Investigation of Warm Mix Asphalt Additives Using the Science of Tribology to Explain Improvements in Mixture Compaction

Sebastian Puchalski – Kraton Polymers

Prof. Hussain Bahia – University of Wisconsin-Madison

INTRODUCTION AND PROBLEM STATEMENT

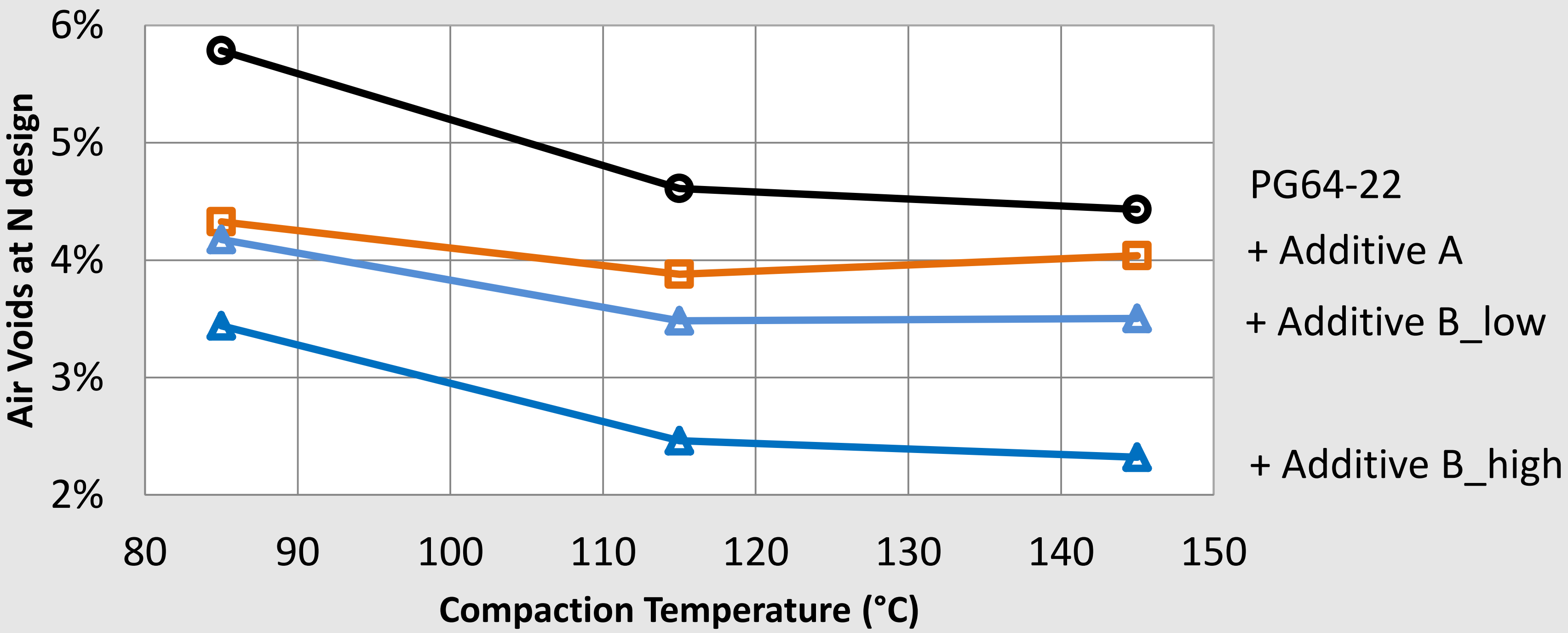
Introduction

- Good HMA compaction commonly translates into high mix density, which is related to pavement quality and durability.
- HMA compaction is a complex process. Yet, in terms of asphalt binder properties, only rotational viscosity is commonly associated with the mix compactibility.
- Warm Mix Asphalt (WMA) made its way into industry as a way to produce asphalt pavements at reduced mixing/construction temperatures.
- WMA effect can be achieved via:
  Foaming asphalt
  Reducing asphalt viscosity
  Using chemical additives
- Chemical additive technologies may encompass categories such as surfactants or friction modifiers.

Problem statement

- While foaming and viscosity reduction technologies are generally understood in terms of their effect on HMA compaction, the chemical additive technologies are not.
- Objective of this presentation is to discuss a method which quantifies the lubricating effect of some chemical additives.

BACKGROUND DATA AND MATERIALS



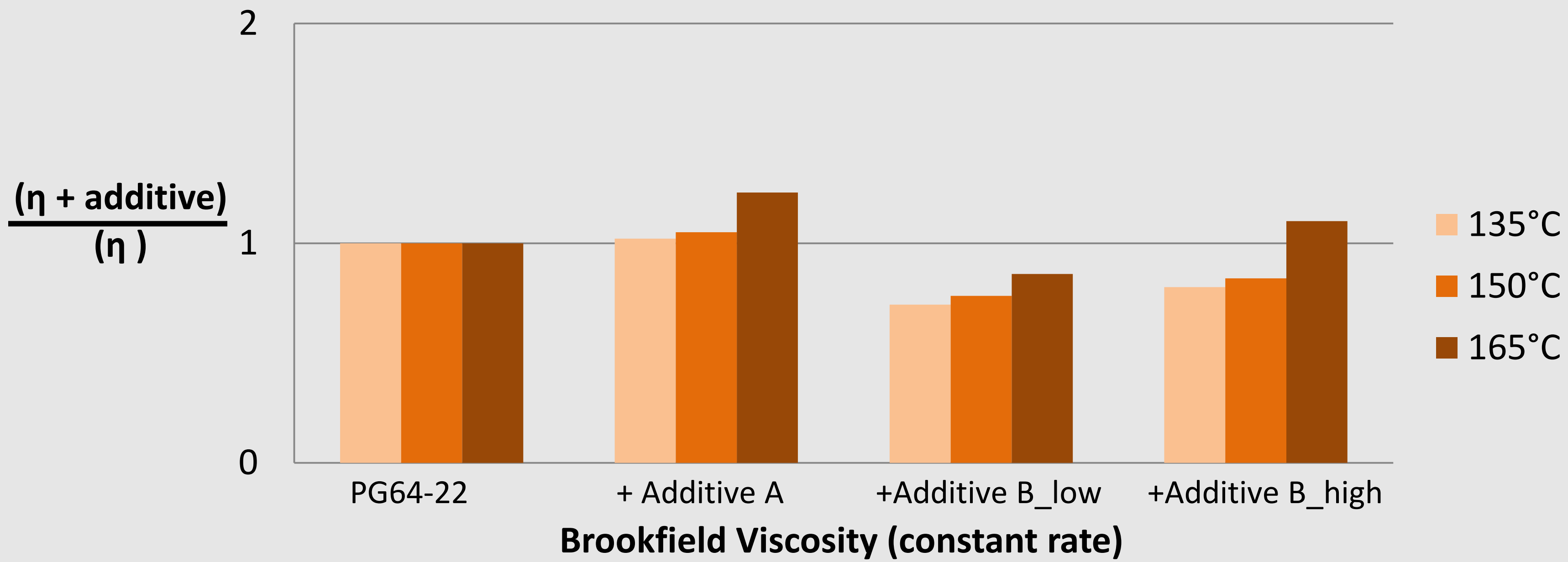
Mix summary:

- Wisconsin E-10 mix (for heavy traffic),
- Coarse granite gradation,
- 5% binder content (fixed)

Source: Hanz, Andrew, Phd Thesis, 2010, Pouya Teymourpour, PhD

VISCOSITY

Viscosity of binders presented in the previous slide is not equal. Yet the difference is not large and goes both ways!



Could the mentioned additives have a lubricating effect that is not captured via viscosity testing?

To answer such question we must defer to the field of tribology.

Source: Hanz, Andrew, Phd Thesis, 2010

TRIBOLOGY

According to Bhushan (2002) Tribo in Greek means rubbing.

According to Google rubbing is Τριβή /triví̱/ in Greek…

…hence trivialogy?

Goal: to understand the nature of interactions between two materials rubbing or sliding past each other and to understand the interfacial phenomena

The phenomena can be classified as:

- Friction
- Wear
- Adhesion

In order to minimize such phenomena lubricant of a sort is typically in order.

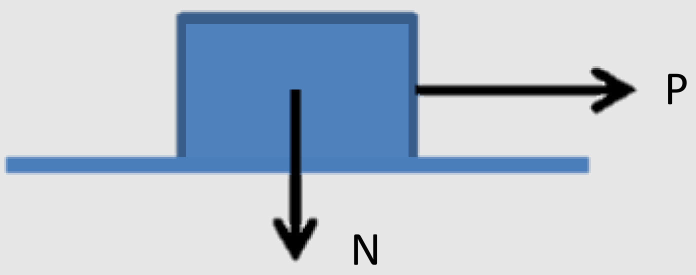
TRIBOLOGY

Linking tribology to asphalt mix compaction let's assume for now that:

- wear in form of aggregate chipping off is not an issue
- there are no appreciable adhesive tensile forces between aggregates (quite accurate)

Then, the only phenomenon we must deal with is friction.

