Evaluating the Workability and Compactibility of Modified Asphalt Mixtures: A New Perspective

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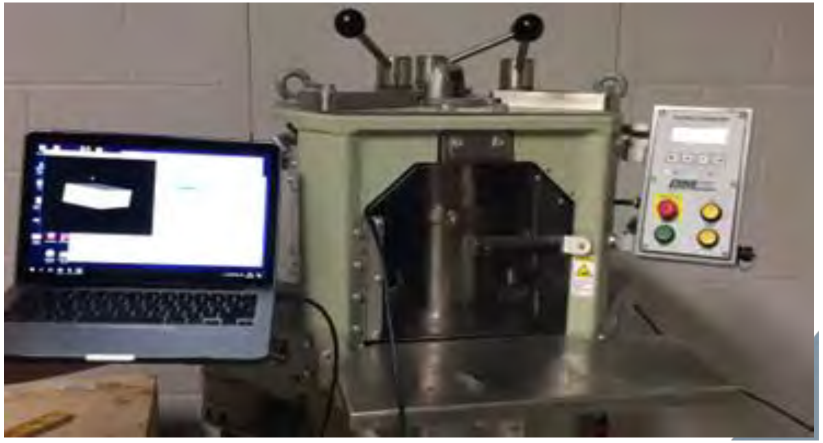



Workability of Modified Mixtures

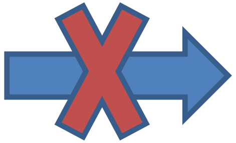
Viscoelastic material

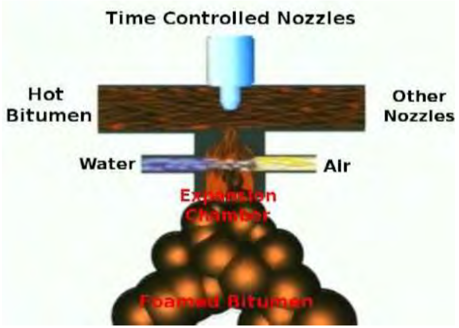
Modified asphalt mixture

Good workability is affected by material property and compaction conditions

Workability Method – Viscosity Measurement

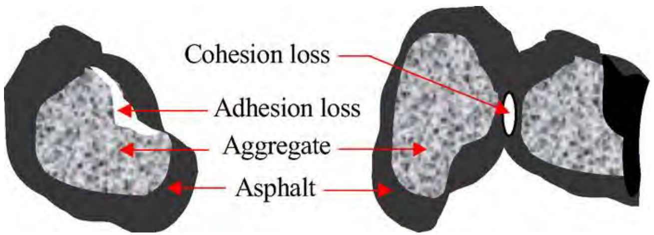
Original asphalt binder and viscous-based technologies

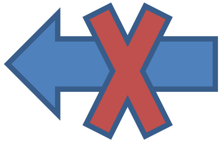




- WMA technologies (e.g., foaming and chemical additives) have less influence on the viscosity of asphalt binder. Such improvement in workability cannot be effectively detected.

Workability Method – Mixing Resistance

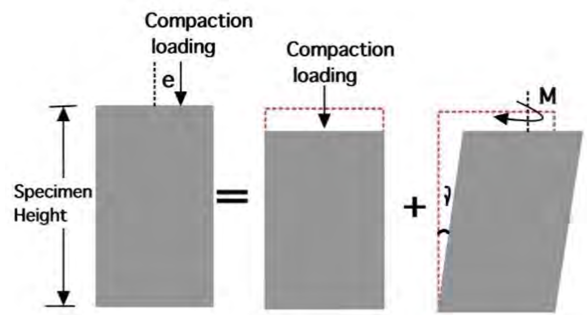




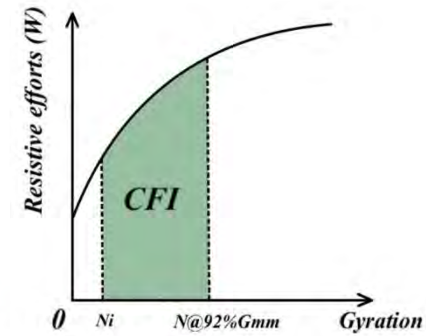
- Not effective in evaluating the coating effects between the aggregates and asphalt binder
- Hardly describe the ease of the asphalt mixture being placed and compacted.

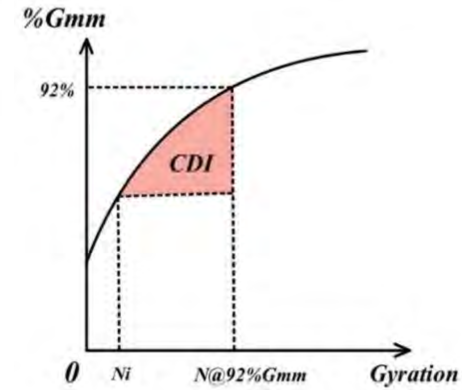
Workability Method -- SGC

Superpave Gyratory Compactor (SGC)



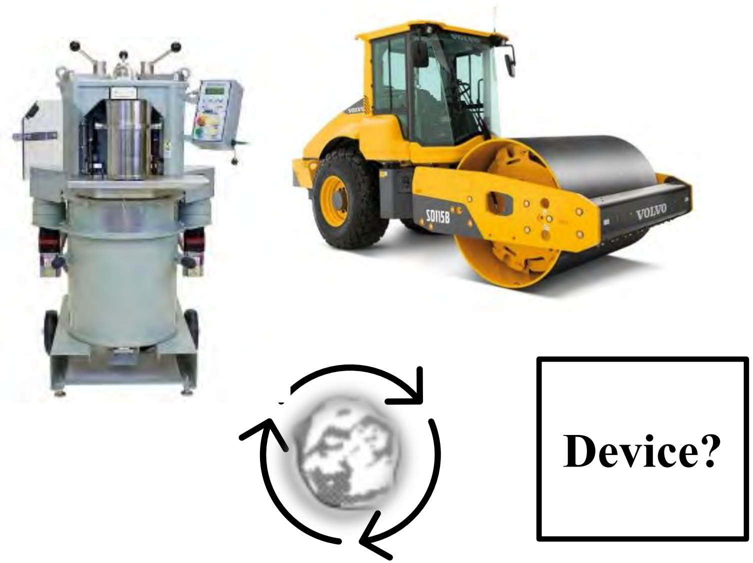
Mechanical or volumetric parameters to evaluate the workability





- SGC can only be used in the lab compaction
- This method was found insensitive to the compaction temperature and the WMA organic additives

New Perspective: Particle Compaction Behaviors



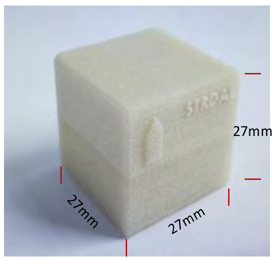
How the aggregate particles move during compaction has a direct impact on the mixture's workability.

