Benelux Smeeroliecongres

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TRIBOLOGICAL SOLUTIONS FROM ANTON PAAR

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ANTON PAAR DEVELOPS, PRODUCES, AND SELLS HIGH-PRECISION MEASURING INSTRUMENTS AND CUSTOMIZED AUTOMATION AND ROBOTIC SOLUTIONS.

FACTS AND FIGURES

ESTABLISHED IN
1922

HEADQUARTERS
IN GRAZ / AUSTRIA

4,200+
EMPLOYEES

OWNED BY THE CHARITABLE
SANTNER FOUNDATION

16 % INVESTMENT
IN RESEARCH AND DEVELOPMENT

FROM ANNUAL TURNOVER
ANTON PAAR GMBH

ALL CRITICAL COMPONENTS
MANUFACTURED IN-HOUSE

BASICS OF TRIBOLOGY

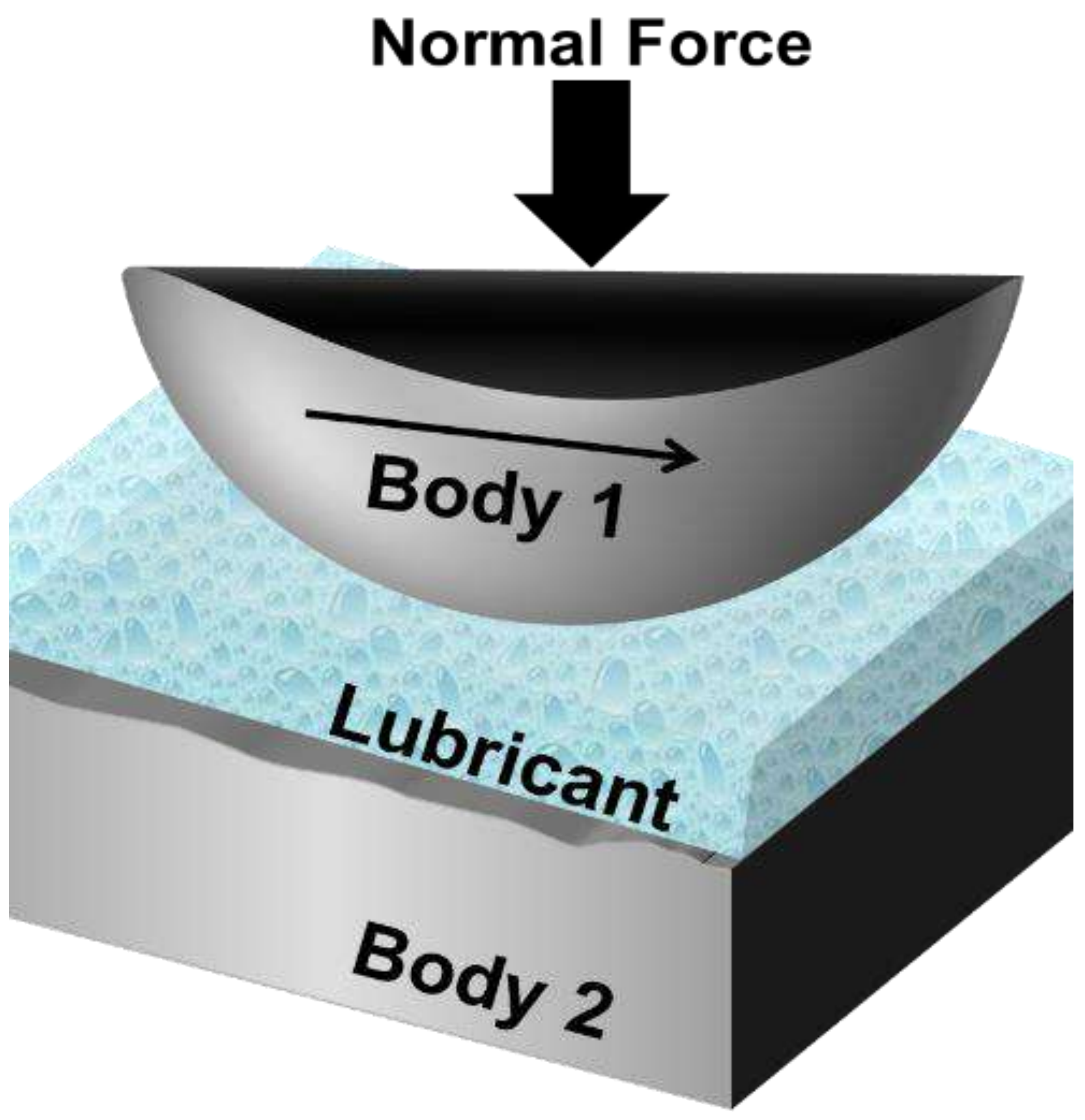
TERMINOLOGY

Tribology

"Tribo(s)" + "logy"

(I rub) (Science)

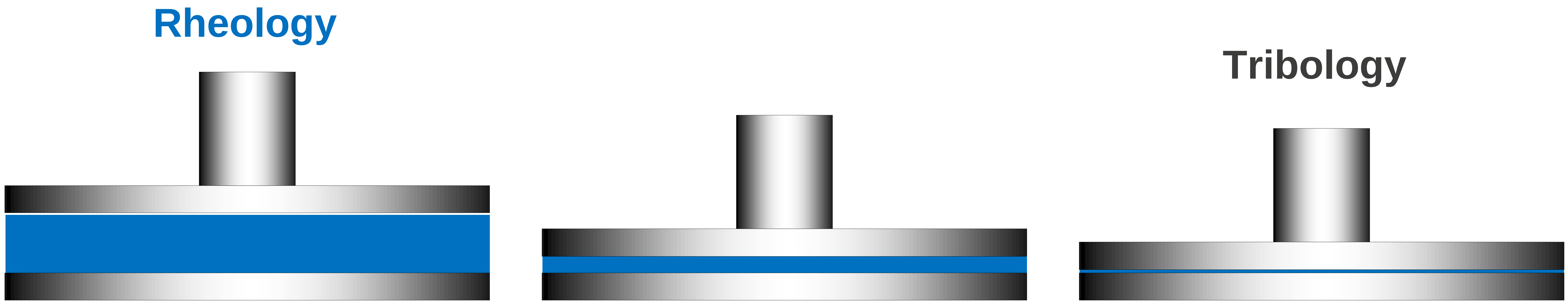
… scientific study of friction, wear, and lubrication.



Tribosystem:

Two bodies (surfaces) moving relative to each other, with or without a medium separating them.

