A SIMPLE TEST TO DETERMINE WORKABILITY AND FIELD COMPACTION TEMPERATURES OF ASPHALT CONCRETE – *DONGRE WORKABILITY TEST (DWT)*

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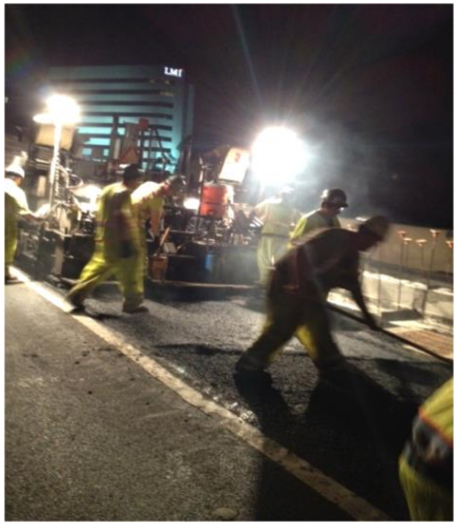

Acknowledgements

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- University of Arkansas – Smith, Braham, and Hall

Details of this Study

- No Federal or State Funds were harmed in this study!
- I used my vast personal wealth to develop this method
- Pine Instruments gave equipment loan
  - and funds for Ruggedness Phase II
- Need more resources to continue this work if people like it
  - Test is designed to be easy and inexpensive for the Federal and State labs to try in-house or have a coordinated study

Name of the Test

- In a moment of creativity inspired by the spirit/spirits
- I have come up with the following name for the test:
- The ‘Dongre Workability Test’ (DWT)
- It is pronounced “DWIGHT”

Outline

- What Was Accomplished - Summary
- Why Develop DWT?
  - Background
- How?
  - Objective and Approach
  - DWT Test Protocol
  - Results
  - Findings
- Implications & Implementation

What Was Accomplished?

- A simple test method (DWT) was developed to determine workability of asphalt mixes
  - Uses Superpave Gyratory Compactor
  - Loose mix is tested
    - Test is done prior to gyratory compaction of mix design specimen
    - After the DWT test is complete Specimen is compacted normally with specified gyrations to get volumetrics
    - Requires new software for the gyratory compactor
- DWT is simple and transparent to the operator
  - Rodding of the loose mix prior to testing is required
- DWT is sensitive to
  - WMA, HMA, Polymer modified HMA, Temperature

Background

- Many binder based tests available
  - Viscosity based Lab Mixing and Compaction Temperatures
    - Limited to unmodified binders
    - Does not account for mix (aggregate gradation) effects
  - DSR based tests
    - Low shear viscosity; High shear viscosity
    - Gerry Reinke's method; Casola method
    - Lubricity Test
      - Do not account for mix effects
- Mix based Tests
  - Bucket Mixer – Variable and noisy data
  - Other issues

Background……….

- Mix based Tests – Superpave Gyratory Compaction
  - Gyratory Shear Measurement/Calculation
  - Energy for compaction
  - University of Wisconsin device
  - Texas A&M WEI – Index
  - Advanced Asphalt (AAT) Method
- These have found limited success
  - Why? – My take on why

Objective

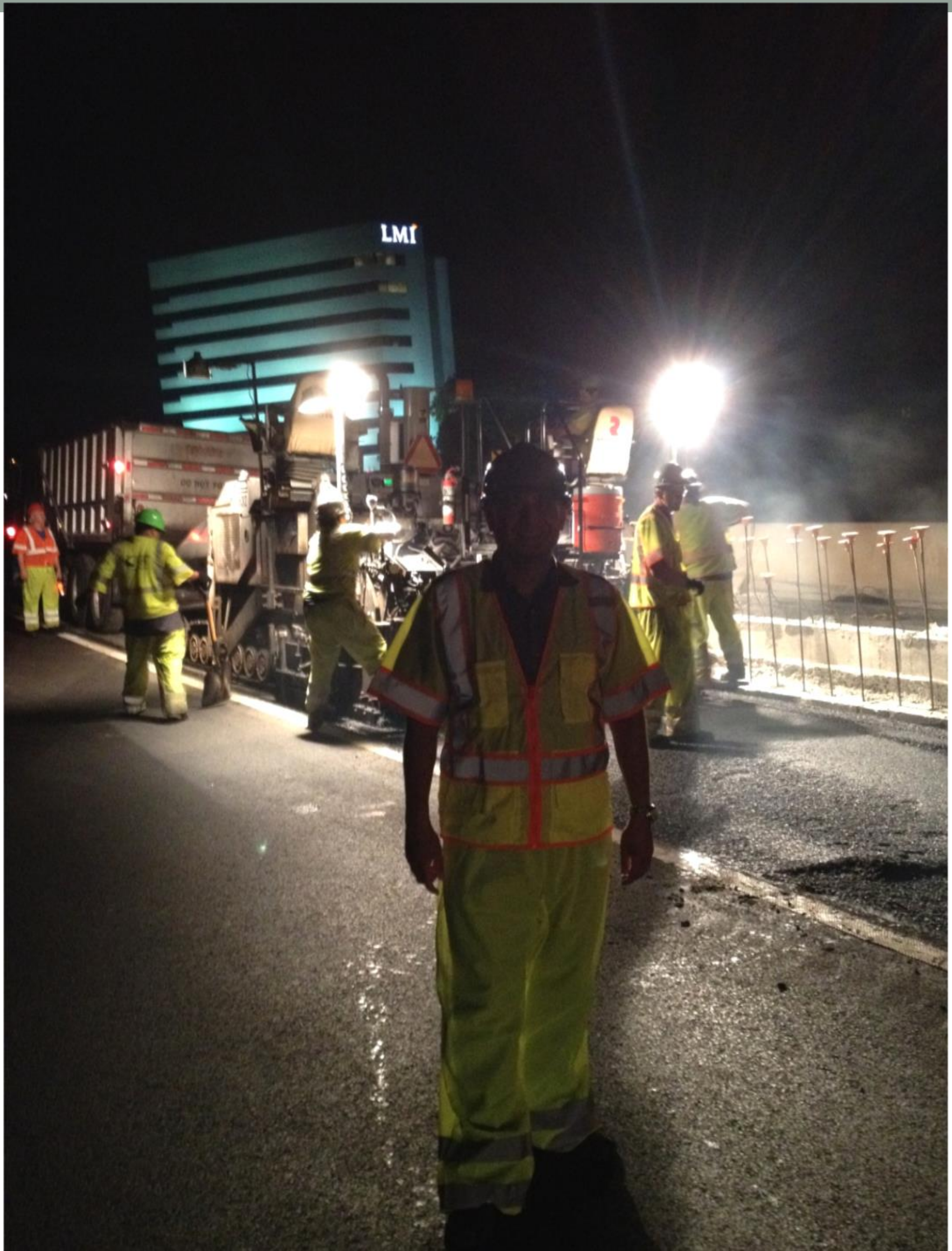
- Develop a simple, low cost, easy to use method to measure workability of Asphalt Mixtures:
  - Test based on existing equipment
  - Simple and repeatable
  - Sensitive to Hot-Mix and Warm-Mix asphalt
  - Establish Field Compaction Temperature Range
    - breakdown temperature
    - finishing temperature
    - TAC – Time Available for Compaction
  - Determine reduction in compaction temperature produced by various warm mix additives

Approach

- What is ‘Workability’ of Asphalt Mixes and Why is it Important?
  - The rheological behavior of the un-compacted mix during construction of asphalt pavements is generally described as the workability of the mix.
  - During construction it is common for the rolling operation to be delayed for a prescribed time before the compaction of the asphalt mix is initiated
  - The delay allows the mix to reach the temperature at which it will consolidate rather than flow. This condition also makes it possible to achieve the desired density for the compacted asphalt mix, which is known to be related to pavement performance.
  - Therefore, the temperature associated with the rheological state where an asphalt mix compacts without flowing is a point of keen interest in pavement construction.