Objective – Develop a Method to Evaluate Workability and Compaction from a Particle Perspective

- **This method should be**
  - Applicable to modified asphalt mixtures
  - Effective for differentiating the effect of additives, binder content, compaction temperature
  - Capable of connecting laboratory and field compaction
  - Ultimately, be indicative of field compaction characteristics

Methodology Development

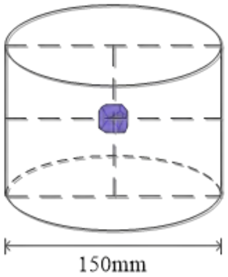
Particle-Size Sensor -- SmartRock

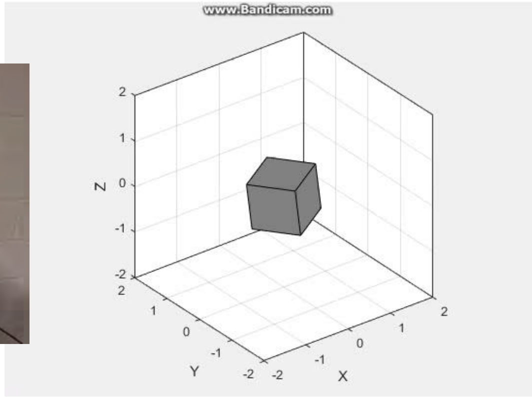


Outside: High-temperature durable shell

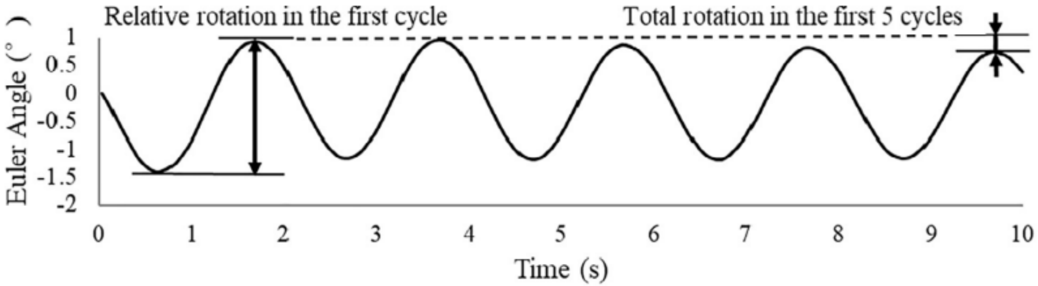
Inside: gyroscope, thermometers. accelerometer, magnetometer

Data collection: Bluetooth BLE technology



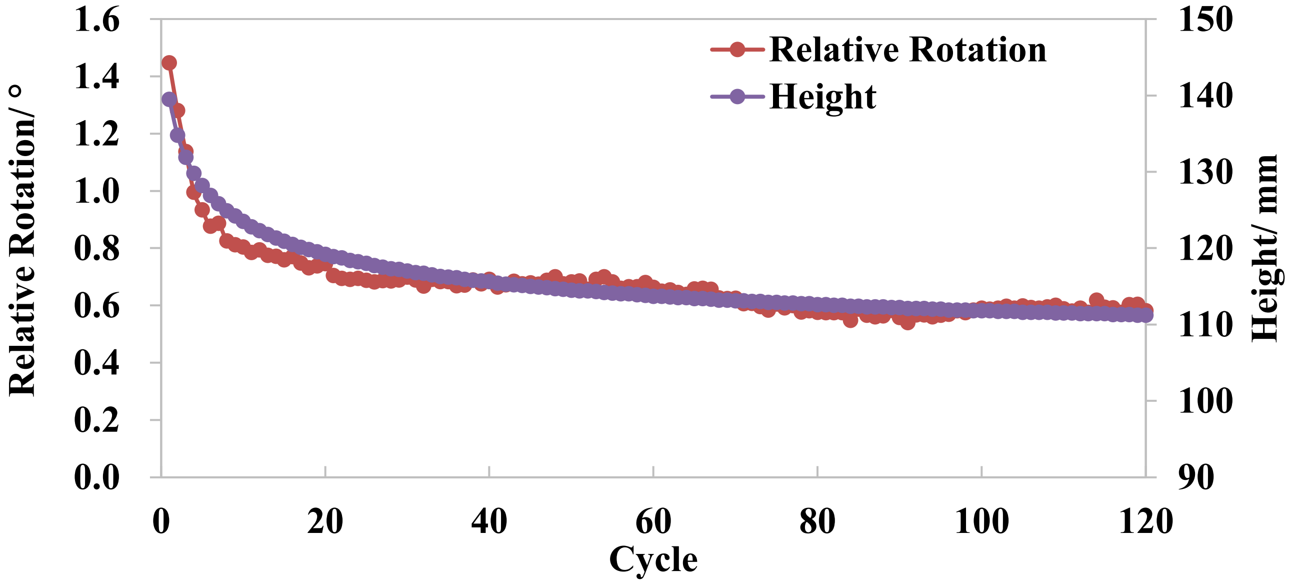


Particle Rotation: What is Relative Rotation?



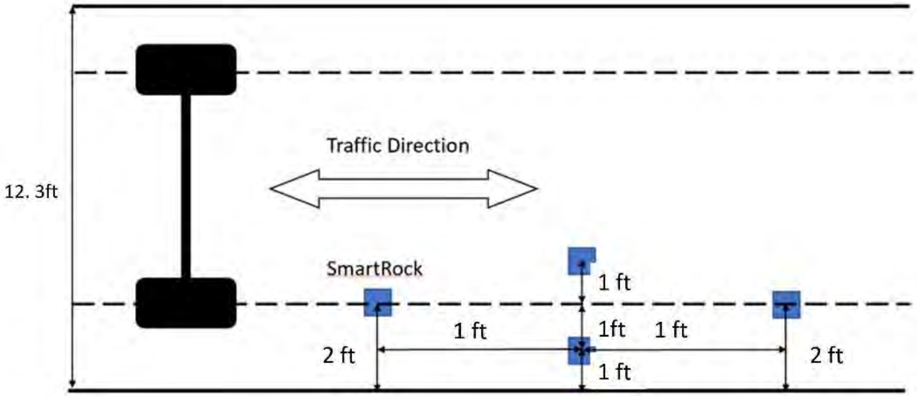
- **Relative Rotation** is the difference between the peak and the valley values of the Euler angle for each cycle.
- The Relative Rotation represents the particle’s maximum fluctuation angle.

