Effect of Specimen Preparation Variables on AMPT Tests

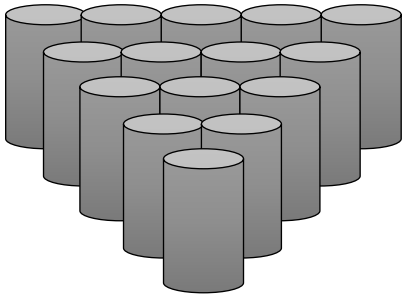
FHWA Cooperative Study at Asphalt Institute

Research Team

- Principal Investigator
  - Mike Anderson, Asphalt Institute
- Joint effort between Asphalt Institute and Advanced Asphalt Technologies
- Two phase study
- AMPT Implementation

Background

- NCHRP 9-29, Phase VI, Report 702

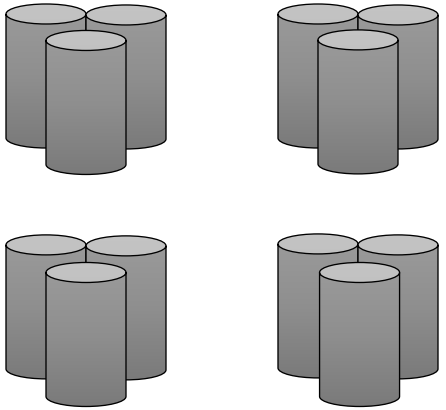


Specimens made in a single lab

Tested by 8 participating labs

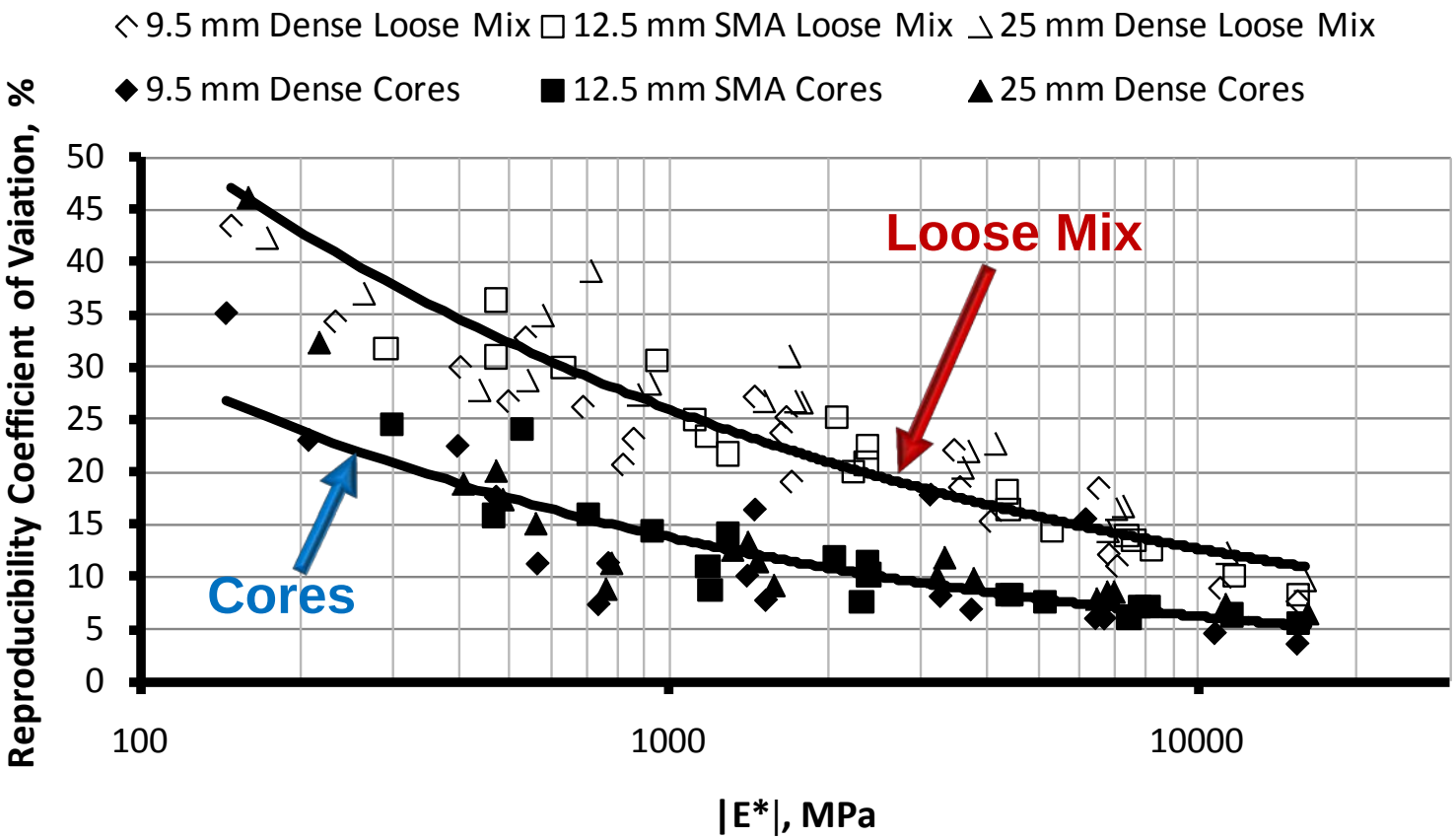
Loose mix shipped to participating labs

Specimens were made & tested in 8 different labs



Background

- NCHRP 9-29 ILS Results:



Phase I

- Focused on sample conditioning (AASHTO R 30) by examining ovens

- Phase I evaluations:
  1. How different is the temperature distribution in various forced-draft ovens?
  2. Does the oven quality make any difference in conditioning of the samples?
  3. Does frequent opening/closing of the ovens' door affect the conditioning of the loose mixtures?

Ovens in Phase I

Grieve (50 ft^3)

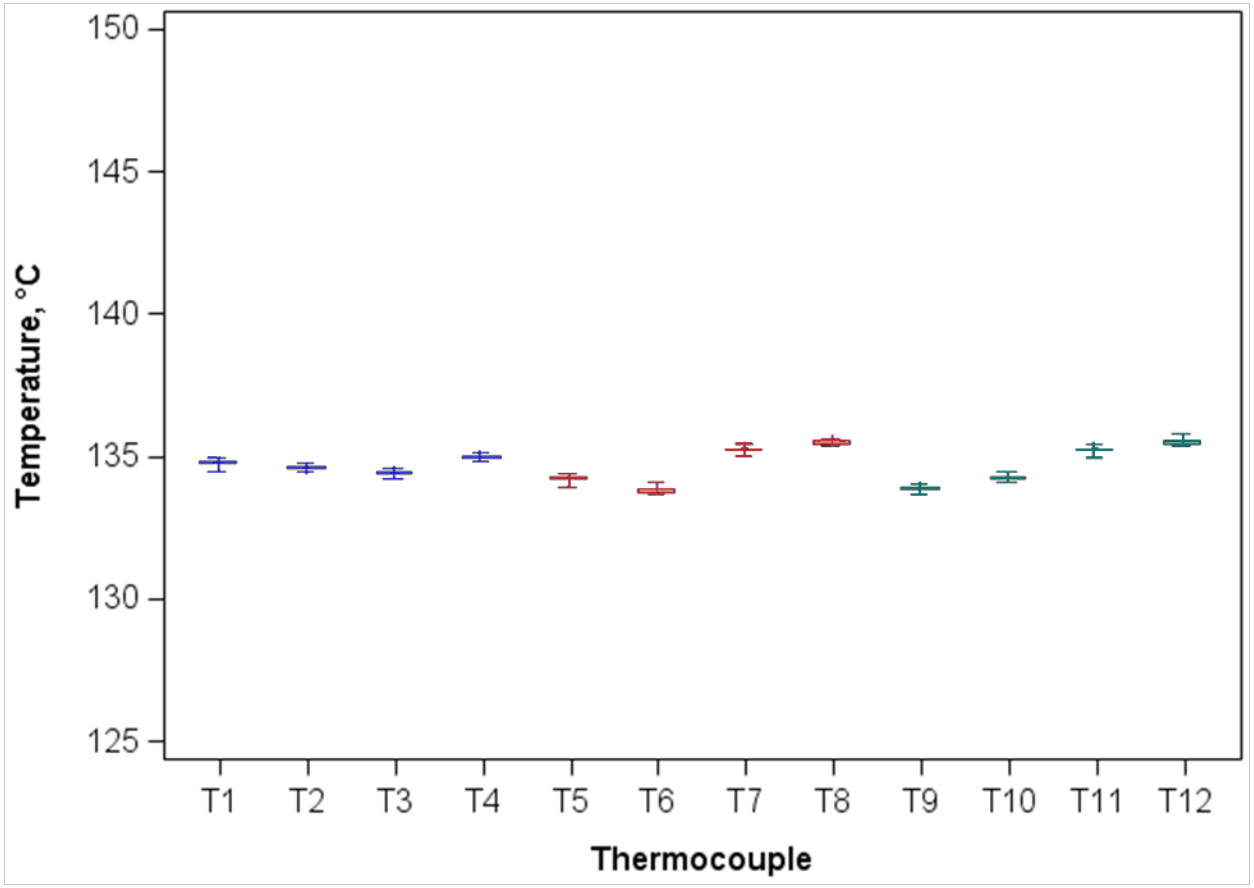
Grieve (26 ft^3)