RHEOLOGY ↔ TRIBOLOGY



- *Inner friction*
- *Rheology characterizes material properties*

- *Friction between surfaces*
- *Tribology characterizes system properties*

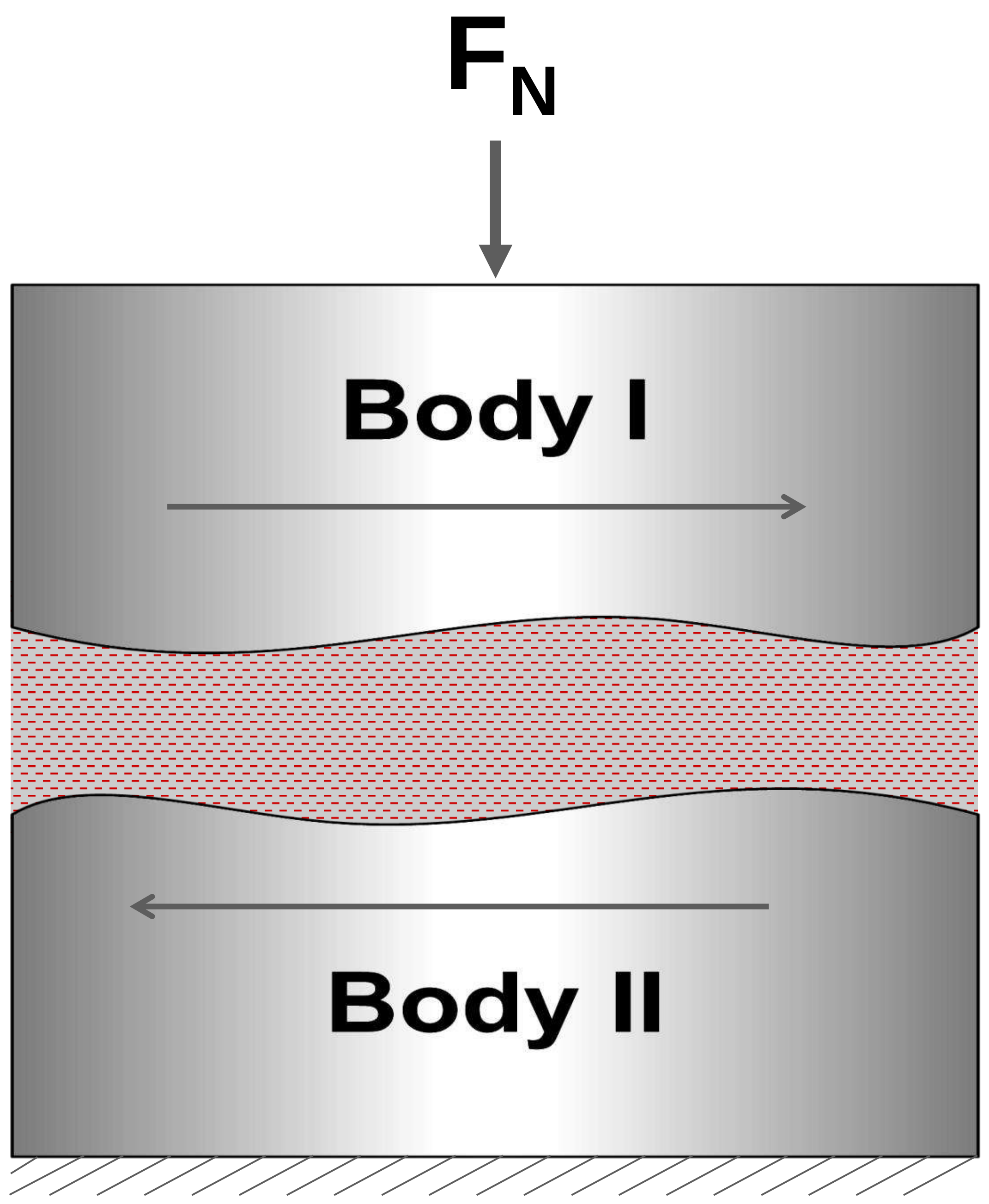
TRIBOLOGICAL INTERACTIONS

What happens…

- Friction losses
- Surface change
- Tribochemical reactions
- Energy dissipation

What we set…

- Environmental conditions
  temperature, humidity, …
- Contact conditions
  pressure, contact type, lubricated/dry, …
- Motion
  linear, rotation, oscillation, …



What we measure…

- Coefficient of friction
- Frictional torque
- Wear
  volume, height, rate, …
- Vibrations
- …

FRICTION COEFFICIENT – FRICTION FACTOR – COF…

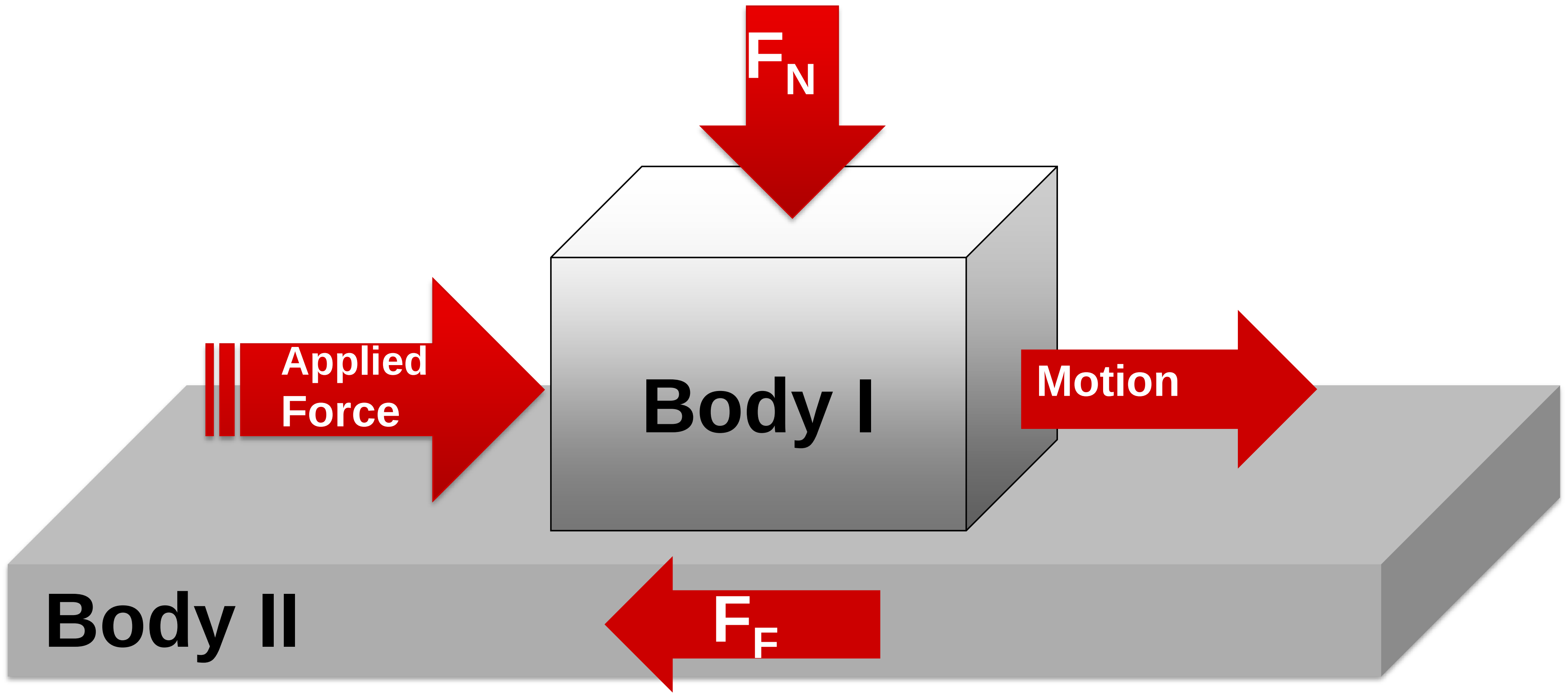
- The friction factor **μ** is the ratio between the frictional force between two bodies (Frictional or Tangential Force $\mathbf{F_F}$) and the force pressing them together (Normal Force $\mathbf{F_N}$).

