ARC Project Update

Quantifying the Effects of Warm Mix Additives using the Asphalt Lubricity Test

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Warm Mix Technical Working Group Meeting

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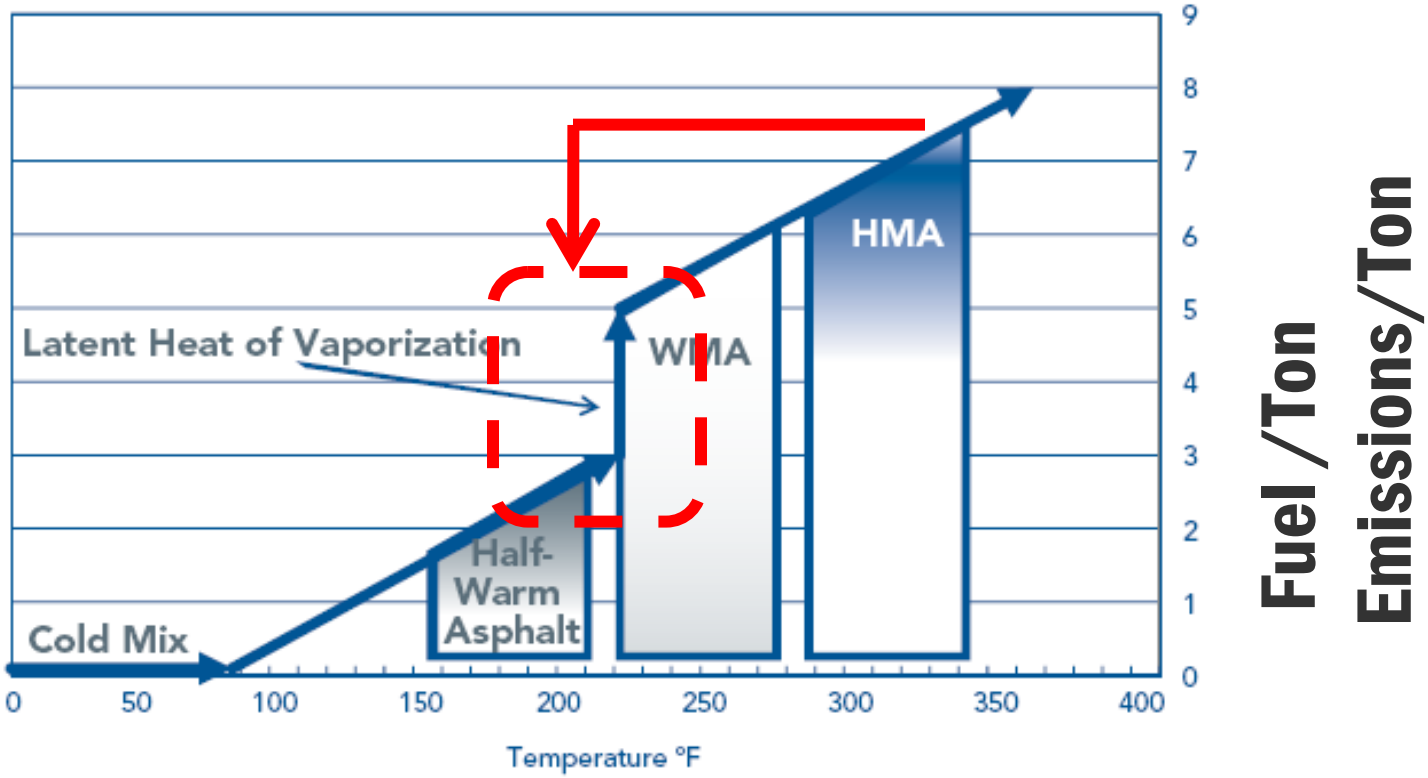
Seattle, WA

Outline of Talk

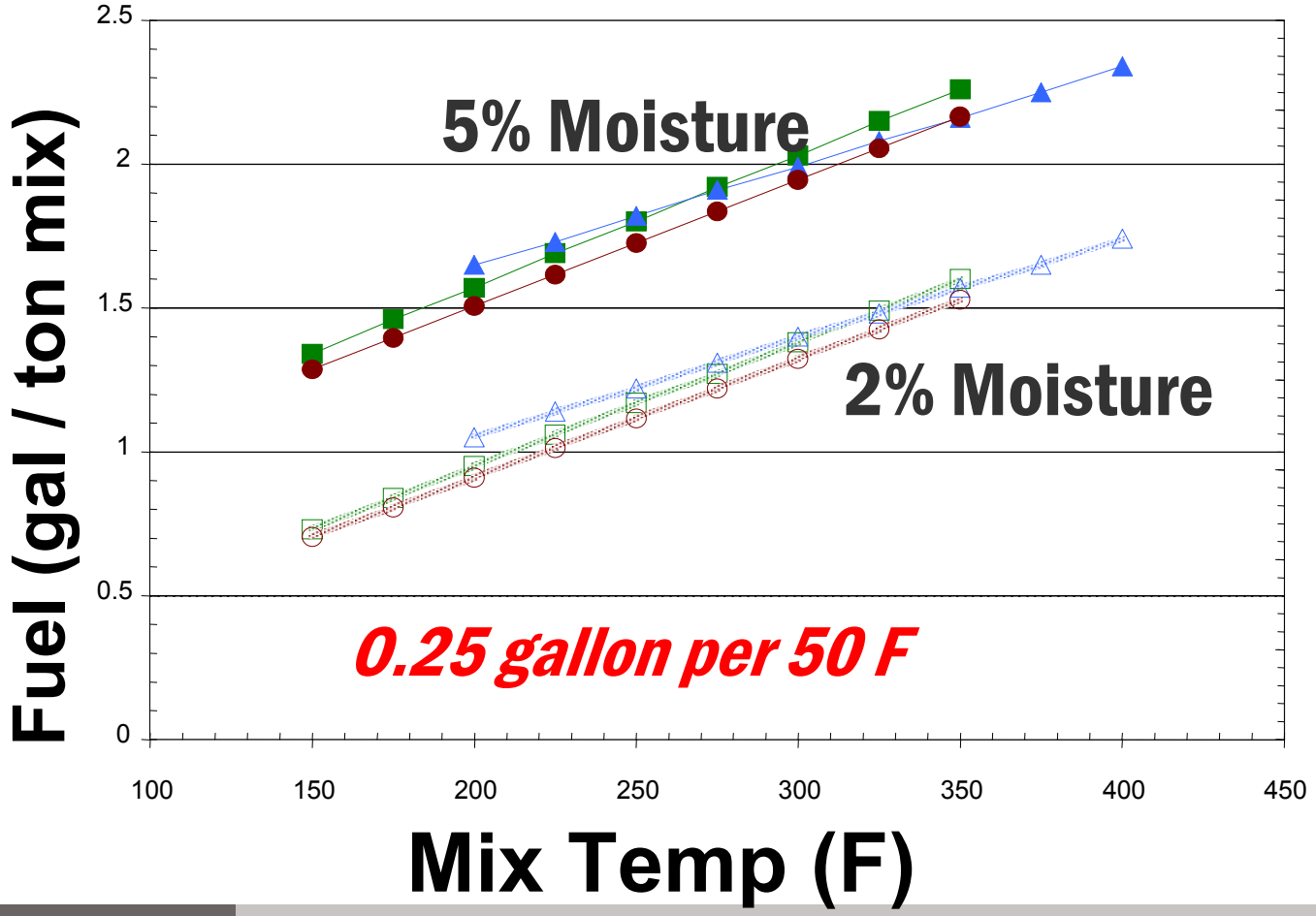
- Background: Research objectives
- Experimental plan : Materials and test methods
- Effects of WMAs on Binders
  - Viscosity
  - Lubricity
- Effects of WMAs on Mixtures
  - Coating
  - Compaction in gyratory
- Relationship between Mixtures and Binders

Benefits of Warm Mix Asphalt : Reduce Energy and Impact on Environment

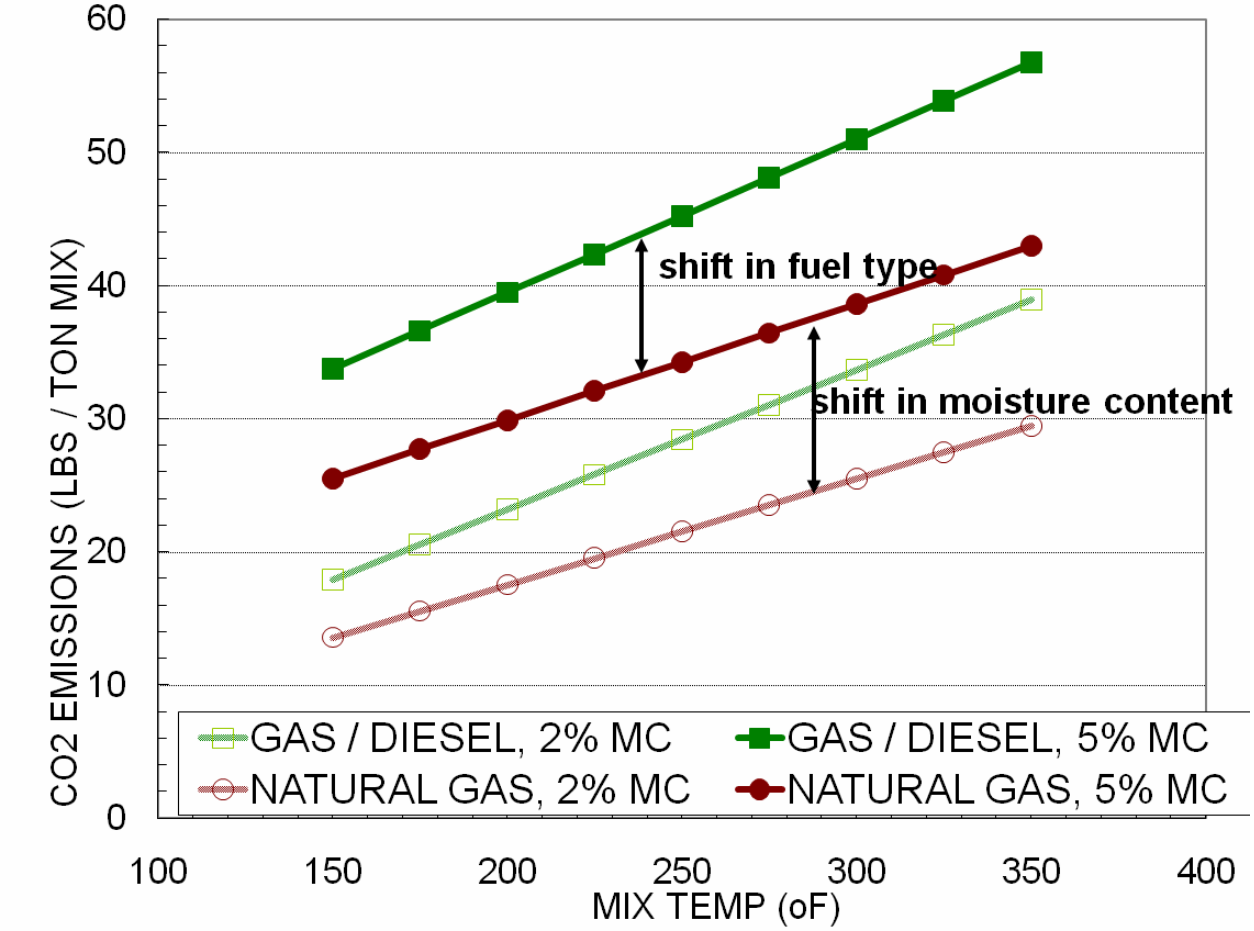


Source: FHWA

Reduction in Fuel Consumption Based on Three Existing Models



Estimated Reduction in Emissions



Study Main Objectives

- Evaluate claims about how Warm Mix Additives (WMA) work.
  - Reducing viscosity ?
  - Micro-foaming ?
  - Lubrication ?
- Determine how much is needed.
  - WMA content versus temperature reduction
  - Cost is based on content, justify use by saving heat energy

Experimental Design - Materials

- Five Warm Mix Additives:
  - Two surfactants: Revix (@.5%) and Rediset (@2 %),
  - One wax additive (Sasobit), and
  - Two foaming processes.
- Two base binders:
  - Unmodified PG64-22 and
  - SBS modified PG 76-22
- Two Mixture Gradations: Fine and Coarse

Mix Preparation with Modified Wirtgen Foaming System

Foamed Asphalt Shot into Bucket

- Binder Temp Held Constant ~160C
- Mixing Temp controlled by aggregate temp.

