NCHRP Project 9-48: Field versus Laboratory Volumetrics and Mechanical Properties

Louay N. Mohammad
Mostafa Elseifi
Sam Cooper, III

Department of Civil and Environmental Engineering
LA Transportation Research Center
Louisiana State University

2015 SEAUPG Annual Meeting
Williamsburg, Virginia
November 16 - 19, 2015

Research Team

Acknowledgements

- **NCHRP**
  - Dr. Ed Harrigan
  - Project Technical Review Panel
- **LADOTD and LTRC Research Staff**
- **Participating Contractors/DOTs**
  - Stark Asphalt — Florida DOT
  - Mathy Const. Co. — Iowa DOT
  - Prairie Const. Co. — Michigan DOT
  - Barriere Const. Co. — South Dakota DOT
  - Diamond B Const. — Virginia DOT
  - Community Asphalt — Wisconsin DOT
- **Texas Transportation Institute**
- **University of Wisconsin**

Outline

- **Objective / Scope**
- **Conduct of Experiment**
- **Preliminary Data Analysis**
  - **Impacts of *process-based factors* on differences specimen types:**
    - **Design (LL), Production (PL) and Construction (PF)**
  - **Compare *mechanistic* properties of 3 specimen types**
    - **LL, PL, PF**
    - **LWT, E* (Axial, Indirect)**
    - **Develop shift factors**
  - **Compare *volumetric* properties of 3 specimen types**
  - **LL, PL, PF**
    - **Develop tolerance recommendation**
- **Summary**

Objective

- **Determine the _cause_ and _magnitude_ of differences and variances in measured volumetric and mechanical properties within and between three specimen types:**
  - **Laboratory-mixed and laboratory compacted (LL)**
    - **Design**
  - **Plant mixed and laboratory compacted (PL)**
    - **Production**
  - **Plant mixed and field compacted (PF)**
    - **Construction**

Experiment

- **Five Process-Based factors**
  - **two contrasting levels -- low and high**

Factor ID	Process	Low (-)	High (+)
1	Baghouse fine	No	Yes
2	Time delay in specimen fabrication (PL)	No	Yes
3	Aggregate absorption	Low	High
4	Aggregate degradation	Soft	Hard
5	Aggregate stockpile in situ properties Moisture Content	Low	High

Experiment

- **Volumetric properties**
  - **AV, VMA, Gmm, AC (Solvent), gradation, Gsb**
  - **LL, PL, PF**
- **Mechanistic properties**
  - **Hamburg LWT**
    - » **LL, PL, PF**
  - **IDT Dynamic modulus**
    - » **LL, PL, PF**
  - **Axial Dynamic Modulus**
    - » **LL, PL**

Experiment

- **Full Factorial design**
  - **2^5 factor combinations x 3 specimen types**
    - » **96 test combinations**
- **Volumetric properties**
  - **96 x 3 x 3 = 864**
- **Mechanistic properties**
  - **96 x 4 x 3 = 1152**
- **Total number of samples**

–2016

Experiment

- **Quarter fractional design**
  - **2^{5-2} factor combinations x 3 specimen types**
    - » **24 test combinations**
- **Volumetric properties**
  - **24 x 3 x 3 = 216**
- **Mechanistic properties**
  - **24 x 4 x 3 = 288**
- **Total number of samples**

–504

Introduction

Outline

Introduction

Task 1: Literature

Task 2: Survey Collect and Analyze Data from Past Research

Task3: Develop Experimental Factorial

Task 4: Execute Experimental Factorial

Task 5: Conduct Data Analysis

Task 6: Develop Specification Recommendations

- **Process-Based Factors**
  - **Present during the production and testing of a mixture.**
    - **Source of the delivery of reclaimed fine material : baghouse fines, reclaimed asphalt pavement**
    - **Time delay in specimen fabrication: reheating, silo storage, sampling location, plant type, use of material transfer device**
    - **Aggregate properties: Absorption, Degradation, Angularity, Surface Texture**
    - **Aggregate stockpile in situ properties: moisture content**






10

Experiment

- **Fractional Factorial Design**
- **Only main effects will be evaluated**
  - **Interactions may not be quantified**