- μ is defined as

$$\mu = \frac{F_F}{F_N}$$

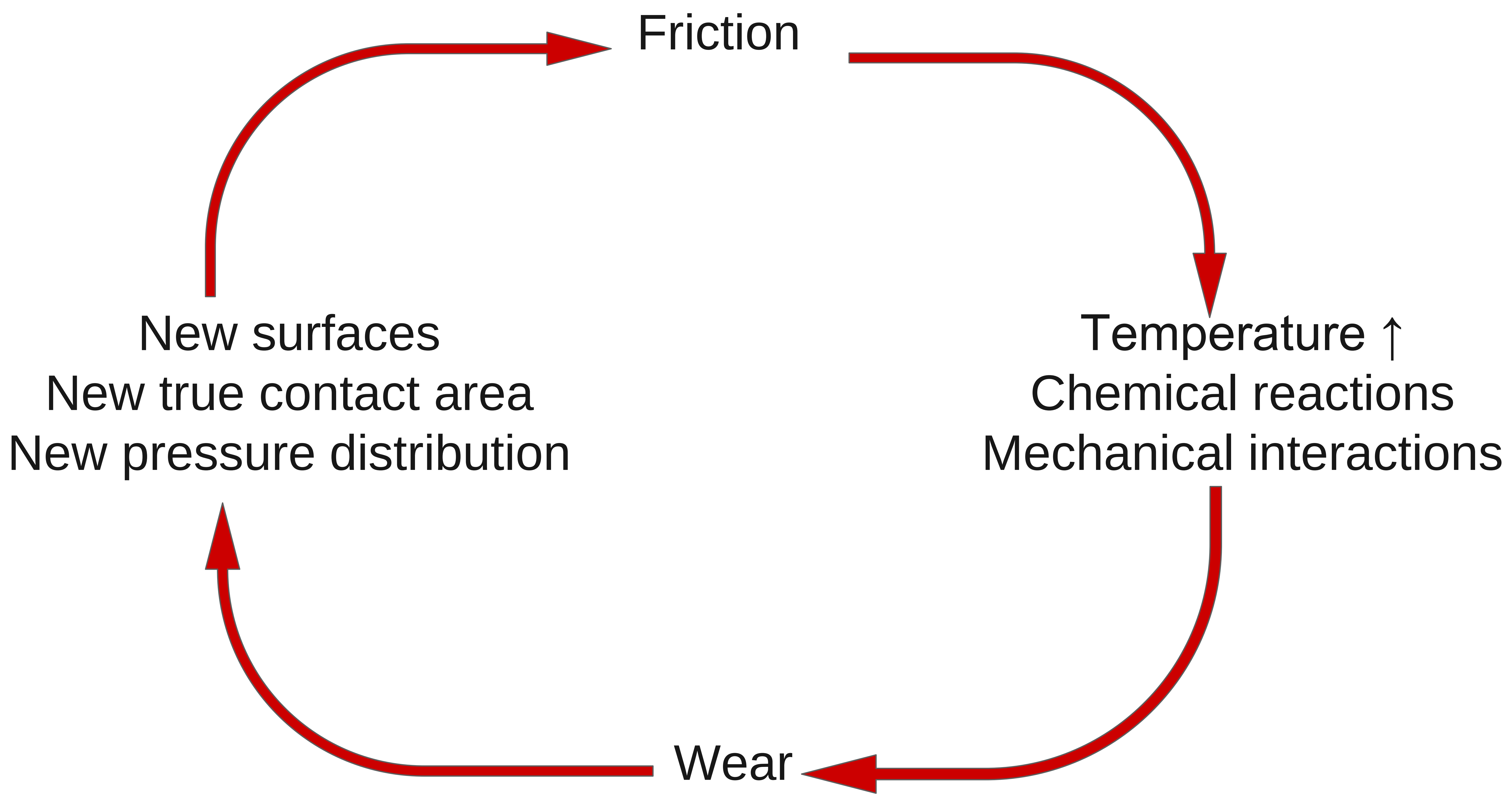
F_F → Friction Force

F_N → Normal Force



Friction Factor, Friction Coefficient, Coefficient of Friction, and μ refer to the same measure.