Foamed Asphalt on Aggregate – Immediately after foaming.

Mix Preparation with Wirtgen System

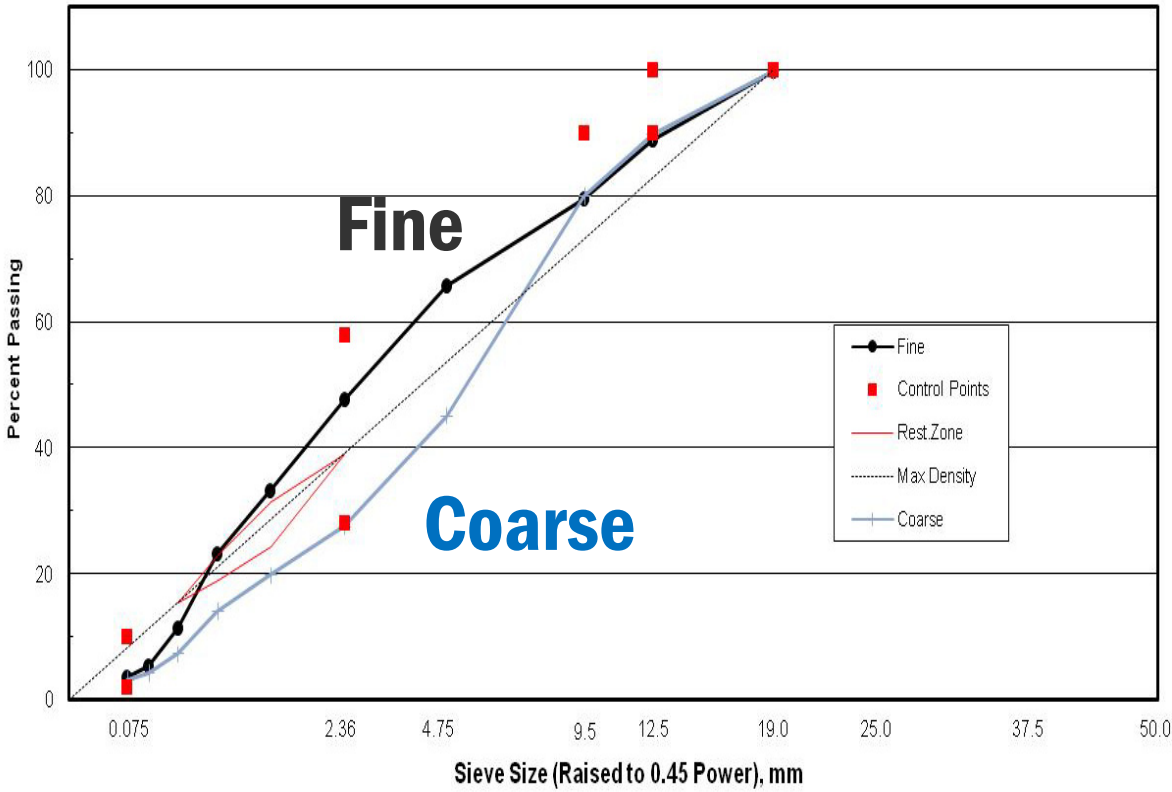
Foamed Asphalt mixed with aggregate. After mixing, normal conditioning/compaction.

Preliminary Foamed Asphalt Properties

- No effect on HT True Grade immediately after foaming
- Minimal effect on measured viscosity.

Aggregates Used in Mixtures

- Mixture testing
  - Fine and Coarse graded mixes
  - 10 million ESALs, mix design
    - (N_{des} =100)
  - Granite aggregate source

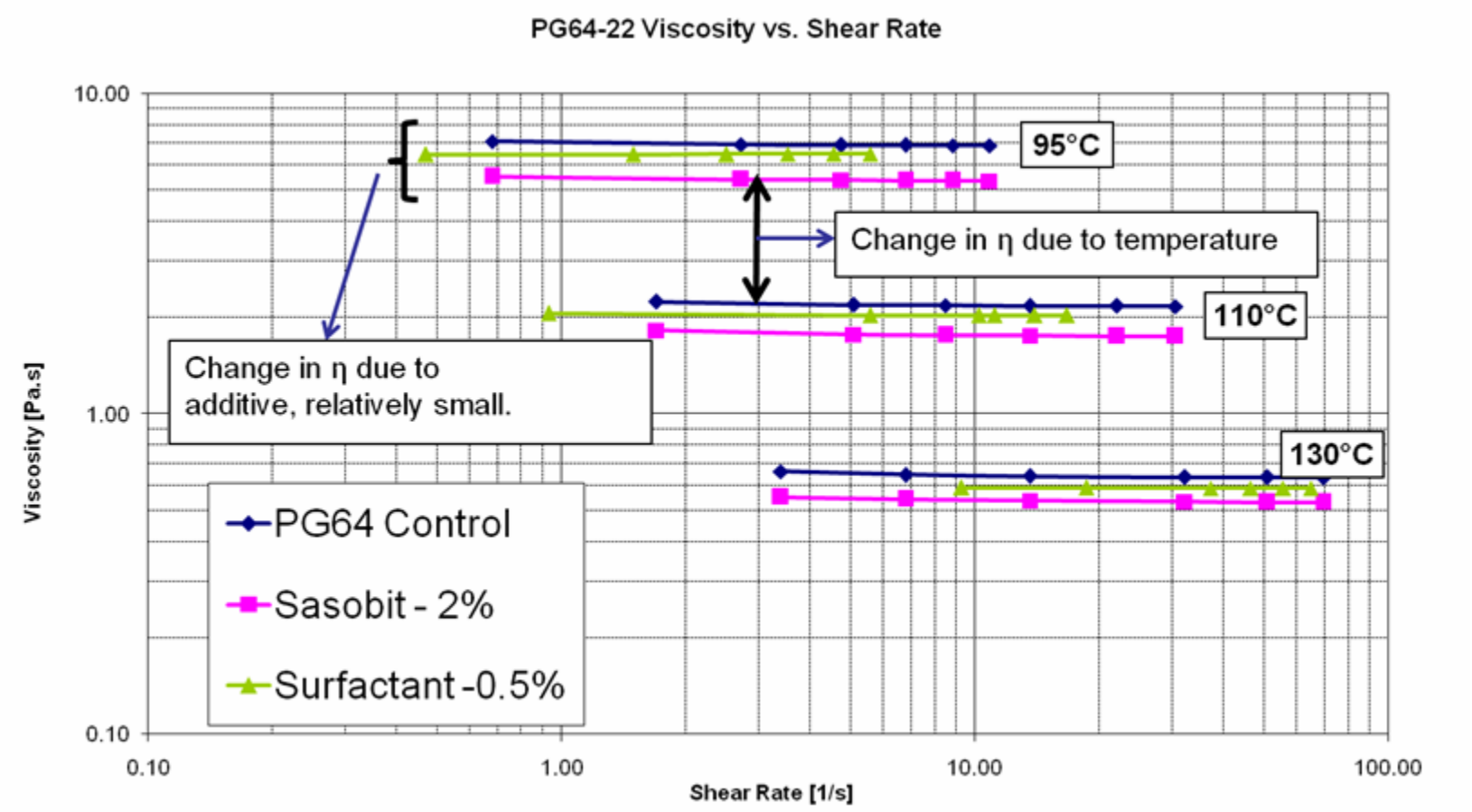


Experimental Plan - Testing

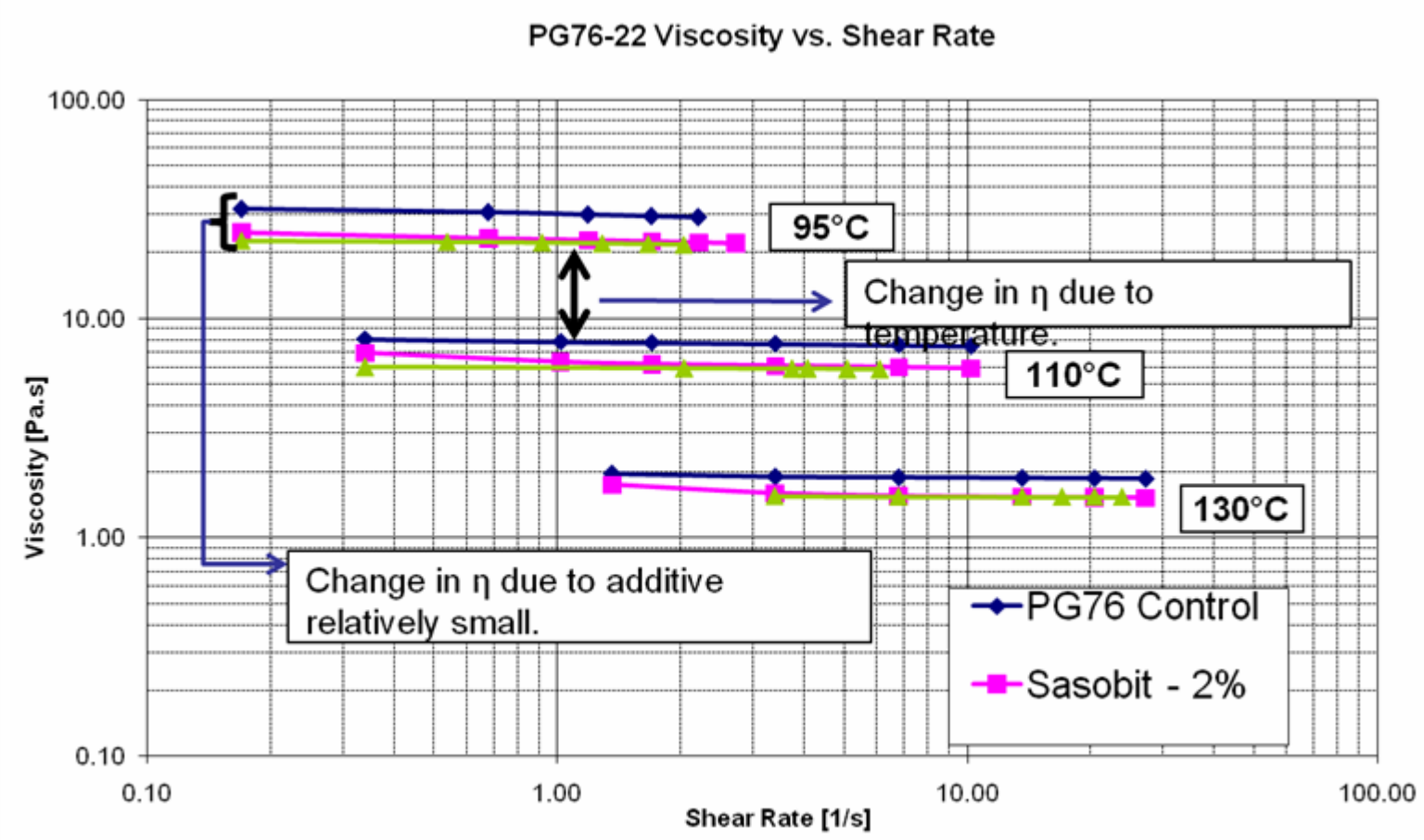
- **Binder** Workability:
  - Asphalt Binder **Viscosity – Rotational Viscometer**
  - Asphalt Binder **Lubricity – New DSR test**
- **Mixture** Workability:
  - Aggregate **Coating: Percent Coated**
  - Gyratory **Compaction Indices**:
    - **Construction Force Index using the GPDA - (CFI)**
    - **Number of Gyrations to 92 % Gmm- N92**