Mixture ID	Baghouse Fines	Reheating	Aggregate Absorption	Aggregate Degradation	Aggregate Moisture Content
Mix 1	No	No	Low	Soft	High
Mix 2	No	No	High	Hard	Low
Mix 3	No	Yes	Low	Hard	Low
Mix 4	No	Yes	High	Soft	High
Mix 5	Yes	No	Low	Hard	High
Mix 6	Yes	No	High	Soft	Low
Mix 7	Yes	Yes	Low	Soft	Low
Mix 8	Yes	Yes	High	Hard	High

Experiment

- **Fractional Factorial Design**
- **Only main effects will be evaluated**
  - **Interactions may not be quantified**

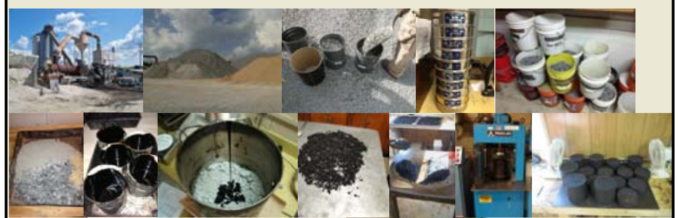
NMAS (mm)	Mixture ID	Baghouse Fines	Time Delay	Aggregate Water Absorption (%)	Aggregate Degradation (Mic.D/LA Abr.)	Stockpile Moisture Content
12.5	Mix 1	No	No	~ 1.0	> 30 / > 40	High
	Mix 2	No	No	~ 4.0	< 20 / < 20	Low
	Mix 3	No	Yes	~ 1.0	< 20 / < 20	Low
	Mix 4	No	Yes	~ 4.0	> 30 / > 40	High
	Mix 5[a,b,c,d,e,f]	Yes	No	~ 1.0	< 20 / < 20	High
	Mix 6	Yes	No	~ 4.0	> 30 / > 40	Low
	Mix 7	Yes	Yes	~ 1.0	> 30 / > 40	Low
	Mix 8	Yes	Yes	~ 4.0	< 20 / < 20	High

Experiment – Field Project

- Survey
- DOTs
- Contractors
- On-going NCHRP Projects

Experiment

- LL Specimen Fabrication
  - Approximately 120 kg of loose mixture required



Experiment

- PL Specimen Fabrication
  - Approximately 120 kg of loose mixture required

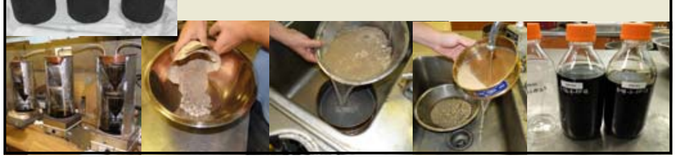
Experiment

- PF Specimen Collection

- Roadway cores collected prior to trafficking
- Each core is trimmed to required specimen size for testing

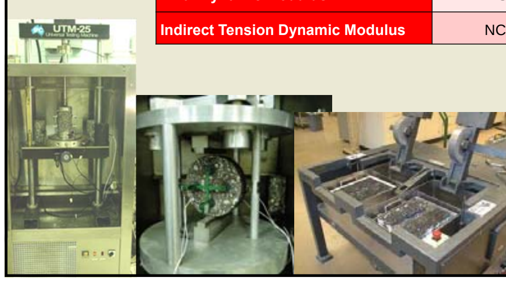
Experiment – Volumetric Properties

Volumetric Property	Test Method
G_{mm}	AASHTO T 209
G_{mb}/Air Voids	AASHTO T 166 AASHTO T 269
Asphalt Content (Extraction)	AASHTO T 164
Aggregate Gradation	AASHTO T 30
Aggregate Bulk Specific Gravity/Absorption	AASHTO T 84 AASHTO T 85



Experiment – Mechanistic Properties

Mechanistic Property	Test Method
Rut Depth (LWT)	AASHTO T 324
Axial Dynamic Modulus	AASHTO T 342
Indirect Tension Dynamic Modulus	NCSU (2004)