- Workability of other materials involve other things
    - Cement concrete – flowability; segregation potential; water content etc.
    - Polymers – Extrusion; moldability
- Early trials
  - Plate with holes; LA abrasion spheres etc


Sharpie
FINE POINT
Permanent Marker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Approach……….

- Test various Unmodified, PMA, WMA binders
- Test different aggregates and gradations
- Both Field and Lab mixes
- Field compaction temperature range (Breakdown and Finishing Temperatures)
  - Determine 'Workability' value
  - Determine a method to determine field compaction temperature range from the workability value

TEST METHOD

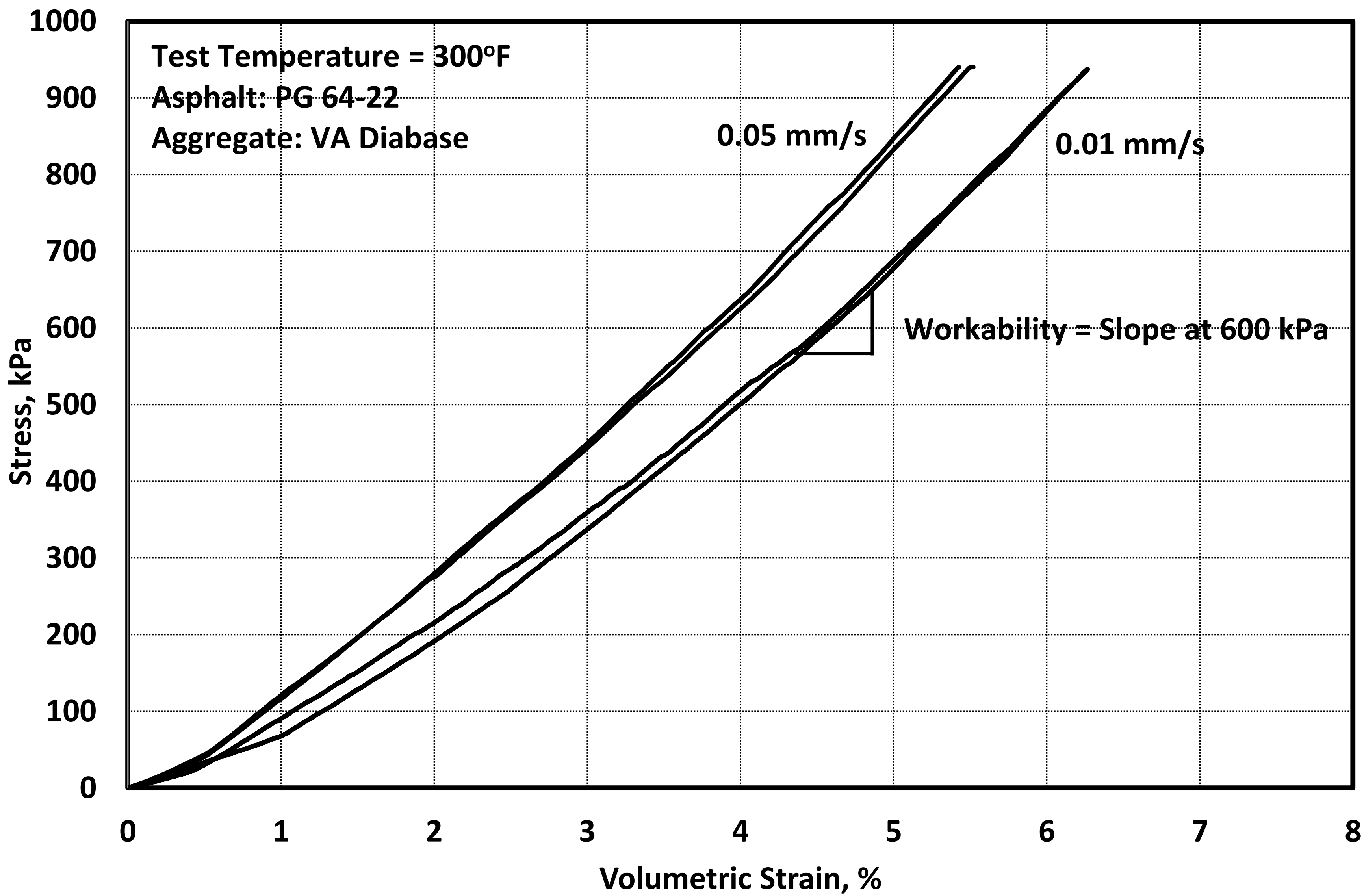
Cost, Testing Protocol and Data Analysis

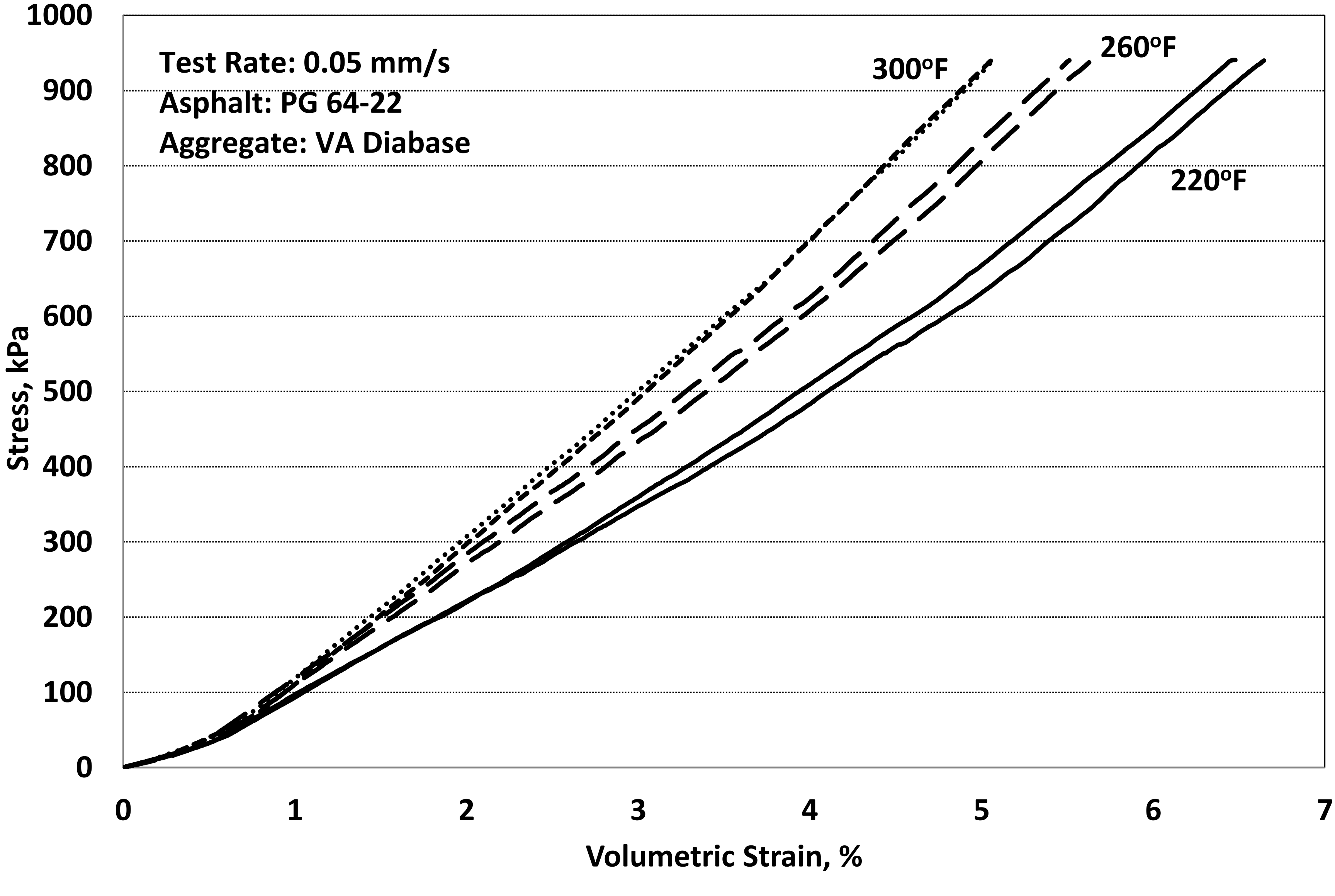
DWT Test

- Cost?
  - It depends!
  - If you have a Gyratory Compactor
    - Machine control and data analysis Software
      - from Pine Instruments
  - If you do not have a Gyratory Compactor
    - I am talking with Pine about making a low cost DWT device
      - Good for Asia and Europe etc
- DWT Test Required Equipment
  - Software
  - Gyratory Compactor