Effect on Viscosity – PG64-22

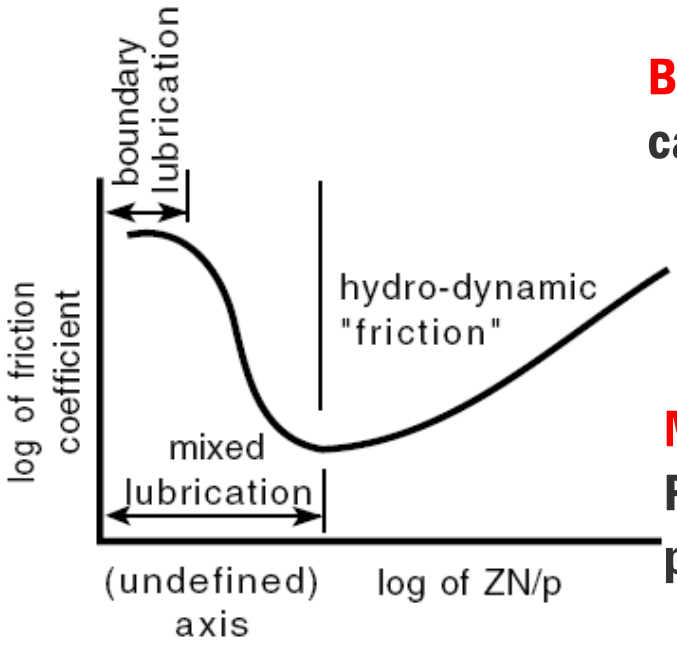
Finding: Effect is small and Shear rate is not important



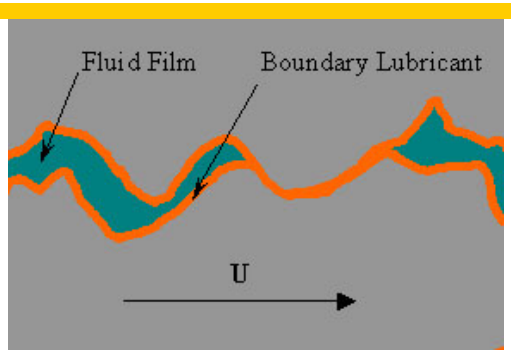
Effect on Viscosity – PG76-22



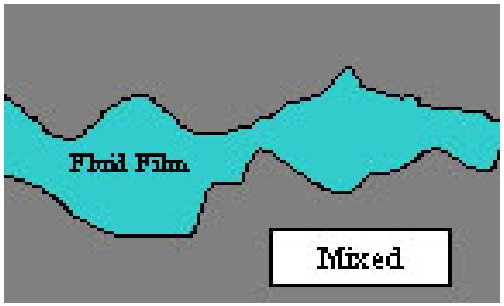
Conventional Analysis of Friction and Wear – Stribeck Curve



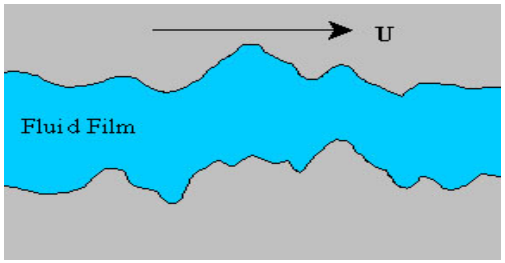
Boundary – Asperities cause friction



Mixed (Partial Contact) – Friction decrease as fluid pushes asperities apart.

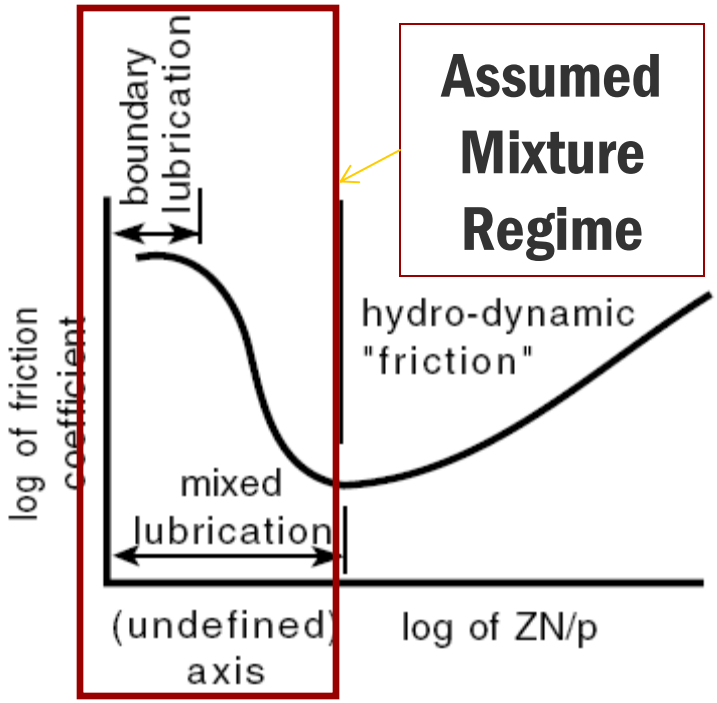


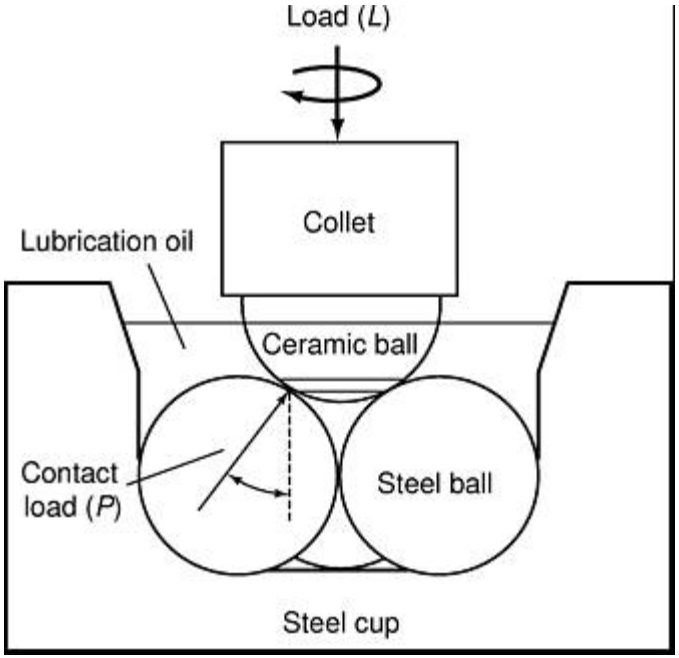
Hyrdodynamic (No Contact)– Friction increase due to viscous drag.



Source: "Modern Tribology Text book, 2000. Society of Tribologists and Lubrication Engineers: http://www.stle.org/resources/lubelearn/lubrication/default.aspx#regimes

Asphalt Lubricity Test – Based on ASTM Standards for oils





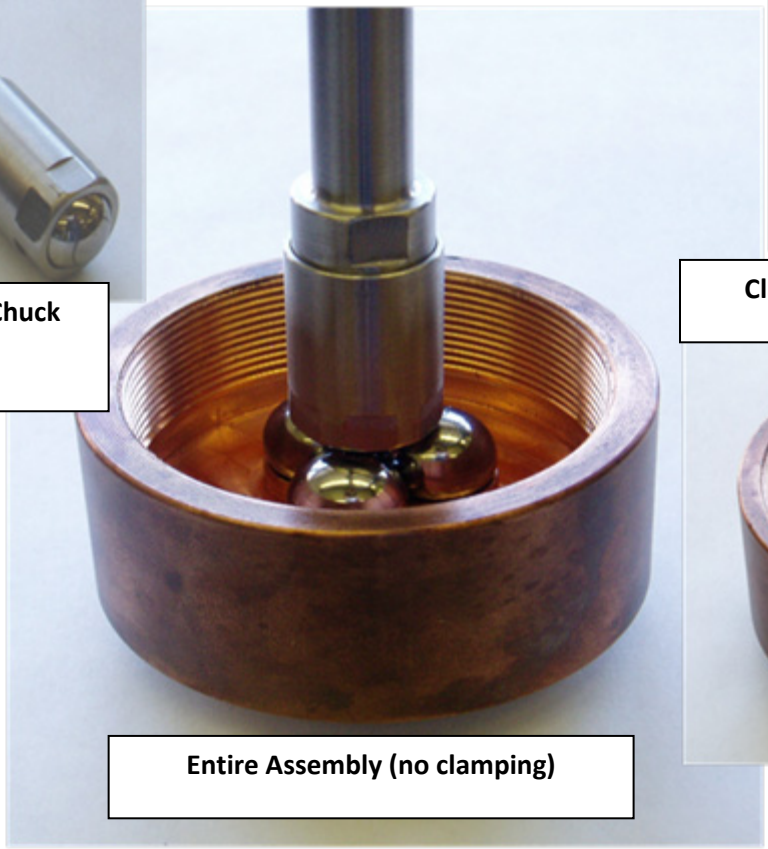
Measurement Tool

Stribeck : Friction a function of viscosity (Z), pressure (P), and speed (N).