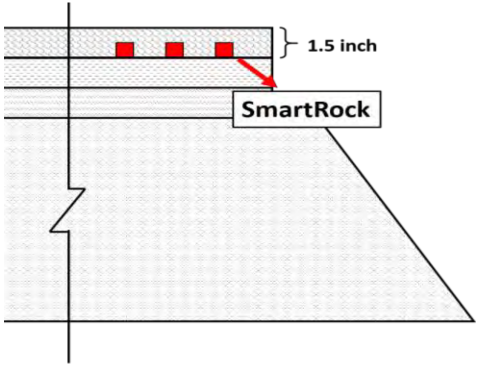
Correlation Between Particle Rotation and Density

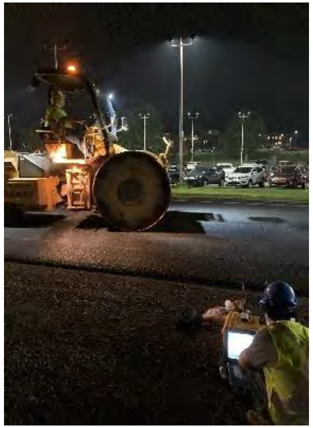


- **Relative rotation** (horizontal direction) is closely related to the height(density) of the asphalt specimen, which allows us to use **particle rotation to characterize the workability.**

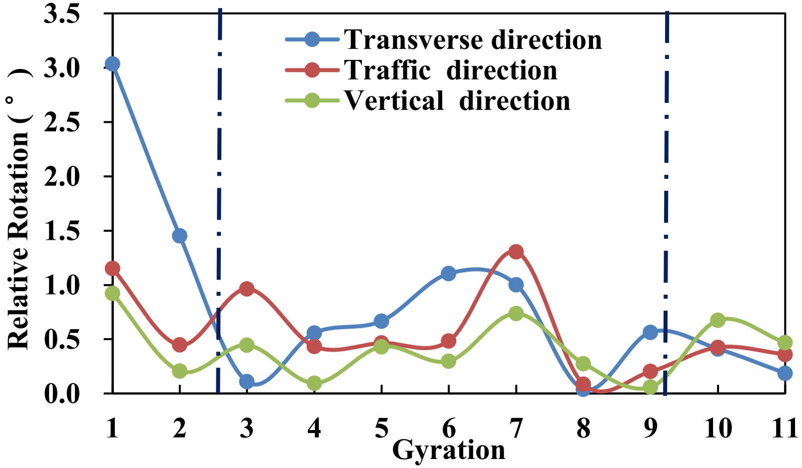
Field Compaction – Hollidaysburg, PA

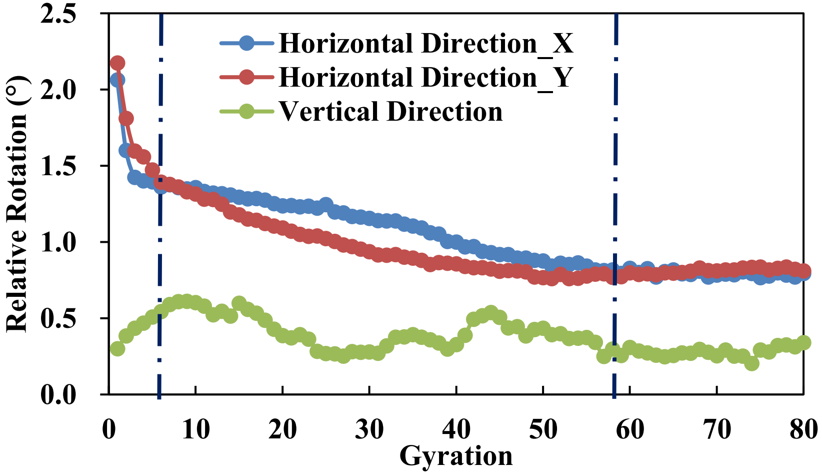






Correlation Between Lab and Field Compaction





Three-stage compaction stages occur in the lab and field compaction

- **Breakdown stage:** Short, most dramatic rotation and speedy decrease.
- **Main compaction stage**: Imbalance interaction between compaction loadings and particle shearing resistances.
- **Finishing stage**: Balanced interaction and static state of compaction.

Statistical Verification of the Correlation

$$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2}}$$

r = correlation coefficient

x_i = values of the x-variable in a sample

$\bar{x}$ = mean of the values of the x-variable

y_i = values of the y-variable in a sample

$\bar{y}$ = mean of the values of the y-variable

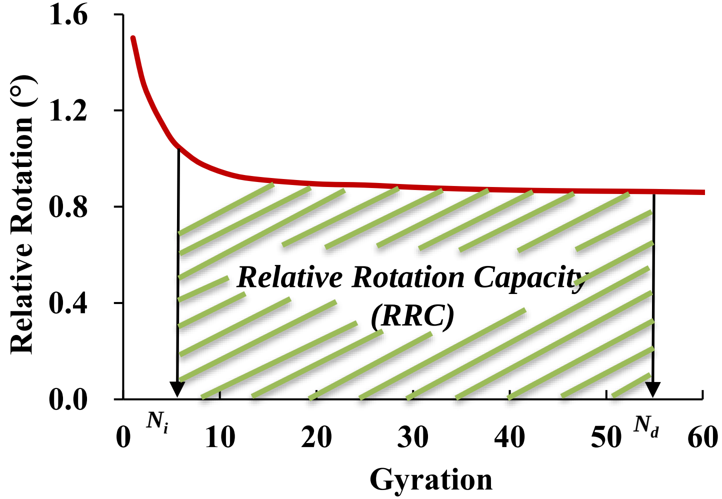
Pearson correlation coefficient (r)

- 0.9 <|r|<1 indicates very highly correlated.
- 0.7 <|r|<0.9 indicates highly correlated.
- 0.5 <|r|<0.7 indicates moderately correlated.
- 0.3 <|r|<0.5 indicates low correlated.
- |r|<0.3 indicates no correlated.