DWT Testing Protocol

- Loose Mix is Tested at 0.05 mm/s Ram Rate
- 4810 g of Asphalt Mixture
  - Mix design (115 mm gyratory specimen)
  - 2 replicates recommended
- The top plate, the mold are all heated to test temp
- Test is stopped at 700 kPa
- Workability is determined as:
  - Slope of the Volumetric Strain (%) and Stress (kPa) at 600 kPa stress level
  - Currently the slope is between 550 kPa and 650 kPa
  - Repeatability is good


Test Temperature = 300°F
Asphalt: PG 64-22
Aggregate: VA Diabase
0.05 mm/s
0.01 mm/s
Workability = Slope at 600 kPa
Stress, kPa
Volumetric Strain, %
0
100
200
300
400
500
600
700
800
900
1000
0
1
2
3
4
5
6
7
8

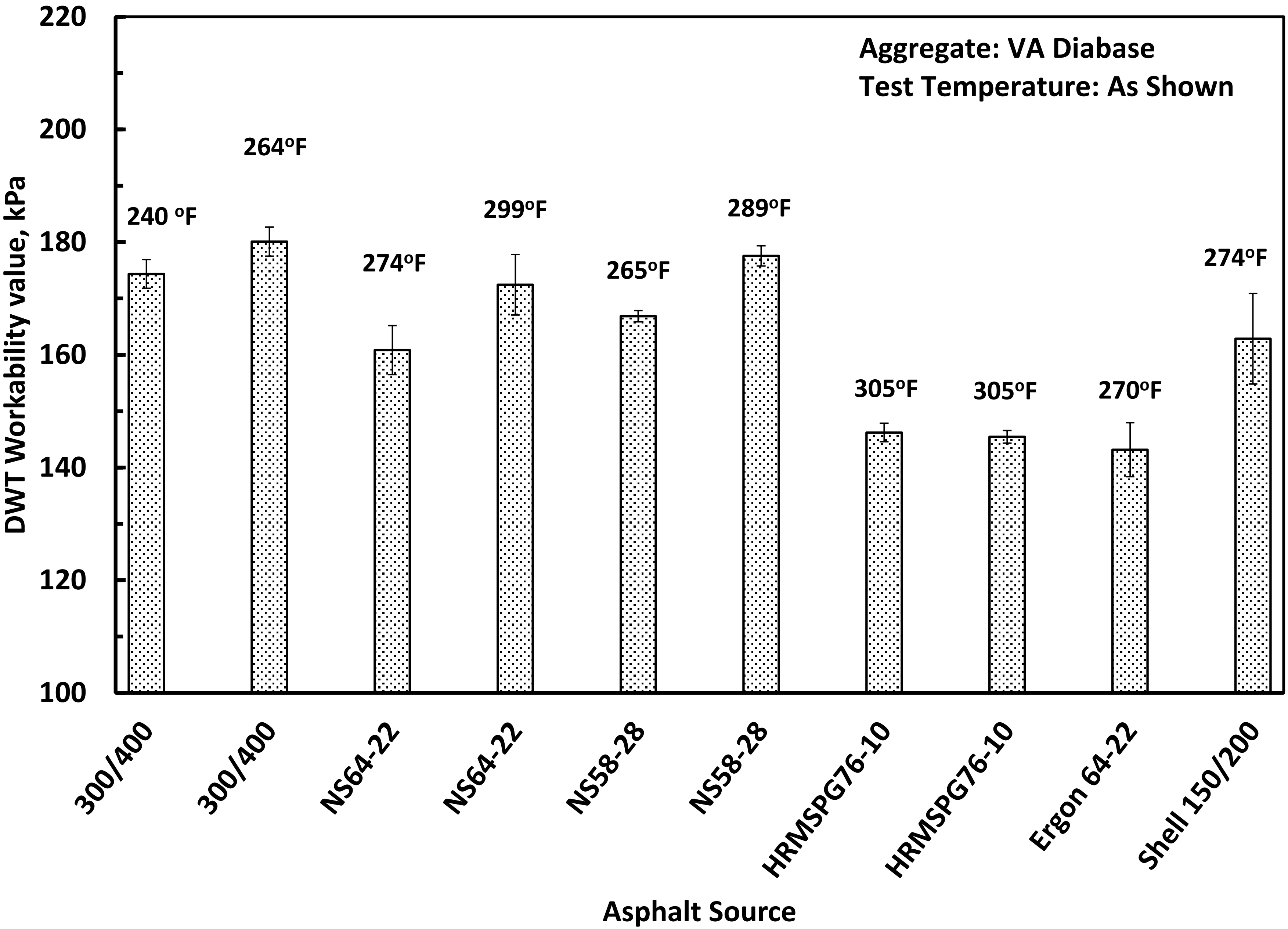


Test Rate: 0.05 mm/s
Asphalt: PG 64-22
Aggregate: VA Diabase
300°F
260°F
220°F
Stress, kPa
Volumetric Strain, %
0
100
200
300
400
500
600
700
800
900
1000
0
1
2
3
4
5
6
7