Asphalt Lubricity Test:
- Photo of new fixture for DSR

Tip of Rotating Chuck

Clamped Ball Assembly



Entire Assembly (no clamping)

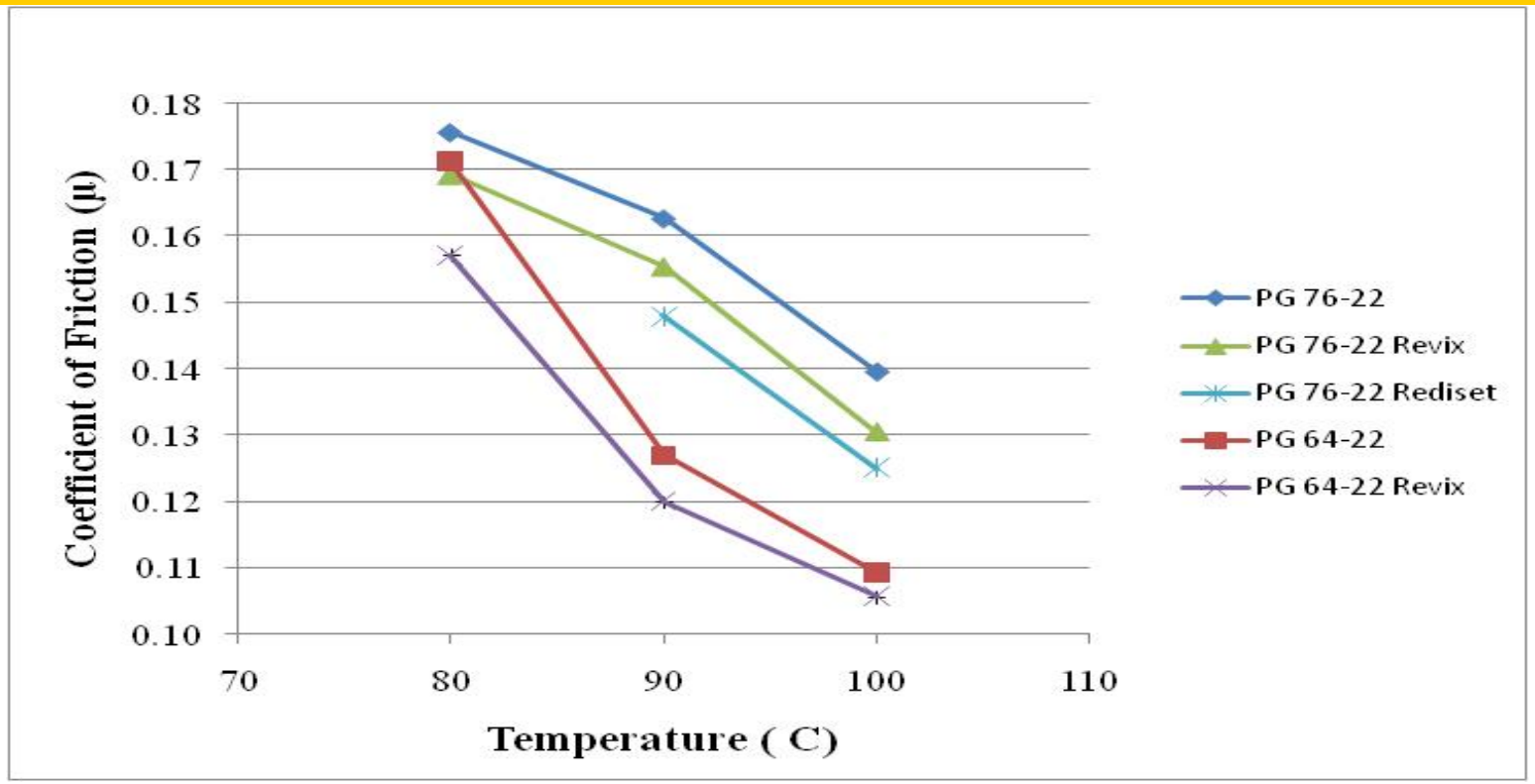
Asphalt Lubricity Test

- **Torque** is monitored under constant **normal force** and **speed**. The coefficient of friction (μ) is obtained from the normal force and torque measured

$$\mu = C \times \frac{T}{P \times d}$$

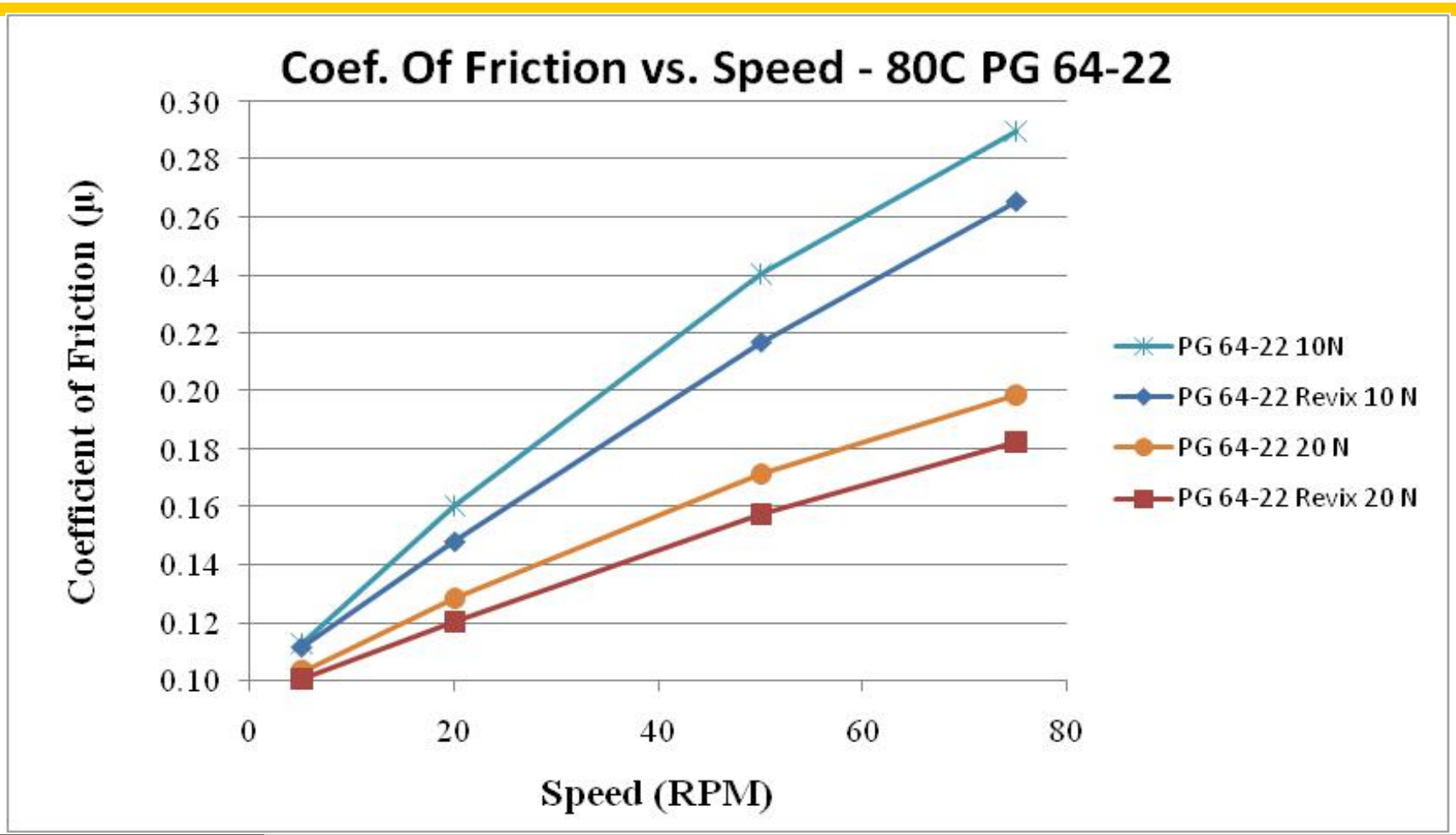
  - Where:
  - C = 2.842 – Value of constant for the four ball testing fixture geometry, T = Torque (N), P = Normal Force (N), d = diameter (m)

New Test Method "Asphalt Lubricity Test" – Initial Results – 50 RPM

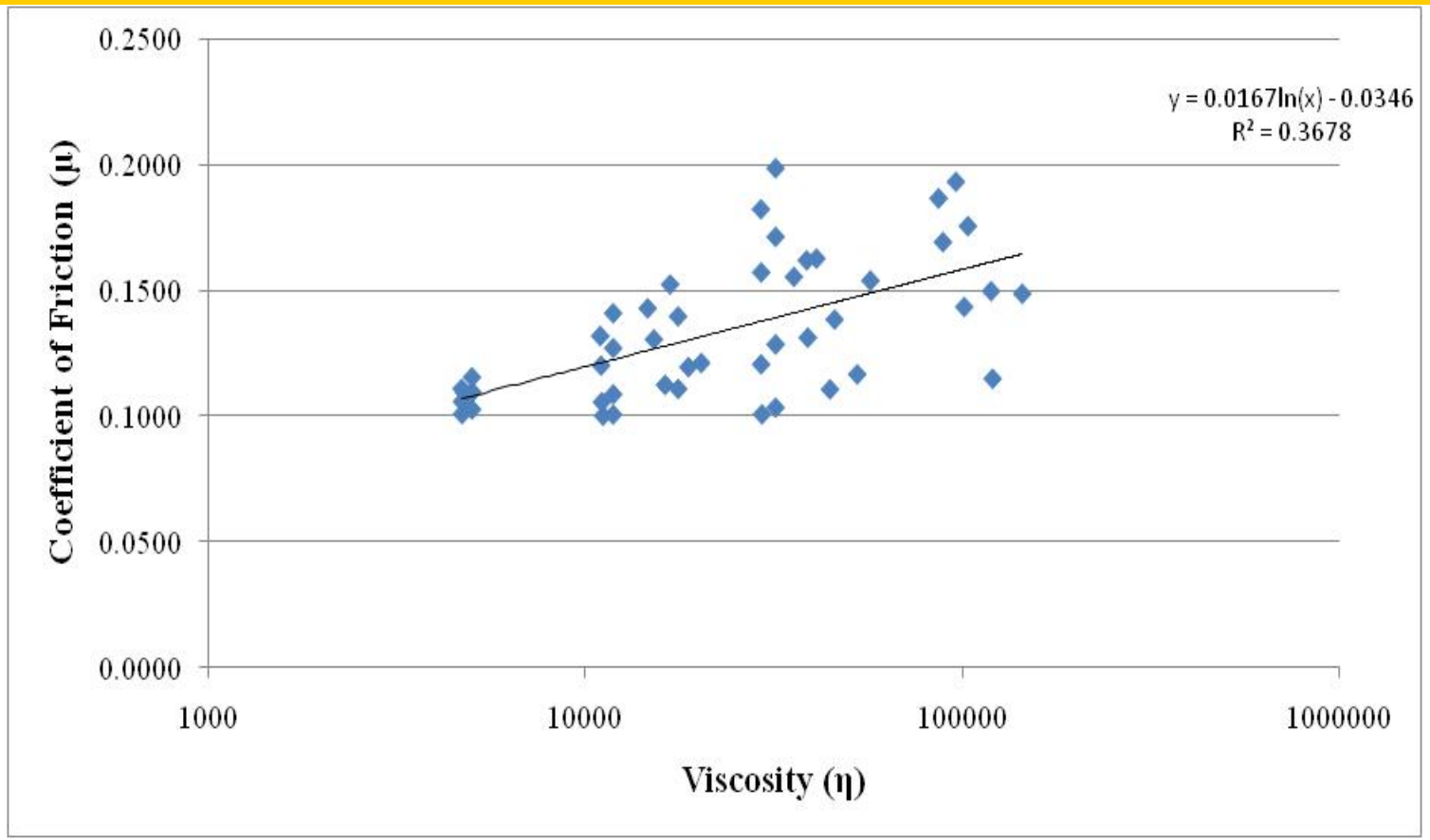


- Effect of Additive ~-0 to - 10% (PG 64), -10 to -15% (PG76)
- Effect of Binder ~-20 to -25%