Individual Mixture Statistics

Data Analysis Methodology

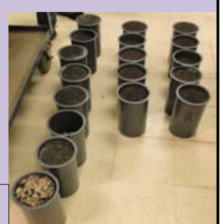
Outline
Introduction
Task 1: Literature
Task 2: Survey Collect and Analyze Data from Past Research
Task3: Develop Experimental Factorial
Task 4: Execute Experimental Factorial
Task 5: Conduct Data Analysis
Task 6: Develop Specification Recommendations

- For Each Parameter (i.e. Air Voids)
  - Delta Analysis
    - difference between means of two specimen types

$$\Delta_{\text{Air Voids,PL-LL}} = \text{Mean}_{\text{Air Voids,PL}} - \text{Mean}_{\text{Air Voids,LL}}$$

Individual Mixture Analysis – Mix 1

Outline
Introduction
Task 1: Literature
Task 2: Survey Collect and Analyze Data from Past Research
Task3: Develop Experimental Factorial
Task 4: Execute Experimental Factorial
Task 5: Conduct Data Analysis
Task 6: Develop Specification Recommendations



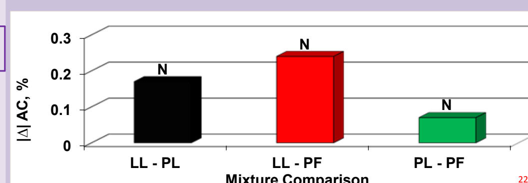
Mixture	Mixture Conditions				
	Baghouse Fines Used	Reheating	Aggregate Absorption, %	Aggregate Degradation (LA Abrasion)	Aggregate Moisture Content, %
Mix1WI	No (–)	Yes/No (–/+)	1.7 (–)	38 (+)	4.8 (+)

Effect of Specimen Type: Asphalt Content Mix 1 -- WI

Outline
Introduction
Task 1: Literature
Task 2: Survey Collect and Analyze Data from Past Research
Task3: Develop Experimental Factorial
Task 4: Execute Experimental Factorial
Task 5: Conduct Data Analysis
Task 6: Develop Specification Recommendations

Specimen Type	AVG	ST.Dev
LL	5.40	0.03
PL	5.57	0.07
PF	5.64	0.23

AC– Delta Summary, %		
LL - PL	LL - PF	PL - PF
-0.17	-0.24	-0.07

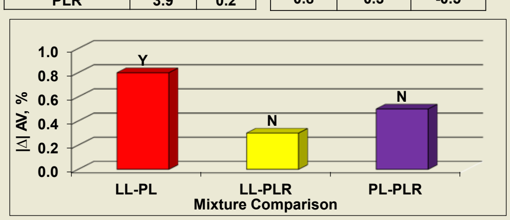


Effect of Specimen Type: Air Voids

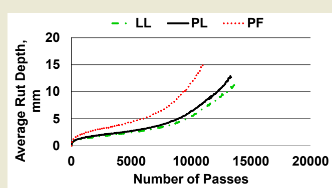
Mix 1 -- WI

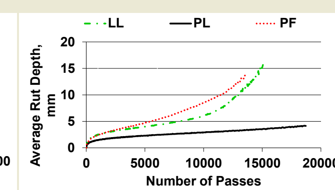
Specimen Type	AVG	ST. Dev
LL	4.2	0.6
PL	3.4	0.3
PLR	3.9	0.2

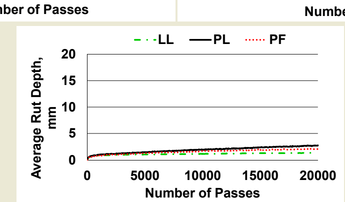
AV – Delta Summary, %		
LL - PL	LL - PLR	PL - PLR
0.8	0.3	-0.5