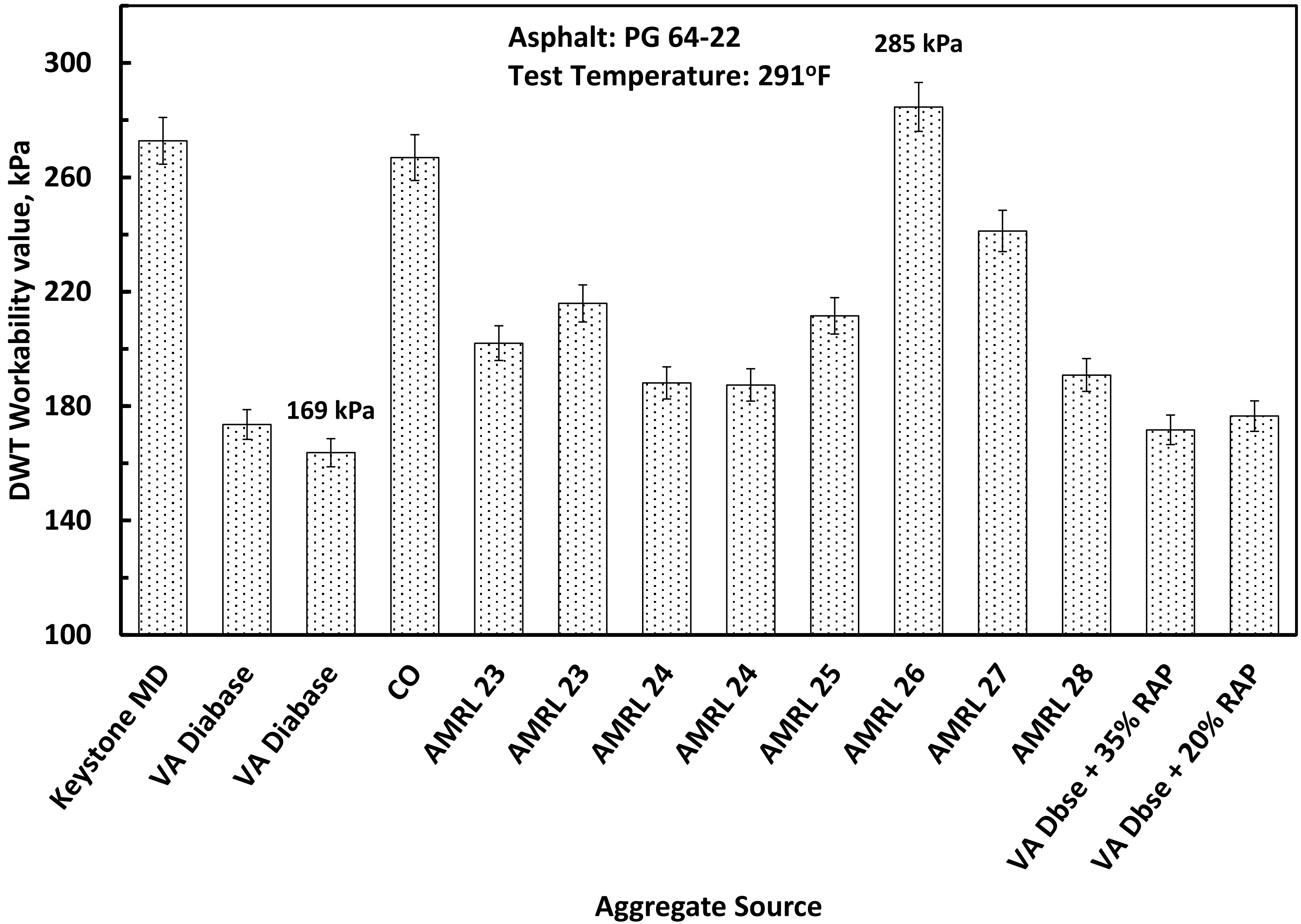
RESULTS

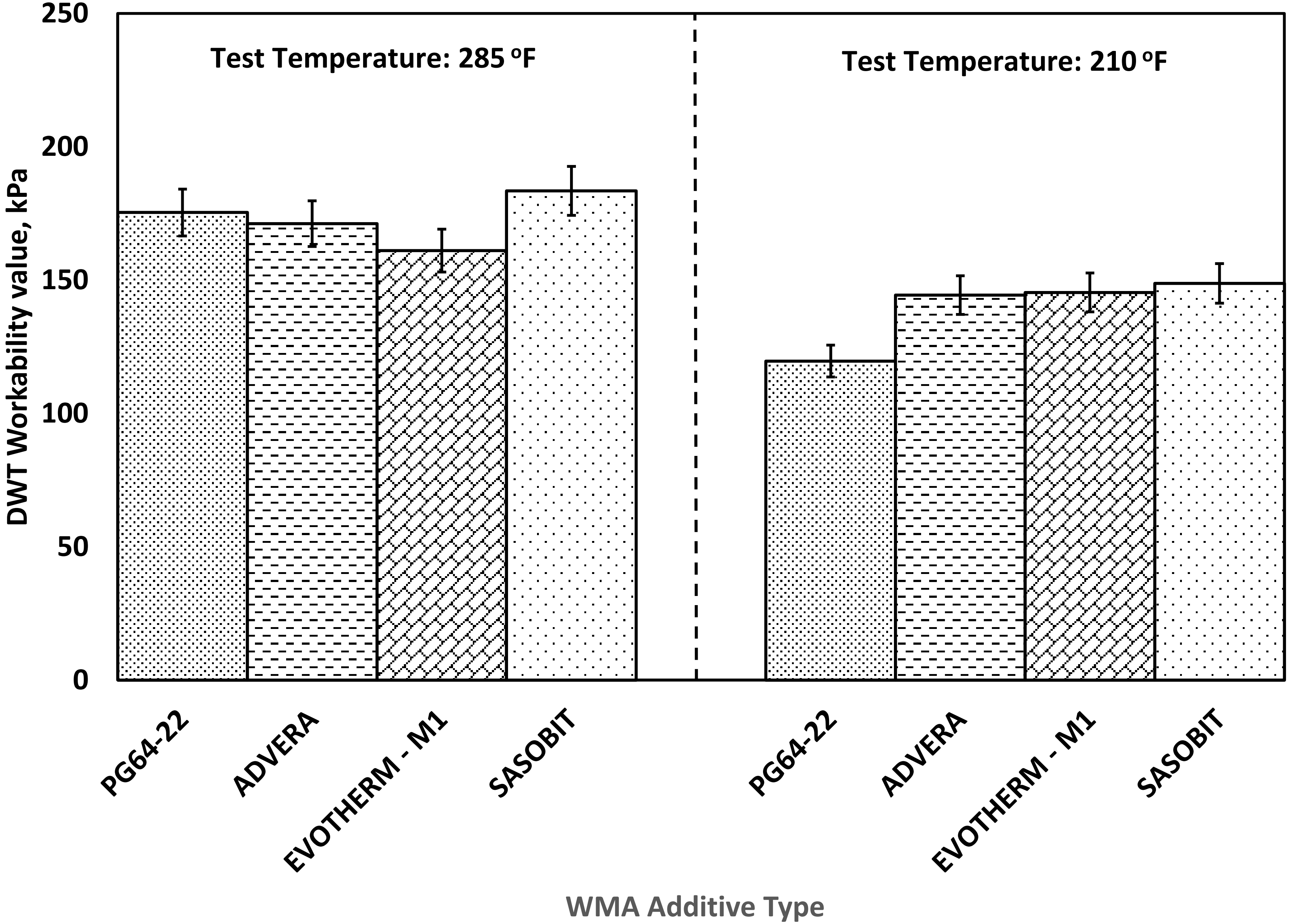
Sensitivity of DWT

- Binder Effects
- Aggregate Effects
- WMA Effects



Aggregate: VA Diabase
Test Temperature: As Shown
DWT Workability value, kPa
220
200
180
160
140
120
100
240 °F
264°F
274°F
299°F
265°F
289°F
305°F
305°F
270°F
274°F
300/400
300/400
NS64-22
NS64-22
NS58-28
NS58-28
HRMSPG76-10
HRMSPG76-10
Ergon 64-22
Shell 150/200
Asphalt Source


Asphalt: PG 64-22
Test Temperature: 291°F
285 kPa
169 kPa
DWT Workability value, kPa
300
260
220
180
140
100
Keystone MD
VA Diabase
VA Diabase
CO
AMRL 23
AMRL 23
AMRL 24
AMRL 24
AMRL 25
AMRL 26
AMRL 27
AMRL 28
VA Dbse + 35% RAP
VA Dbse + 20% RAP
Aggregate Source