Effect of Normal Force and Speed on Asphalt Lubricity

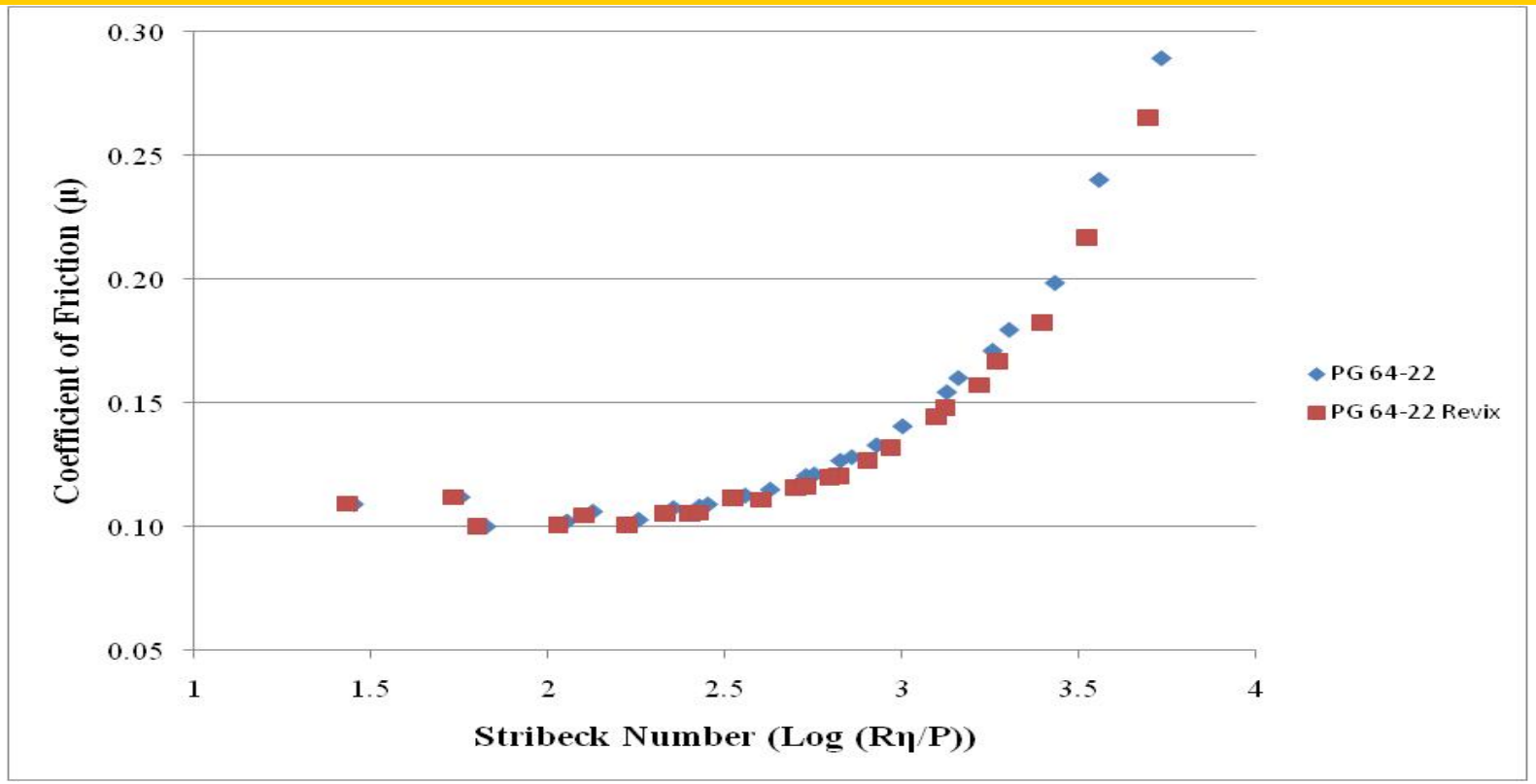


Is Lubricity Independent of Viscosity ? Yes…



No strong relationship

“Asphalt Lubricity “ Results follow the Stribeck curve – Encouraging trend



- Majority of data is in “Hydrodynamic range”: μ increases due to viscous drag
- Results are consistent with analysis of common lubricants.

Mixture Workability

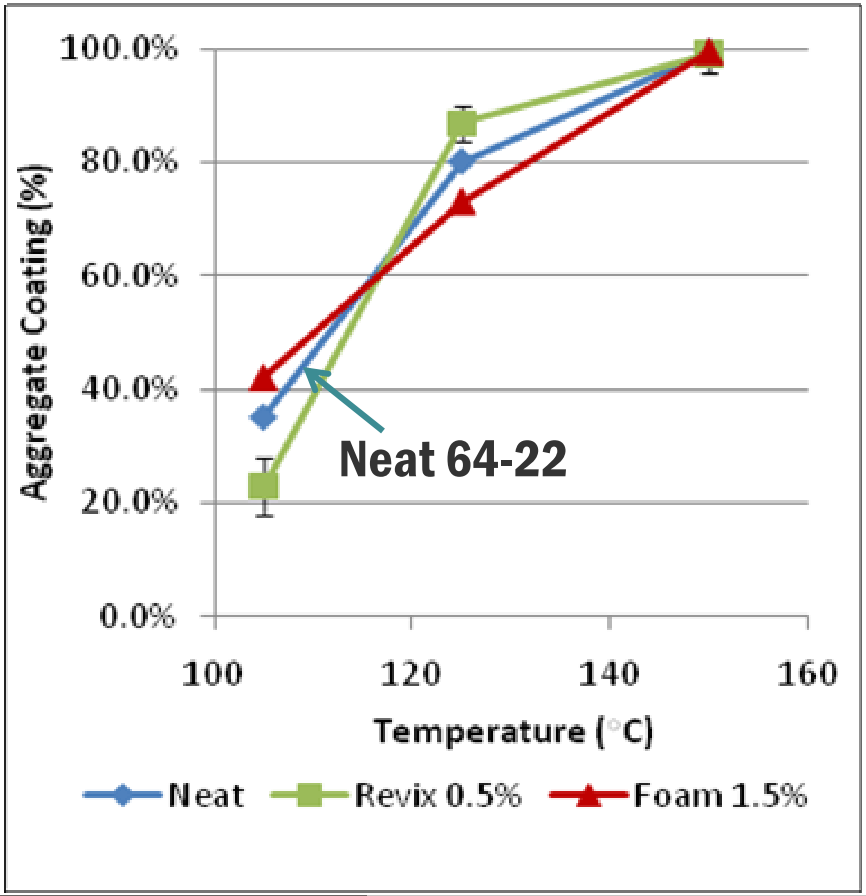
- Evaluation Criteria
  - Aggregate Coating (% Coated Particles)
  - Gyratory Compaction indices
    - Gyrations to 92% Gmm
    - Construction Force Index (CFI) using the GPDA

Aggregate Coating

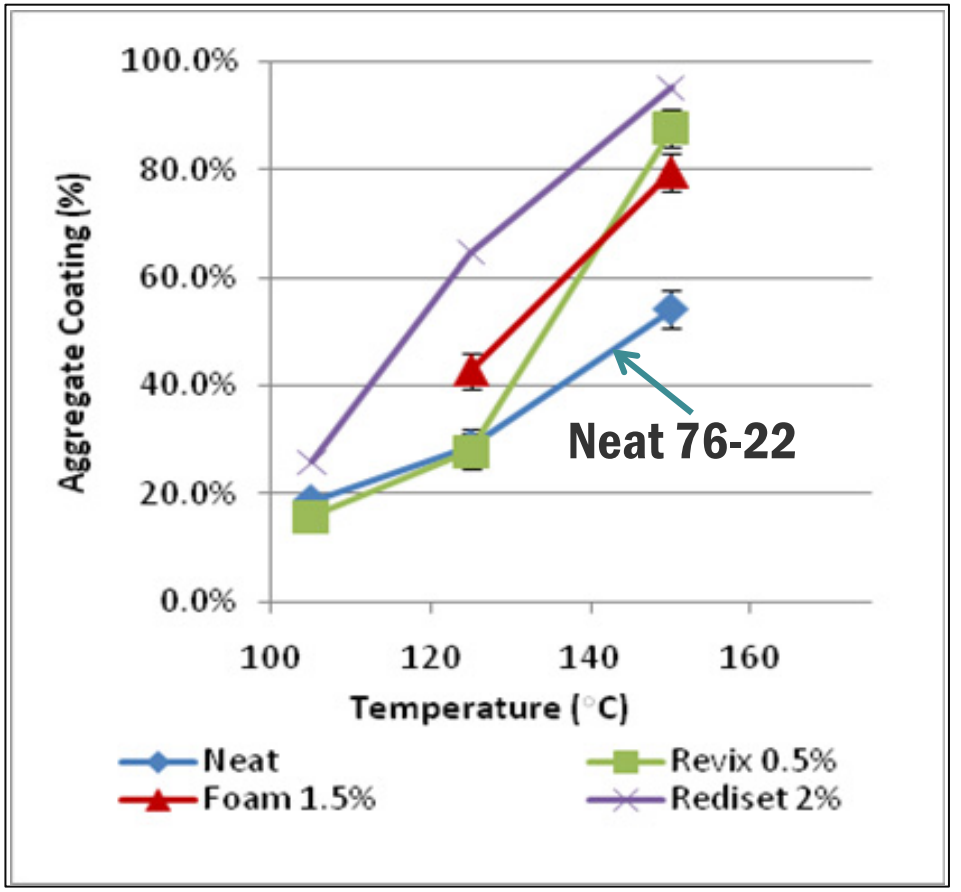
- Aggregate coating procedure (AASHTO T195)
  - Mixing at the prescribed temperature (held constant at 1.5 minutes)
- Separating coarse from fine (3/8” sieve).
  - Each coarse particle is examined.
- Coated particle: no aggregate surface exposed.
- Percent aggregate coating: ratio of coated particles to total particles.