Blue-M (8.3 ft^3)

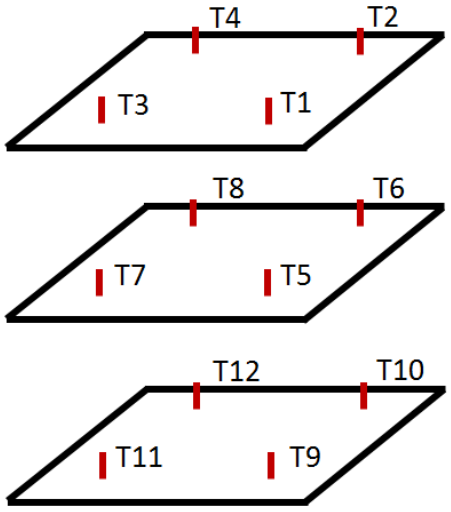
Quincy
(7.8 ft^3)

Evaluation 1: Grieve Oven Temperature

Closed oven, 4-hour conditioning simulation

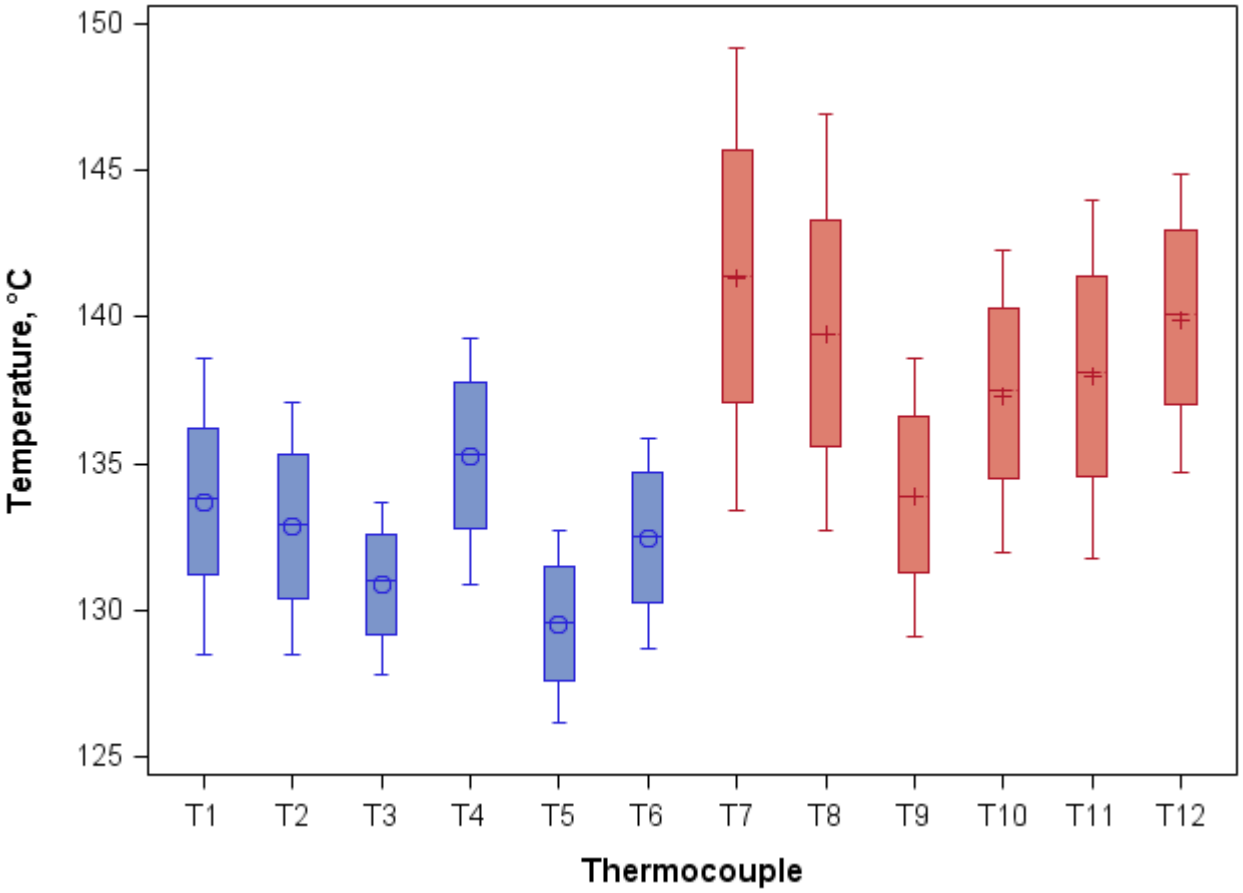


Temperature variability
133.5 - 135.9 °C

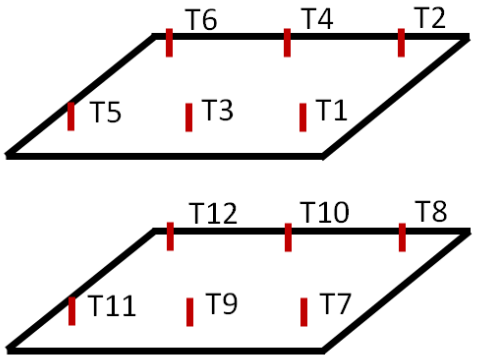


Evaluation 1: Quincy Oven Temperature

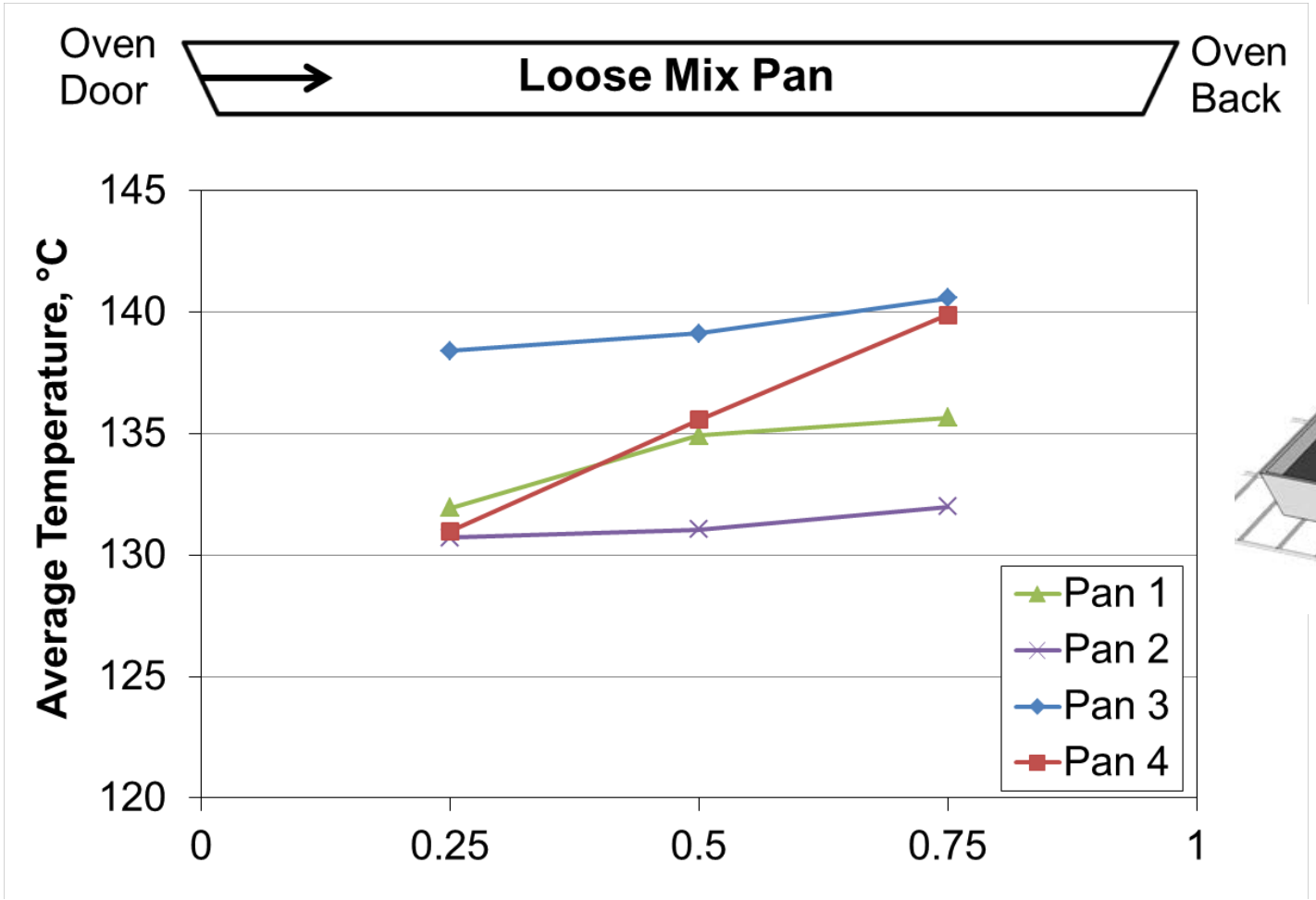
Closed oven, 4-hour conditioning simulation