CYCLE OF TRIBOLOGICAL INTERACTION



Dynamic nature of Tribology

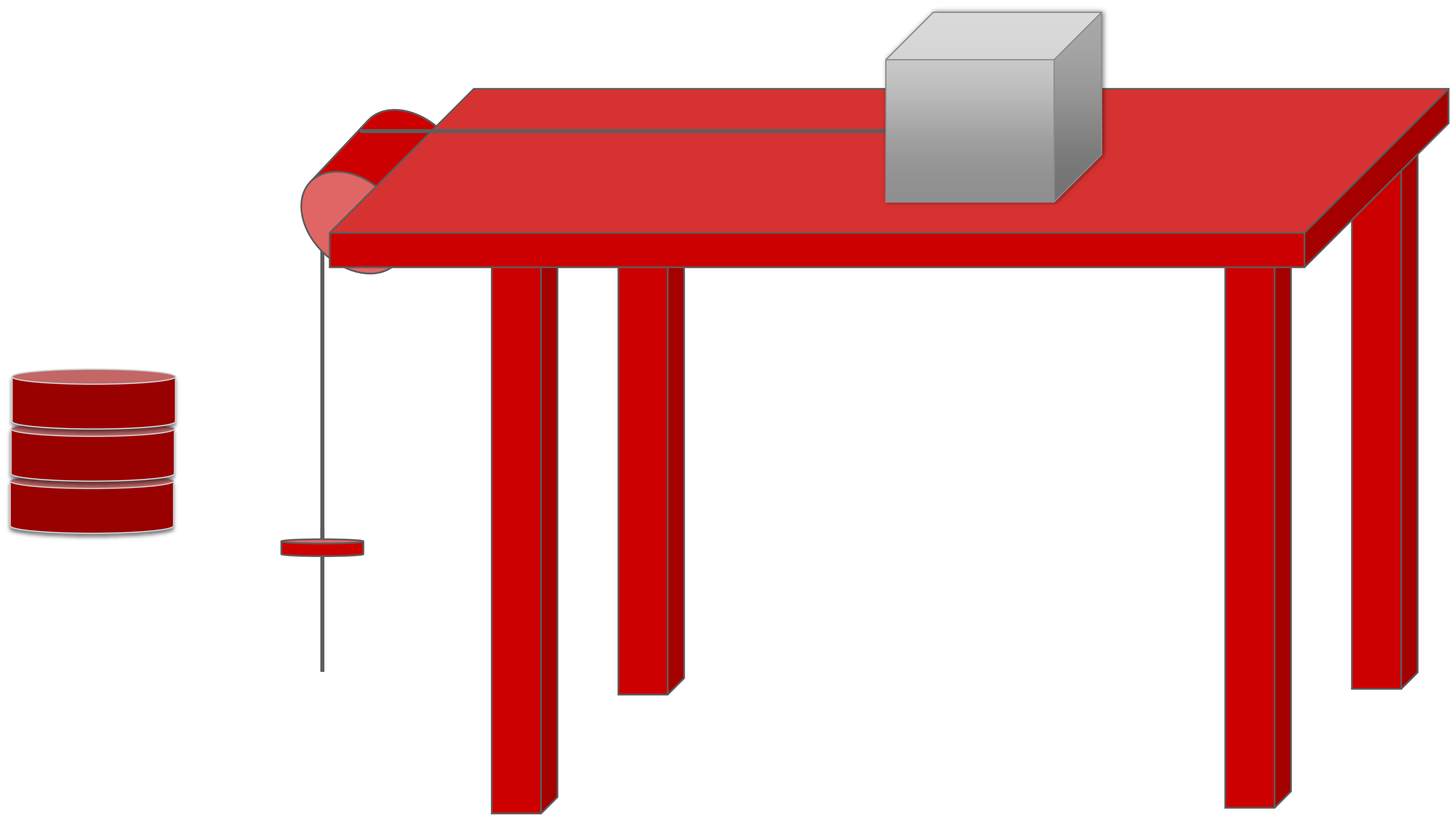
Typical Measurements

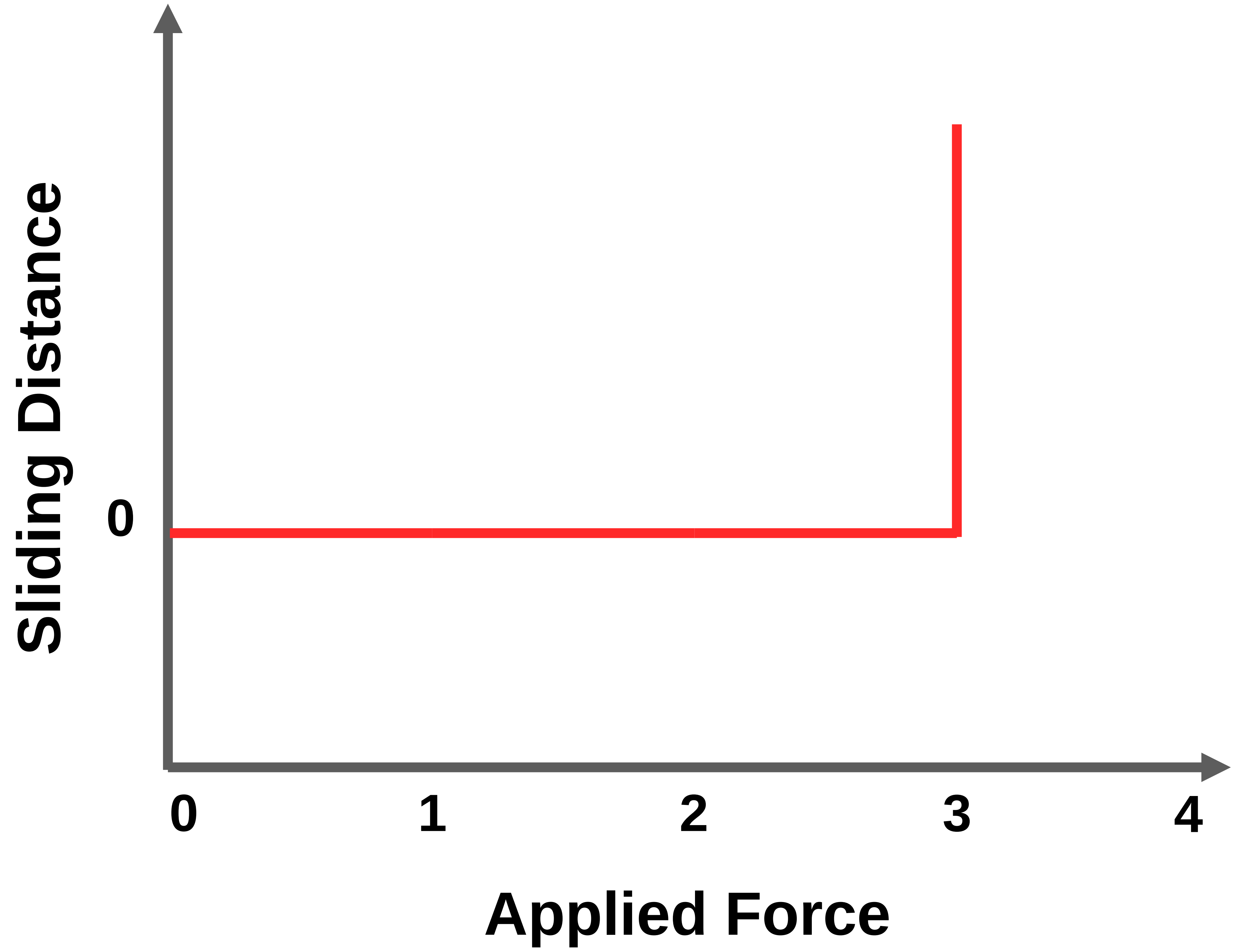
LIMITING FRICTION

LIMITING FRICTION (STATIC FRICTION)

- What is Static Friction?
  - In simple terms, it is the friction that inhibits relative motion between two interacting surfaces at rest.
- What is Limiting Friction?
  - It is the peak value of static friction. To initiate relative motion between two interacting surfaces, it is necessary to overcome the limiting frictional force prevailing at the contact.
- How to measure Limiting Friction?
  - Consider sliding a block on a table (see next slide). Here, the applied force on the block is gradually increased and the corresponding displacement observed. Once the applied force exceeds the limiting force inhibiting sliding between the surfaces, the object begins to slide.

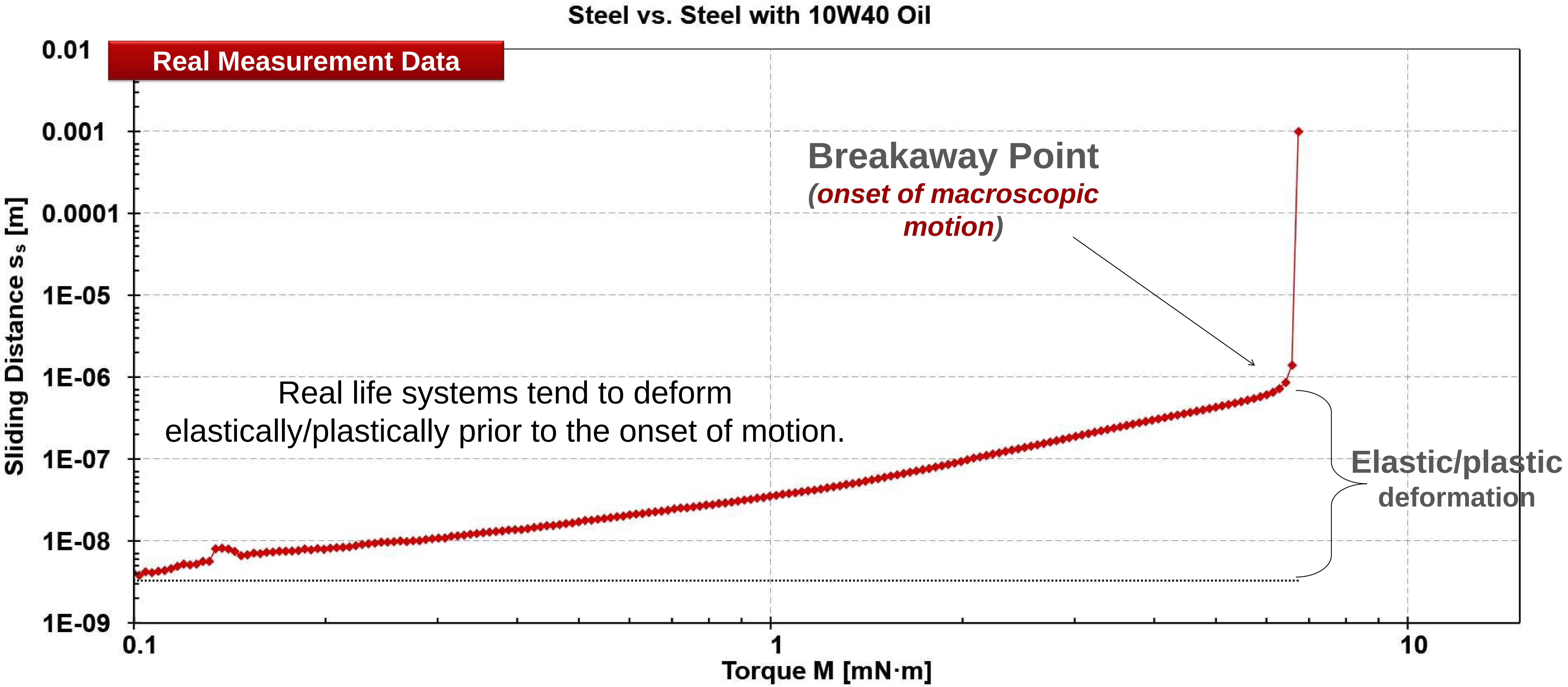
LIMITING FRICTION (STATIC FRICTION)





A particular minimum amount of force is required to generate macroscopic motion!