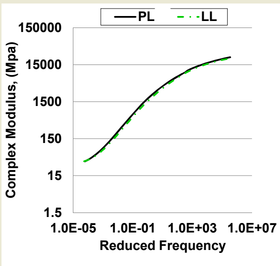
Effect of Specimen Type: LWT Test



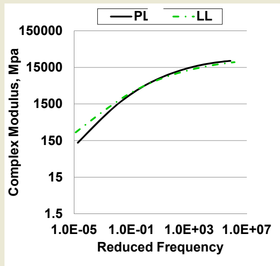




Effect of Specimen Type:
Axial Dynamic Modulus

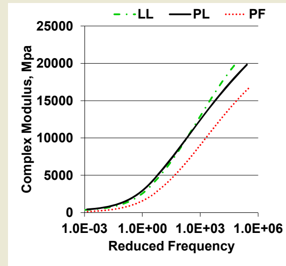


Mix 5 SD

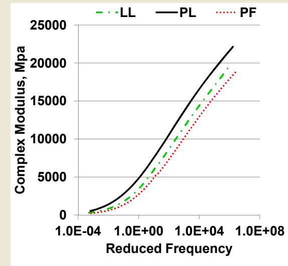


Mix 8 LA

Effect of Specimen Type:
IDT Dynamic Modulus



Mix 3MN



Mix 5VA

Combined Mixture Analysis

27

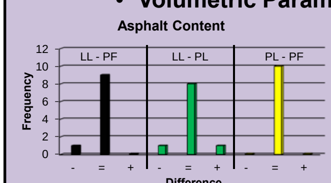
Data Analysis Methodology – Combined Analysis

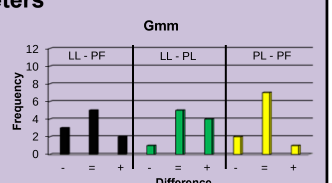
- Meta-Analysis:
  - A statistical technique used to combine various data sets into one meta-data set
  - Objective: to determine the magnitude and cause of variability between specimen types
  - Combine delta analyses of individual mixtures.

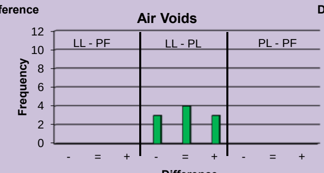
28

Summary of Differences Among Specimen Types
Design (LL), Production (PL), Construction (PF),

- Volumetric Parameters



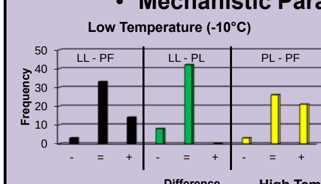


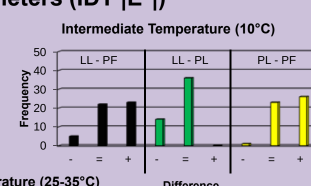


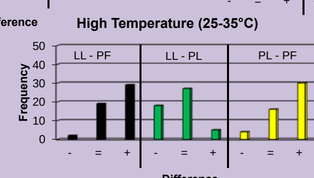
29

Summary of Differences Among Specimen Types
Design (LL), Production (PL), Construction (PF),

- Mechanistic Parameters (IDT |E*|)







30

Summary of Differences Among Specimen Types
Design (LL), Production (PL), Construction (PF),

- Volumetric Parameters

Statistical Difference / Practical Difference

Comparison	VTM	VMA	VFA	Gmm	AC	Gsb
LL vs PF		----		50%/20%	10%/0%	20%/20%
LL vs PL	60%/20%	30%/10%	80%/50%	70%/20%	20%/20%	40%/10%
PL vs PF		----		30%/20%	10%/10%	10%/10%

- Mechanistic Parameters

Comparison	LWT	Axial E*	IDT E*
LL vs PF	38%	----	57%
LL vs PL	18%	55%	29%
PL vs PF	52%	----	61%

31

Summary of Differences Among Specimen Types
Design (LL), Production (PL), Construction (PF),

Outline
Introduction
Task 1: Literature
Task 2: Survey Collect and Analyze Data from Past Research
Task3: Develop Experimental Factorial
Task 4: Execute Experimental Factorial
Task 5: Conduct Data Analysis
Task 6: Develop Specification Recommendations

- Volumetric Testing:
  - Statistically significant volumetric differences observed throughout 10 mixtures tested.
  - Effect of time delay was not significant for volumetric for mixtures evaluated.
  - Asphalt content
    - Specimens type were not statistically different.
  - Gmm
    - Statistical differences were noted for Gmm between three specimen types
  - Air voids
    - Significant differences mainly due to Gmm influences

32

Summary of Differences Among Specimen Types
Design (LL), Production (PL), Construction (PF),