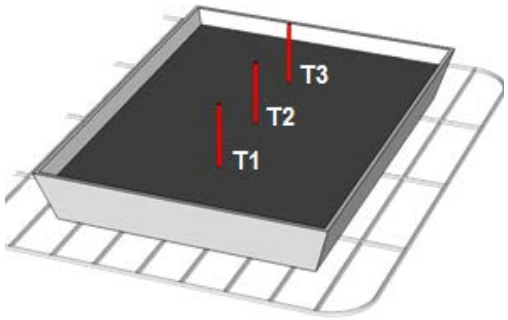


Temperature variability
126.2 – 149.2 °C

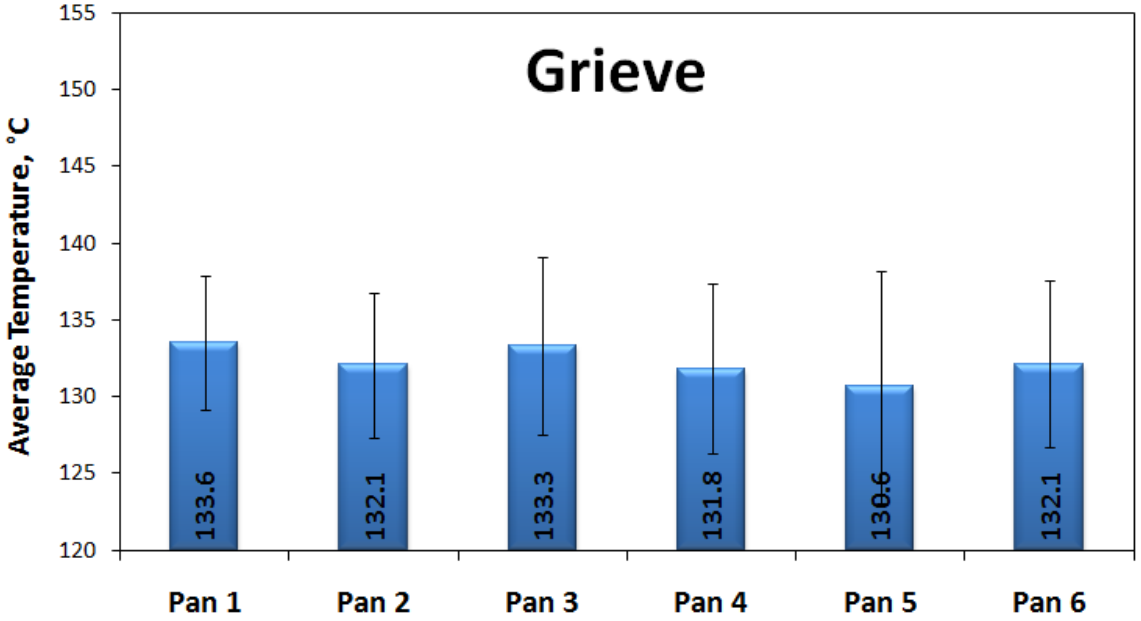


Evaluation 2: Mix Temperature in Quincy Oven

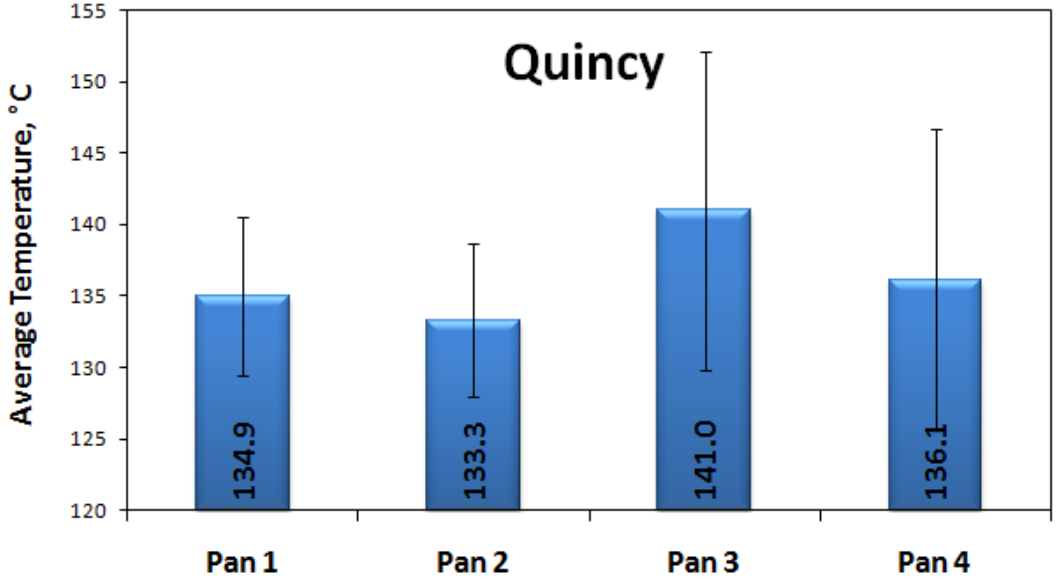




Evaluation 3: Opening & Closing Oven Doors

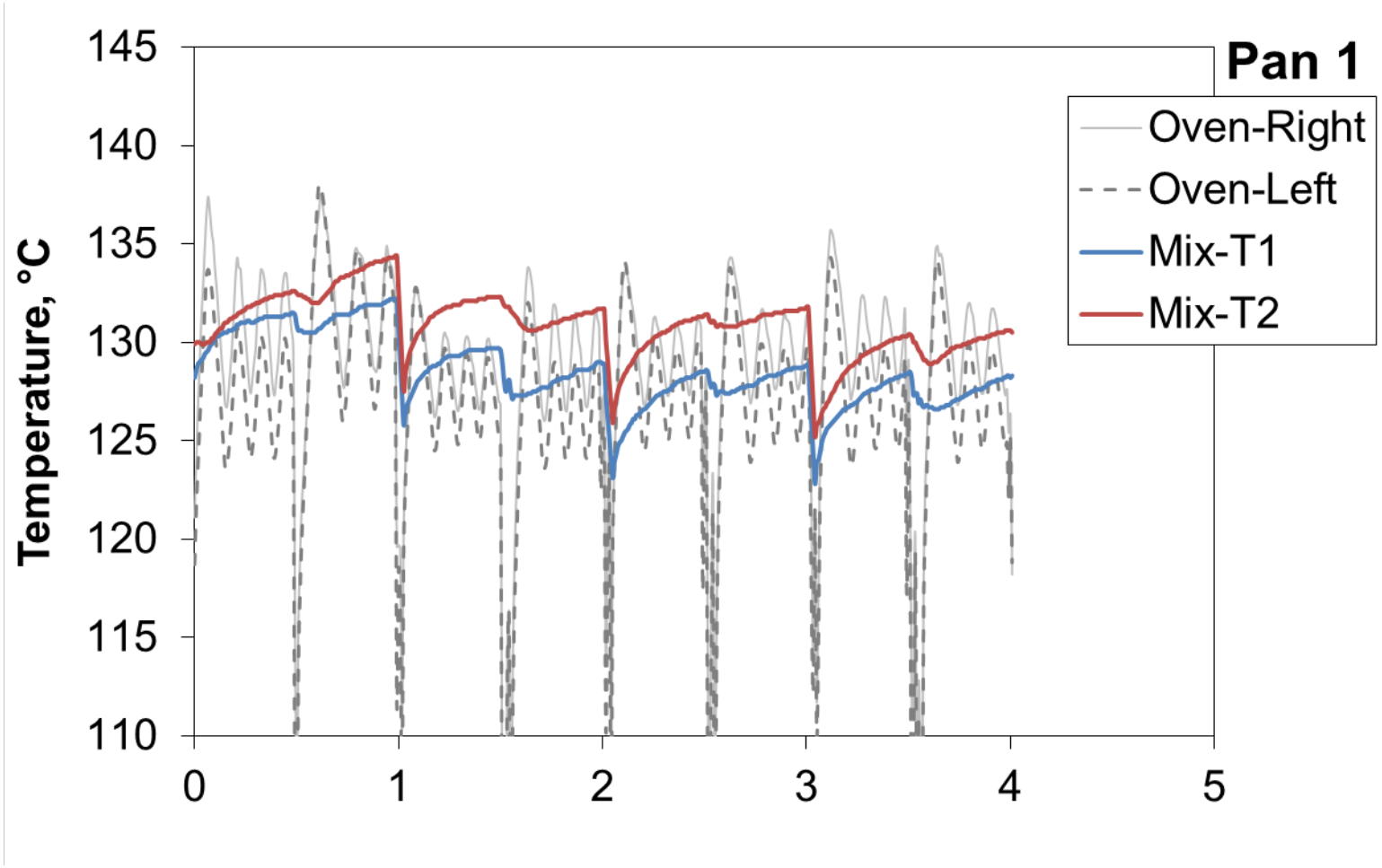


Oven <u>air</u> temperature. Oven door opened/closed regularly to stir the mix.