BREAKAWAY TORQUE DATA



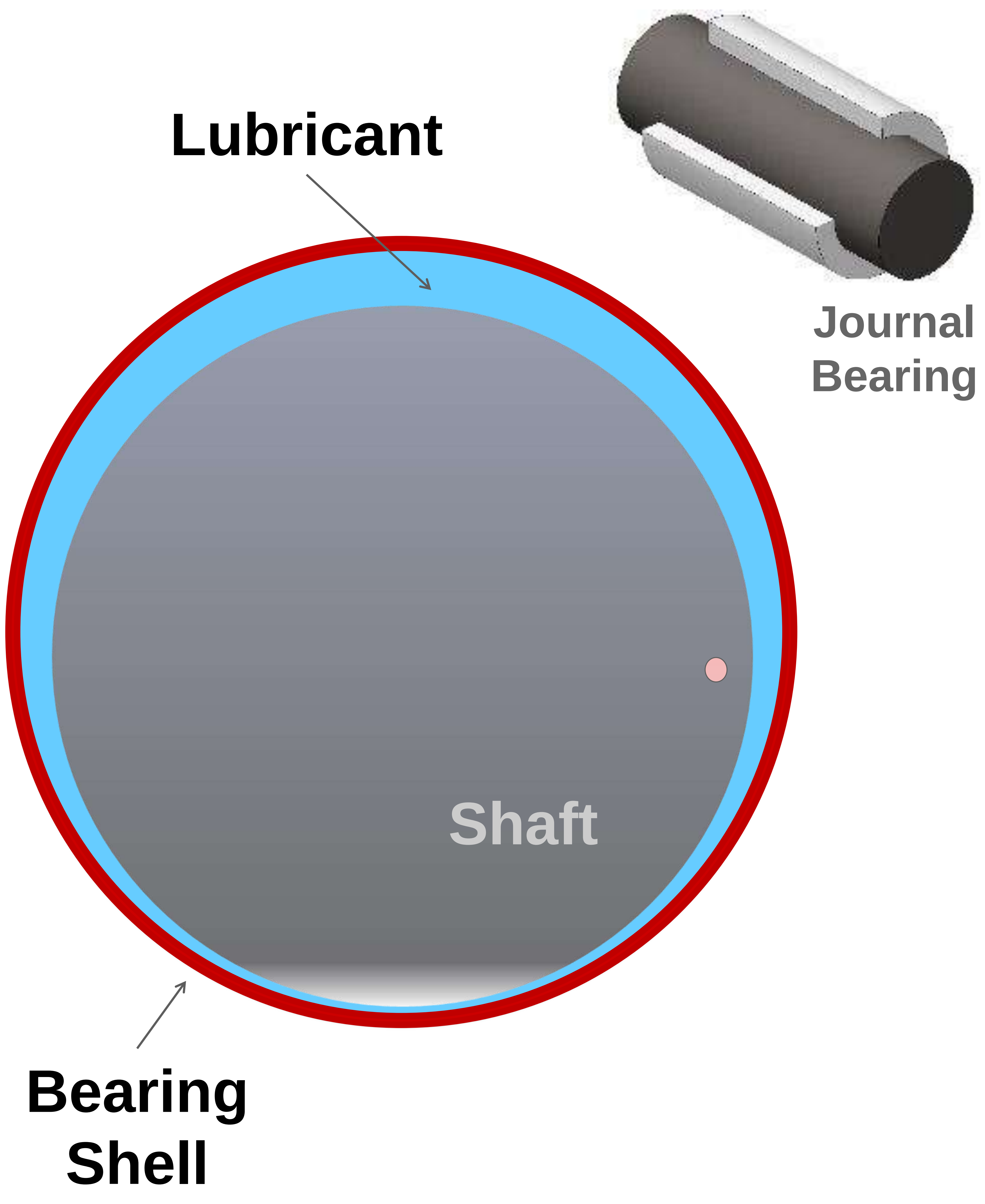
Typical Measurements

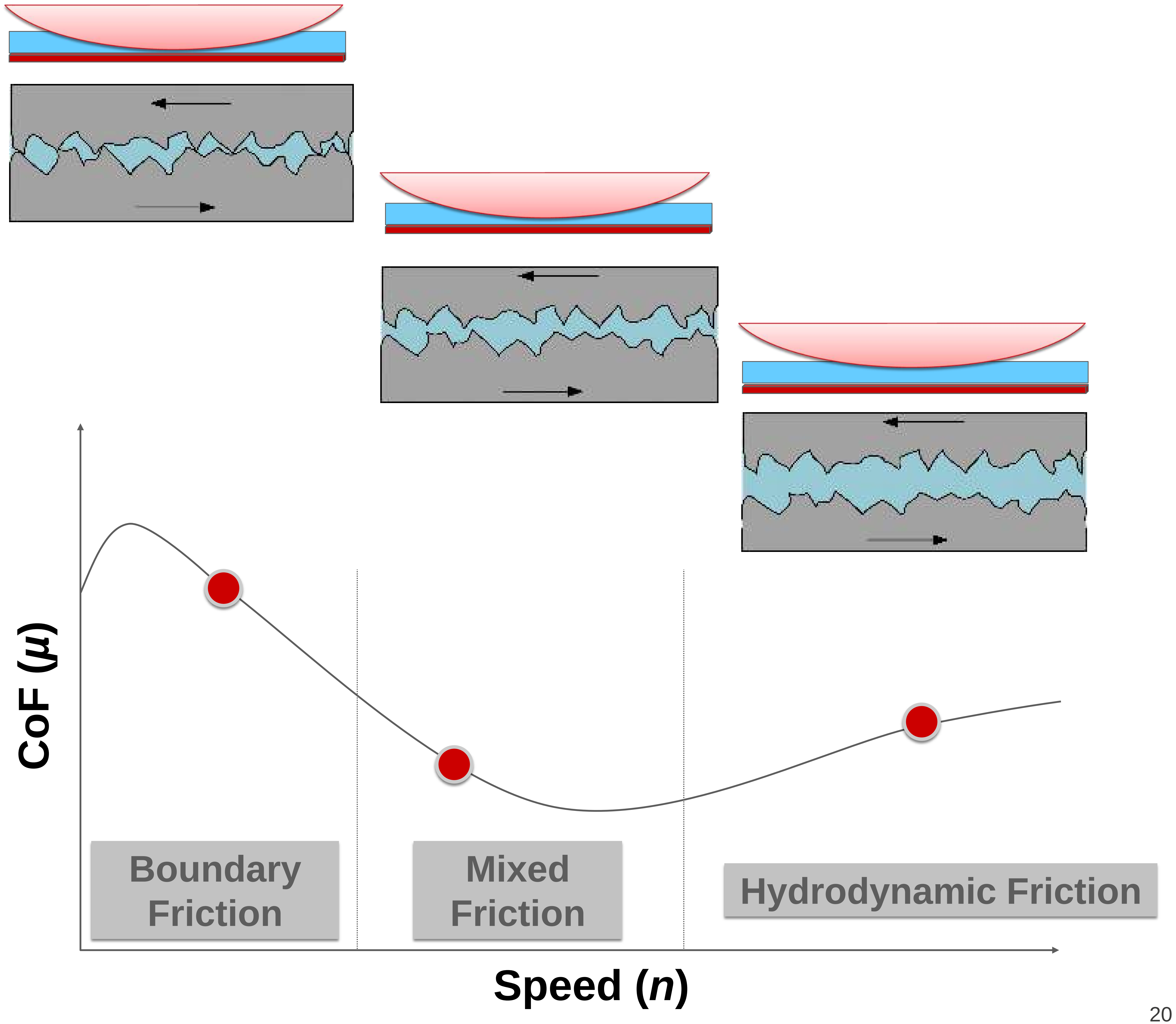
STRIBECK CURVES

STRIBECK CURVES

- What is a Stribeck Curve?
  - In their simplified form, Stribeck curves depict friction coefficient as a function of siding velocity. With a lubricated tribosystem, a Stribeck curve offers insights into their friction or lubrication regimes – see next slide.

STRIBECK CURVE





LUBRICATION REGIMES

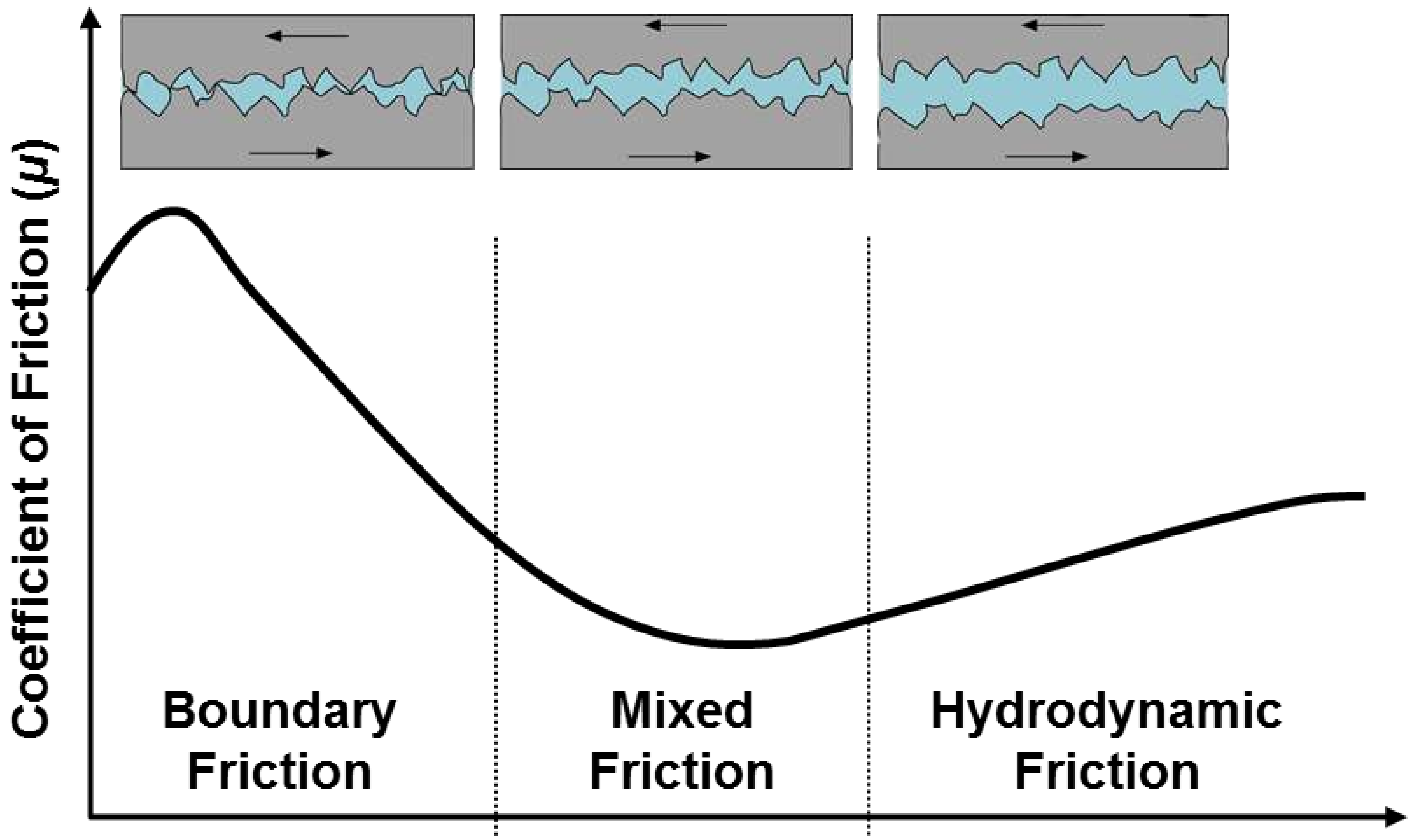
Boundary Friction

- No fluid/lubricant film
- Asperity (body/body) contact
- High friction and wear…

At low speed, the lubricant is squeezed out of the contact and does not offer effective lubrication. As the speed increases, more of the lubricant is entrained into the contact. At high speeds, there is a sufficiently thick load-bearing lubricant film which hinders surface to surface contact.

Mixed Friction

- Lubricant film just thick enough to separate the surfaces
- Asperities come in contact occasionally
- Low friction and wear …