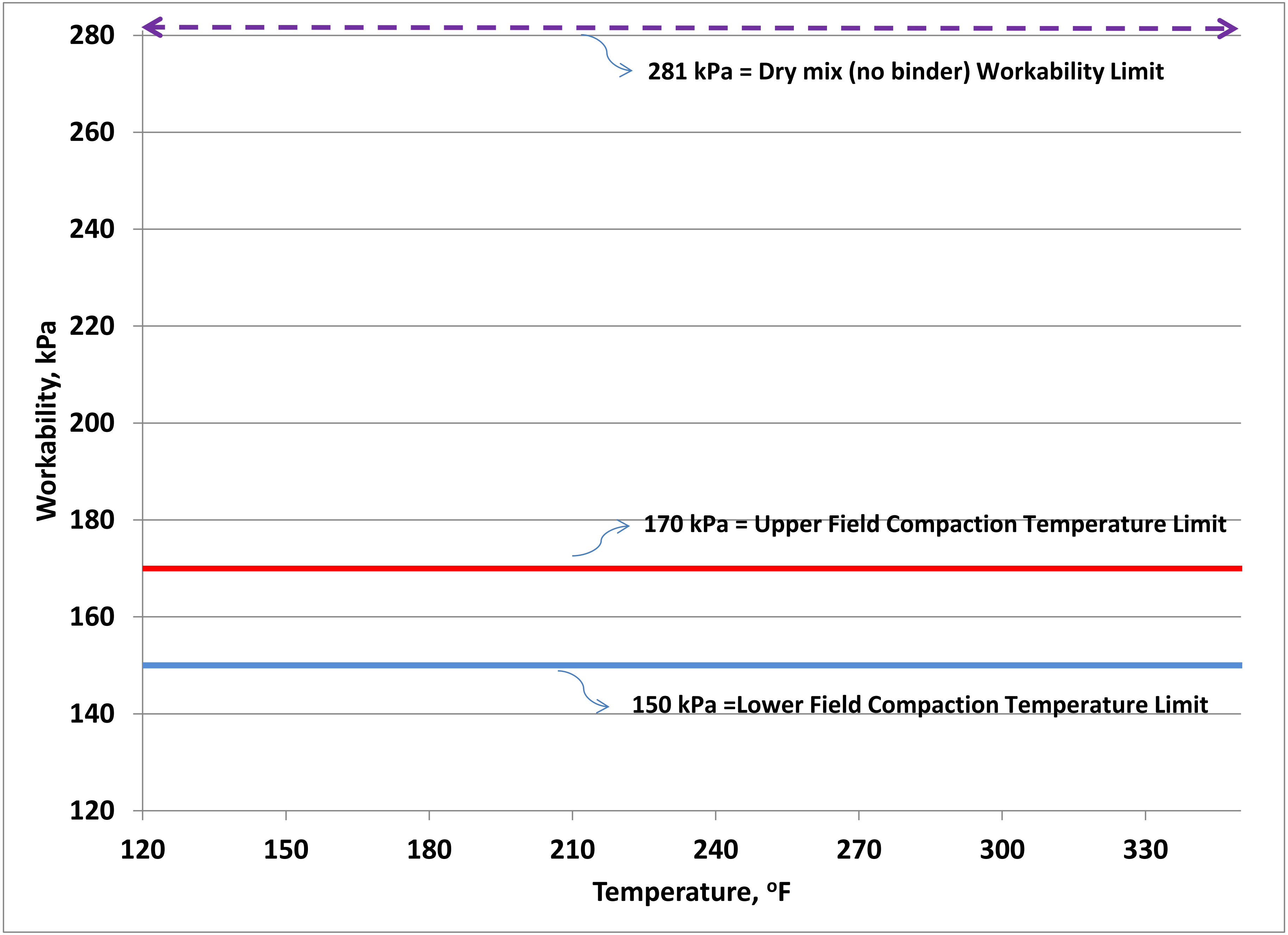
Test Temperature: 285 oF
Test Temperature: 210 oF
250
200
150
100
50
0
DWT Workability value, kPa
PG64-22
ADVERA
EVOTHERM - M1
SASOBIT
PG64-22
ADVERA
EVOTHERM - M1
SASOBIT
WMA Additive Type

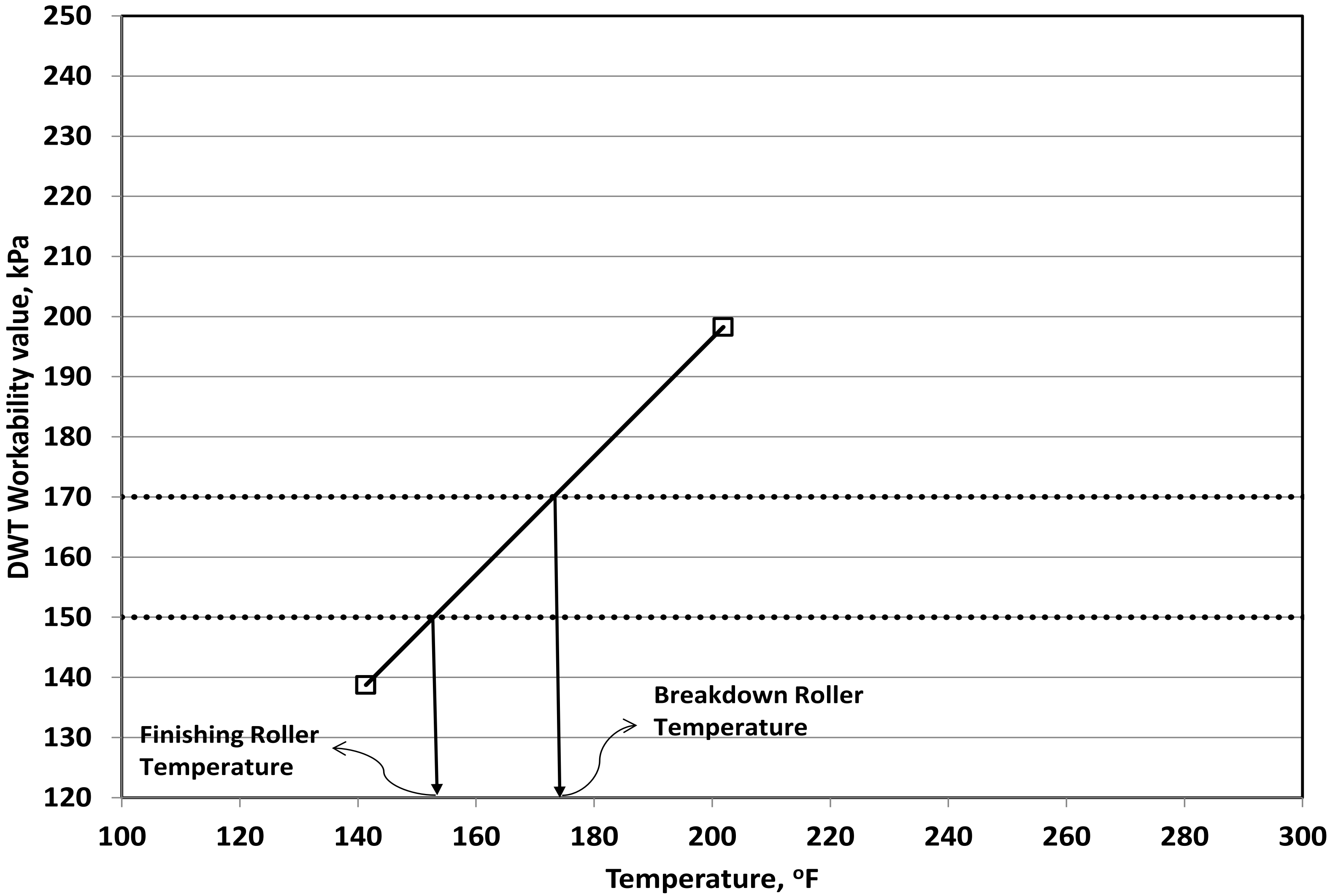
IMPLICATIONS

Use of DWT Test

So What?