What Happens When I Open the Door?

Evaluation 4: Quincy oven, mix stirring



Phase I Conclusions

- Oven quality and power makes a large difference in stability and recovery
- Mix temperature varies during conditioning
- Opening the oven doors to stir the mix may not be prudent and can lower the mix temperature (less aged) in some ovens

Phase II Objectives

- To identify the sample preparation variables that significantly affect the AMPT test results
- To determine the acceptable range for the significant factors
- To make recommendations to minimize the AMPT test variability

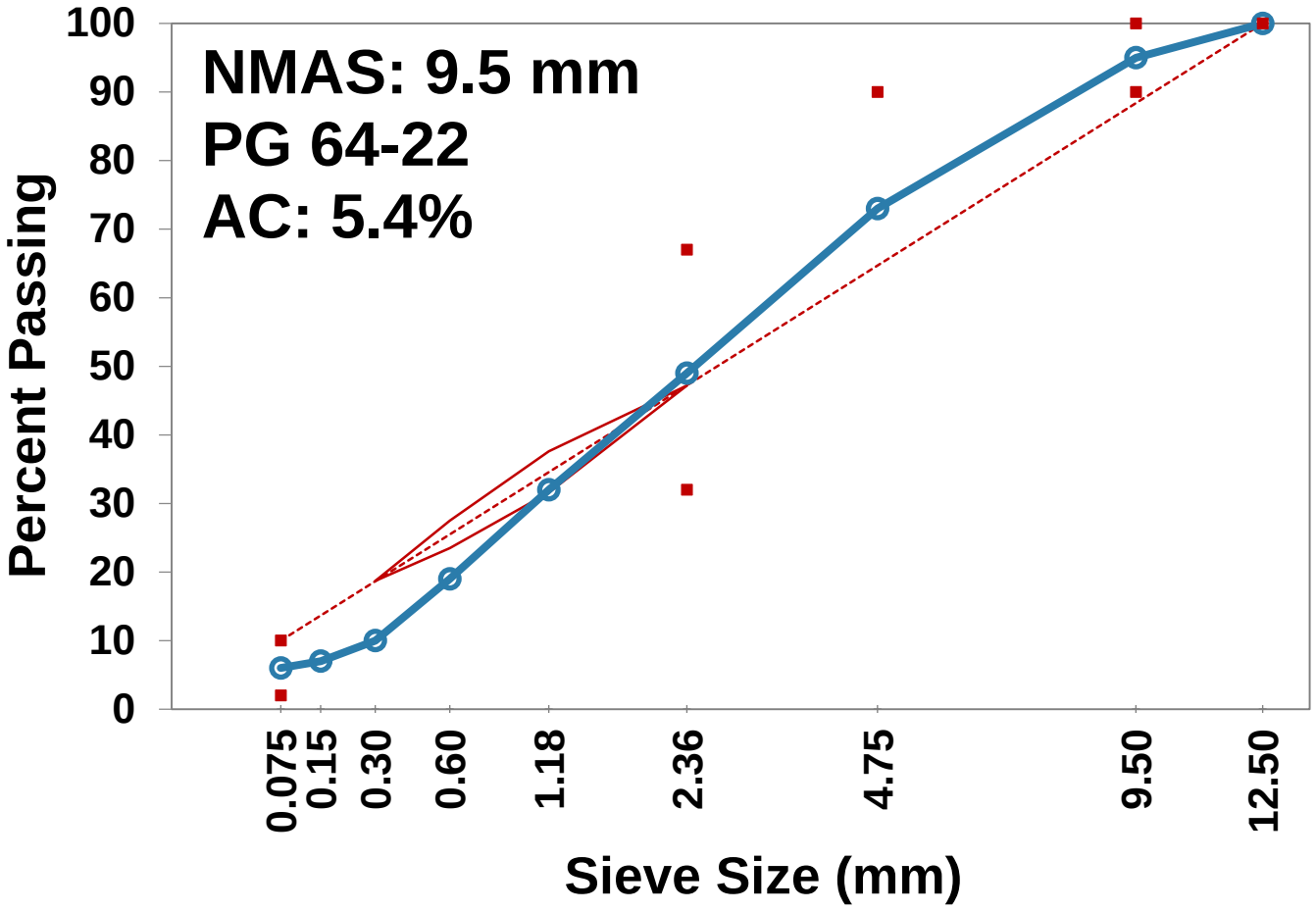
Variables

No.		Low	High
1	Mixing Temperature	139°C (282°F)	159°C (318°F)
2	Binder Time at Mixing Temperature	30 min	3 hours
3	Mixer Type	Bucket with hand agitation	Planetary with wire whip
4	Mixing Time	90 sec	180 sec
5	Loose Mix Conditioning Temp.	130°C (266°F)	140°C (284°F)
6	Loose Mix Conditioning Depth	25 mm	50 mm

Variables

No.		Low	High
7	Loose Mix Stirring	Not stirring	Stirring every 60-min
8	Mold Loading	Scoop	Gyro loader
9	Placement in Mold	No Rodding	Rodding 10 times at 2/3 depth
10	Additional Time at Compaction Temp.	0 min	30 min
11	Gyratory Specimen Height	170 mm	180 mm
12	Test Specimen Air Voids	6.0±0.5%	8.0±0.5%

Lab Standard Mix



Sieve	JMF
3/8 "	95
#4	73
#8	49
#16	32
#30	19
#50	10
#100	7
#200	6.0

Ruggedness Study

Experiment Design:

***Resolution IV, 1/256th Partially Replicated Factorial* Design**

- No main effects are confounded with any 2-factor interactions
- With three replicates, total number of 96 samples were tested

Test Matrix

	Specimen Groups																													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Mixing Temp.	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+
Binder Time at Mix T.	-	-	+	+	-	-	+	+	-	-	+	+	-	-	+	+	-	-	+	+	-	-	+	+	-	-	+	+	-	-	+	+
Mixer Type	-	-	-	-	+	+	+	+	-	-	-	-	+	+	+	+	-	-	-	-	+	+	+	+	-	-	-	-	+	+	+	+
Mixing Time	-	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+	-	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+
Mix Cond. Temp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Mix Cond. Depth	-	+	+	-	+	-	-	+	+	-	-	+	-	+	+	-	+	-	-	+	-	+	+	-	-	+	+	-	+	-	-	+
Mix Stirring	-	-	-	-	+	+	+	+	+	+	+	+	-	-	-	-	+	+	+	+	-	-	-	-	-	-	-	-	+	+	+	+
Mold Loading	-	-	+	+	-	-	+	+	+	+	-	-	+	+	-	-	+	+	-	-	+	+	-	-	-	-	+	+	-	-	+	+
Placement in Mold	-	+	-	+	-	+	-	+	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	-	+	-	+	-	+	-	+
Time at Comp. Temp.	-	-	+	+	+	+	-	-	-	-	+	+	+	+	-	-	+	+	-	-	-	-	+	+	+	+	-	-	-	-	+	+
Specimen Height	-	+	-	+	+	-	+	-	-	+	-	+	+	-	+	-	+	-	+	-	-	+	-	+	+	-	+	-	-	+	-	+
Specimen Air Voids	-	+	+	-	-	+	+	-	-	+	+	-	-	+	+	-	+	-	-	+	+	-	-	+	+	-	-	+	+	-	-	+

