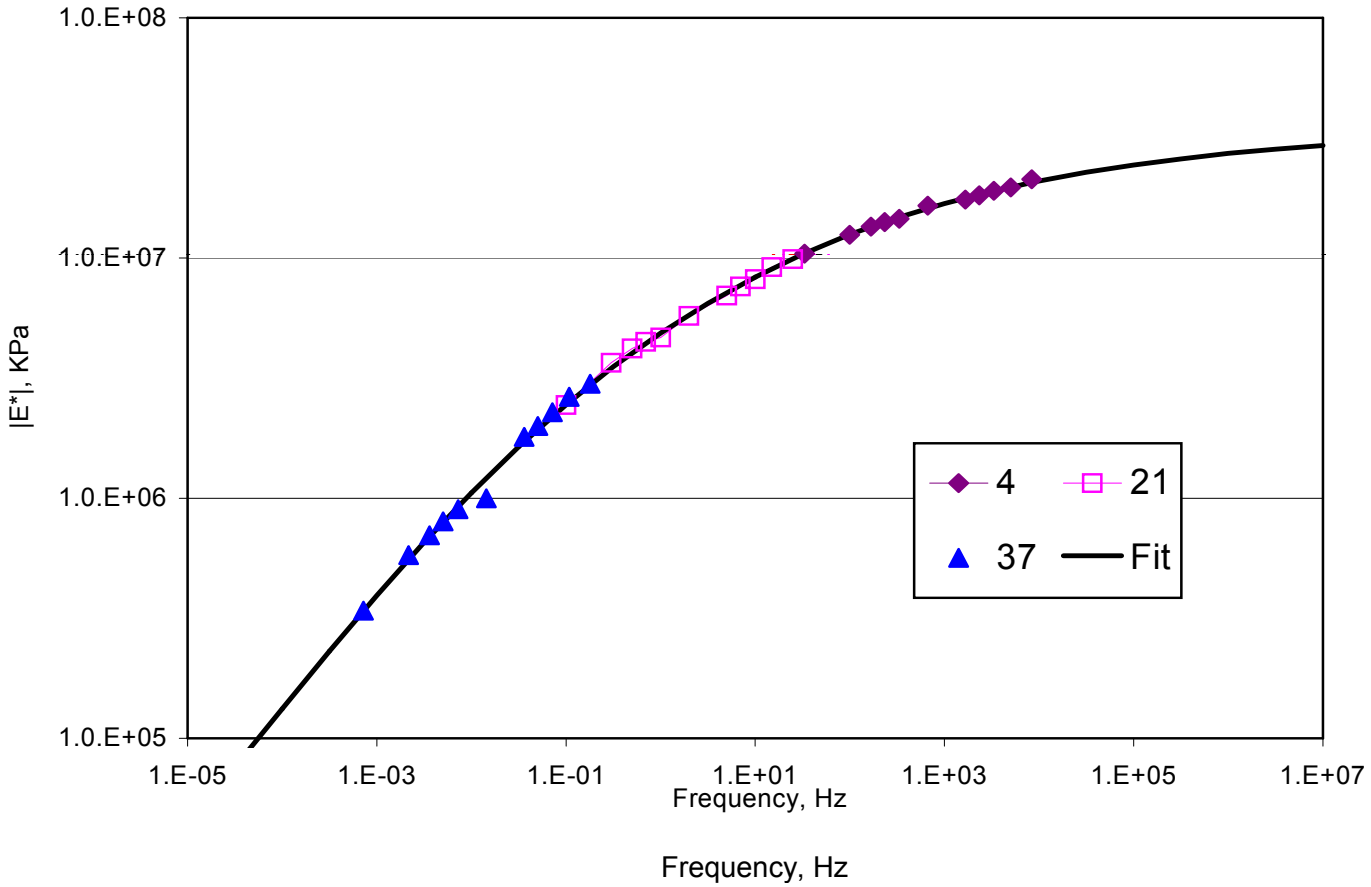



Five temperatures

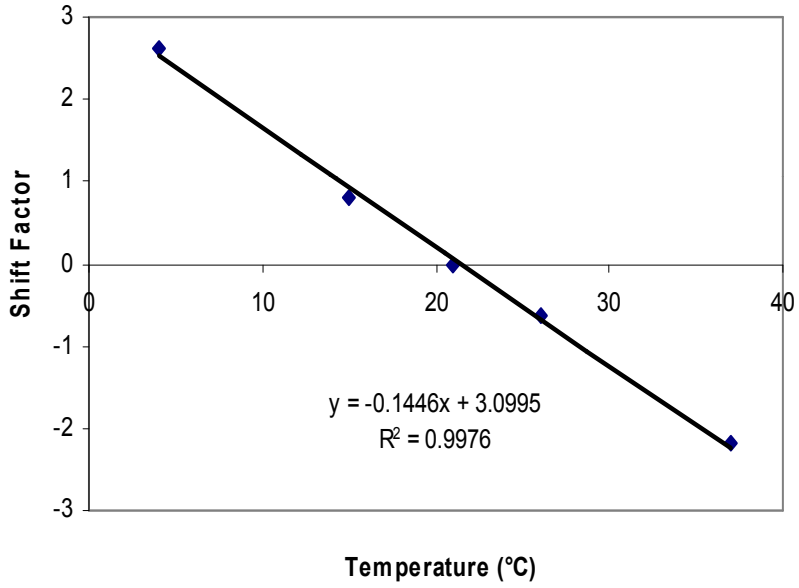



Three temperatures

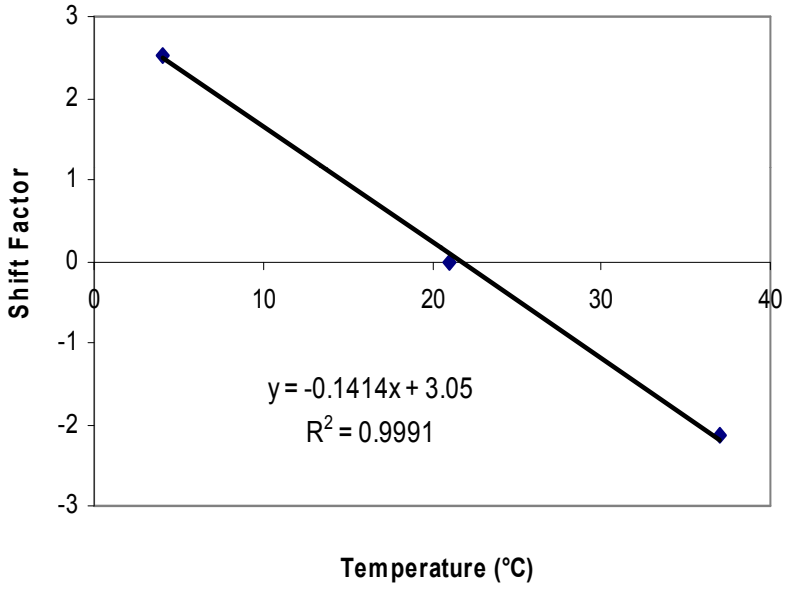
# Five vs. Three Temperatures



# Shift Factors




Five temperatures

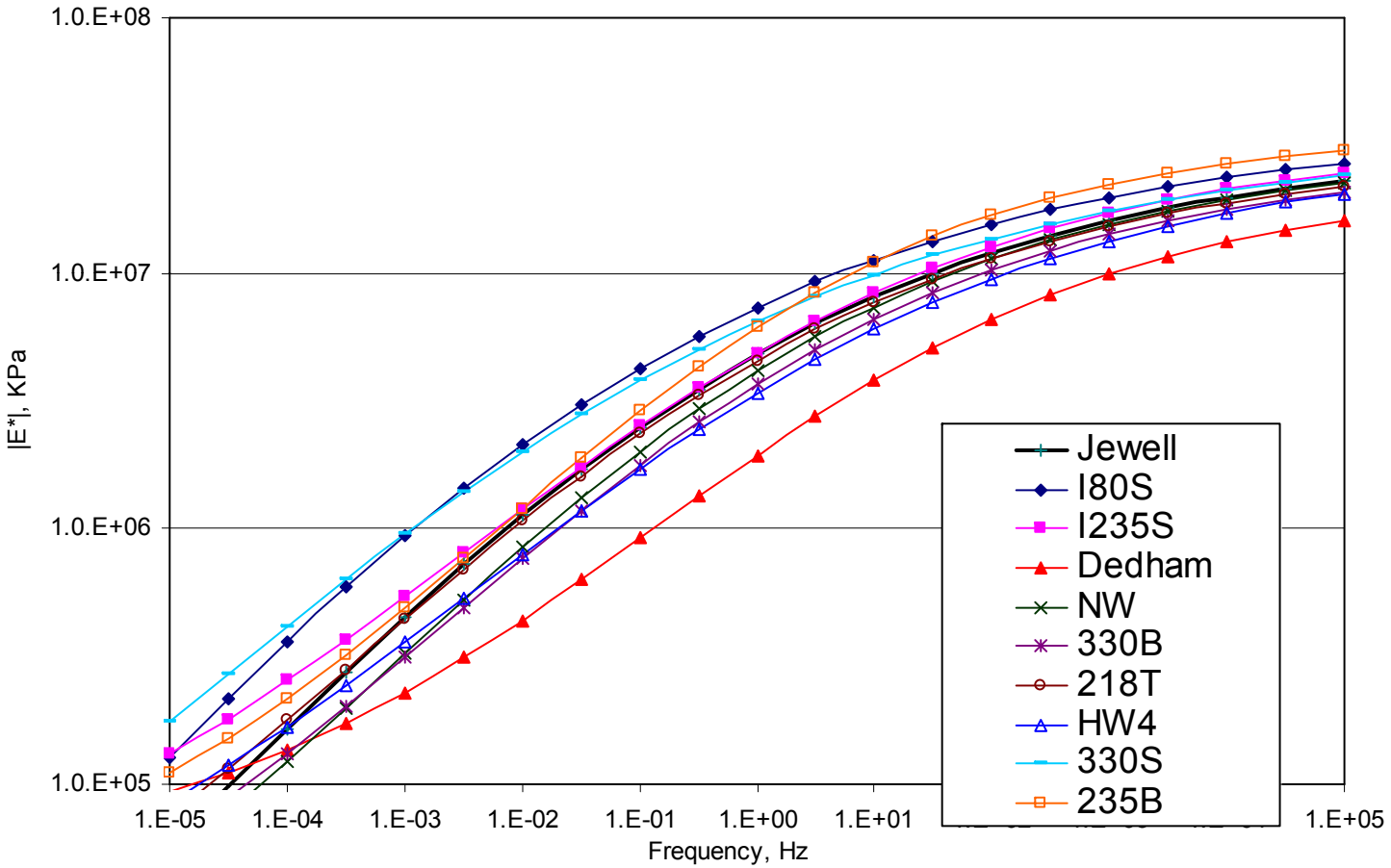



Three temperatures

# Dynamic Modulus for Iowa Mixtures

- **Selected temperatures**
  - 4.4, 21 and 37°C
- **Selected frequencies**
  - 25, 15, 10, 5, 2, 1, 0.5, 0.3 and 0.1
- **21 projects based on traffic level and binder PG**
  - 1M, 3M, 10M, 30M and 100M ESALs
  - PG58-28, 64-28, 64-22, 70-22 and 76-28

# Test Results for Iowa Mixtures



# Summary

- **Dynamic modulus shake down test**
  - Five temperatures and eleven frequencies
  - Two different strain levels
- **No statistical difference found**
  - strain level, replicates
- **No accumulated damage found**
- **Master curve build**
- **E* test protocol built for Iowa mixtures**
  - Three temperatures & Nine frequencies
- **Mix performance appears to coincide with volumetric design levels**

# Acknowledgements


- Iowa DOT
  - John Hinrichsen
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- Mike Heitzman
- Members of APAI

***Thank you!***

**Questions?**