Reference: https://www.andrews.edu/~calkins/math/edrm611/edrm05.htm#PEAR

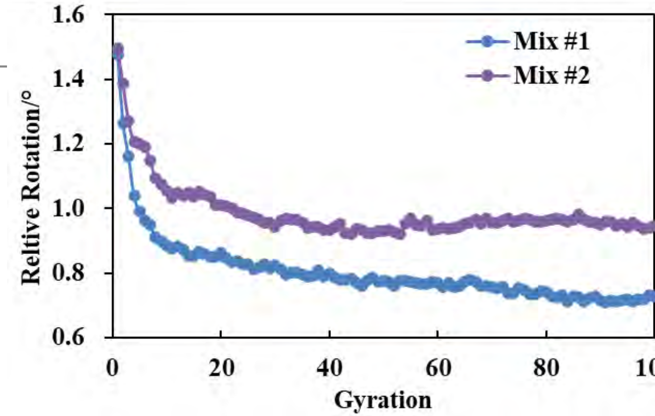
- **Density-based Pearson Correlation coefficient:** ***r=0.818 (Highly Correlated)***
  Correlation between the particle rotation curves to achieve the same density using the lab and field compaction
- **Energy-based Pearson Correlation coefficient:** ***r=0.806 (Highly Correlated)***
  Correlation between the particle rotation curves under the same amount of compaction energy using the lab and field compaction

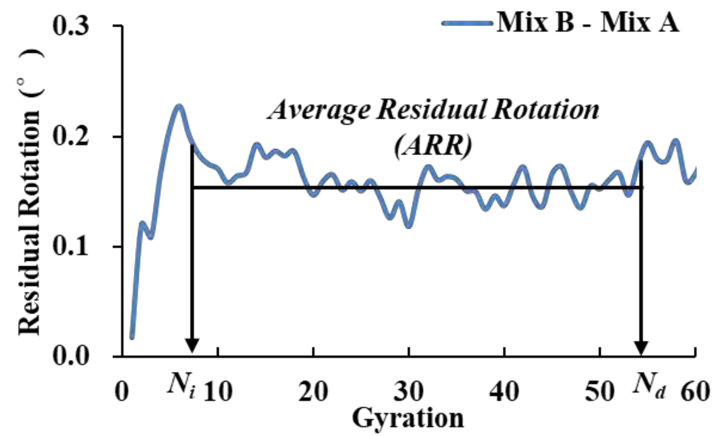
Workability Quantification



Relative rotation capacity (RRC)

$$RRC = \sum_{i=N_i}^{N_d} \frac{(RR_{i+1} + RR_i) \times l}{2}$$





Average residual rotation (ARR)

$$ARR = \sum_{i=N_i}^{N_d} \frac{ReR_i}{N_d - N_i} \times Q$$

Workability of WMA

Design of Experiments – 5 types of mixtures

Parameters	Mix 1	Mix 2*	Mix 3	Mix 4	Mix 5
Type	HMA12.5	**HMA12.5**	WMA12.5	WMA12.5	WMA12.5
Binder	PG 64-22	**PG 64-22**	PG 64-22	PG 64-22	PG 64-22
Pb (%)	5.9	**5.9**	5.9	5.9	5.9
Additive dosage (%)	0	**0**	0.35	0.7	0.7
Compaction temp (°F)	230	**290**	260	230	290

Same base mixture (same gradation and asphalt binder and content)

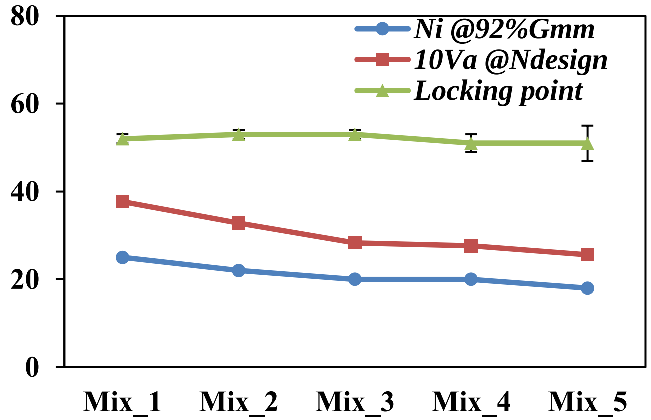
Different dosages of **additives** and **compaction temperature**