3 replicates, 96 total specimens

Test Matrix

Specimen #7

	Specimen Groups																															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Mixing Temp.	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+
Binder Time at Mix T.	-	-	+	+	-	-	+	+	-	-	+	+	-	-	+	+	-	-	+	+	-	-	+	+	-	-	+	+	-	-	+	+
Mixer Type	-	-	-	-	+	+	+	+	-	-	-	-	+	+	+	+	-	-	-	-	+	+	+	+	-	-	-	-	+	+	+	+
Mixing Time	-	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+	-	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+
Mix Cond. Temp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Mix Cond. Depth	-	+	+	-	+	-	-	+	+	-	-	+	-	+	+	-	+	-	-	+	-	+	+	-	-	+	+	-	+	-	-	+
Mix Stirring	-	-	-	-	+	+	+	+	+	+	+	+	-	-	-	-	+	+	+	+	-	-	-	-	-	-	-	-	+	+	+	+
Mold Loading	-	-	+	+	-	-	+	+	+	+	-	-	+	+	-	-	+	+	-	-	+	+	-	-	-	-	+	+	-	-	+	+
Placement in Mold	-	+	-	+	-	+	-	+	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	-	+	-	+	-	+	-	+
Time at Comp. Temp.	-	-	+	+	+	+	-	-	-	-	+	+	+	+	-	-	+	+	-	-	-	-	+	+	+	+	-	-	-	-	+	+
Specimen Height	-	+	-	+	+	-	+	-	-	+	-	+	+	-	+	-	+	-	+	-	-	+	-	+	+	-	+	-	-	+	-	+
Specimen Air Voids	-	+	+	-	-	+	+	-	-	+	+	-	-	+	+	-	+	-	-	+	+	-	-	+	+	-	-	+	+	-	-	+

3 replicates, 96 total specimens

Example: Specimen #7

	Factor	Level	Level Value
1	Mixing Temperature	-	139°C (282°F)
2	Binder Time at Mixing Temp.	+	3 hours
3	Mixer Type	+	Planetary with wire whip
4	Mixing Time	-	90 sec
5	Loose Mix Conditioning Temp.	-	130°C (266°F)
6	Loose Mix Conditioning Depth	-	25 mm
7	Loose Mix Stirring	+	Stirring every 60-min
8	Mold Loading	+	Gyro loader
9	Placement in Mold	-	No rodding
10	Additional Time at Compaction Temp.	-	0 min
11	Gyratory Specimen Height	+	180 mm
12	Test Specimen Air Voids	+	8%

Input from AI-FHWA Studies

- Ambient Specimen Storage (TRB 2014)
  - Storage time
  - Storage in bag
  - Time of cutting/coring
- Effect of mixing, conditioning, and compaction temperatures (TRB 2014)
  - Various temperatures and conditioning durations for neat and modified binders

Phase II Goal

- Quantitative Factors:
  - Determine the allowable tolerances of factors based on allowable E* test error
- Qualitative Factors:
  - Improving AMPT tests reproducibility
- Refining the AASHTO PP 60 standard

E* Results (10 Hz, 20°C)

Factor	Dynamic Modulus		Phase Angle	
	P-value	Significant at α=0.05	P-value	Significant at α=0.05
Mixing Temperature	0.8262	--	<0.0001	Yes
Binder Time at Mixing Temperature	0.1812	--	0.6966	--
Mixer Type	0.2011	--	0.9828	--
Mixing Time	0.1685	--	0.7546	--
Loose Mix Conditioning Temperature	0.0467	Yes	<0.0001	Yes
Loose Mix Conditioning Depth	0.8137	--	0.1498	--
Loose Mix Stirring	0.4941	--	0.0343	Yes
Mold Loading	0.1017	--	0.9389	--
Placement in Mold	0.0818	--	0.0004	Yes
Additional Time at Compaction Temp	0.5462	--	0.3069	--
Gyratory Specimen Height	0.6127	--	0.0776	--
Test Specimen Air Voids	<0.0001	Yes	<0.0001	Yes

E* Results (1 Hz, 20°C)

Factor	Dynamic Modulus		Phase Angle	
	P-value	Significant at α=0.05	P-value	Significant at α=0.05
Mixing Temperature	0.5614	--	<0.0001	Yes
Binder Time at Mixing Temperature	0.0761	--	0.8457	--
Mixer Type	0.4680	--	0.3146	--
Mixing Time	0.3456	--	0.2171	--
Loose Mix Conditioning Temperature	0.0002	Yes	<0.0001	Yes
Loose Mix Conditioning Depth	0.2706	--	0.1042	--
Loose Mix Stirring	0.0321	Yes	0.0212	Yes
Mold Loading	0.0638	--	0.8593	--
Placement in Mold	0.0794	--	0.0005	Yes
Additional Time at Compaction Temp	0.1409	--	0.0920	--
Gyratory Specimen Height	0.7283	--	0.1093	--
Test Specimen Air Voids	<0.0001	Yes	<0.0001	Yes

E* Results (0.1 Hz, 20°C)

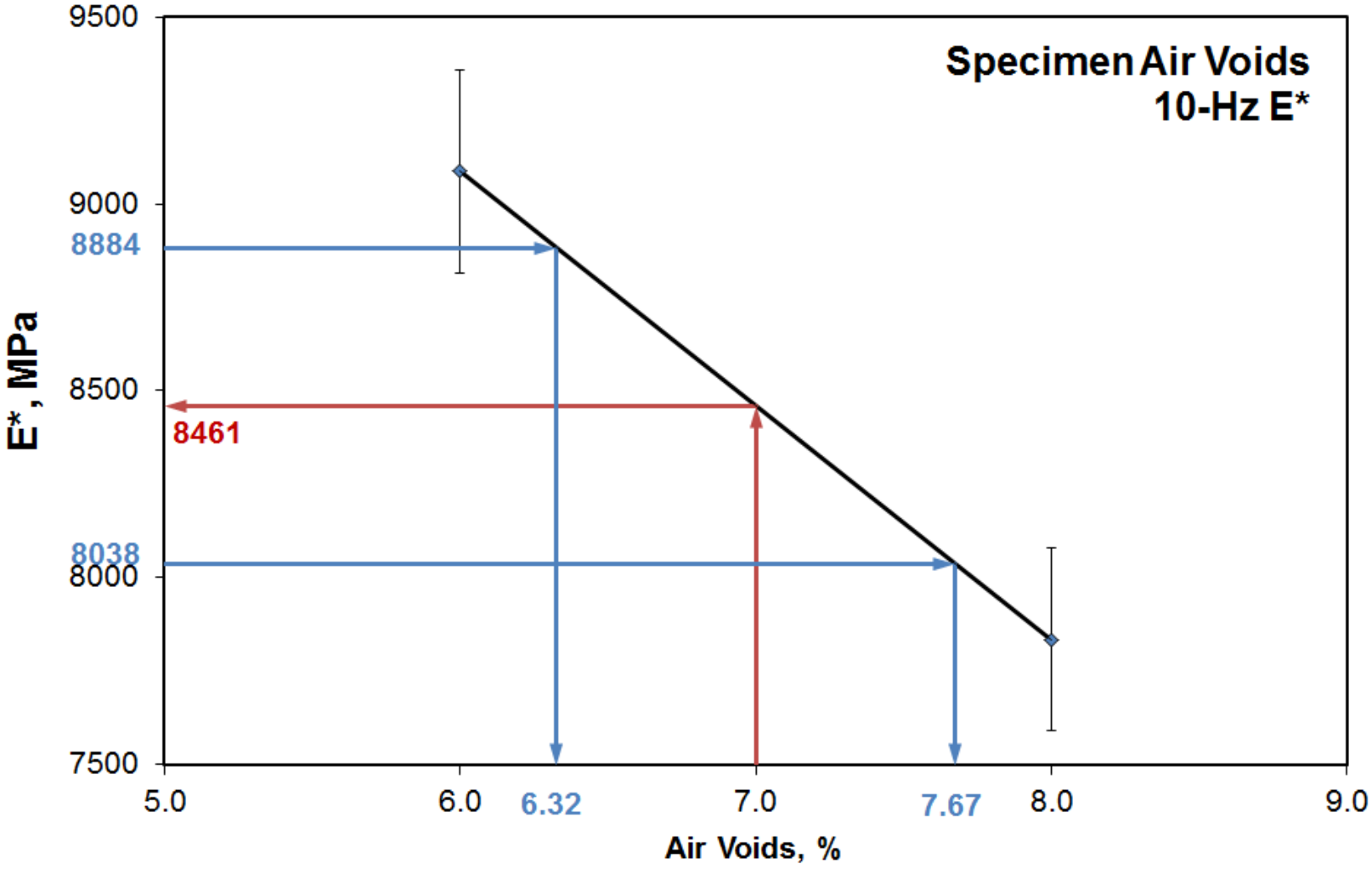
Factor	Dynamic Modulus		Phase Angle	
	P-value	Significant at α=0.05	P-value	Significant at α=0.05
Mixing Temperature	0.2210	--	<0.0001	Yes
Binder Time at Mixing Temperature	0.0440	Yes	0.9600	--
Mixer Type	0.8201	--	0.1132	--
Mixing Time	0.9393	--	0.1982	--
Loose Mix Conditioning Temperature	<0.0001	Yes	0.0003	Yes
Loose Mix Conditioning Depth	0.0520	--	0.2968	--
Loose Mix Stirring	0.0011	Yes	0.3964	--
Mold Loading	0.0645	--	0.7485	--
Placement in Mold	0.0572	--	0.0068	Yes
Additional Time at Compaction Temp	0.0227	Yes	0.0460	Yes
Gyratory Specimen Height	0.9989	--	0.4393	--
Test Specimen Air Voids	<0.0001	Yes	<0.0001	Yes