Outline
Introduction
Task 1: Literature
Task 2: Survey Collect and Analyze Data from Past Research
Task3: Develop Experimental Factorial
Task 4: Execute Experimental Factorial
Task 5: Conduct Data Analysis
Task 6: Develop Specification Recommendations

- Mechanistic Testing:
  - Field cores exhibited statistically significant differences when compared to laboratory compacted specimens.
  - LWT:
    - Lab compaction vs Field compaction exhibited large and significant differences
  - Axial Dynamic Modulus:
    - in general, no difference between design (LL) and production (PL) specimens for low and intermediate temperatures.
  - IDT Dynamic Modulus:
    - 4 to 50% differences between three sample types.

33

Effect of Process-Based Factors

34

Effect of Process-Based Factors
Design (LL), Production (PL), Construction (PF),

Property	Comparison	Significant Process
AV, %	Design (LL) - Production (PL)	Stockpile Moisture
VMA, %		None
VFA, %		None
AC	Design (LL) - Production (PL)	Baghouse fine return and aggregate absorption
	Design (LL) - Construction (PF)	Baghouse fine return
	Production (PL) - Construction (PF)	None
Gmm	Design (LL) - Production (PL)	None
	Design (LL) - Construction (PF)	
	Production (PL) - Construction (PF)	
Gsb	Design (LL) - Production (PL)	None
	Design (LL) - Construction (PF)	
	Production (PL) - Construction (PF)	
Gradation	Design (LL) - Production (PL)	Baghouse fine return and aggregate hardness
	Design (LL) - Construction (PF)	Baghouse fine return, aggregate hardness, and stockpile moisture
	Production (PL) - Construction (PF)	None

35

Effect of Process-Based Factors
Design (LL), Production (PL), Construction (PF),

Outline
Introduction
Task 1: Literature
Task 2: Survey Collect and Analyze Data from Past Research
Task3: Develop Experimental Factorial
Task 4: Execute Experimental Factorial
Task 5: Conduct Data Analysis
Task 6: Develop Specification Recommendations

- Mechanistic:
  - No effect of process-based factors for all specimen comparisons



36

Magnitude of Volumetric Differences

Volumetric Properties Comparison
Tolerance Recommendation

Outline
Introduction
Task 1: Literature
Task 2: Survey Collect and Analyze Data from Past Research
Task3: Develop Experimental Factorial
Task 4: Execute Experimental Factorial
Task 5: Conduct Data Analysis
Task 6: Develop Specification Recommendations

- Compare volumetric properties of three specimen types
  - LL, PL, and PF
- Determine magnitude of differences among specimen types
- Develop tolerance recommendations
- Determined by averaging differences for all mixtures and applying confidence interval based on combined standard deviation

Volumetric Properties Comparison
Tolerance Recommendation – Design vs Production

Outline
Introduction
Task 1: Literature
Task 2: Survey Collect and Analyze Data from Past Research
Task3: Develop Experimental Factorial
Task 4: Execute Experimental Factorial
Task 5: Conduct Data Analysis
Task 6: Develop Specification Recommendations

Comparison	Property	Avg	Min	Max	Confidence Limit 95%
Design (LL) / Production (PL)	AV,%	0.6	0.0	1.3	0.8
	VMA,%	0.4	0.0	2.1	1.2
	VFA,%	4.0	0.3	9.9	5.4
	AC,%	0.2	0.0	0.4	0.2
	Gmm	0.014	0.002	0.039	0.020
	Gsb	0.011	0.002	0.025	0.014
	Passing 0.075 mm, %	0.4	0.0	0.9	0.5

Volumetric Properties Comparison
Tolerance Recommendation – Design vs Production

Outline
Introduction
Task 1: Literature
Task 2: Survey Collect and Analyze Data from Past Research
Task3: Develop Experimental Factorial
Task 4: Execute Experimental Factorial
Task 5: Conduct Data Analysis
Task 6: Develop Specification Recommendations