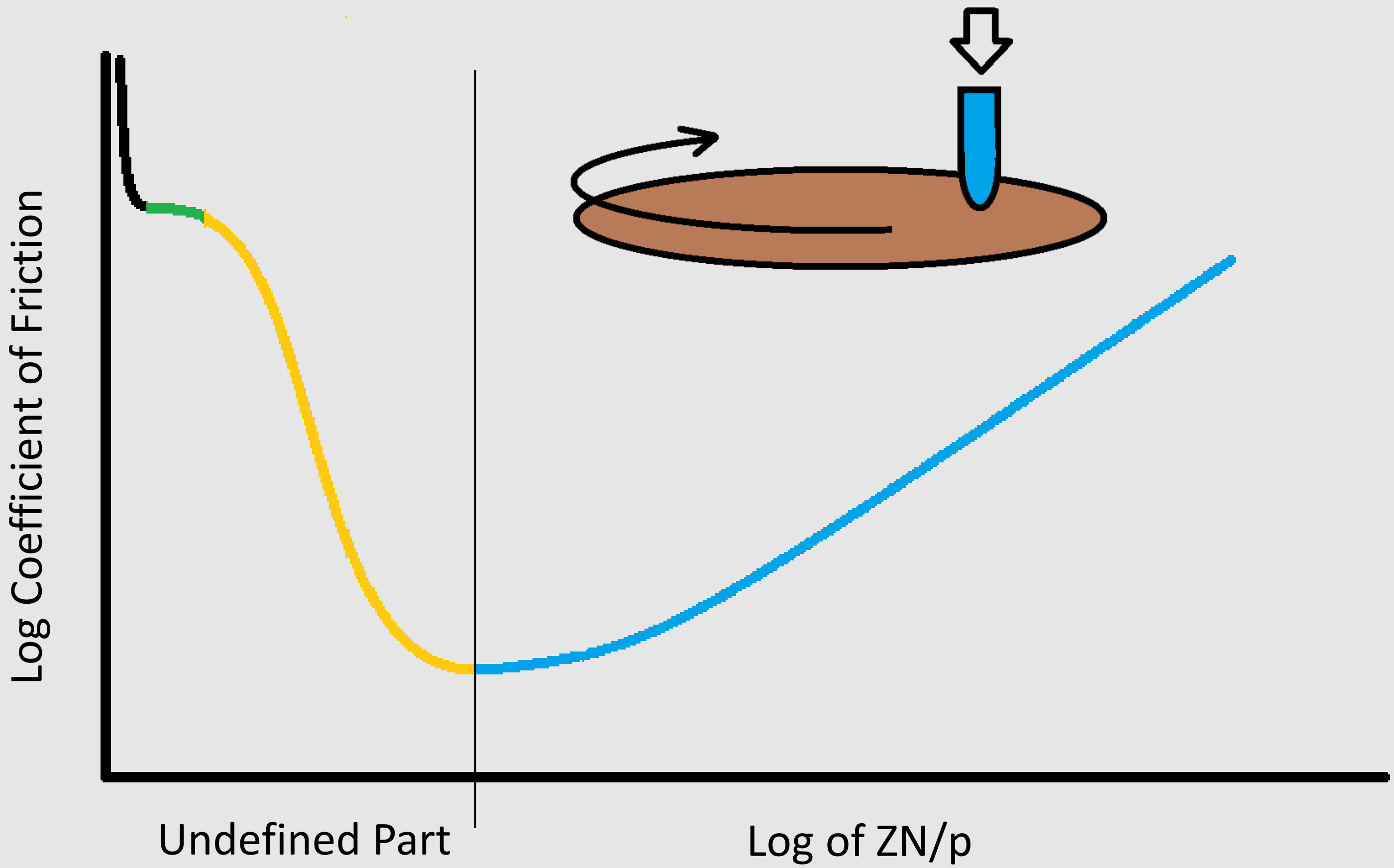
Since we like to quantify things, let's use a <u>coefficient of friction, μ.</u>



$$\mu = \frac{P}{N}$$

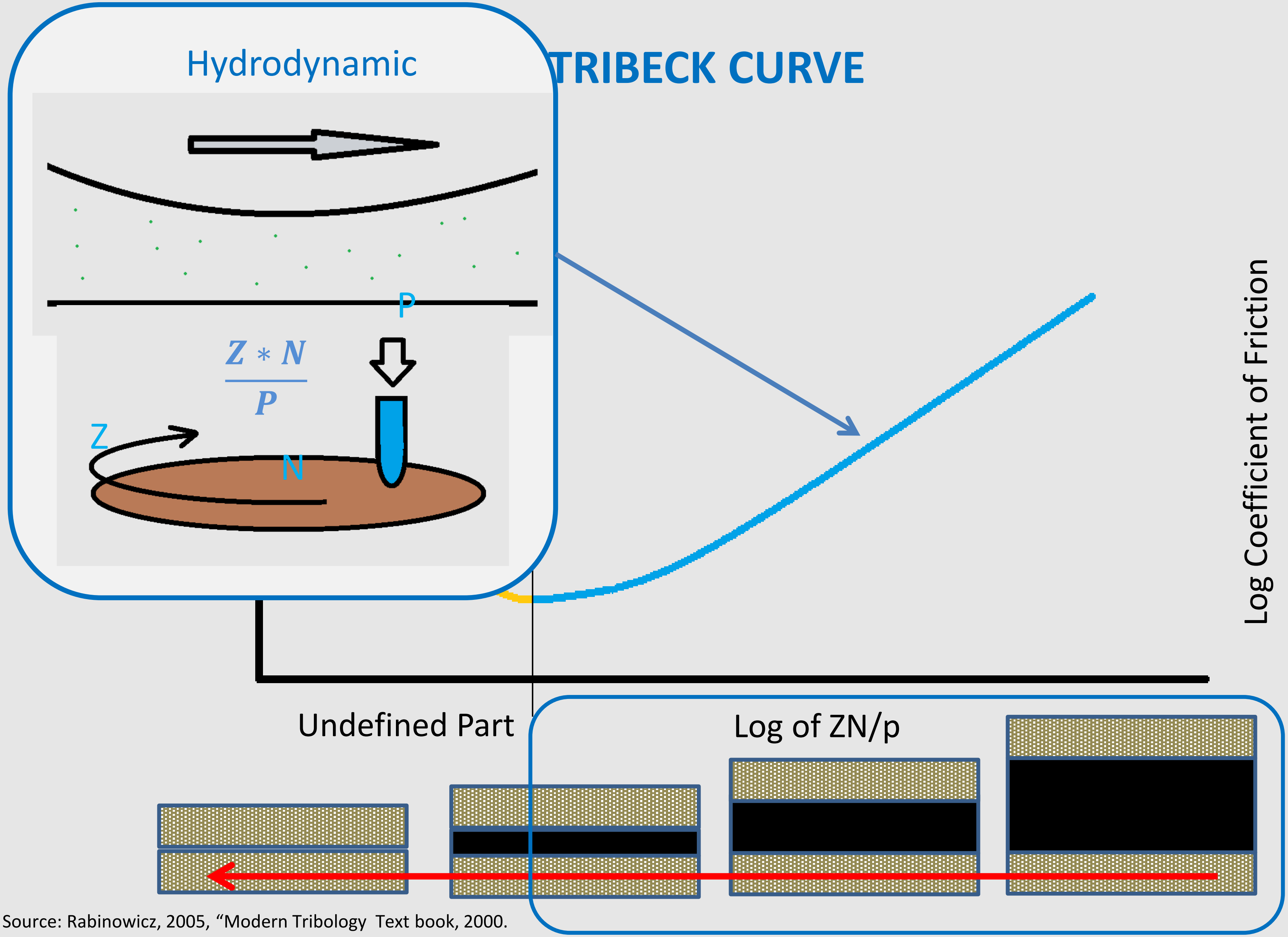
It is a simple ratio that can be easily measured.
<u>Keep in mind that the ratio is a system property (depends on substrates and lubricant)</u>

STRIBECK CURVE



Source: Rabinowicz, 2005, “Modern Tribology Text book, 2000.