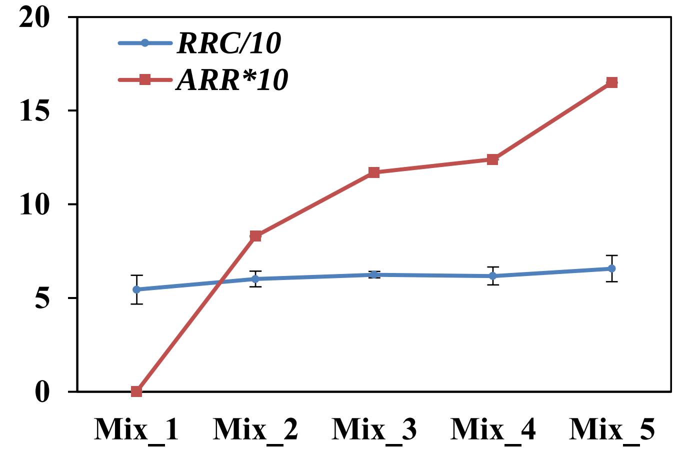
WMA Chemical additives: Evotherm M1

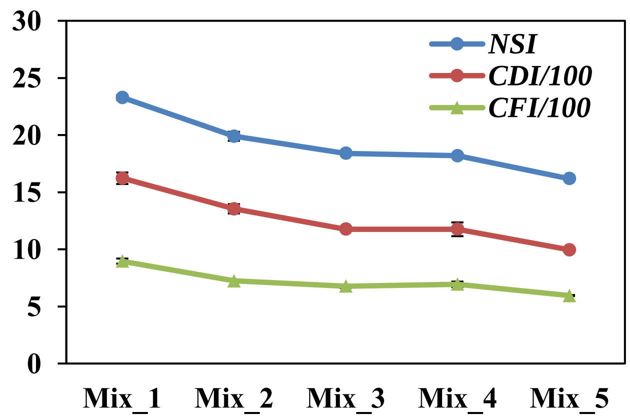
Comparison of Workability Parameters

Parameters		Mix #1	Mix #2	Mix #3	Mix #4	Mix #5
Mixture type		HMA	**HMA**	WMA	WMA	WMA
Additive dosage		0%	**0%**	0.35%	0.7%	0.7%
Compaction temperature		110°C	**143°C**	127°C	110°C	143°C
Volumetric	N_i @92% G_{mm}	25±0	**22±0**	20±0	20±0	18±0
	Va @N_{design}	3.77%	**3.28%**	2.83%	2.76%	2.56%
	locking point	52±1	**53±1**	53±1	51±2	51±4
Mechanical	*CDI*	1623.5±0.5	**1355.2±0.4**	1177.2±0.1	1176.7±0.6	995.6±0.1
	CFI	897.4±22.4	**724.7±0.2**	677.8±16.6	695.0±23.5	596.3±3.4
	NSI	23.3±0.2	**19.9±0.4**	18.4±0.0	18.2±0.1	16.2±0.0
Kinematic	*RRC*	54.45±7.70	**60.12±4.20**	62.43±1.71	61.73±4.77	65.69±6.95
	ARR	0	**0.83**	1.17	1.24	1.65

Comparison to Conventional Parameters

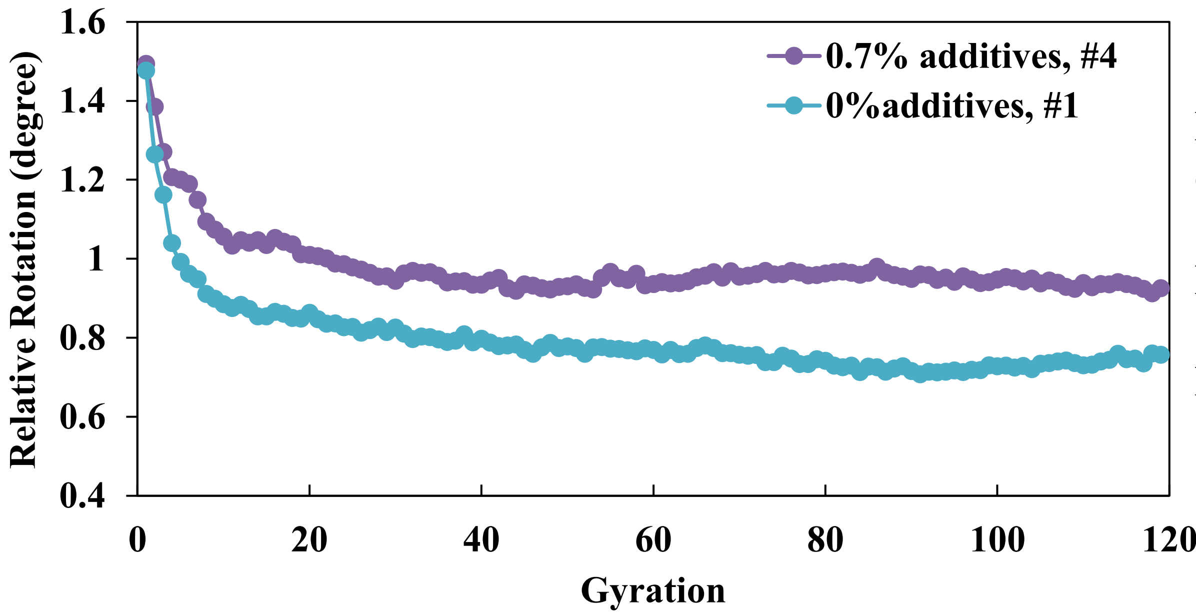






- Consistent workability for five mixtures:
  Mix #1 < Mix #2 < Mix #3 ≈ Mix #4 < Mix #5

Workability Evaluation for Single Mixture



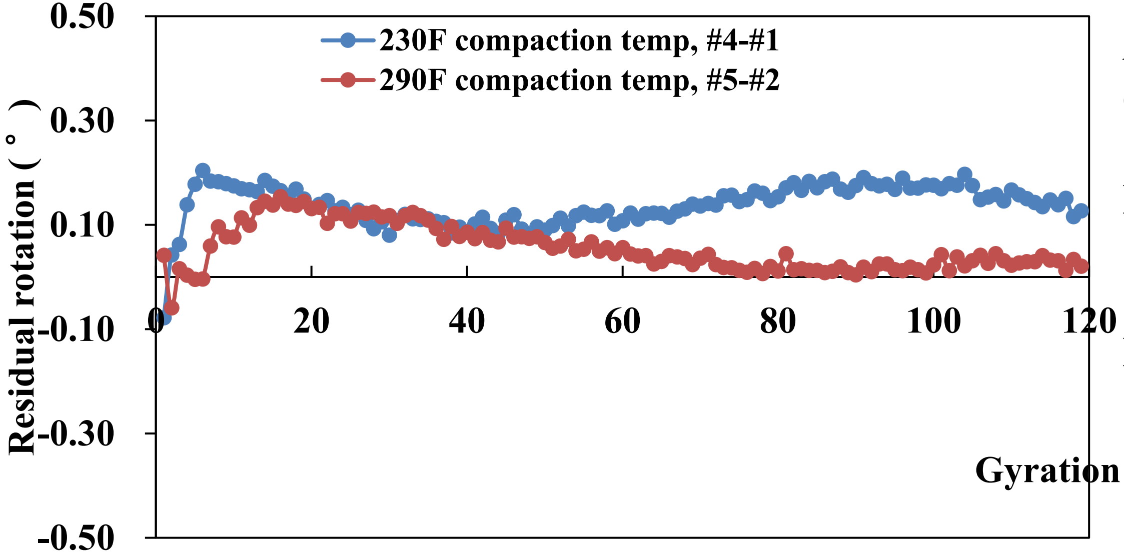
Relative Rotation Capacity (RRC)