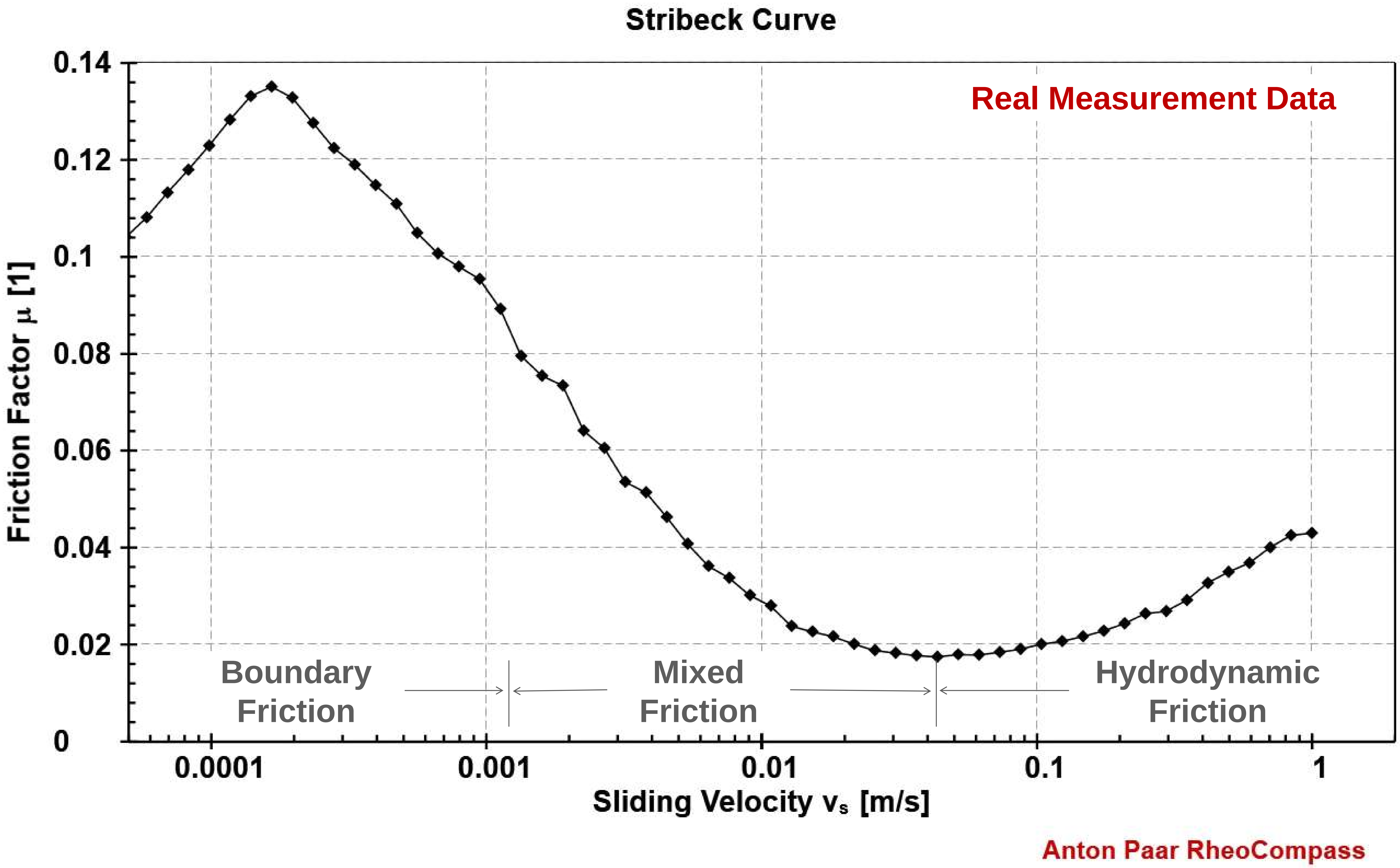


Hydrodynamic Friction

- Lubricant film totally separates the surfaces
- No asperity contact
- Friction only due to viscosity
- No wear*…

** while there is absence of wear due to asperity contact, other types of wear such as erosion, cavitation, etc. can still occur.*

STRIBECK CURVE



Glass ball vs. PDMS with sunflower oil as lubricant

- **Normal Force: 3 N**
- **Temperature: 22 °C**

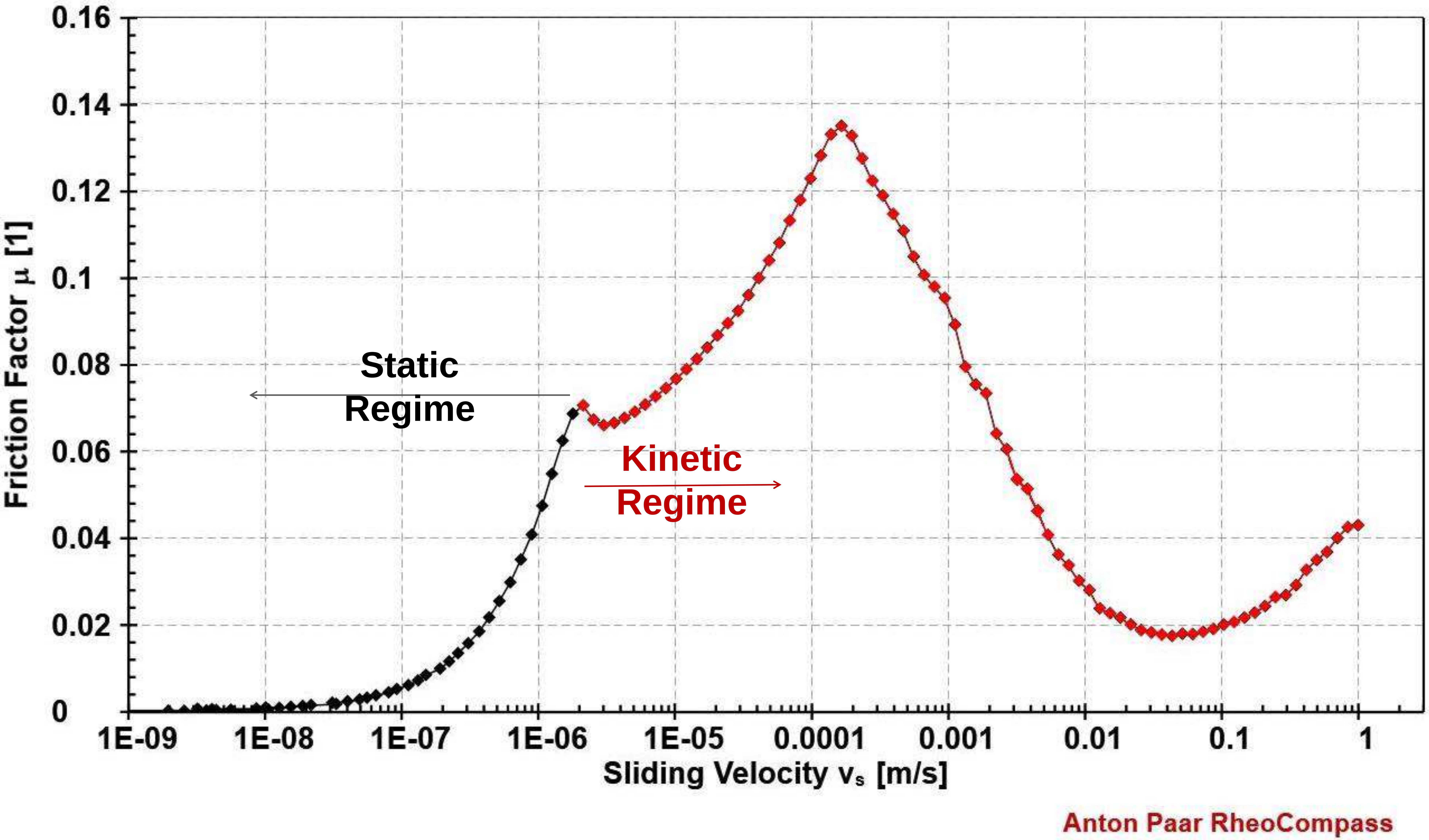
The uniqueness of this setup is presented in the next slide.

EXTENDED STRIBECK CURVES

- What is an Extended Stribeck Curve?
  - While Stribeck curves provide information about the frictional resistance of a lubricated tribosystem in the kinetic regime, extended Stribeck curves, like the name suggests, extends the Stribeck curves into the static regime – see next slide.