TRIBECK CURVE



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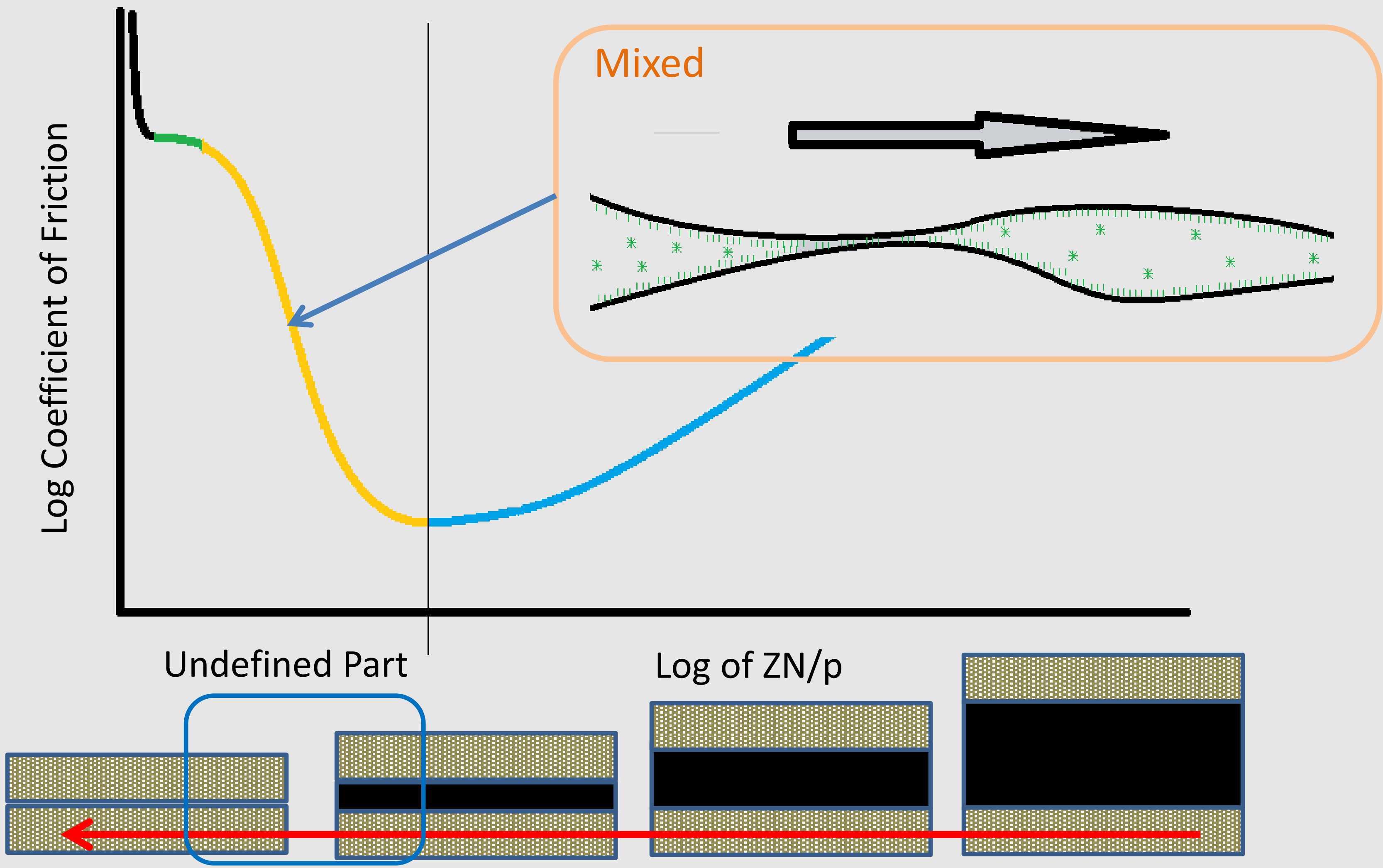
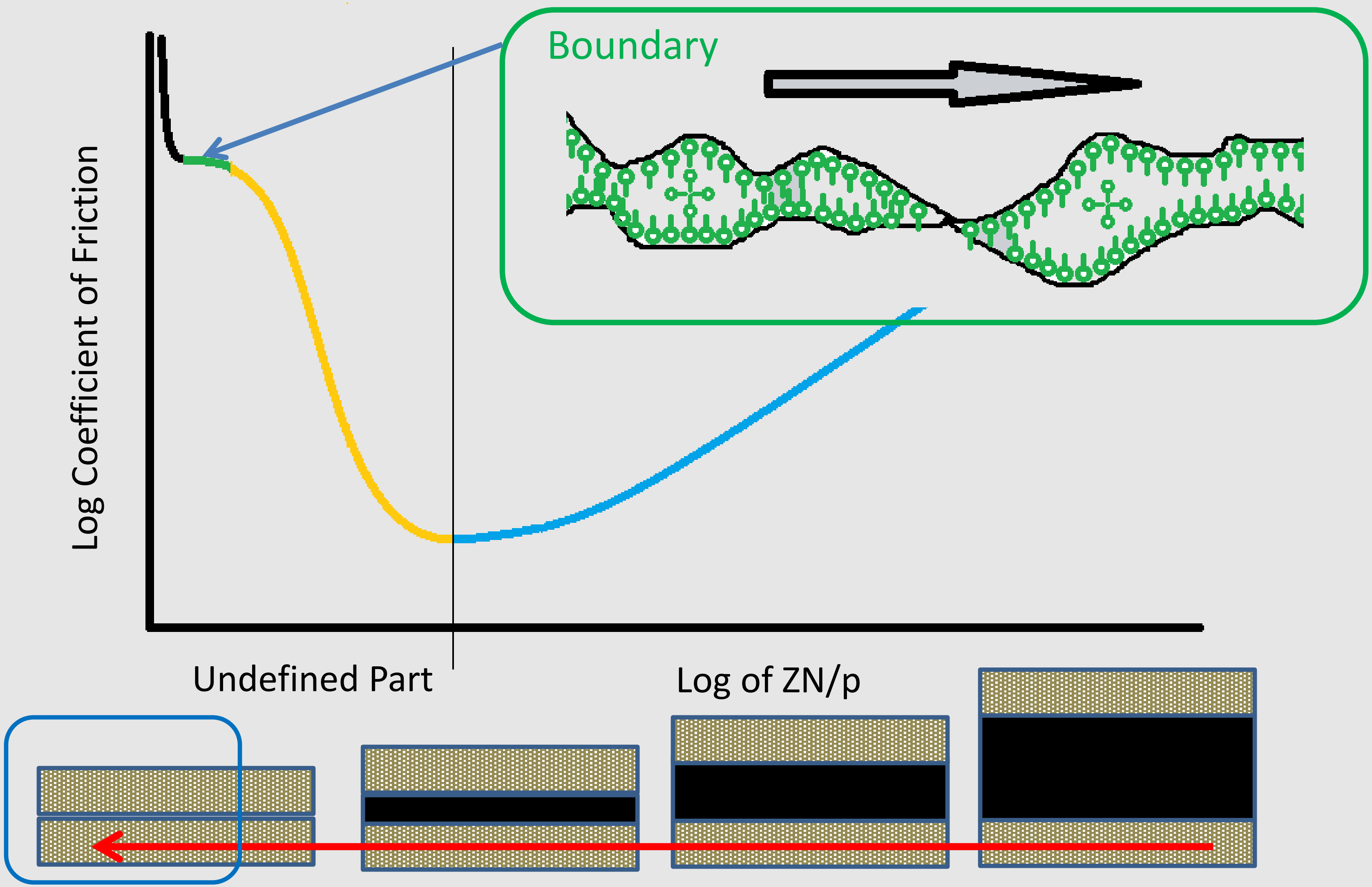
STRIBECK CURVE



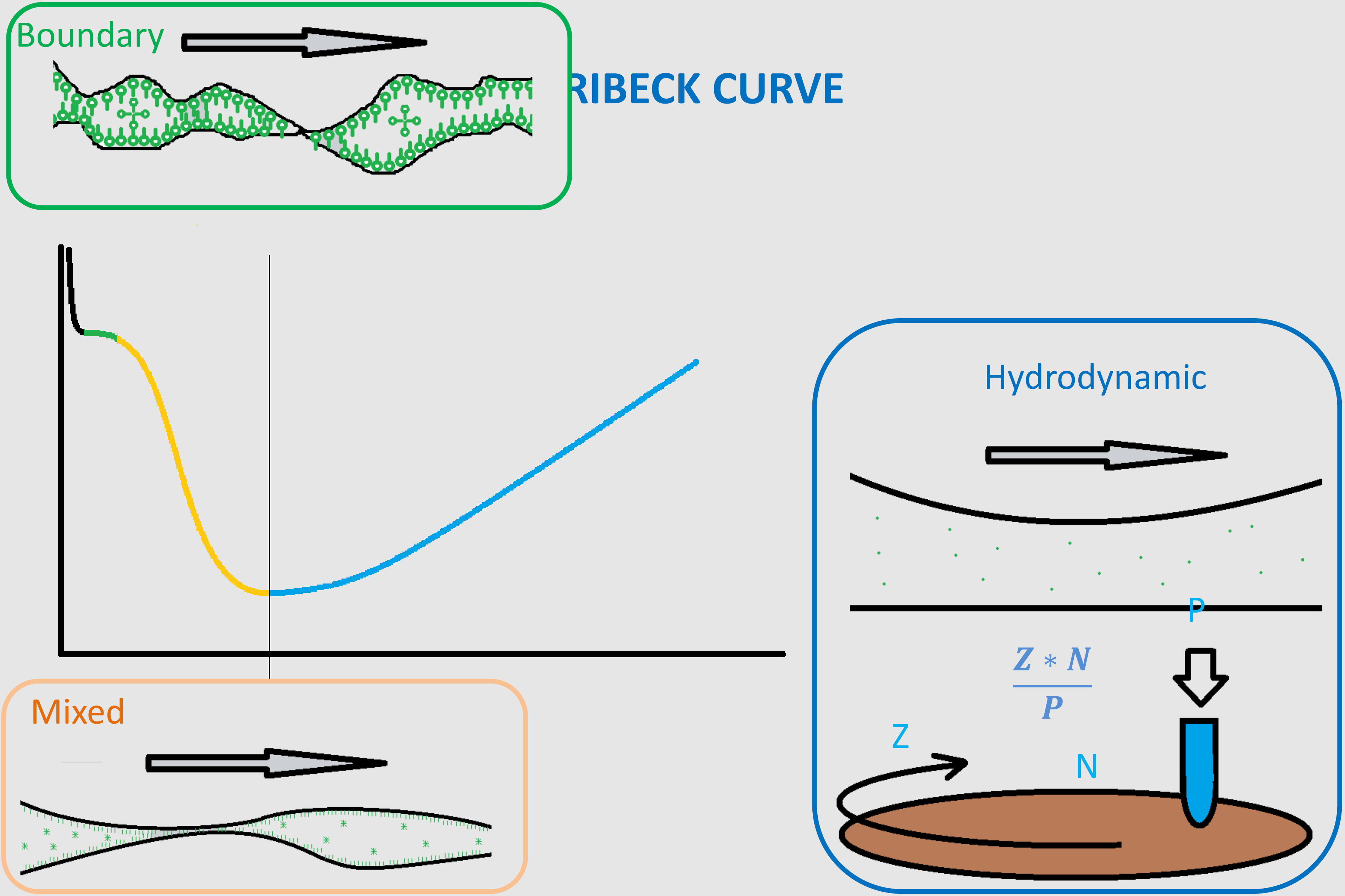
Source: Rabinowicz, 2005, “Modern Tribology Text book, 2000.