Comparison	Property	Avg	Min	Max	Confidence Limit 95%
Design (LL) / Production (PL)	AV,%	0.6	0.0	1.3	0.8
	VMA,%	0.4	0.0	2.1	1.2
	VFA,%	4.0	0.3	9.9	5.4
	AC,%	0.2	0.0	0.4	0.2
	Gmm	0.014	0.002	0.039	0.020
	Gsb	0.011	0.002	0.025	0.014
	Passing 0.075 mm, %	0.4	0.0	0.9	0.5

Volumetric Properties Comparison
Tolerance Recommendation – Design vs Construction

Outline
Introduction
Task 1: Literature
Task 2: Survey Collect and Analyze Data from Past Research
Task3: Develop Experimental Factorial
Task 4: Execute Experimental Factorial
Task 5: Conduct Data Analysis
Task 6: Develop Specification Recommendations

Comparison	Property	Avg	Min	Max	Confidence Limit 95%
Design (LL) / Construction (PF)	AC,%	0.2	0.0	0.3	0.2
	Gmm	0.011	0.000	0.020	0.013
	Gsb	0.010	0.001	0.033	0.019
	Passing 0.075 mm, %	0.7	0.1	1.3	0.7

Volumetric Properties Comparison
Tolerance Recommendation – Production vs Construction

Outline
Introduction
Task 1: Literature
Task 2: Survey Collect and Analyze Data from Past Research
Task3: Develop Experimental Factorial
Task 4: Execute Experimental Factorial
Task 5: Conduct Data Analysis
Task 6: Develop Specification Recommendations

Comparison	Property	Avg	Min	Max	Confidence Limit 95%
Production (PL) / Construction (PF)	AC,%	0.1	0.0	0.4	0.2
	Gmm	0.009	0.001	0.027	0.018
	Gsb	0.008	0.000	0.031	0.017
	Passing 0.075 mm, %	0.5	0.1	0.8	0.5

Outline
Introduction
Task 1: Literature
Task 2: Survey Collect and Analyze Data from Past Research
Task3: Develop Experimental Factorial
Task 4: Execute Experimental Factorial
Task 5: Conduct Data Analysis
Task 6: Develop Specification Recommendations

Volumetric Properties Comparison

Tolerance Recommendation – Asphalt Content

- Design (LL) vs Production (PL): ± 0.2%
- Design (LL) vs Construction (PF): ± 0.2%
- Production (PL) vs Construction (PF): ± 0.2%

- Above Tolerance
- At Tolerance
- Below Tolerance
- Not Specified

43

Magnitude of Mechanistic Differences

44

Outline
Introduction
Task 1: Literature
Task 2: Survey Collect and Analyze Data from Past Research
Task3: Develop Experimental Factorial
Task 4: Execute Experimental Factorial
Task 5: Conduct Data Analysis
Task 6: Develop Specification Recommendations

Mechanistic Properties Comparison

Shift Factors

- Compare mechanistic properties of three specimen types
  - LL, PL, and PF
- Develop Shift Factors
  - Loaded Wheel Tracking Test
  - Axial Dynamic Modulus
  - IDT Dynamic Modulus
- Developed by comparing average values to each specimen type.
  - For example:
    - LL avg / PL avg (for each parameter)
    - Repeat for other specimen comparisons

45

Outline
Introduction
Task 1: Literature
Task 2: Survey Collect and Analyze Data from Past Research
Task3: Develop Experimental Factorial
Task 4: Execute Experimental Factorial
Task 5: Conduct Data Analysis
Task 6: Develop Specification Recommendations

Mechanistic Properties Comparison

Shift Factors – LWT

- Recommended Shift

–Design (LL) to Production (PL): 1.0
–Design (LL) to Construction (PF) : 0.75
–Production (PL) to Construction (PF): 0.75

– Specification Requirement: 12 mm
– Lab Design ≤ 9 mm

46

Outline
Introduction
Task 1: Literature
Task 2: Survey Collect and Analyze Data from Past Research
Task3: Develop Experimental Factorial
Task 4: Execute Experimental Factorial
Task 5: Conduct Data Analysis
Task 6: Develop Specification Recommendations

Mechanistic Properties Comparison

Shift Factors – Axial Dynamic Modulus

- Recommended Shift
  - Shift may need to be utilized at higher temperatures
    - » May relate to binder oxidation in plant produced mixtures