Flow Number

Factor		P-value	Significant at α=0.05
1	Mixing Temperature	0.0002	Yes
2	Binder Time at Mixing Temperature	0.8569	--
3	Mixer Type	0.0053	Yes
4	Mixing Time	0.9712	--
5	Loose Mix Conditioning Temperature	<0.0001	Yes
6	Loose Mix Conditioning Depth	0.0569	--
7	Loose Mix Stirring	<0.0001	Yes
8	Mold Loading	0.2364	--
9	Placement in Mold	<0.0001	Yes
10	Additional Time at Compaction Temp	0.0107	Yes
11	Gyratory Specimen Height	0.7050	--
12	Test Specimen Air Voids	<0.0001	Yes

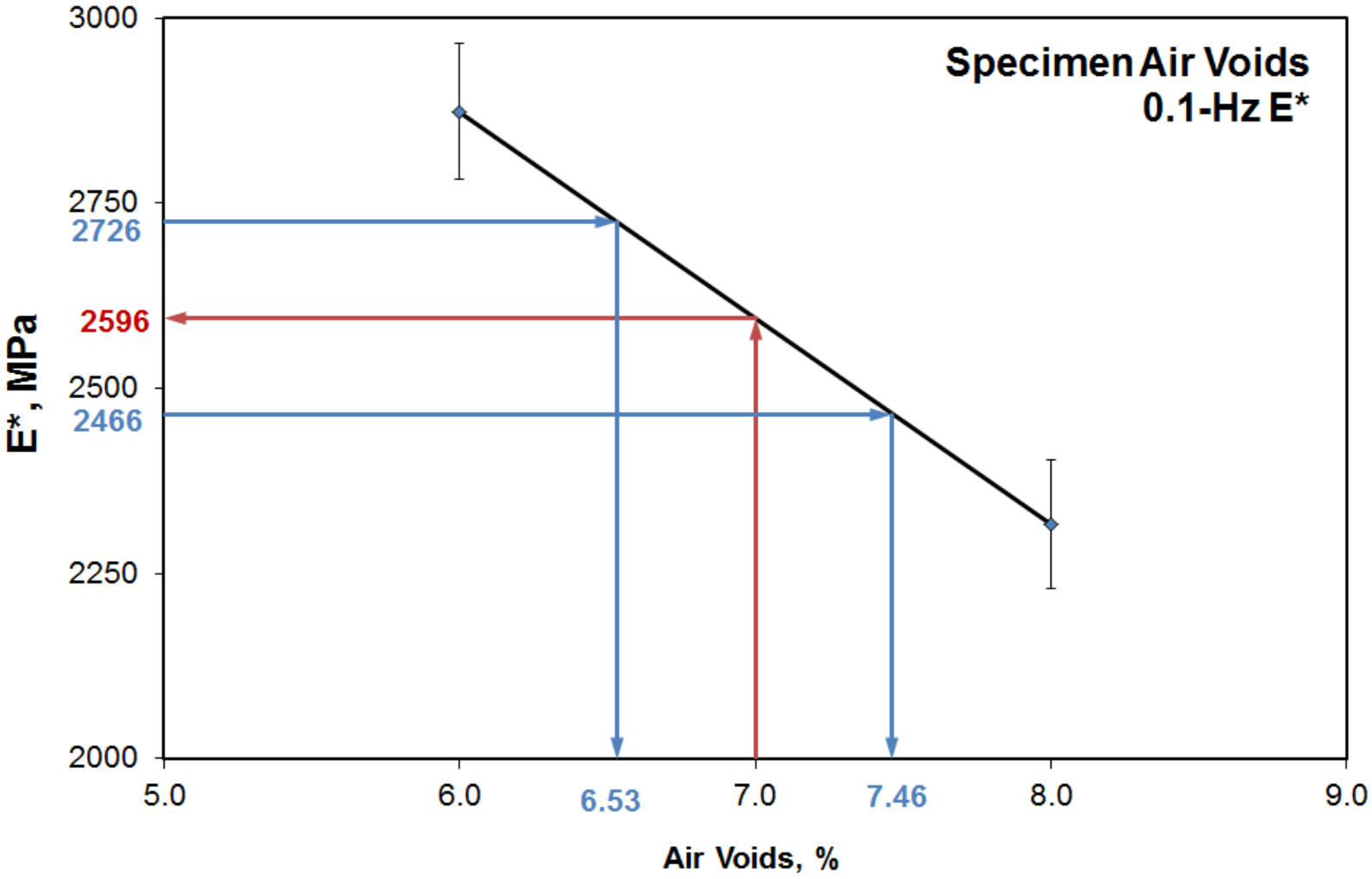
Air Voids and E* Variability

±0.67% variation in air voids would cause a ±5% average error in 10 Hz E*



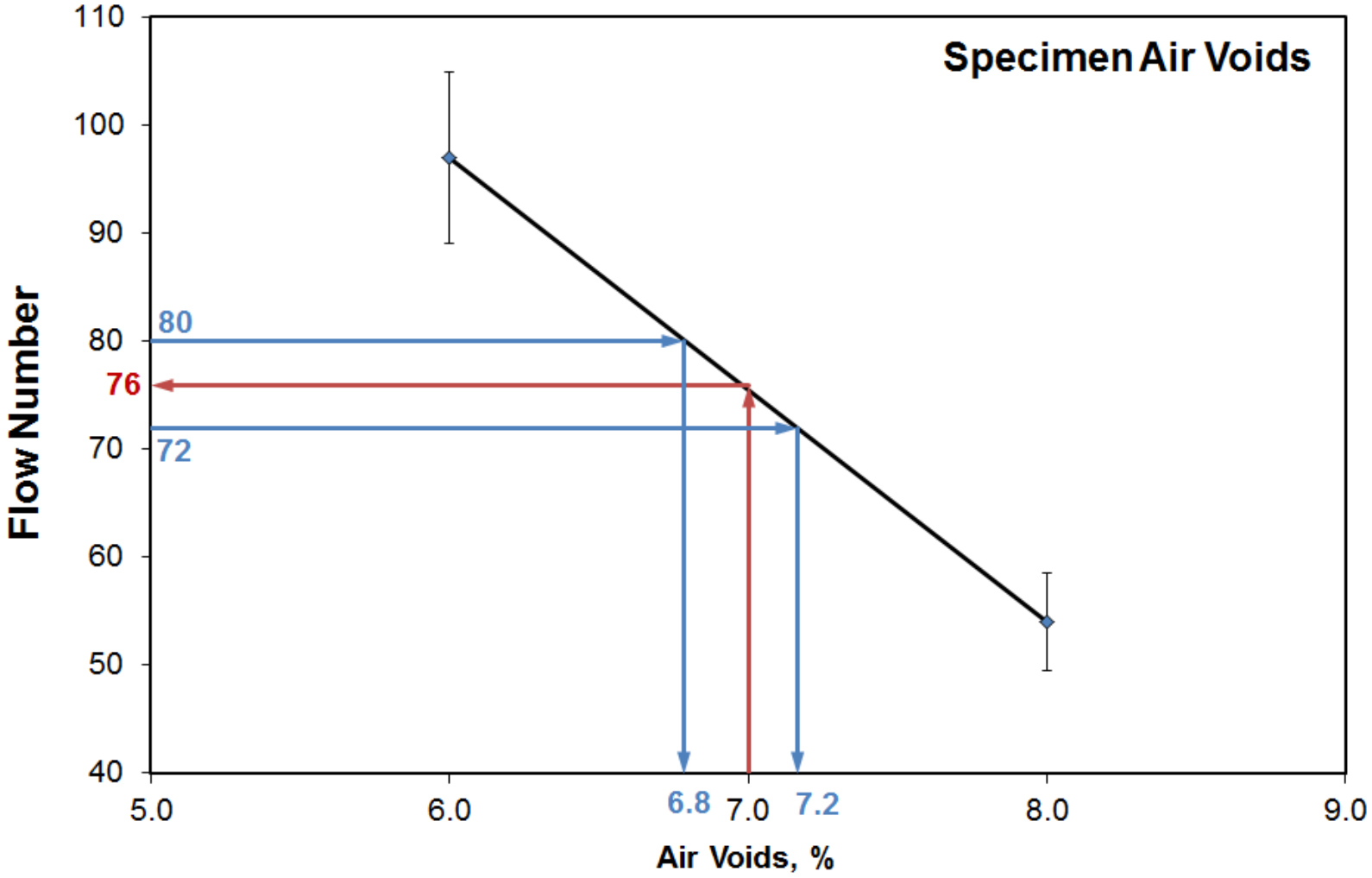
Air Voids and E* Variability

±0.46% variation in air voids would cause a ±5% average error in 0.1 Hz E*



Air Voids and FN Variability

±0.2% variation in air voids would cause a ±5% average error in Flow Number



Summary

Factor	10-Hz E*	10-Hz δ	1-Hz E*	1-Hz δ	0.1-Hz E*	0.1-Hz δ	FN
Mixing Temperature		✓		✓		✓	✓
Binder Time at Mixing Temperature					✓		
Mixer Type							✓
Mixing Time							
Loose Mix Conditioning Temp	✓	✓	✓	✓	✓	✓	✓
Loose Mix Conditioning Depth							
Loose Mix Stirring		✓	✓	✓	✓		✓
Mold Loading							
Placement in Mold		✓		✓		✓	✓
Additional Time at Compaction Temp					✓		✓
Gyratory Specimen Height							
Test Specimen Air Voids	✓	✓	✓	✓	✓	✓	✓