STRIBECK CURVE



Source: Rabinowicz, 2005, "Modern Tribology Text book, 2000.

RIBECK CURVE

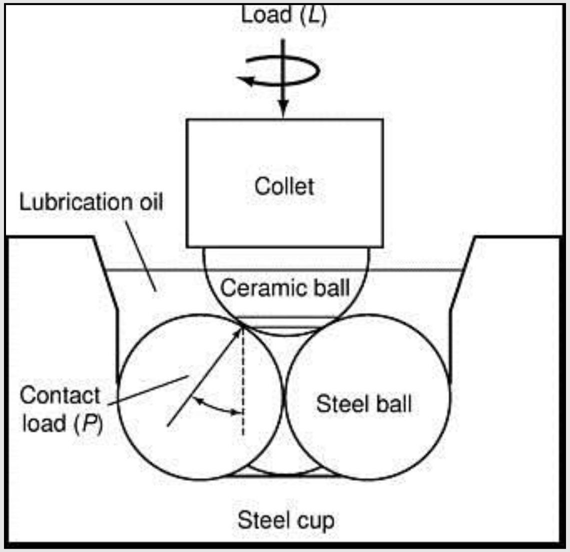


Source: Rabinowicz, 2005, “Modern Tribology Text book, 2000.

ASPHALT LUBRICITY TEST

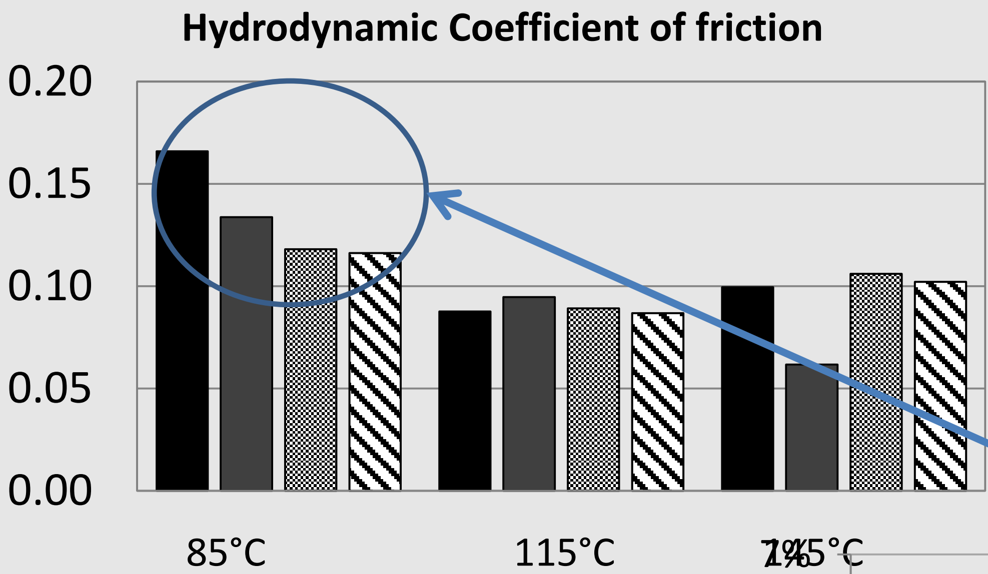
Now the question is: What regime is most suitable to describe asphalt binder during mix compaction?

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



Source: Hanz, Faheem, Mohmoud, Bahia, 2010

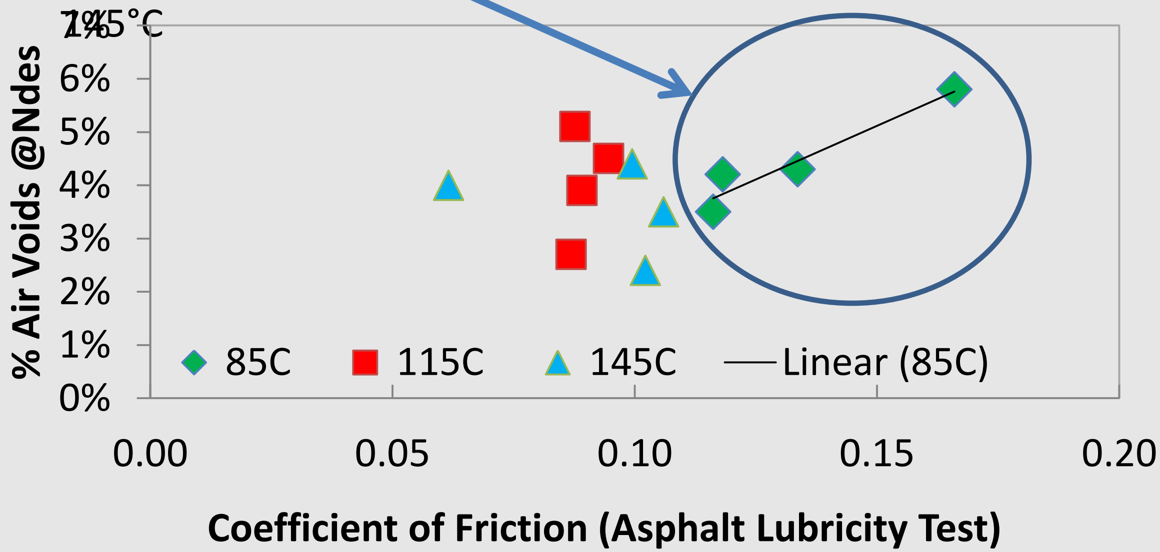
ASPHALT LUBRICITY TEST



Seems to provide good indication of relative ranking at relatively low mixing temperatures.
- hydrodynamic mode

Ranking:

1. Additive B_high
2. Additive B_low
3. Additive A
4. PG64-22

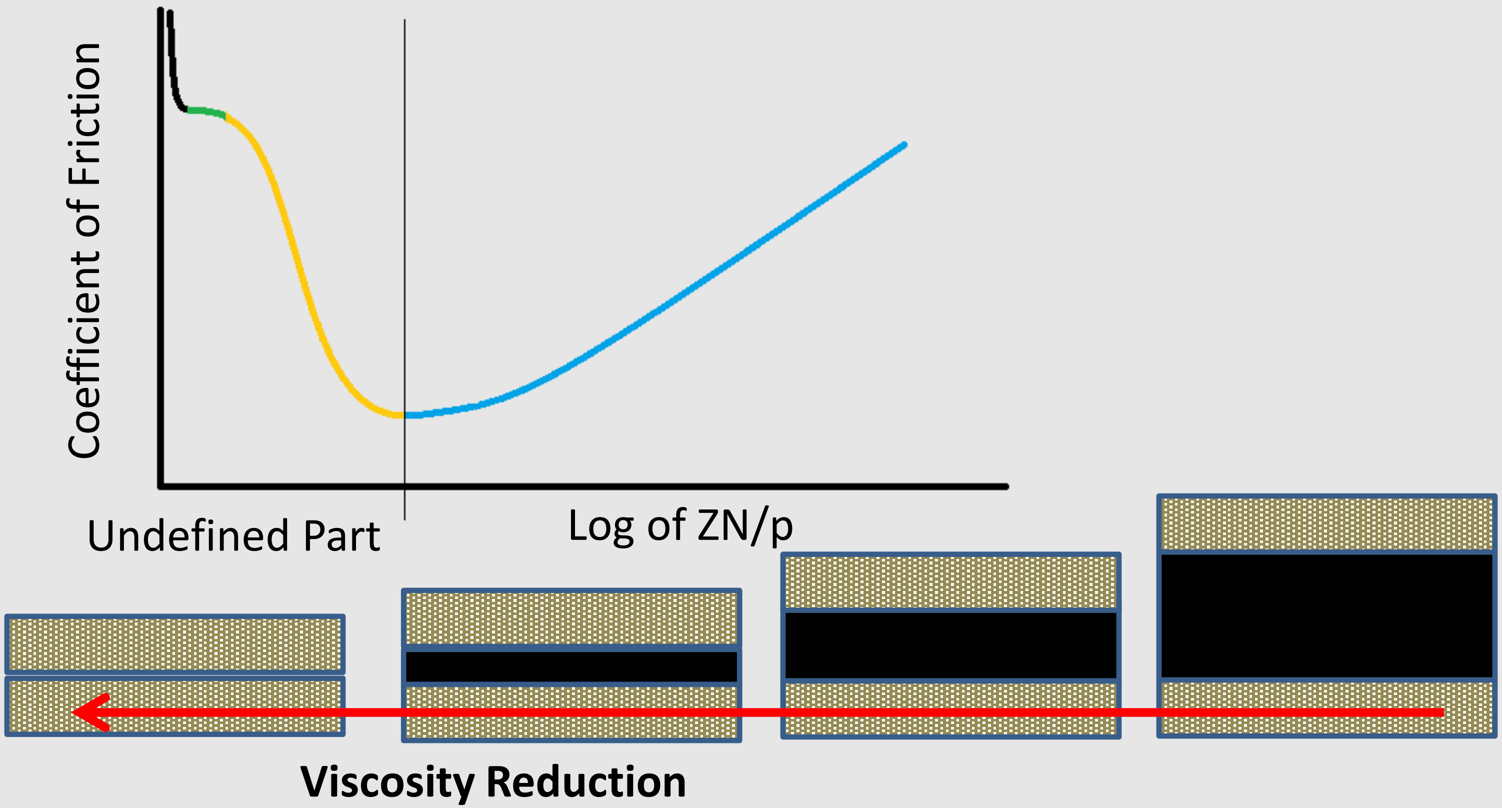


Source: Hanz, Andrew, PhD Thesis, 2010, Pouya Teymourpour, PhD

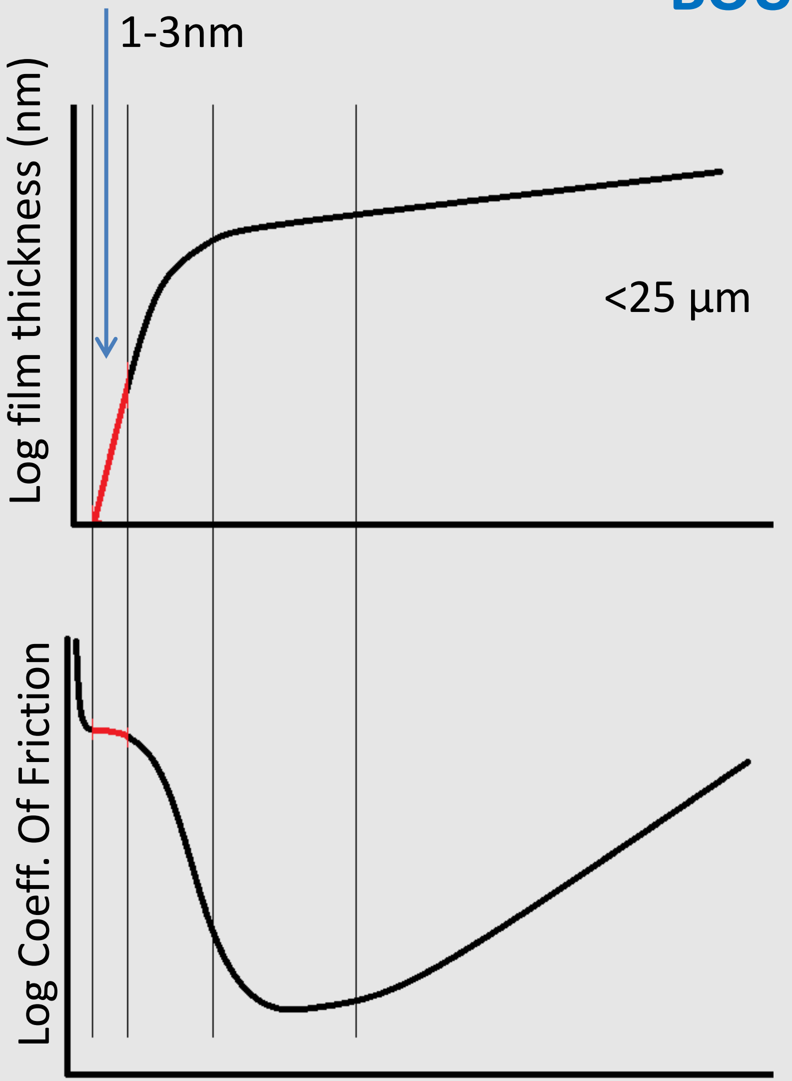
STRIBECK CURVE VS COMPACTION

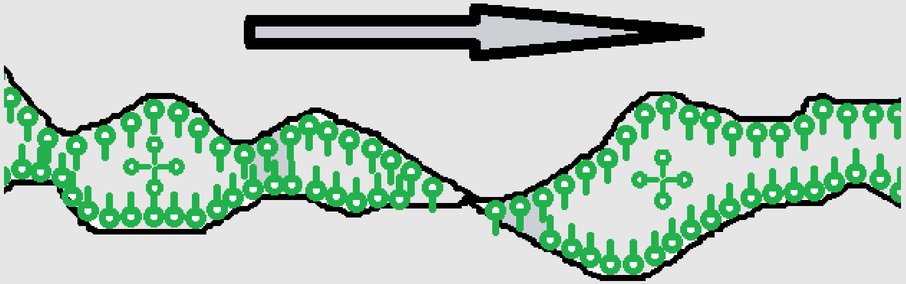
Could it be because as mix temperatures rise, the aggregate/mastic particles start running into each other more often creating friction?

Also, as viscosity is reduced due to temperature climb, the Sommerfeld number naturally pushes the lubrication mode to the left of the Stribeck curve!



BOUNDARY REGIME

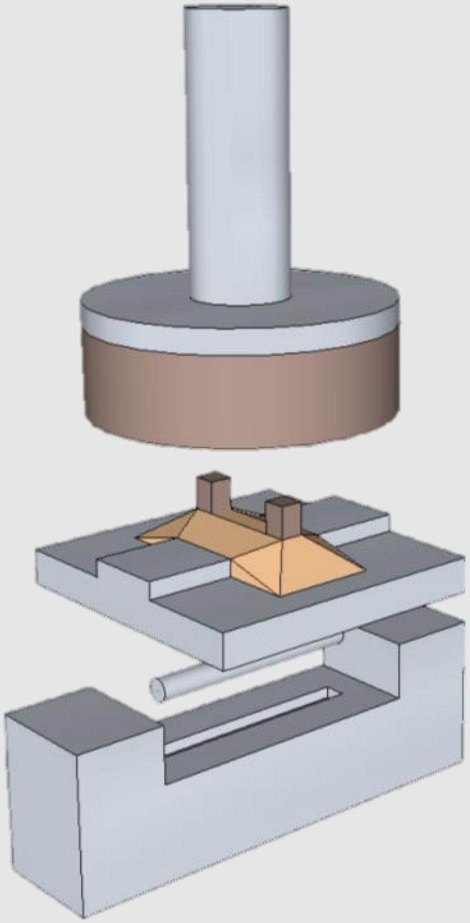




- Bulk flow properties of lubricant play little role
- Mono- and multimolecular films provide lubrication
- Important physical film properties: melting point, shear strength, hardness.
- Boundary lubricants form easily sheared film

Source: Bhushan, Bharat. *Introduction to Tribology.* New York: John Wiley & Sons, 2002.