Mix 4: 61.73

Mix 1: 54.54

- **Mix 4 (230F, 0.7% additive) vs. Mix 1 (230F, 0% additive)**

Compare the Effect of WMA Additive



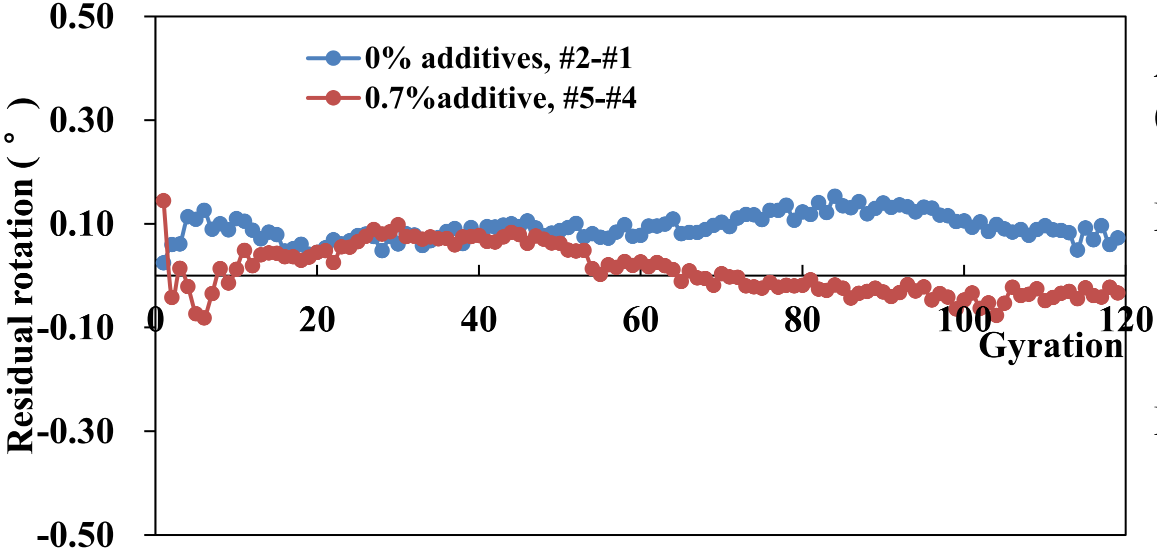
Average residual rotation (ARR)

Mix 4-Mix 1: 1.24

Mix 5-Mix 2: 0.82

- **Blue: Mix 4 (230F, 0.7% additive) vs. Mix 1 (230F, 0% additive)**
- **Red: Mix 5 (290F, 0.7% additive) vs. Mix 2 (290F, 0% additive)**

Effect of Compaction Temperature



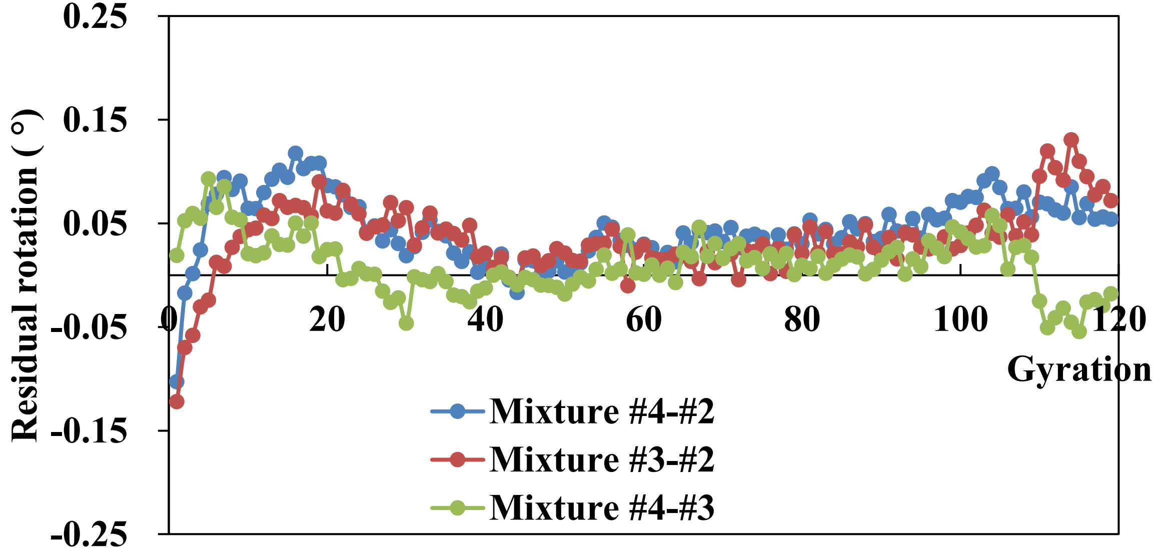
Average residual rotation (ARR)

Mix 2-Mix 1: 0.83

Mix 5-Mix 4: 0.41

- **Blue: Mix 2 (290F, 0% additive) vs. Mix 1 (230F, 0% additive)**
- **Red: Mix 5 (290F, 0.7% additive) vs. Mix 4 (230F, 0.7% additive)**

Combined Effect of Temperature and Additive



Average residual rotation (ARR)

Mix 3-Mix 2: 0.34
Mix 4-Mix 2: 0.41

Mix 4-Mix 3: 0.07

- **Blue: Mix 4 (230F, 0.7% additive) vs. Mix 2 (290F, 0% additive)**
- **Red: Mix 3 (260F, 0.35% additive) vs. Mix 2 (290F, 0% additive)**
- **Green: Mix 4 (230F, 0.7% additive) vs. Mix 3 (260F, 0.35% additive)**

Workability of Plastics Modified Mixture

Project of Plastic mixtures – 6 types of mixtures

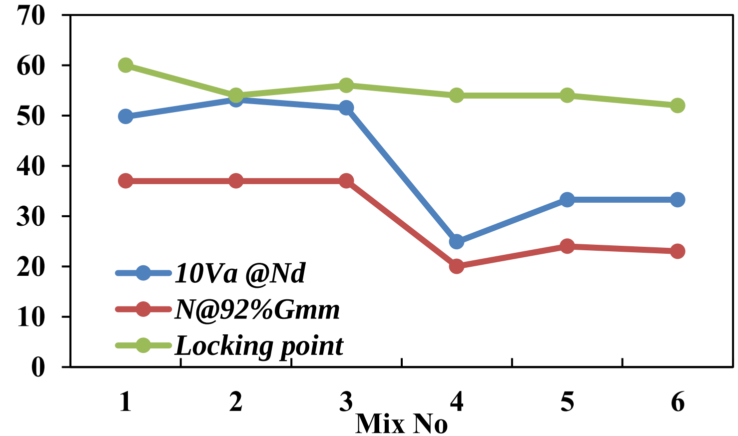
No.	Binder Content	Plastic	Method	Antistrip	RAP
1	5.2%	0%	/	0.5%	15%
2	5.2%	9%	Dry	0.5%	15%
3	5.2%	9%	Wet	0.5%	15%
4*	6.0%	0%	/	0.5%	15%
5	6.0%	9%	Dry	0.5%	15%
6	6.0%	9%	Wet	0.5%	15%