Comparison	Temperature, °C	Average Shift	Shift Range	
			Minimum	Maximum
Design (LL) / Production (PL)	-10.0	1.0	0.7	1.1
	4.4	1.0	0.7	1.1
	25.0	0.9	0.6	1.1
	37.8	0.8	0.5	1.1
	54.4	0.8	0.5	1.2

47

Outline
Introduction
Task 1: Literature
Task 2: Survey Collect and Analyze Data from Past Research
Task3: Develop Experimental Factorial
Task 4: Execute Experimental Factorial
Task 5: Conduct Data Analysis
Task 6: Develop Specification Recommendations

Mechanistic Properties Comparison

Shift Factors – IDT Dynamic Modulus

- Recommended Shift
  - Need for shift increase with test temperature.
    - » IDT Dynamic modulus is highly sensitive to binder properties and aggregate orientation at elevated temperatures

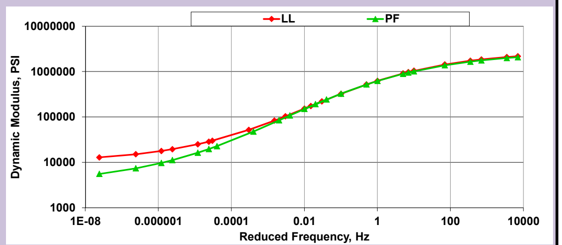
Temperature, °C	Comparison	Average Correction	Correction Range	
			Minimum	Maximum
-10	Design (LL)/Production (PL)	1.0	0.8	1.1
	Design (LL)/Construction (PF)	1.0	0.9	1.3
	Production (PL)/Construction (PF)	1.1	0.9	1.4
10	Design (LL)/Production (PL)	0.9	0.8	1.1
	Design (LL)/Construction (PF)	1.2	0.8	1.5
	Production (PL)/Construction (PF)	1.3	0.9	1.7
35	Design (LL)/Production (PL)	1.0	0.6	1.4
	Design (LL)/Construction (PF)	1.4	0.9	2.1
	Production (PL)/Construction (PF)	1.5	0.8	2.2

48

Mechanistic Properties Comparison
Use of Shift Factor – IDT Modulus

Outline
Introduction
Task 1: Literature
Task 2: Survey Collect and Analyze Data from Past Research
Task3: Develop Experimental Factorial
Task 4: Execute Experimental Factorial
Task 5: Conduct Data Analysis
Task 6: Develop Specification Recommendations

- Apply shift factor
- PF to LL

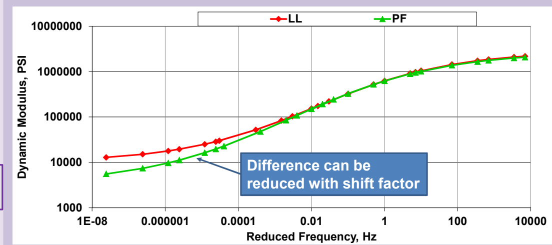


49

Mechanistic Properties Comparison
Use of Shift Factor – IDT Modulus

Outline
Introduction
Task 1: Literature
Task 2: Survey Collect and Analyze Data from Past Research
Task3: Develop Experimental Factorial
Task 4: Execute Experimental Factorial
Task 5: Conduct Data Analysis
Task 6: Develop Specification Recommendations

- Apply shift factor
- PF to LL

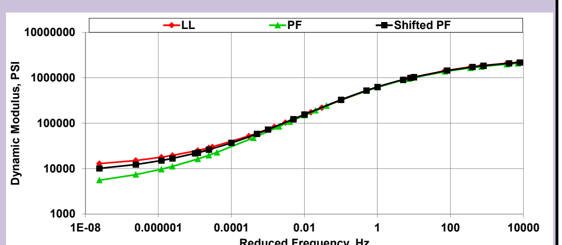


50

Mechanistic Properties Comparison
Use of Shift Factor – IDT Modulus

Outline
Introduction
Task 1: Literature
Task 2: Survey Collect and Analyze Data from Past Research
Task3: Develop Experimental Factorial
Task 4: Execute Experimental Factorial
Task 5: Conduct Data Analysis
Task 6: Develop Specification Recommendations