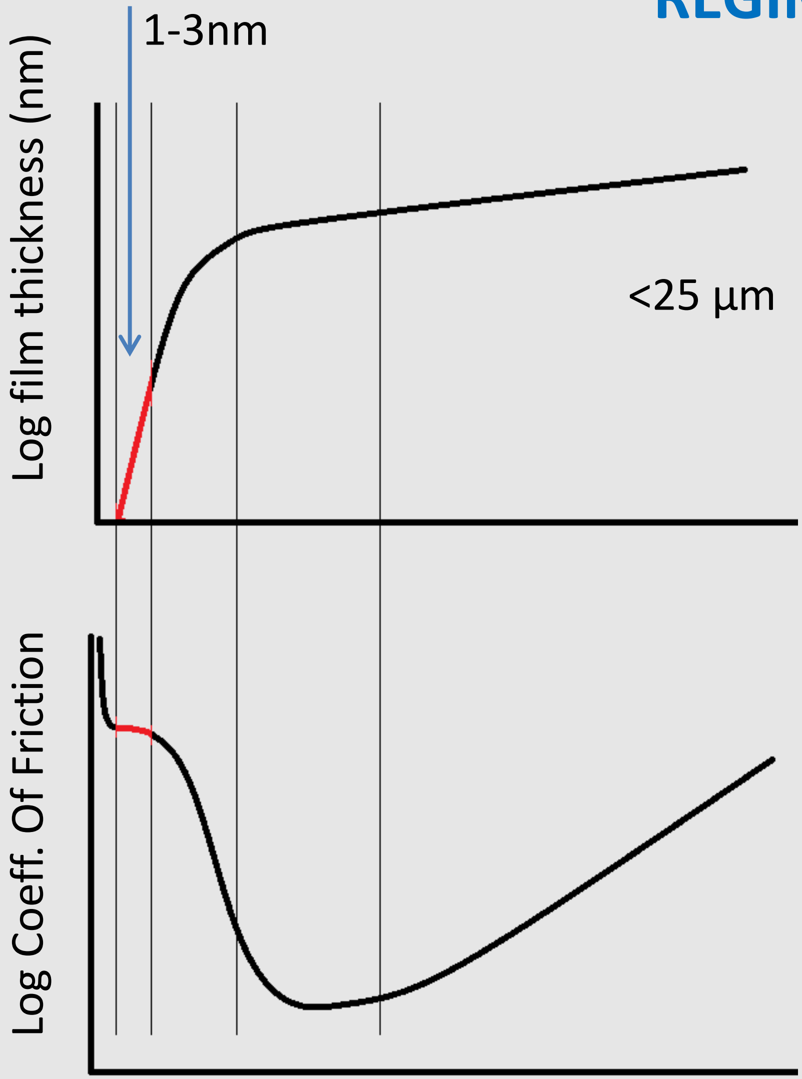
ASPHALT BOUNDARY LUBRICITY TEST

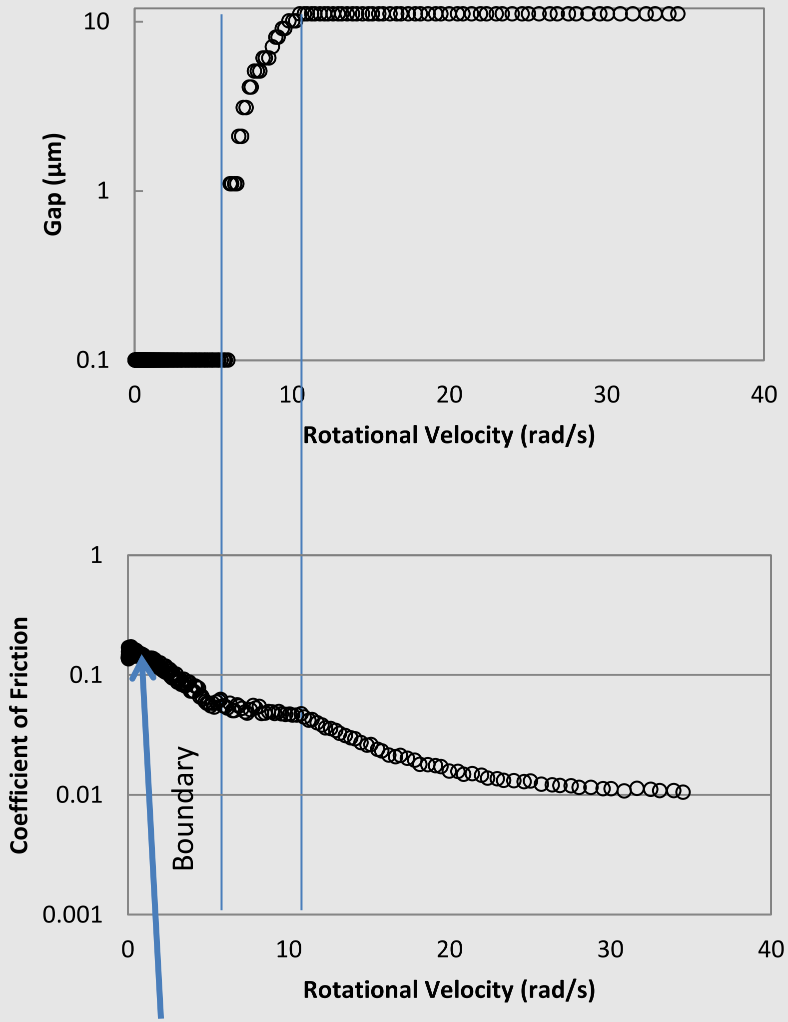


$$CoF = \frac{Torque}{Radius\ * Normal\ Force}$$

Source: Puchalski, 2012

REGIME VALIDATION



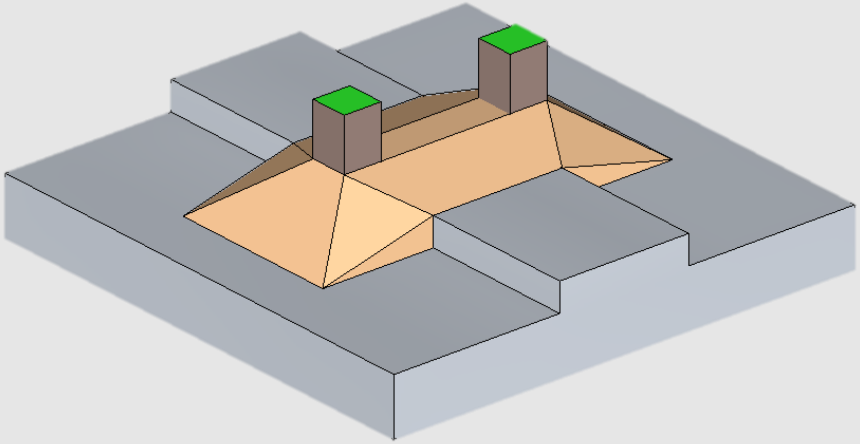


Constant Test Speed: 0.05 rad/s

Source: Bhushan, Bharat. *Introduction to Tribology.* New York: John Wiley & Sons, 2002.