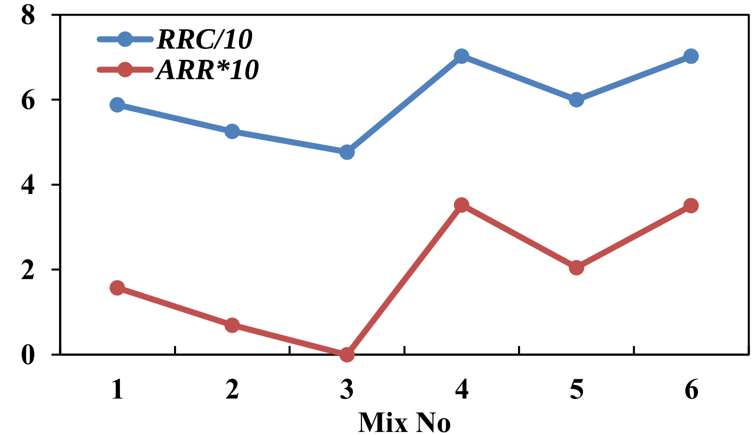
- Same **gradation** and **asphalt** properties;
- Same **mixing and compaction temperature;**
- Same **types** of plastics (LDPE)
- Different content of **virgin binder** and **plastic**

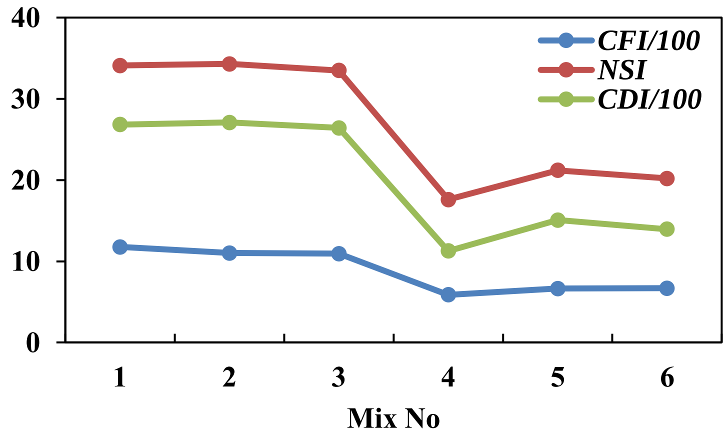
Comparison of Workability Parameters

Parameter		Mix_1	Mix_2	Mix_3	Mix_4	Mix_5	Mix_6
Volumetric	Va @Nd	4.97±0.07	5.31±0.11	5.15±0.08	**2.49±0.27**	3.33±0.22	3.33±0.20
	N92	37±2	37±2	37±2	**20±9**	24±7	23±8
	Locking point	60±2	54±4	56±4	**54±4**	54±8	52±5
Mechanical	CFI	1176.8±6.9	1102.4±2.5	1093.5±7.1	**587.9±15.2**	665.7±8.2	668.4±9.6
	NSI	3410±0.7	3430±1.8	3350±3.4	**1760±11.4**	2120±8.7	2020±10.2
	CDI	2684.3±2.7	2709.5±4.1	2642±3.4	**1128.7±13.7**	1507.9±10.0	1396.4±11.1
Kinematic	RRC	58.78±2.41	52.55±2.87	47.70±4.75	**70.23±4.57**	59.98±5.23	70.23±9.20
	ARR	15.71	6.94	0.00	**35.22**	20.52	35.09

Comparison to Conventional Parameters





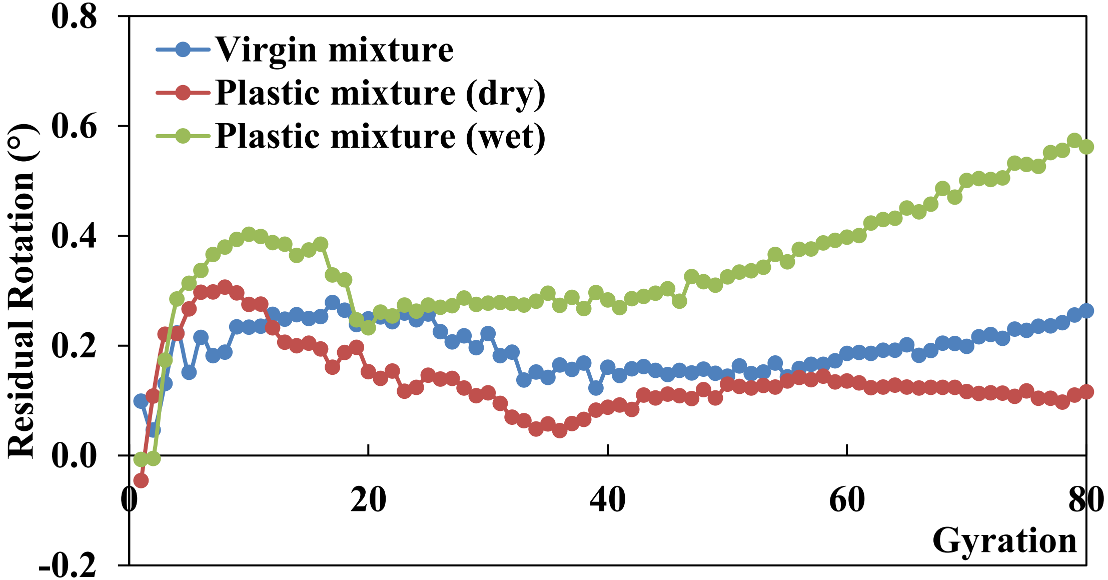


- Consistent workability for five mixtures:

Mix 3 < Mix 2 < Mix 1 < Mix 5 < Mix 6 = Mix 4

- Kinematic parameters (ARR and RRC) are more sensitive to plastic processing methods.