Aggregate Coating (fine gradation)

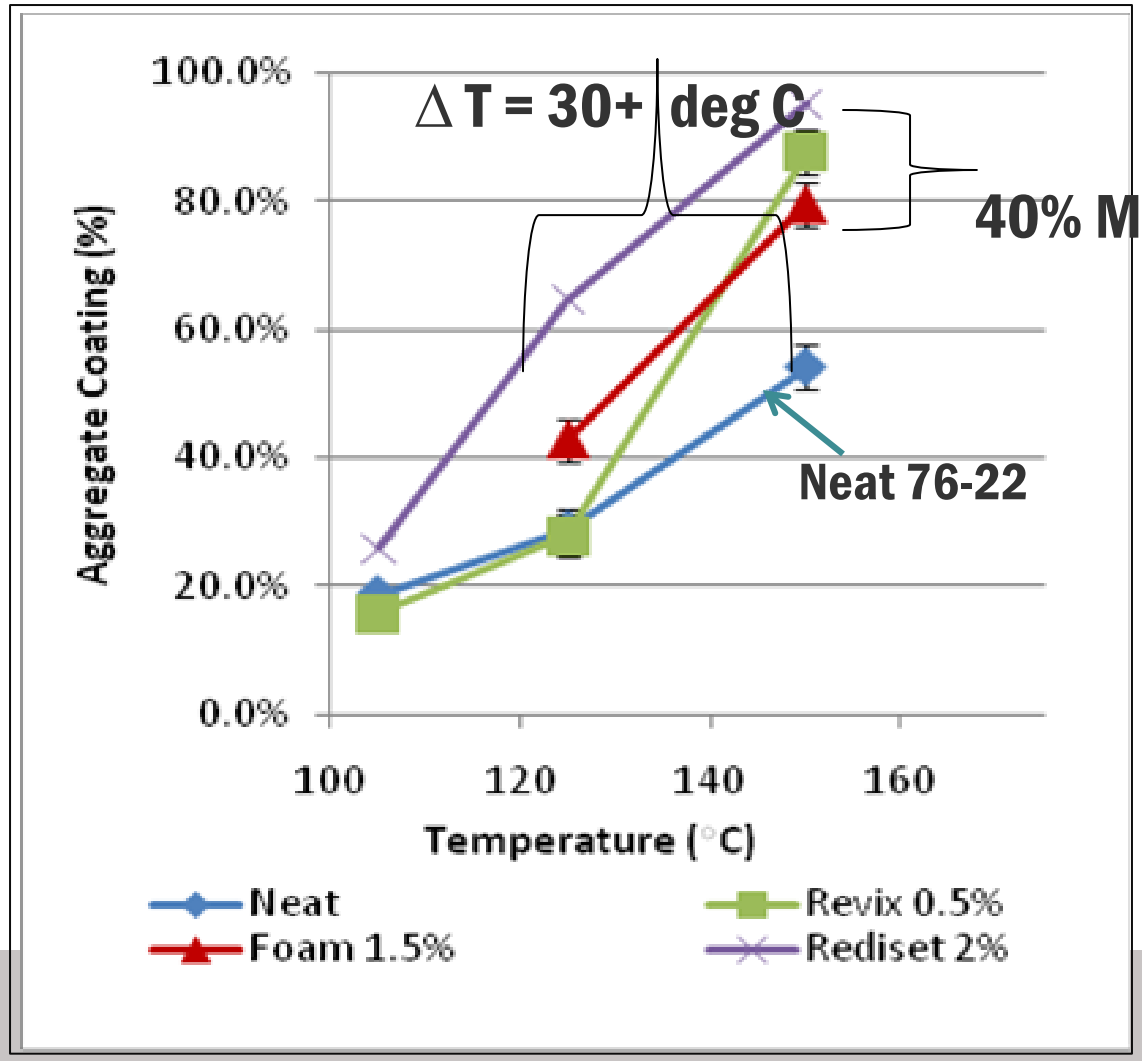
PG 64-22



PG 76-22

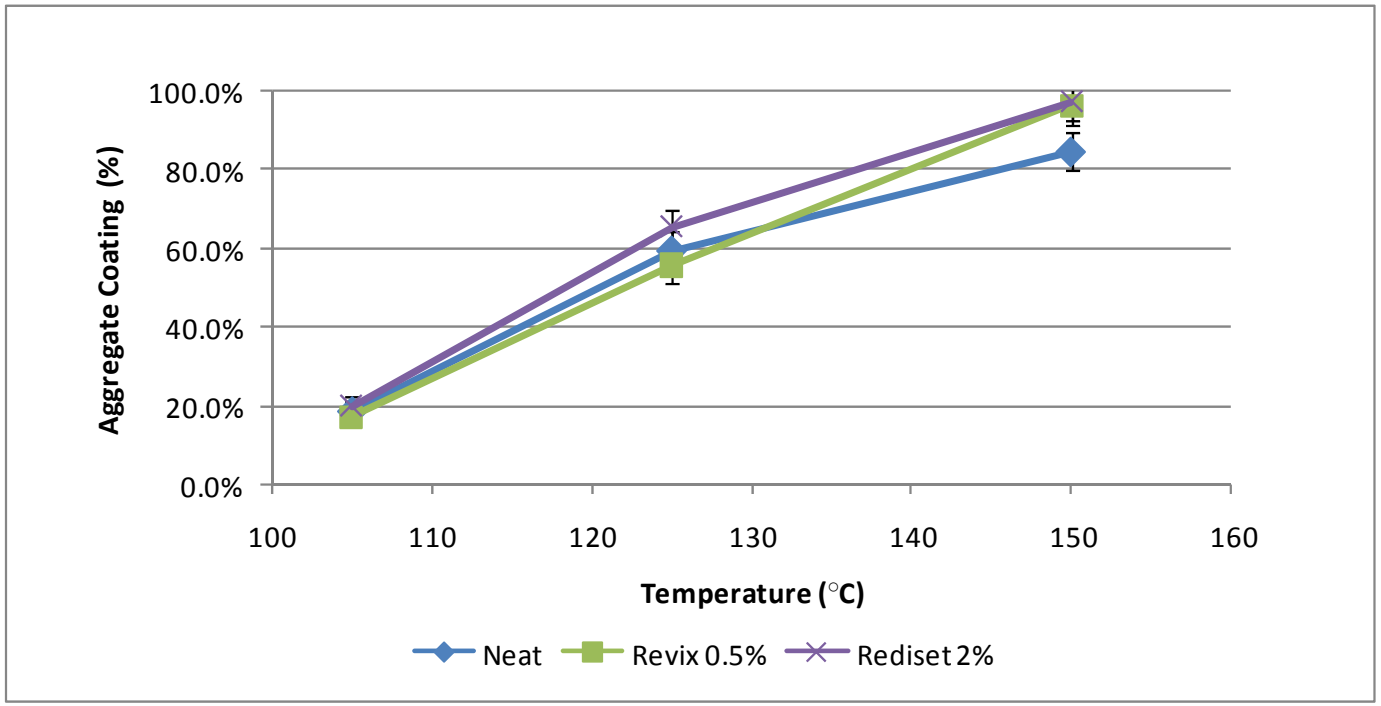


Aggregate Coating (fine gradation)