SUBSTRATE TYPES

Contact Pressure Levels



100kPa, 500kPa, 1MPa

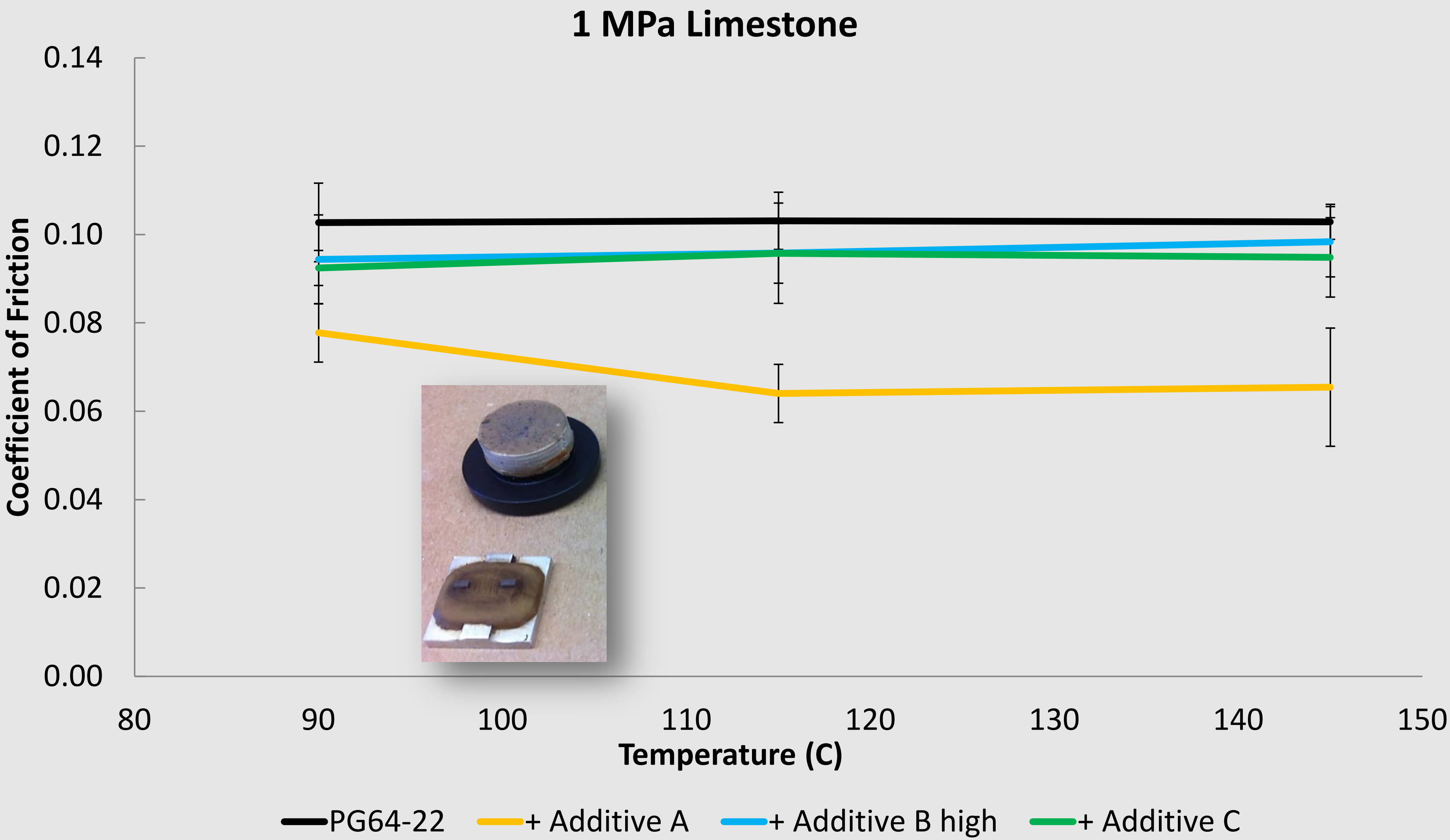
Aggregate types

Limestone Granite

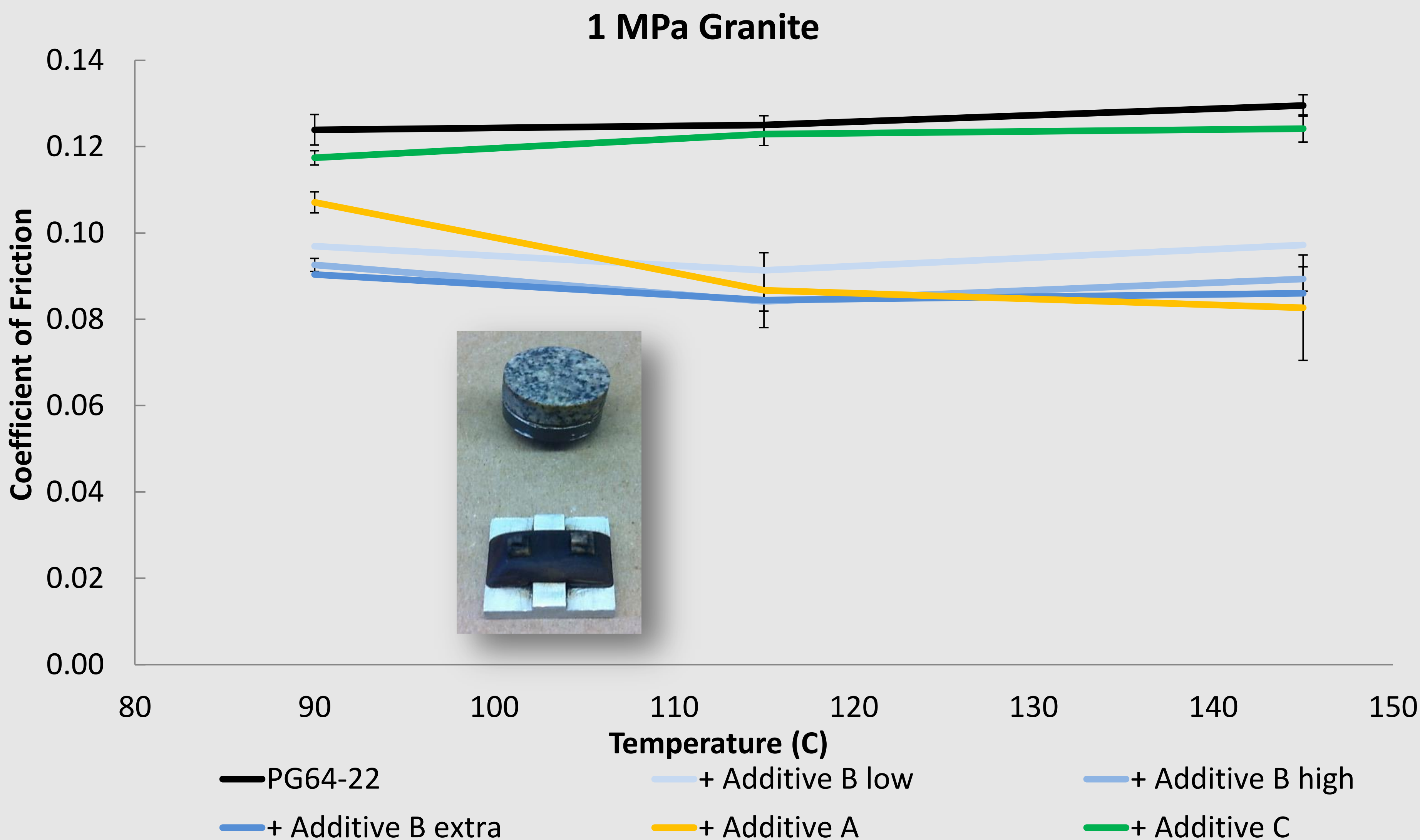
Temperature Levels

85°C, 115°C, 145°C

RESULTS


1 MPa Limestone
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Coefficient of Friction
80
90
100
110
120
130
140
150
Temperature (C)
PG64-22
+ Additive A
+ Additive B high
+ Additive C

RESULTS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0.02
0.00
80
90
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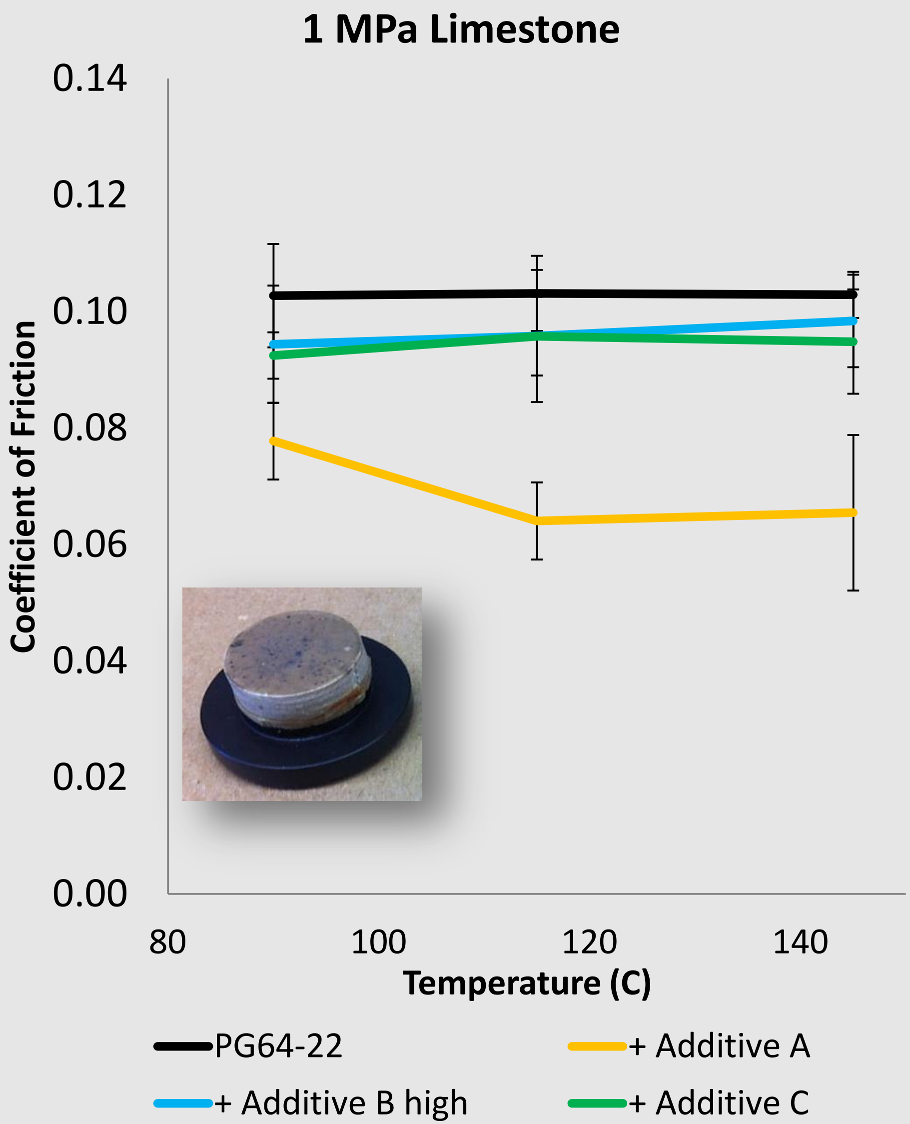
110
120
130
140
150
Temperature (C)
PG64-22
+ Additive B low
+ Additive B high
+ Additive B extra
+ Additive A
+ Additive C

RESULTS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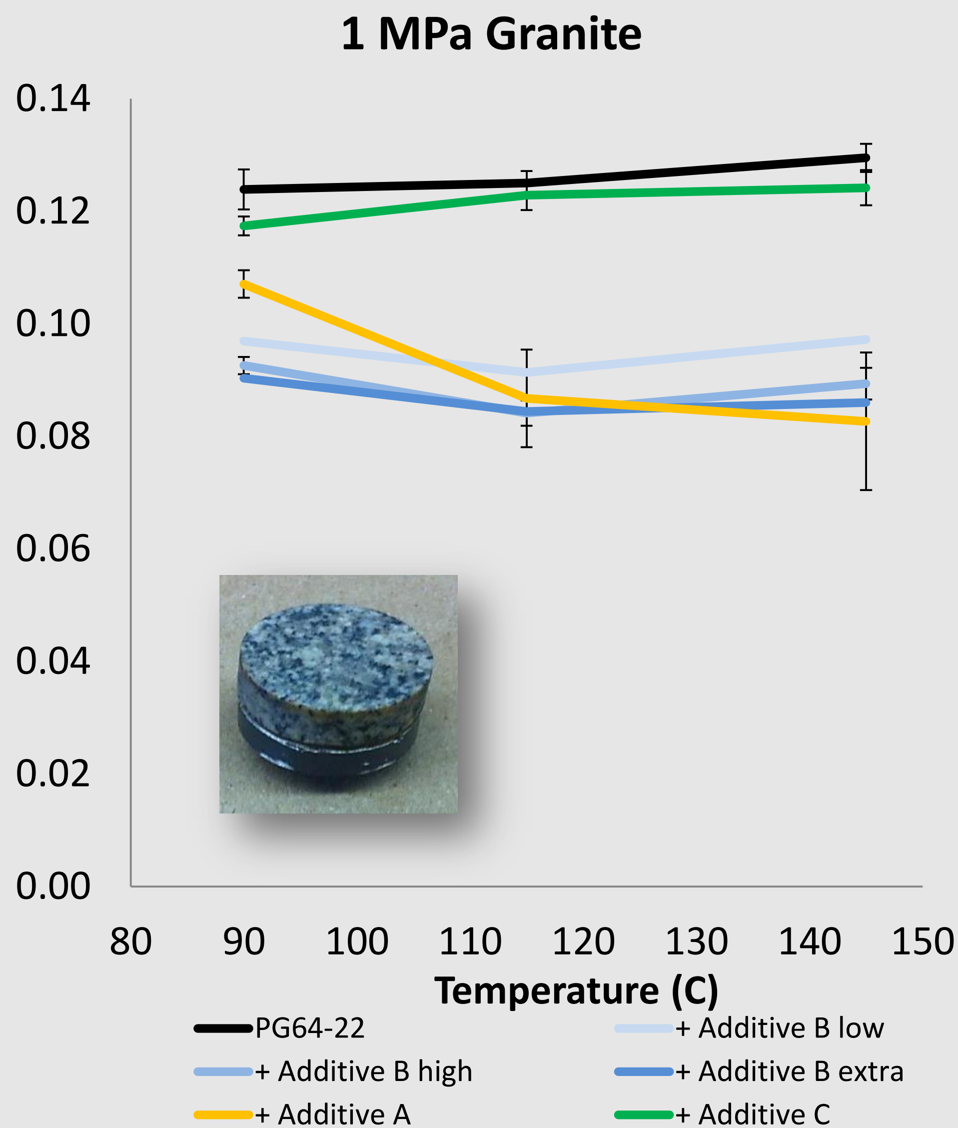
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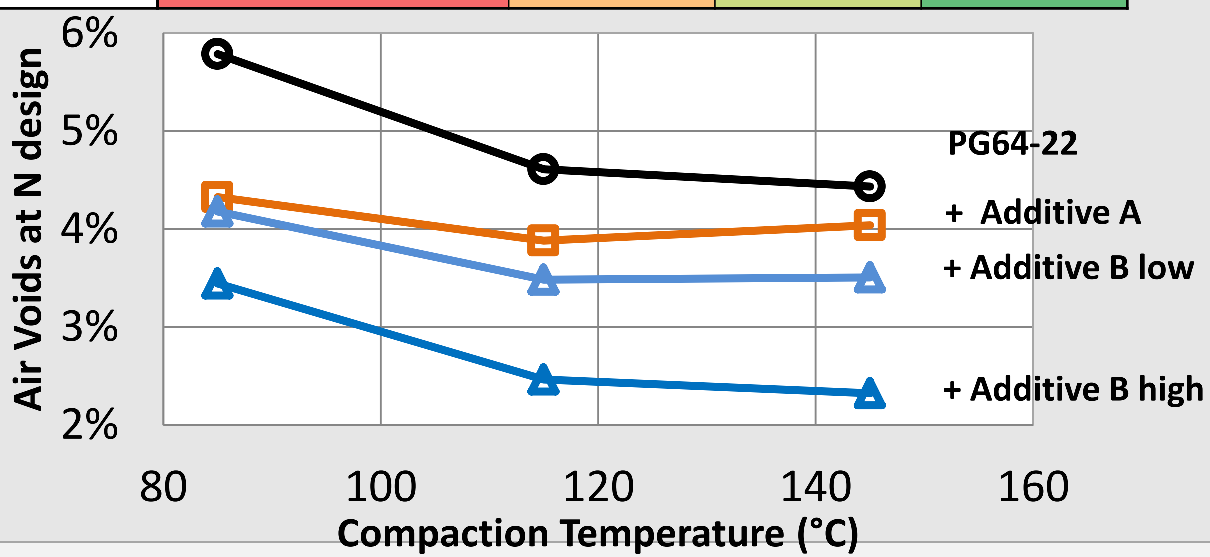
PG64-22
+ Additive B low
+ Additive B high
+ Additive B extra
+ Additive A
+ Additive C