Effect of Binder Content



Average residual rotation (ARR)

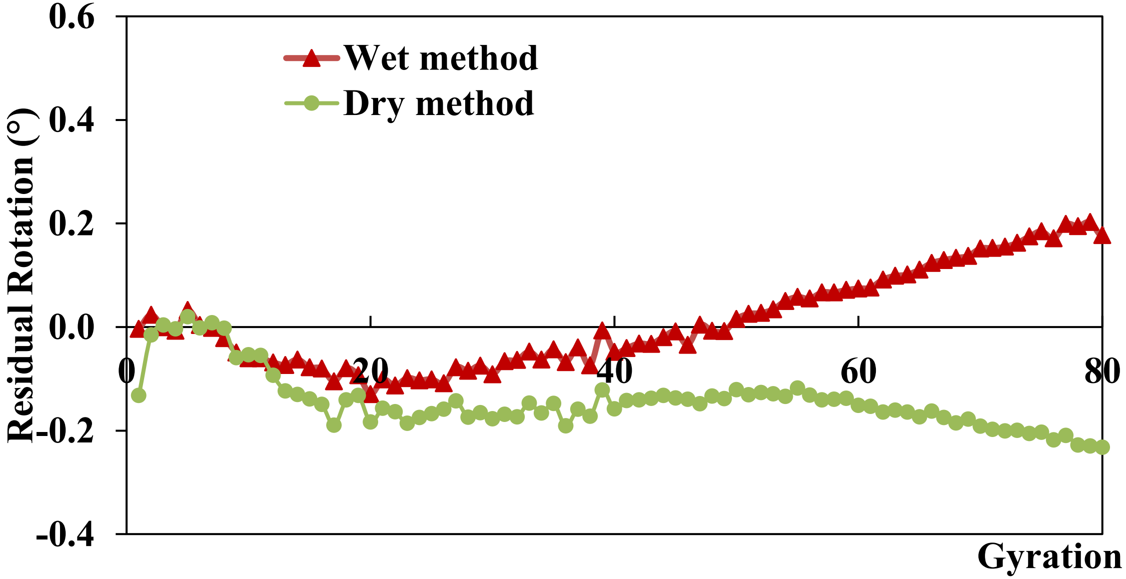
Mix 6-Mix 3: 3.51 (Different)

Mix 4-Mix 1: 1.95 (Different)

Mix 5-Mix 2: 1.36 (Different)

- **Green: Mix 6 (6.0%*Pb*, wet plastic mixture) vs. Mix 3 (5.2% *Pb*, wet plastic mixture)**
- **Blue: Mix 4 (6.0% *Pb*, virgin mixture) vs. Mix 1 (5.2% *Pb*, virgin mixture)**
- **Red: Mix 5 (6.0% *Pb*, dry plastic mixture) vs. Mix 2 (5.2% *Pb*, dry plastic mixture)**

Effect of Plastics (9% LDPE) with Different Mixing Methods



Average residual rotation (ARR)

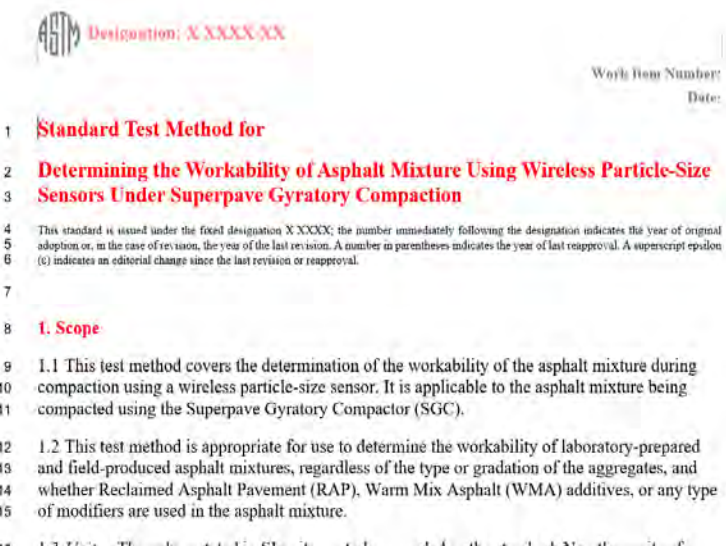
Mix 6-Mix 4: -0.01 (Equivalent)

Mix 5-Mix 4: -1.47 (Different)

- **Red: Mix 6 (6.0% *Pb*, wet plastic mixture) vs. Mix 4 (5.2% *Pb*, virgin mixture)**
- **Green: Mix 5 (6.0% *Pb*, dry plastic mixture) vs. Mix 4 (6.0% *Pb*, virgin mixture)**

Conclusions

- A **new method** to evaluate the workability and compactibility of the asphalt mixtures is developed – *draft ASTM standard*
  - Based on particle rotation
  - Can be related to field compaction characteristics
  - Applicable to **modified asphalt mixtures**



Designation: X XXXX-XX

Work Item Number:
Date:

Standard Test Method for

Determining the Workability of Asphalt Mixture Using Wireless Particle-Size Sensors Under Superpave Gyratory Compaction

This standard is issued under the fixed designation X XXXX; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of the last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of the workability of the asphalt mixture during compaction using a wireless particle-size sensor. It is applicable to the asphalt mixture being compacted using the Superpave Gyratory Compactor (SGC).

1.2 This test method is appropriate for use to determine the workability of laboratory-prepared and field-produced asphalt mixtures, regardless of the type or gradation of the aggregates, and whether Reclaimed Asphalt Pavement (RAP), Warm Mix Asphalt (WMA) additives, or any type of modifiers are used in the asphalt mixture.

- Factors like **temperature, WMA additives, asphalt content, plastics type, and plastics processing method**, all have an impact on workability and compactibility.
  - By adding 0.35-0.7% Evotherm additive, the compaction temperature can be reduced by 30F to 60F.
  - With the same binder content, the wet mixing method produced LDPE modified mixture has better workability than the mixture produced by the dry method.

Other questions we might answer with the new tool

- Effect of aggregate gradation and angularity on the workability and compactibility of the asphalt mixtures
- How to determine design parameters, like additive type and dosage, and binder content, for sufficient workability?
- How to adjust and modify compaction parameters, both in the lab and field, to improve compaction quality?

ACKNOWLEDGEMENT

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Thank you!
Questions?

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