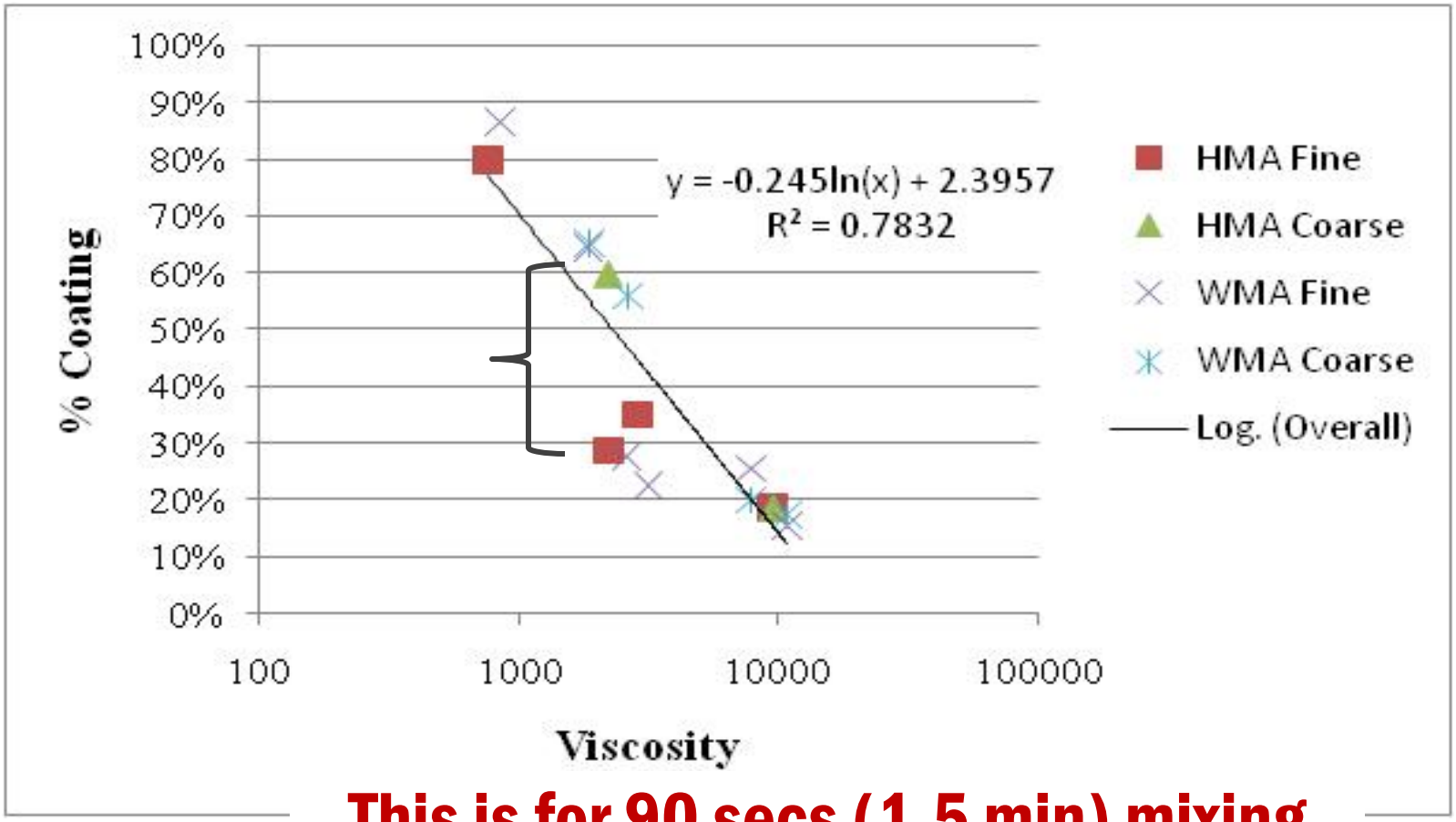


Aggregate Coating (coarse mix) Much less Effect

- PG 76-22

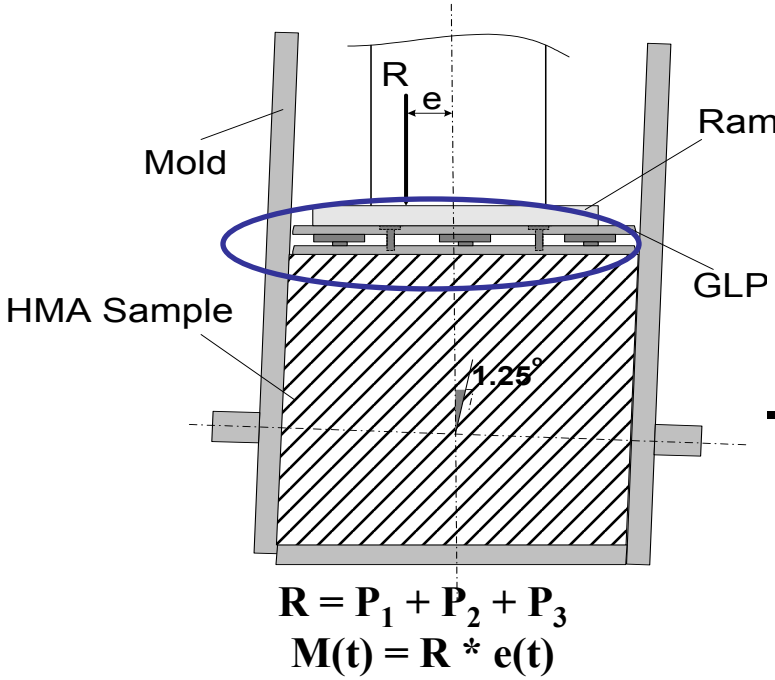


Coating of Aggregates as a Function of Binder Viscosity

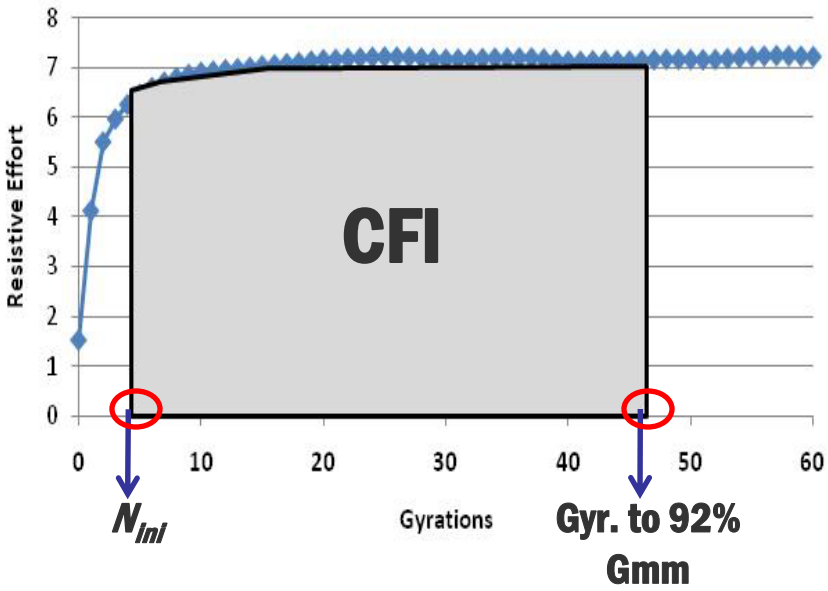


This is for 90 secs (1.5 min) mixing

Mixture Compaction- Densification Measured in Gyratory + PDA



PDA Plate

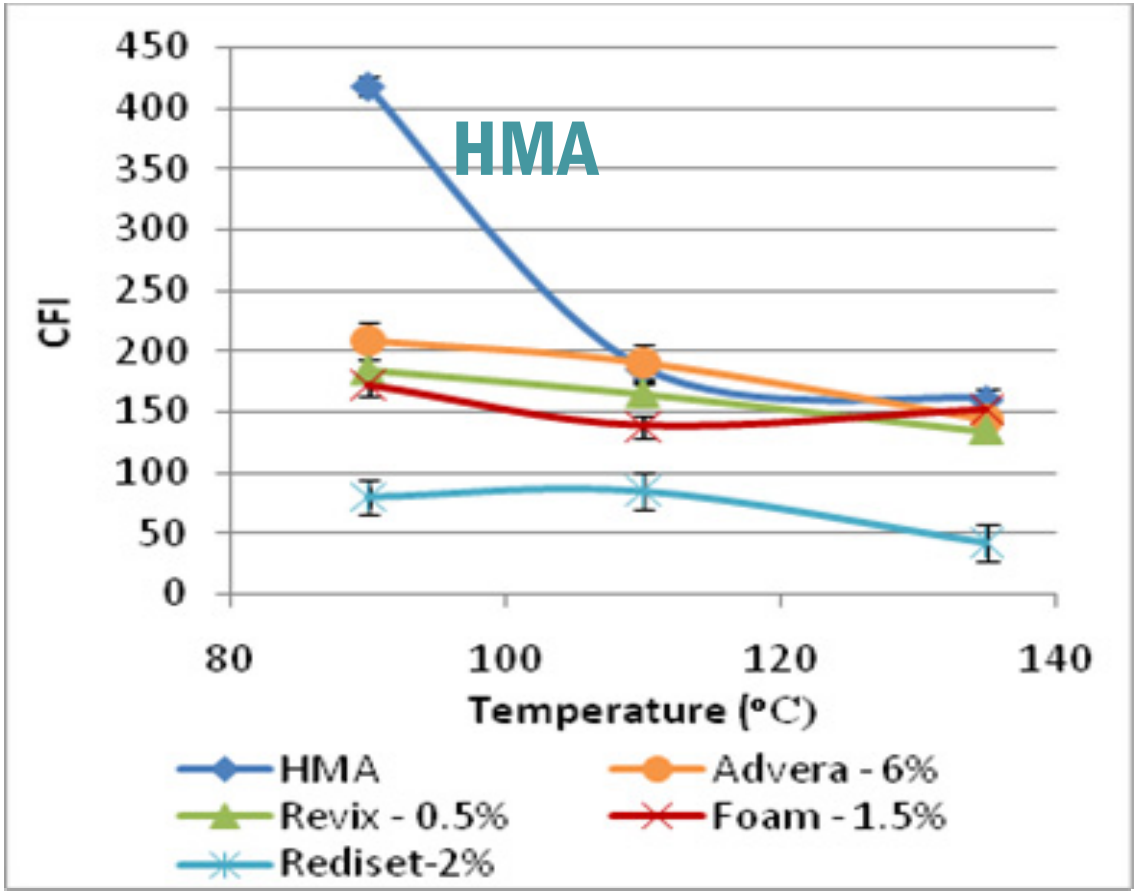


$$R = P_1 + P_2 + P_3$$

$$M(t) = R * e(t)$$

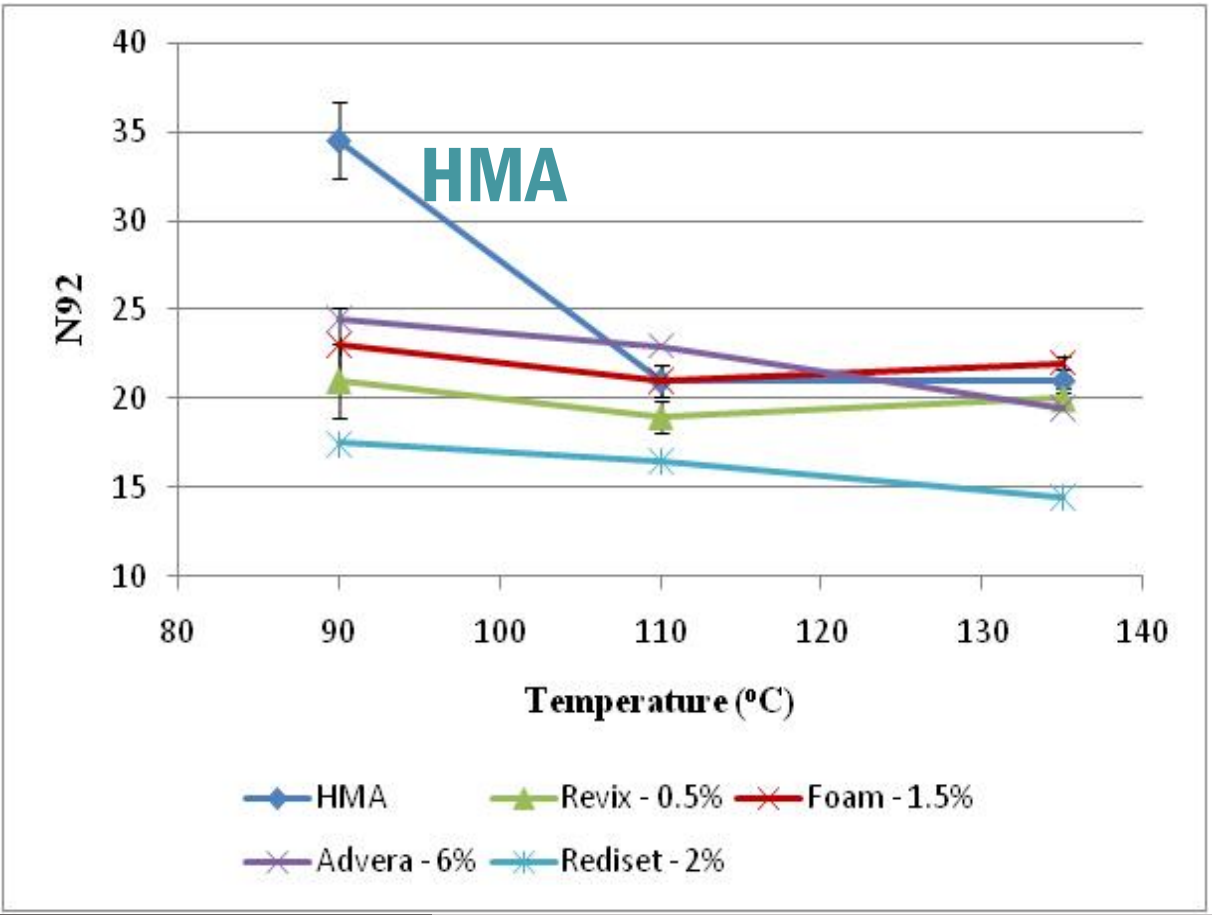
- Pressure Distribution Analyzer (PDA) allow for
  - Calculating resistive forces in the mix during compaction (*w*)
  - Construction Force Index (CFI) : area under the Resistive Force (*w*) vs. Gyration curve

Effects of WMAs on CFI (Mixture Workability)



- Major WMA effects are measured only at 90°C for foaming and Revix.
- Rediset at 2% show higher effects at all temperatures.