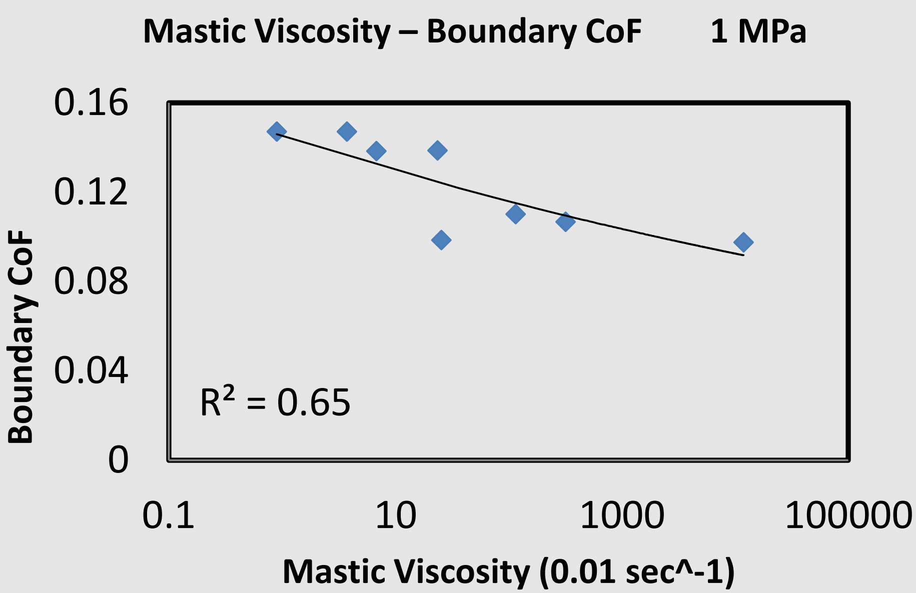
MIXTURE CORRELATION

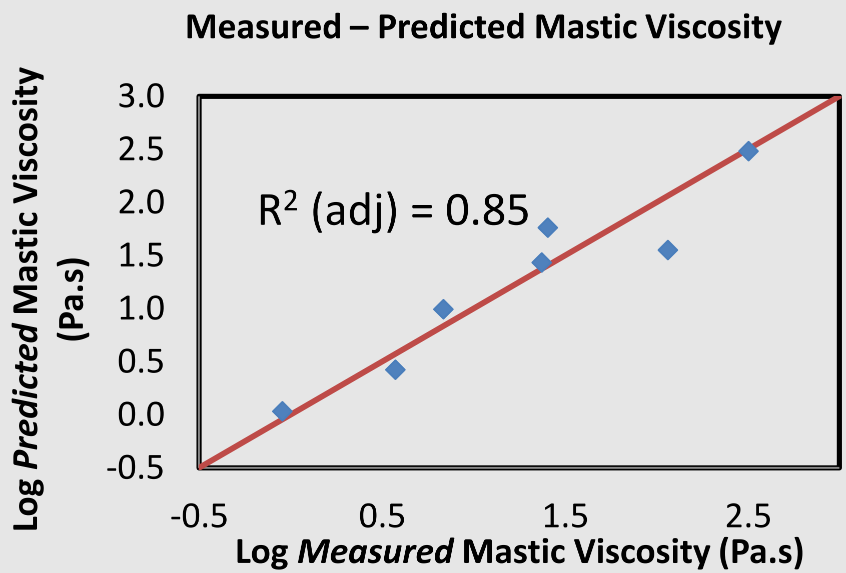
Temperature (°C)	Variable	PG64-22	Additive A	Additive B high	Additive B Low
145	Air Voids Ndes	4	3	2	1
	CoF 100kPa	4	1	2	3
	CoF 500kPa	4	1	3	2
	CoF 1MPa	4	1	3	2
115	Air Voids Ndes	4	3	2	1
	CoF 100kPa	4	1	3	2
	CoF 500kPa	4	1	3	2
	CoF 1MPa	4	2	3	1
85	Air Voids Ndes	4	3	2	1
	CoF 100kPa	4	1	2	3
	CoF 500kPa	4	3	2	1
	CoF 1MPa	4	3	2	1

Gradation: Coarse
Aggregate: Granite
Base binder: PG64-22
Binder content: 5%



MASTIC VISCOSITY CORRELATION





+ Binder Viscosity =

Best Subsets Regression:

Log(Mastic Viscosity) = 5.23 + 0.829 Log(Binder Viscosity) - 33 Boundary CoF

Partial data source: : Sefidmazgi, N. R., Teymourpour, P., Bahia, H. U.

OBSERVATIONS

- Asphalt binder may act as a lubricant
- Boundary lubrication regime has little dependence on lubricant's viscosity as opposed to hydrodynamic regime

Coefficient of friction

- Boundary lubrication regime as evaluated in the test, showed to be sensitive to the presence of WMA additives
- Coefficient of friction in boundary regime is dependent on aggregate substrate type
- Boundary and hydrodynamic lubrication are factors in asphalt mix compaction
- Boundary coefficient of friction cannot be directly related to improvements in mixture compaction . It may serve, though, as an additional tool to help understand and evaluate WMA behavior.

WMA additives

- WMA additives may improve boundary coefficient of friction
- Certain WMA additives may improve the boundary CoF regardless of aggregate substrate type, while others may only work with a specific mineralogy

Mastic viscosity

Mastic viscosity can be modeled as a function of boundary lubrication and binder viscosity.

CONCLUSIONS

- Warm mix additives affect asphalt concrete compaction
- It is important to look at asphalt as a lubricant at compaction temperatures
- Lubricating effect of warm mix additives cannot be solely captured through viscosity testing. Tribology should be used instead.

ACKNOWLEDGEMENTS AND REFERENCES

- Dr. Andrew Hanz
- Dr. Nima Sefidmazgi
- Dr. Pouya Teymourpour

References

Bhushan, Bharat. *Introduction to Tribology.* New York: John Wiley & Sons, 2002.

Hanz, Andrew. "Quantifying the Impacts of Warm Mix Asphalt on Constructability and Performance." *PhD Thesis.* Madison: University of Wisconsin – Madison, 2012.

Hanz, Andrew, Ahmed Faheem, Enad Mahmoud, and Hussain U Bahia. "Measuring Effects of Warm Mix Additives Using a Newly Developed Asphalt Binder Lubricity Test for the DSR." *Transportation Research Record*, 2010: 85-92.

Rabinowicz, Ernest. *Friction and Wear of Materials.* New York City: John Wiley & Sons, Inc., 1995.

Puchalski, S. Investigation of Warm Mix Asphalt Additives Using the Science of Tribology to Explain Improvements in Mixture Compaction. Master of Science Thesis, Madison, WI, 2012.

Sefidmazgi, N. R., Teymourpour, P., Bahia, H. U. " Effect of Particle Mobility on Aggregate Structure Formation in Asphalt Mixtures, "Journal of the Association of Asphalt Paving Technologists, Vol. 82, 2013, pp. 16-34.“

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