- OK! So we have a way to measure workability
  - So What?
- Determination of Field Compaction Temperatures
  - Currently it is field experience and test strip based
- Determination of Temperature Reduction obtained using WMA additives
  - Currently experience based
  - No way to verify in the lab
- A method has been developed
  - Similar to the old viscosity based method
  - Determine workability at two temperatures (145^{o}F and 225^{o}F)
  - Use chart to determine the field compaction temperature and/or temperature reduction obtained from WMA additives


281 kPa = Dry mix (no binder) Workability Limit
170 kPa = Upper Field Compaction Temperature Limit
150 kPa =Lower Field Compaction Temperature Limit
Workability, kPa
280
260
240
220
200
180
160
140
120
120
150
180
210
240
270
300
330
Temperature, °F



DWT Workability value, kPa
250
240
230
220
210
200
190
180
170
160
150
140
130
120
100
120
140
160
180
200
220
240
260
280
300
Temperature, oF
Finishing Roller Temperature
Breakdown Roller Temperature

Asphalt Source	Aggregate Source	Mix Type	Predicted Field Compaction Temperature, ^{o}F		Actual Field Compaction Temperature ^{o}F	Time Available For Compaction (TAC), minutes	
			Finish	BrkDwn		Summer	Winter
64-22+ADV	VA Diabase	WMA - Advera	192	228	N/A - Lab Mix	23	17
64-22+M1	VA Diabase	WMA - Evotherm	203	233	N/A - Lab Mix	17	13
64-22+SAS	VA Diabase	WMA - Sasobit	185	221	N/A - Lab Mix	26	18
82-22	VA Diabase	PMB	230	335	N/A - Lab Mix	37	30
CRMB	N/A	WMA - CRMB + Sasobit	170	211	$176^{o}F$	21	14
PG 70-22	MO	PMB	237	328	N/A - Lab Mix	37	21
PG 70-28	VA Diabase	PMB	248	320	N/A - Lab Mix	21	16
PG 76-22	VA Diabase	PMB -2	225	258	$243^{o}F$	13	10
PG 94-22	NCAT N7-3	PMB	229	253	$240^{o}F$	10	8
PG 76-22-Foamed	VADOT	Std. PMB	162	178	215 - 190 ^{o}F	N/A	N/A
PG 76-22-Foamed	VADOT	SBS+PE	170	190	220 - 200 ^{o}F	N/A	N/A
PG 76-22-Foamed	VADOT	TB Rubber	171	183	N/A	N/A	N/A

Binder Source	Aggregate Source	Mix Type	Predicted Field Compaction Temperature, °F		Predicted Temperature Reduction, °F	
			Finish	BrkDwn	Finish	BrkDwn
Mixed in Lab at 300 °F						
PG 64-22	VA Diabase	UNMod	232	260		
64-22+ADV	VA Diabase	WMA - Advera	215	280	-17	20
64-22+M1	VA Diabase	WMA - Evotherm	213	290	-19	30
64-22+SAS	VA Diabase	WMA - Sasobit	210	254	-22	-6
Mixed in Lab at 260 °F						
64-22+ADV	VA Diabase	WMA - Advera	192	228	-40	-32
64-22+M1	VA Diabase	WMA - Evotherm	203	233	-29	-27
64-22+SAS	VA Diabase	WMA - Sasobit	185	221	-47	-39

IMPEMENTATION

Use of DWT Test

Implementation Approach

- Ruggedness of DWT
  - Phase 1 – Complete
  - Phase II – Testing just completed - Data being analyzed
- Precision Estimates – from Ruggedness phase 1
  - Within Laboratory Variation
  - Between Laboratory Variation
- Implementation Proposal
  - Incorporation of DWT in the Superpave mix design process

DWT RUGGEDNESS

Phase I

DWT Test Factors and Limits (ASTM C1067)

	Factor	High Level "X"	Low Level "x"
A	Rodding	Rod	No Rod
B	Rod Type	Round	Flat
C	Tamping	Tamp	No Tamp
D	Specimen Mass	4810	4000g
E	Stress at 0.05mm/s start	80kPa	40kPa
F	Final Stress	950kPa	700kPa
G	Offset Temp	+15	+5

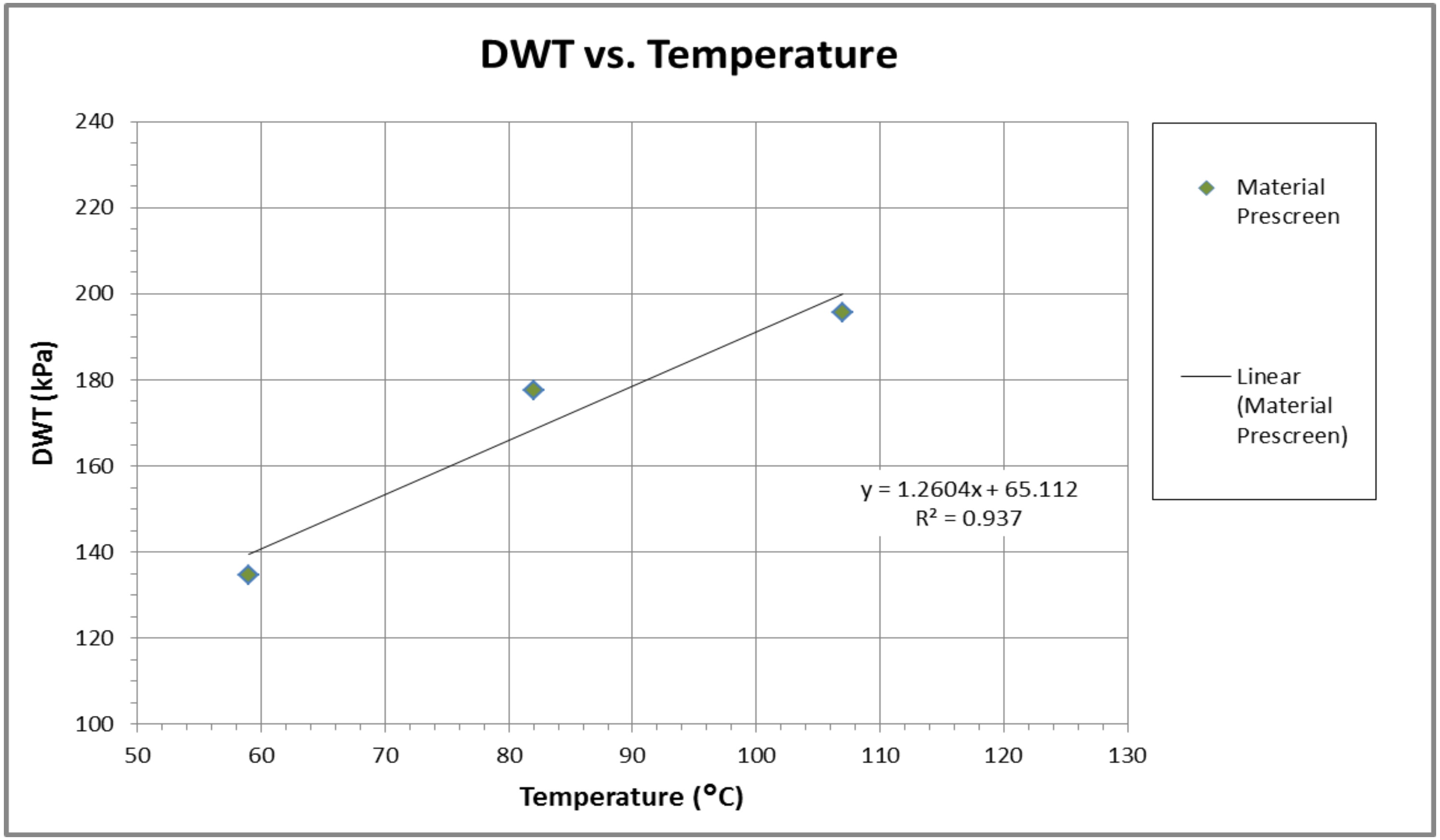
Experiment Design

- ASTM C1067 Ruggedness Standard
- ONE Asphalt Mixture
  - AMRL Sample 33 – Gyratory Proficiency sample
  - 12.5 mm Fine mix – VA Limestone
  - PG 64-22 Unmodified binder
- THREE Test Temperatures
  - 135 ^{o}F (57^{o}C);
  - 180 ^{o}F (82^{o}C); and
  - 225 ^{o}F (107^{o}C)
- ONE Laboratory