Conclusions

- Most of the variables in the study had a significant effect on dynamic modulus, phase angle, or flow number results

- Most effective factors:
  - Specimen air voids
    - 1% increase in the specimen air voids => 1-Hz dynamic modulus decreased by 442 MPa
  - Loose mix conditioning temp
  - Loose mix stirring

Conclusions

- Stirring the mix during conditioning resulted in higher dynamic modulus, and stiffer samples
- Variations in the significant factors can increase the error and variability in the AMPT tests results
- Limits need to be set on significant factors to control the variability of the dynamic modulus and flow number tests

Recommendations

- New standard practice should be created for sample preparation
  - Not limited to AMPT E* samples
  - Would apply to IDT, DC(t), SCB, and beam fatigue
  - Possibly apply to APA, HWT, and other proof tests

Recommendations

Factor	Recommended Limitations
Mixing Temperature	Target temperature ± 1°C (3% error in FN and phase angles)
Binder Time at Mixing Temperature	< 30 minutes
Mixer Type	Planetary mixer
Mixing Time	< 180 seconds
Loose Mix Conditioning Temp	Total temperature variation < 5°C (5% error in FN and E*)
Loose Mix Conditioning Depth	No extra limit required and the current limit of 25 to 50 mm seems to be sufficient

Recommendations

Factor	Recommended Limitations
Loose Mix Stirring	Mix samples must be stirred
Mold Loading	No limit required to specify using a gyro loader or a scoop
Placement in Mold	No rodding
Additional Time at Compaction Temp	< 5 minutes (2.5% error in FN)
Gyratory Specimen Height	170 to 190 mm height
Test Specimen Air Voids	7.0±0.5% (5% error in E* and 10% error in FN)

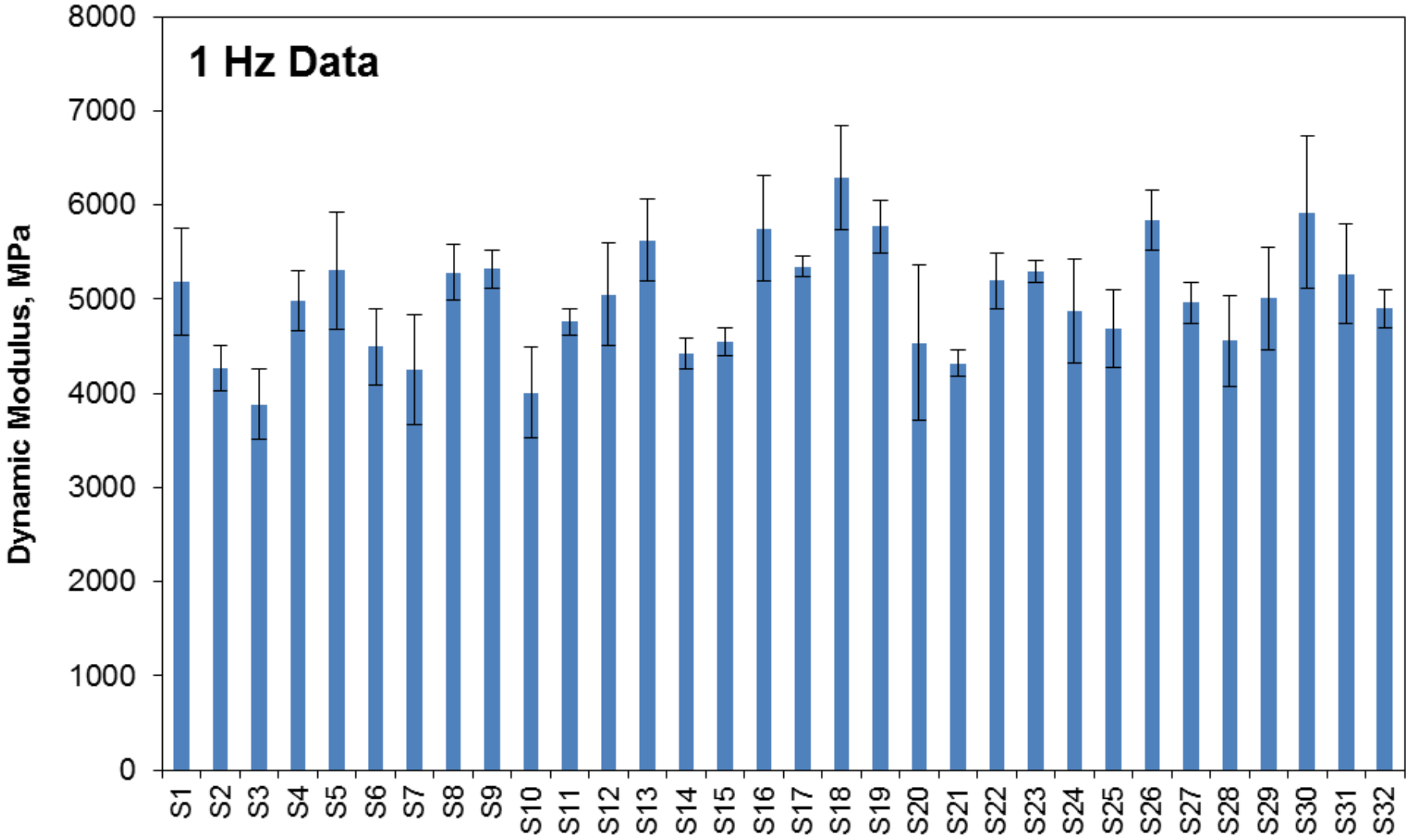
Thank you

Alias Structure up to 2 FI

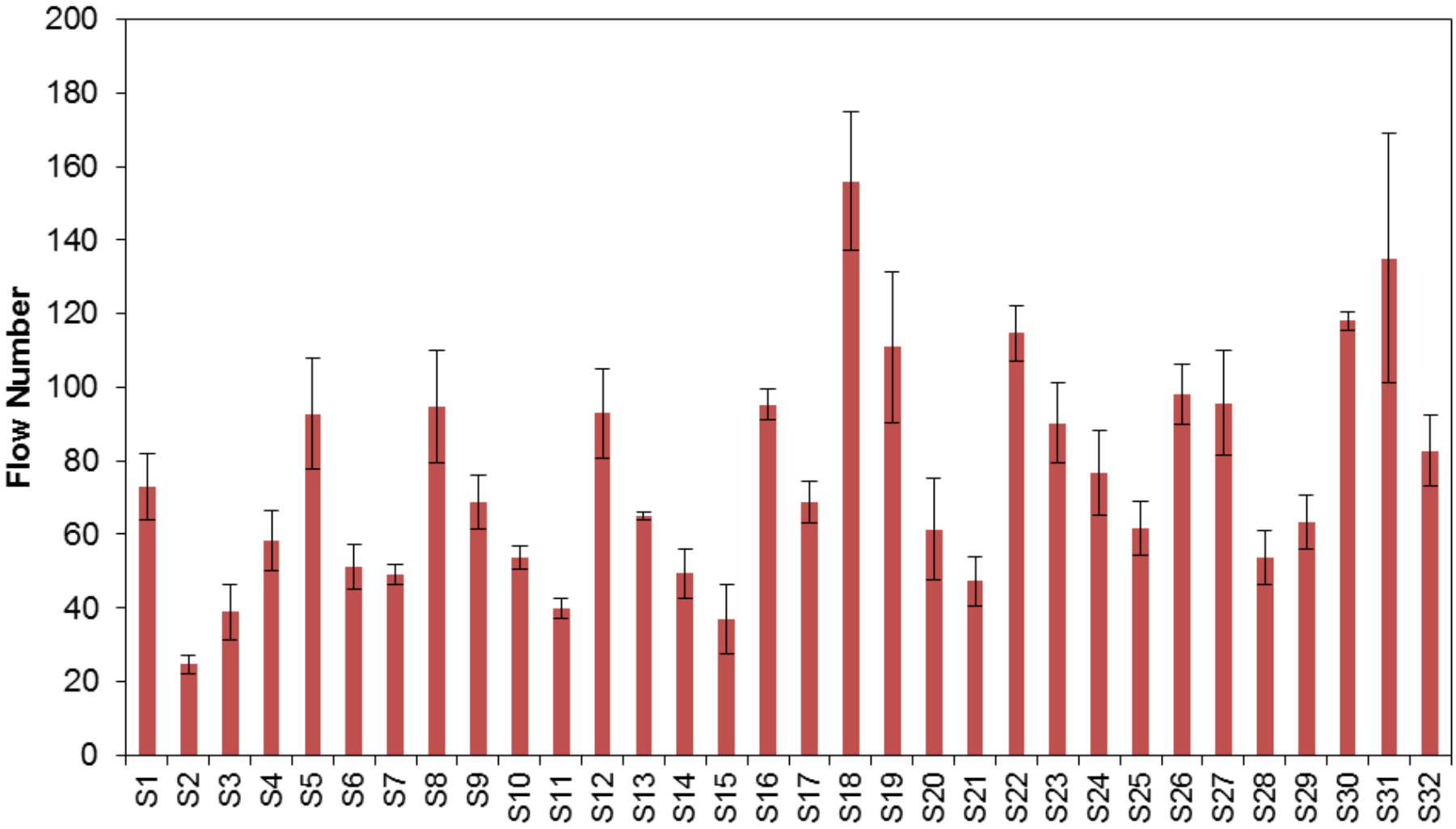
- X1
- X2
- X3
- X4
- X5
- X6
- X7
- X8
- X9
- X10
- X11
- X12