Mixture Workability



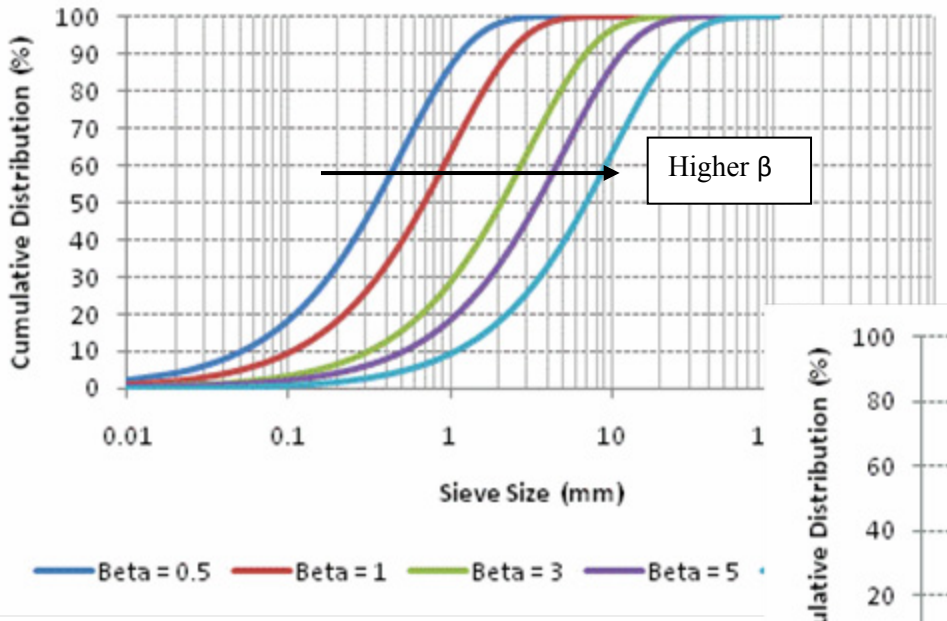
- There are minor effects of Revix and foaming at 110 and 125 C.
- Rediset has more effects .
- Major WMA effects is recognized only at 90°C.

Regression Analysis

- **Model Parameters**
  - Asphalt Binder Workability
    - Viscosity: Tested at 105C and 125C
    - Lubricity: Tested at 90C and 100C
  - Gradation
    - Quantified using Beta
      - Fine: 4.29
      - Coarse: 6.34

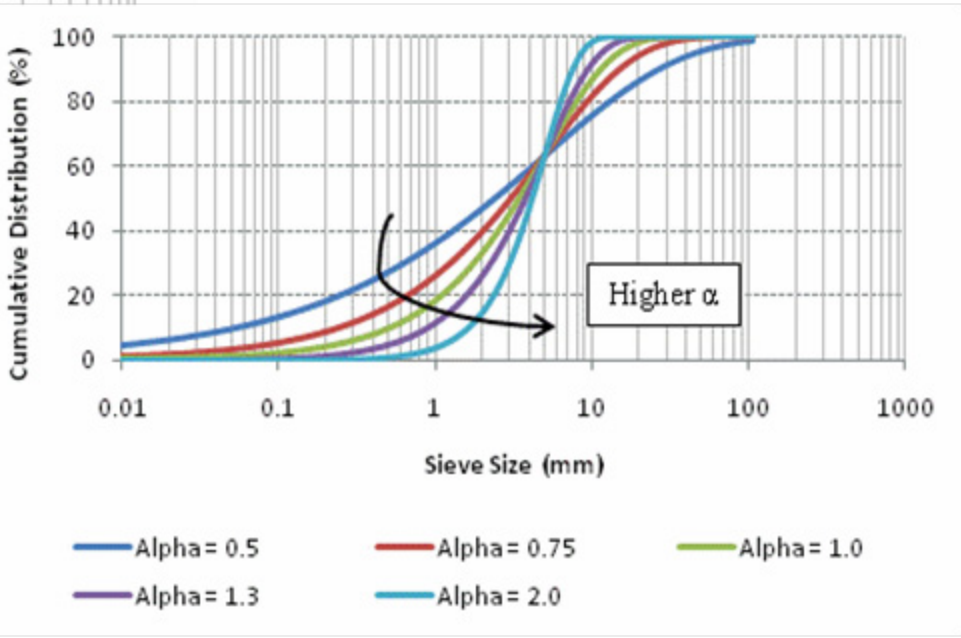
- **Response**
  - Mixture Workability – CFI and N92
  - Aggregate Coating - % Coated

Gradation Analysis and Modeling



$$F(x, \alpha, \beta) = 1 - e^{-\left(x/\beta\right)^{\alpha}}$$

Weibull distribution

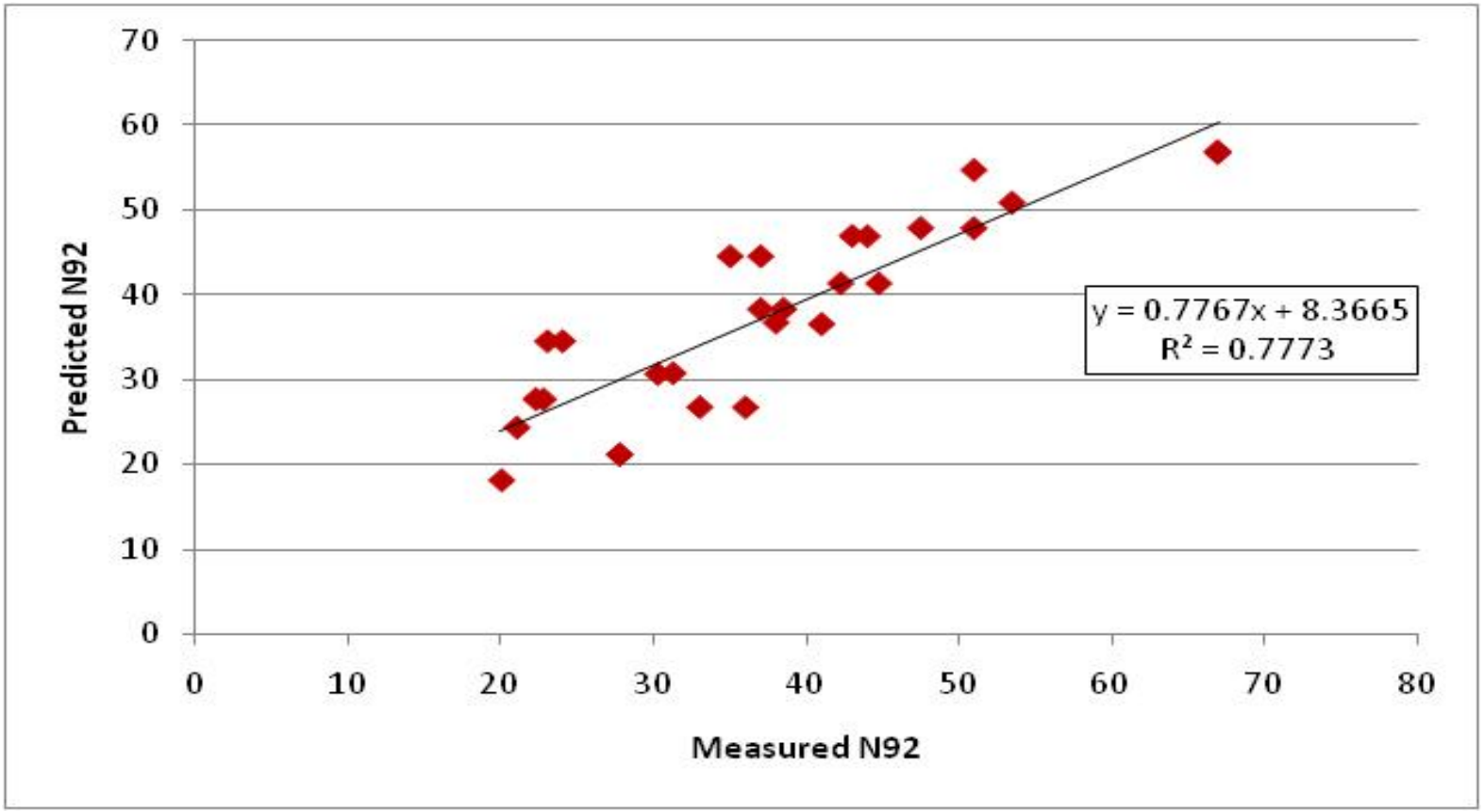


Regression Results (N92)

- **N92 = - 59.6 + 9.87 Beta + 356 Coef. Friction - 0.000104 Visc**

Predictor	Coef	SE Coef	T	P
Constant	-59.6	25.41	-2.35	0.028
Beta	**9.87**	**1.187**	**8.32**	**0.000**
Coef. Friction	**356**	**229**	**1.56**	**0.133**
Visc	-0.0001	0.00038	-0.27	0.787

Regression Results (N92)

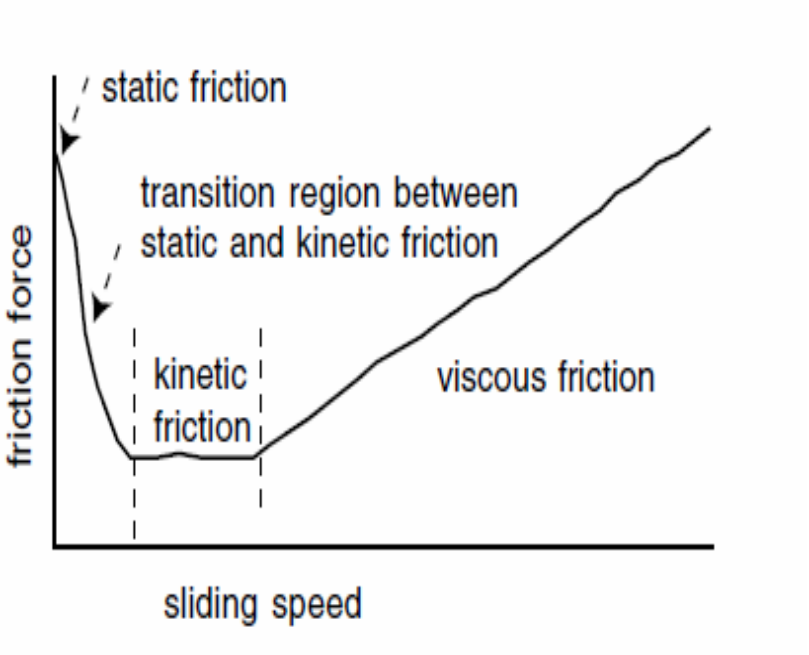


Summary of Interim Findings

- Warm Mix Additives affect lab coating & compaction.
  - Minor reduction in viscosity
  - Further work needed to quantify effects of lubricity (internal resistance to flow)
- Main effects are at lower temperatures (< 100 C).
- Cost need to be justified by energy savings & environmental impact.

Interim Findings – Comparison of Lubricity to Mix Workability

- Current Analysis
  - Gradation (B) dominates
  - However…Further work on lubricity is needed.
- Measure "kinetic friction" zone to define min. μ
- Need effect of WMA Additives on min. coef. Friction.



Lubricity – Next Steps

- Current Procedure limited
  - Temp: Range limited by heating system.
  - Normal Force: Machine limitations
- New Geometry Under Development
  - Higher temperatures/Normal Force
- Assessment of "Lubricity Test" for WMA
  - Based on entire Stribeck Curve, not just region of "viscous drag"

Acknowledgments

- Federal Highway Administration
- Western Research Institute
- Suppliers of additives