AMRL Sample 33 Mixture Gradation

Size (mm)	% Passing	G_{sb}	Absorption
19.0	100	---	---
12.5	94.1	2.696	0.4
9.5	84.7	2.696	0.4
4.75	56.3	2.696	0.4
2.36	28	2.720	0.9
0.075	5.6	2.720	0.9
%AC	4.1	PG 64-22	

DWT Value at Three Test Temperatures
135 ºF (57ºC); 180 ºF (82ºC); 225 ºF (107ºC);



Summary of F Values
135°F (57°C) and 180°F (82°C)

Summary of F Values All Factors						Significant F >=		5.59
Material	Lab	Rodding	Rod Type	Tamp	Spec. Mass	Stress at 0.05m m/s start	Final Stress	Offset Temp
135°F (57°C)	1	1038.38	2.66	0.00	0.28	0.00	3.44	0.58
180°F (82°C)	1	58885.67	210.76	0.41	821.64	0.07	36.40	17.49

Modified (M1) DWT Test Factors and Limits (ASTM C1067)

	Factor	High Level "X"	Low Level "x"
A	DUMMY FACTOR	Left	Right
B	Rod Type	Round	Flat
C	Tamping	Tamp	No Tamp
D	Specimen Mass	4810	4000g
E	Stress at 0.05mm/s start	80kPa	40kPa
F	Final Stress	950kPa	700kPa
G	Offset Temp	+15	+5

Summary of F Values for Modified M1 180°F (82°C) and 225°F (107°C)

Summary of F Values All Factors						Significant F >=		5.59
Material	Lab	Rodding	Rod Type	Tamp	Spec. Mass	Stress at 0.05m m/s start	Final Stress	Offset Temp
180°F (82°C)M1	1	4.31	407.73	30.90	0.01	0.12	0.22	0.26
225°F (107°C)M1	1	0.39	49.59	0.00	15.17	0.81	0.00	1.23

Modified (M2) DWT Test Factors and Limits (ASTM C1067)

	Factor	High Level "X"	Low Level "x"
A	DUMMY FACTOR 1	Left	Right
B	DUMMY FACTOR 2	Up	Down
C	Tamping	Tamp	No Tamp
D	Specimen Mass	4810	4000g
E	Stress at 0.05mm/s start	80kPa	40kPa
F	Final Stress	950kPa	700kPa
G	Offset Temp	+15	+5

Summary of F Values for Modified M2 180°F (82°C) and 225°F (107°C)

Summary of F Values All Factors						Significant F >=		5.59
Material	Lab	Rodding	Rod Type	Tamp	Spec. Mass	Stress at 0.05m m/s start	Final Stress	Offset Temp
180°F (82°C)M2	1	0.00	0.00	0.58	6.36	0.00	2.54	0.01
225°F (107°C)M2	1	0.00	0.00	0.00	3.22	0.00	0.00	0.00

Ruggedness Conclusions

- Rodding pre-compaction proved to be extremely significant.
- Rod Type is important. Use of a blunt, round rod is required.
- Tamping with a rubber mallet is not important when a blunt rod is used.
- Specimen mass is significant over the tested high/low limits.
- Stress at 0.05mm/s start range of 40kPa to 80kPa is reasonable.
- Final Stress range of 700 to 950 is acceptable.
- Offset Temperature range control of 10°F ±5°F (3°C to 8°C) is adequate.

Ruggedness Recommendation – Phase II

Recommended Test Factors and Limits for Further Testing

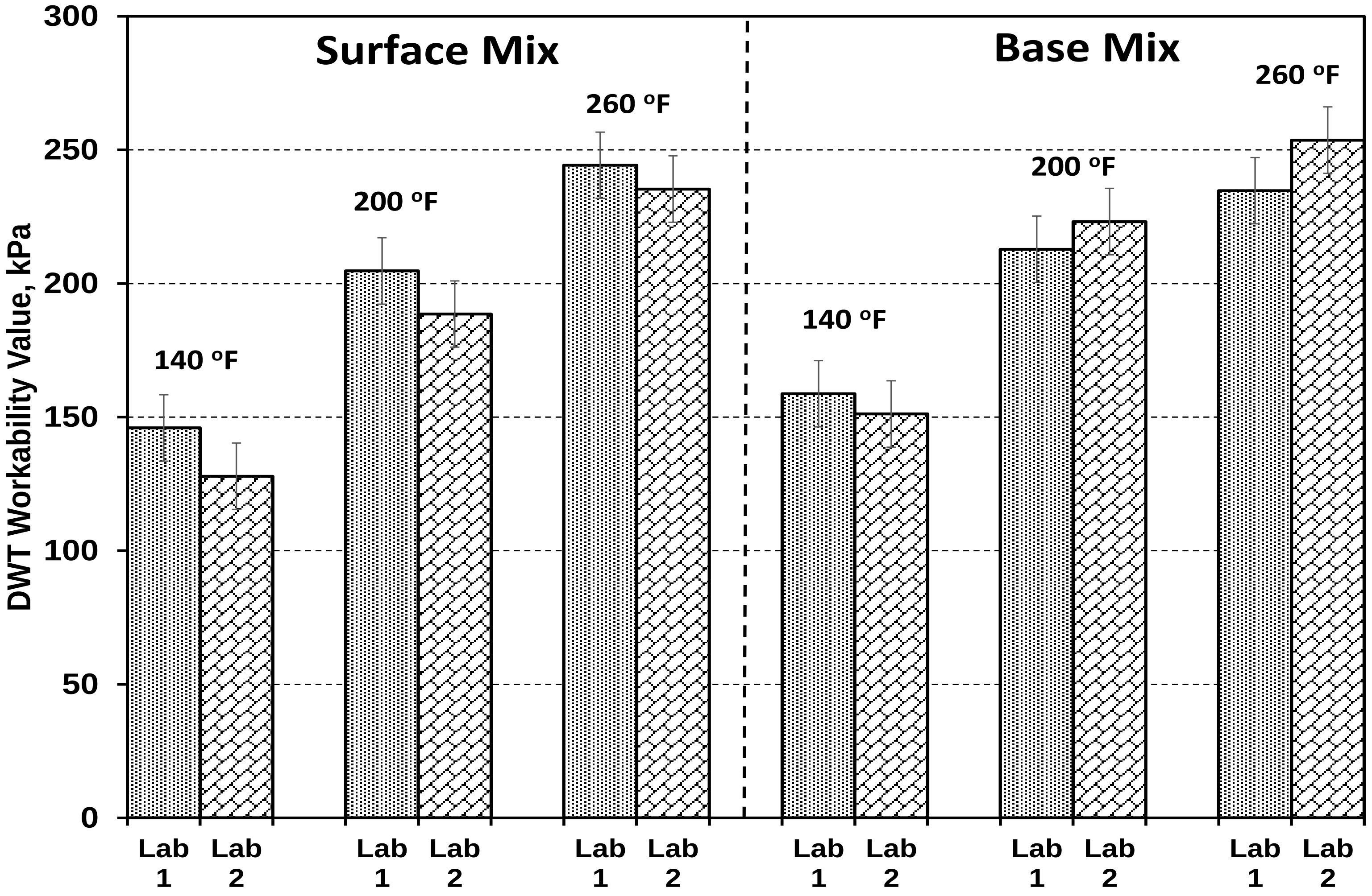
	Factor	High Level "X"	Low Level "x"
A	Number of Rodding Strokes	25	15
B	Delay after rodding to start test, s	60	< 15
C	Depth of Rodding	Refusal	Refusal -1”
D	Specimen Mass, g	5000	4600
E	Loading Rate (0.05mm/sec ±10%)	0.06	0.04
F	Dummy Factor 1		
G	Dummy Factor 2		