- **X6*X7 + X5*X12 + X10*X11 + X1*X2 + X8*X9**
- **X5*X11 + X6*X8 + X10*X12 + X7*X9 + X1*X3**
- **X6*X10 + X5*X9 + X7*X11 + X8*X12 + X1*X4**
- **X1*X5 + X3*X11 + X2*X12 + X4*X9**
- **X1*X6 + X2*X7 + X3*X8 + X4*X10**
- **X2*X6 + X1*X7 + X4*X11 + X3*X9**
- **X3*X6 + X1*X8 + X2*X9 + X4*X12**
- **X4*X5 + X2*X8 + X3*X7 + X1*X9**
- **X1*X10 + X4*X6 + X2*X11 + X3*X12**
- **X3*X5 + X1*X11 + X2*X10 + X4*X7**
- **X2*X5 + X3*X10 + X4*X8 + X1*X12**
- **X5*X10 + X7*X8 + X6*X9 + X11*X12 + X2*X3**
- **X5*X8 + X6*X11 + X7*X10 + X2*X4 + X9*X12**
- **X5*X7 + X8*X10 + X6*X12 + X9*X11 + X3*X4**
- **X5*X6 + X8*X11 + X9*X10 + X7*X12**

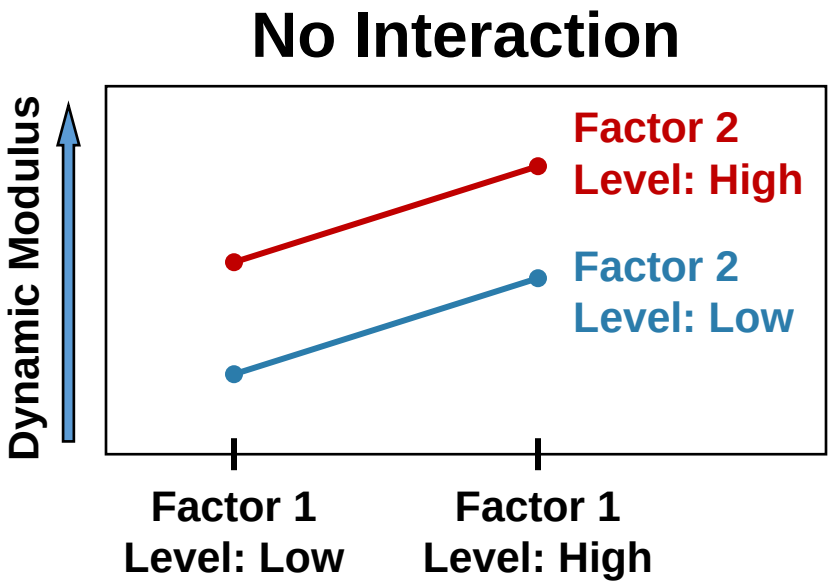
Average Dynamic Modulus Data at 1.0-Hz Loading Frequency, 20°C

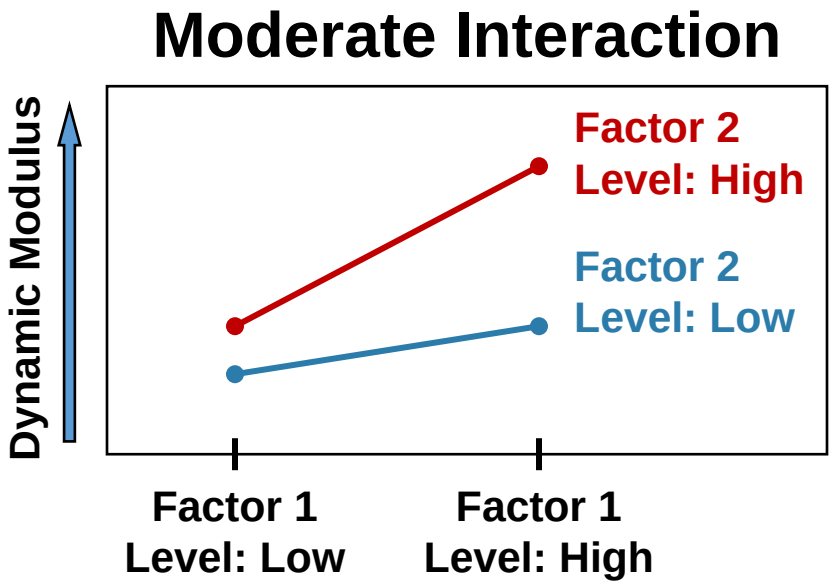


Average Flow Number Data at 54°C

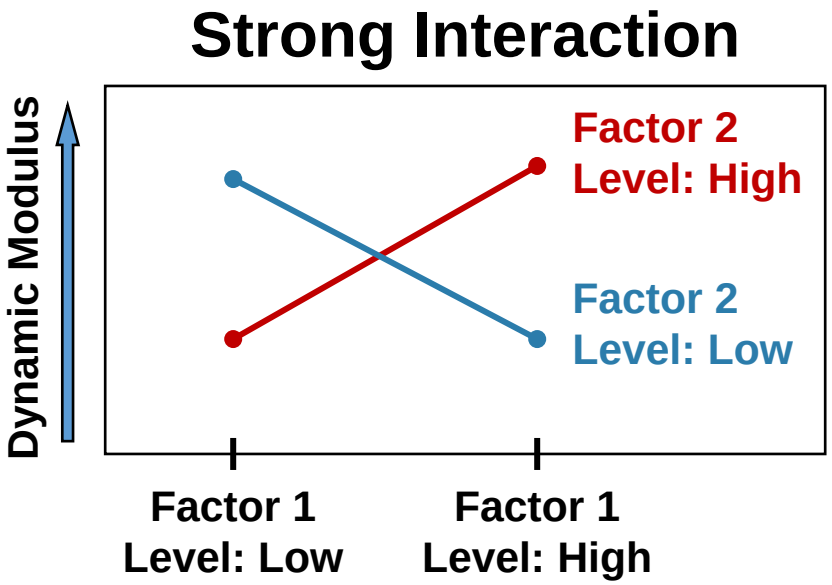


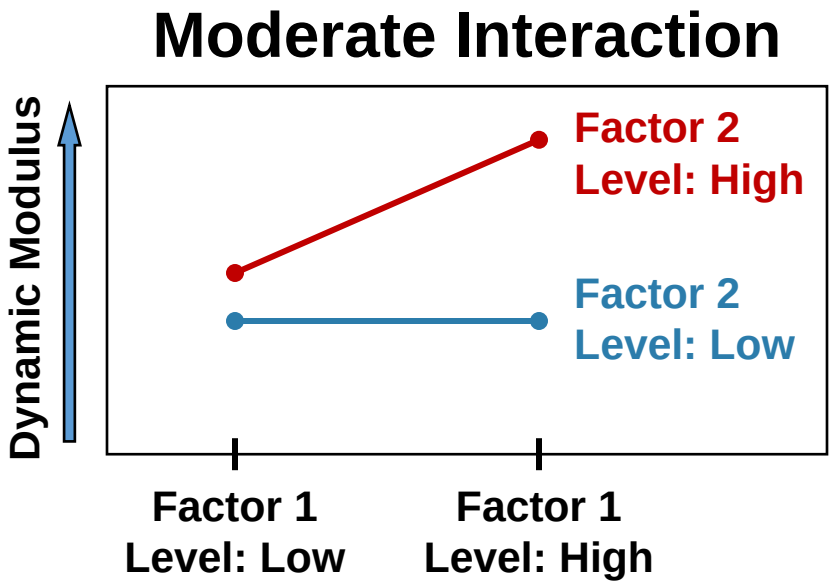
Interactions





Interactions





Phase II Goal