- Apply shift factor
- PF to LL



51

Implementation Recommendations

Outline
Introduction
Task 1: Literature
Task 2: Survey Collect and Analyze Data from Past Research
Task3: Develop Experimental Factorial
Task 4: Execute Experimental Factorial
Task 5: Conduct Data Analysis
Task 6: Develop Specification Recommendations

- **Design Recommendations**
  - Introduce baghouse fines into laboratory produced mixtures

Baghouse fines returned during production?
↓ Yes
Determine quantity returned
↓ 0.5 - 3%
"Pepper" Laboratory Mixture with appropriate baghouse material

Implementation Recommendations

Outline
Introduction
Task 1: Literature
Task 2: Survey Collect and Analyze Data from Past Research
Task3: Develop Experimental Factorial
Task 4: Execute Experimental Factorial
Task 5: Conduct Data Analysis
Task 6: Develop Specification Recommendations

- **Performance Based Specification**
  - **LWT** – Consider shift factors when evaluating expected rut depth of field compacted specimens

Comparison	Conversion
Design (LL) / Production (PL)	1.0
Design (LL) / Construction (PF)	0.75
Production (PL) / Construction (PF)	0.75

53

Implementation Recommendations

Outline
Introduction
Task 1: Literature
Task 2: Survey Collect and Analyze Data from Past Research
Task3: Develop Experimental Factorial
Task 4: Execute Experimental Factorial
Task 5: Conduct Data Analysis
Task 6: Develop Specification Recommendations

- **Design Recommendations**
  - **Axial Dynamic Modulus** – Consider shift factors when evaluating expected modulus values
  - May be important for **performance prediction and pavement design**

Comparison	Temperature, °C	Conversion
Design (LL)/ Production (PL)	-10.0	1.0
	4.4	1.0
	25.0	0.9
	37.8	0.8
	54.4	0.8

54

Implementation Recommendations

- Design Recommendations
  - Axial Dynamic Modulus – Consider shift factors when evaluating expected modulus values
  - May be important for performance prediction and pavement design

Comparison	Temperature, °C	Conversion
Design (LL)/ Production (PL)	-10.0	1.0
	4.4	1.0
	25.0	0.9
	37.8	0.8
	54.4	0.8

PL modulus 20% higher than LL at high temperature

55

Outline
Introduction
Task 1: Literature
Task 2: Survey Collect and Analyze Data from Past Research
Task3: Develop Experimental Factorial
Task 4: Execute Experimental Factorial
Task 5: Conduct Data Analysis
Task 6: Develop Specification Recommendations

Implementation Recommendations

- Design Recommendations
  - Indirect Tension Dynamic Modulus – Consider shift factors when evaluating expected modulus values

Temperature, °C	Comparison	Average Correction	Correction Range Minimum	Correction Range Maximum
-10	Design (LL)/Production (PL)	1.0	0.8	1.1
	Design (LL)/Construction (PF)	1.0	0.9	1.3
	Production (PL)/Construction (PF)	1.1	0.9	1.4
10	Design (LL)/Production (PL)	0.9	0.8	1.1
	Design (LL)/Construction (PF)	1.2	0.8	1.5
	Production (PL)/Construction (PF)	1.3	0.9	1.7
35	Design (LL)/Production (PL)	1.0	0.6	1.4
	Design (LL)/Construction (PF)	1.4	0.9	2.1
	Production (PL)/Construction (PF)	1.5	0.8	2.2

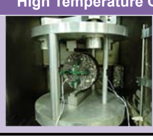
56

Outline
Introduction
Task 1: Literature
Task 2: Survey Collect and Analyze Data from Past Research
Task3: Develop Experimental Factorial
Task 4: Execute Experimental Factorial
Task 5: Conduct Data Analysis
Task 6: Develop Specification Recommendations

Implementation Recommendations

- Design Recommendations
  - Indirect vs Axial Dynamic Modulus
  - May be used to predict field core modulus from laboratory tested material

IDT vs. Axial	Conversion
Low Temperature Comparison, -10°C	0.81
Intermediate Temperature Comparison, 10°C	0.75
High Temperature Comparison, 25 - 35°C	0.90



57

THANK YOU