Additional Laboratories - FHWA (TFHRC), Univ of Ark, and DLSI
Additional Mixes -Two Mixes at three Temperatures each

Preliminary Single Operator Precision Estimate from Ruggedness Phase I

Material	DWT Average kPa	Standard Deviation	Coefficient of Variation
Mix A 82ºC	186.4	8.9	4.8%
Mix A 107ºC	201.7	11.8	5.9%
Mix S 62°C	131.9	11.0	8.3%
Mix S 85°C	170.4	13.8	8.1%
Mix S 102°C	195.2	19.4	9.9%
Mix F 62°C	130.8	6.7	5.1%
Mix F 102°C	178.9	11.7	6.5%
Mix F 130°C	201.9	15.3	7.6%

Between – Lab Precision Estimate



Between – Lab Precision Estimate

Mix	Two-Lab Average DWT Value, kPa	Two-Lab Standard Deviation, kPa	Two-Lab COV
Surface 140°F	137	9.3	9%
Surface 200°F	197	5.8	6%
Surface 260°F	240	2.6	3%
Base 140°F	155	3.5	3%
Base 200°F	218	3.4	3%
Base 260°F	244	5.5	5%
Pooled data			**5%**

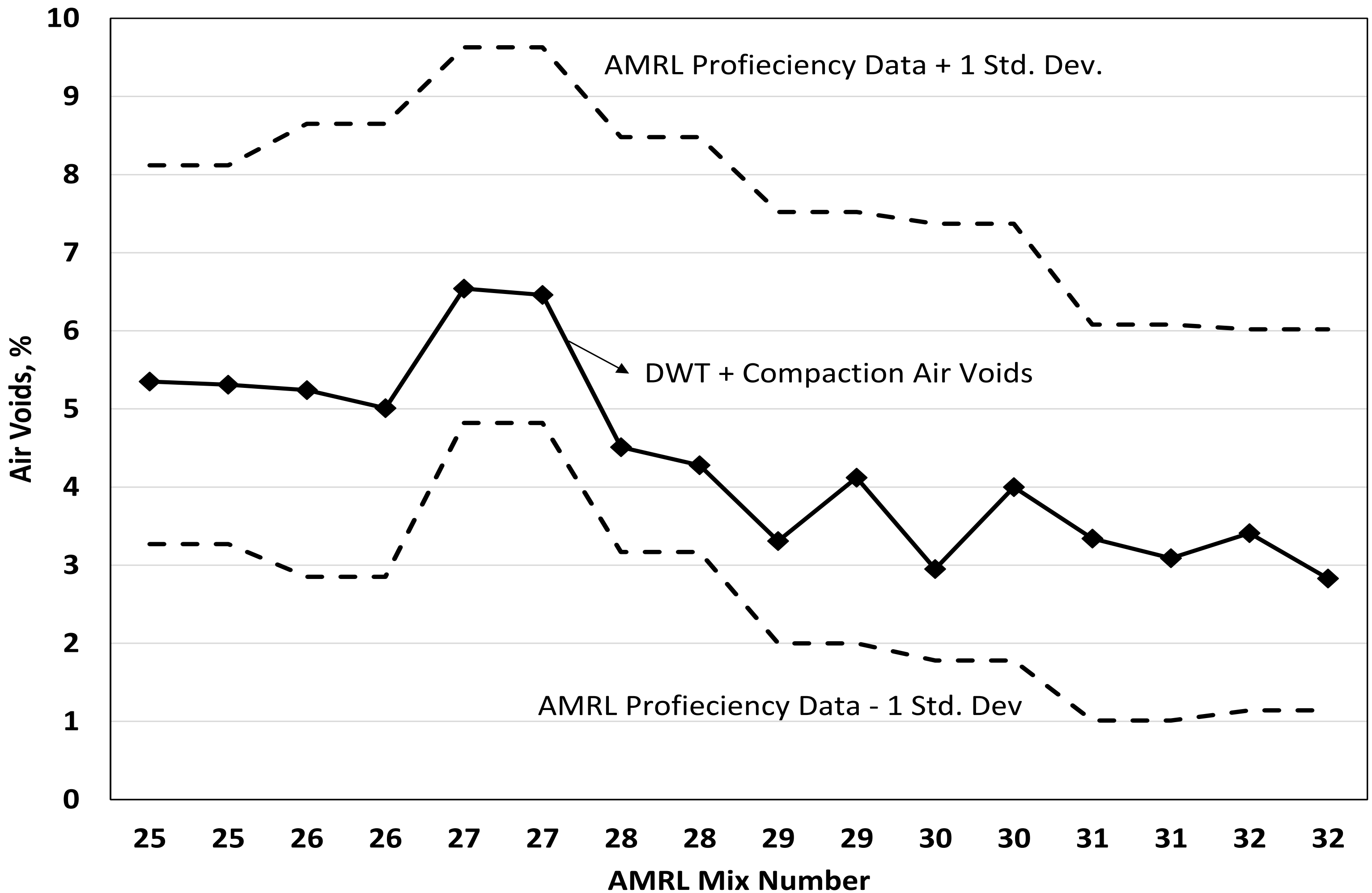
Implementation Proposal – Mix Production QC

- We can Implement the DWT Test as follows
  - Before compacting a QC volumetric specimen using the Gyratory Compactor do the DWT test first by loading the loose mix to 700 kPa at 0.05 mm/s
    - Currently the loose mix is loaded to 600 kPa at 8.4 mm/s
- This change will be transparent to the user but will provide additional DWT information that can be used in QC testing rapidly
- The compaction can proceed normally (as is done now) once 600 kPa load is reached at 0.05 mm/s and the operator chooses to proceed
  - if the DWT value is within limits
  - DWT value and limits pre-determined during mix design

The BIG QUESTION!

- How are SGC volumetric parameters affected if DWT is conducted prior to compacting a volumetric QC specimen?
  - Air Voids √
  - Gmb
  - Final Height
  - Initial Height

Effect on SGC Air Voids



Conclusions

- “DWT” - A simple, low-cost, easy to use test method was developed to measure:
  - Workability of asphalt mixes
    - HMA, WMA, PMA+HMA
    - Field Compaction Temperature Range
    - Temperature Reduction of WMA additives (Energy Savings)
- The ‘DWT’ is capable of resolving workability differences:
  - WMA mixes
  - Different Binder Sources
  - Different Aggregate Sources
  - Different Mixing Temperatures

Conclusions…….

- Given the Findings DWT may be Implemented as Follows:
  - As a Part of The Normal Mix Design Procedure
  - In Field QC/QA method
  - As a Measure of Warm Mix Additive Effectiveness in reduction of Field Compaction Temperature

Next Steps

- Calculating another Workability Parameter
  - Energy under the DWT curve
- Theoretical Analysis
  - Can the DWT stress-Strain curve be used with FEM method developed by Texas A&M
    - Modelling of Hot-Mix Asphalt Compaction – Koneru et al.
- Modelling of DWT Stress-Strain Curves
  - It appears that the DWT curve maybe related to the gradation curve
  - For example: Early attempts indicate that the inverse of 0.45 power maybe used to fit the linear portion of the DWT curve!
- Effect of RAP, RAS, and Aging on DWT values and compaction Temperatures – CTAA 2014 paper

Next Steps……………….

- ASTM Work Item No.: WK41154
  - Sub committee ballot in fall 2013
- Ruggedness Phase II underway
- After Ruggedness complete – ILS Study
- ETG presentation
  - ETG updates
- ASTM Standard
  - Richard Steger Committee 4.20

Questions?

- Thank You for Listening!