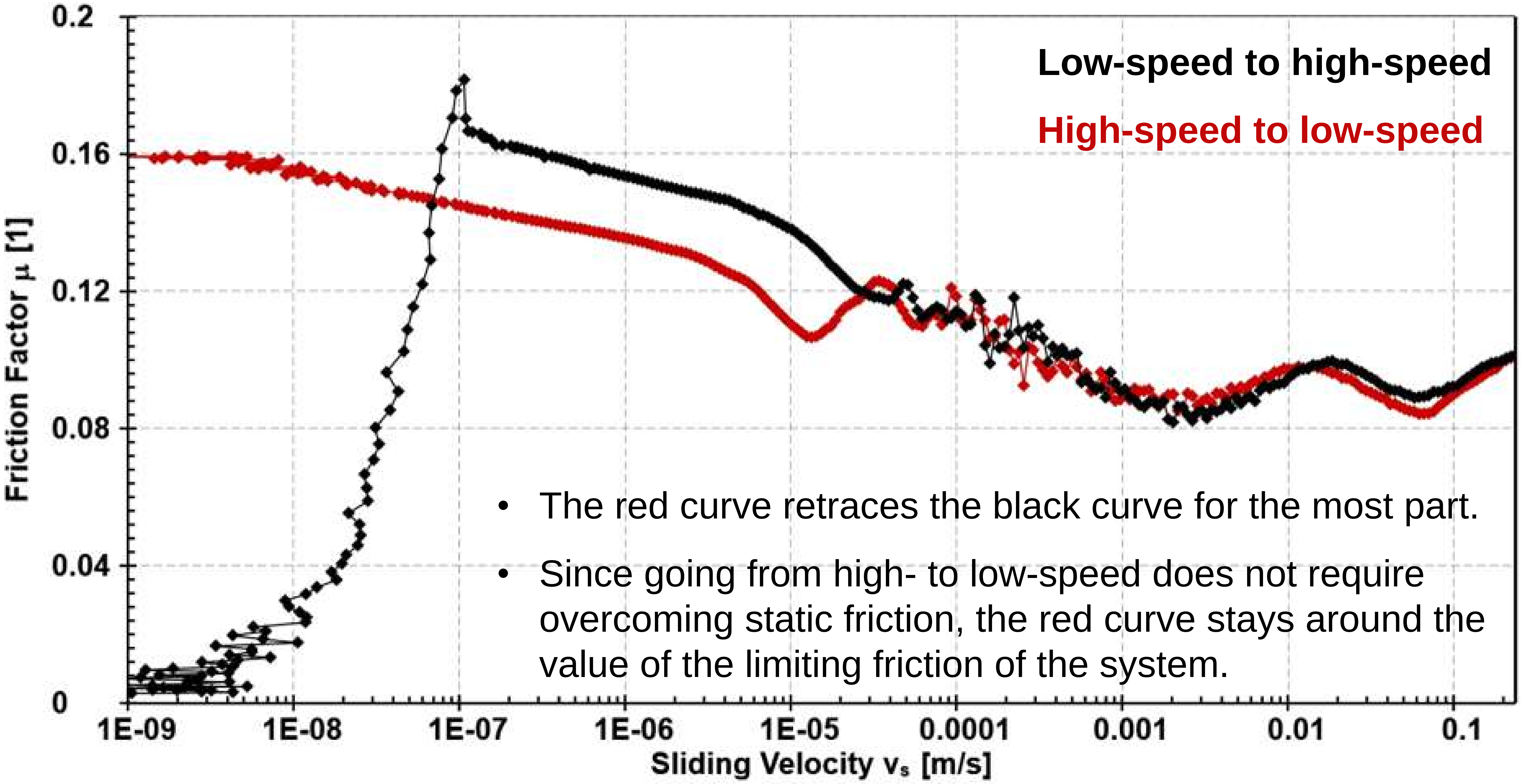
  - What is the advantage of Extended Stribeck Curves?
    - These curves give information about the evolution of friction in the static regime, and the transition into kinetic regime.
    - It is also possible to obtain values of limiting friction of the tribosystem from these curves.

EXTENDED STRIBECK CURVE



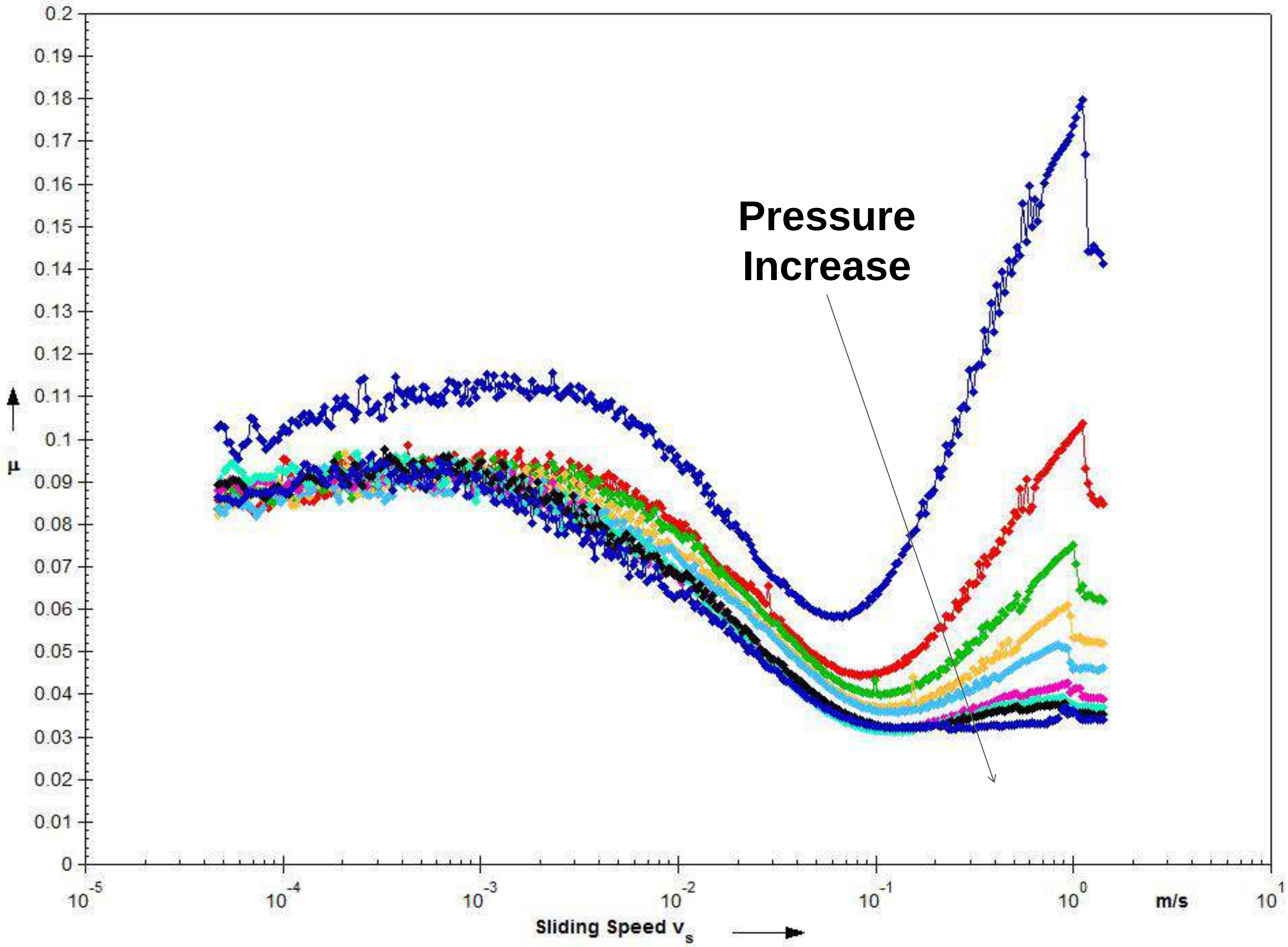
In addition to measuring friction in the kinetic regime, this setup is can also capture the evolution of friction in the static regime.

EXTENDED STRIBECK CURVE (III)



- The red curve retraces the black curve for the most part.
- Since going from high- to low-speed does not require overcoming static friction, the red curve stays around the value of the limiting friction of the system.

EFFECT OF PRESSURE



As the contact pressure increases:

- transition from mixed to fluid friction shifts to higher rotational speeds
- friction coefficient in fluid friction regime decreases (due to a thinner fluid film)

Typical Measurements

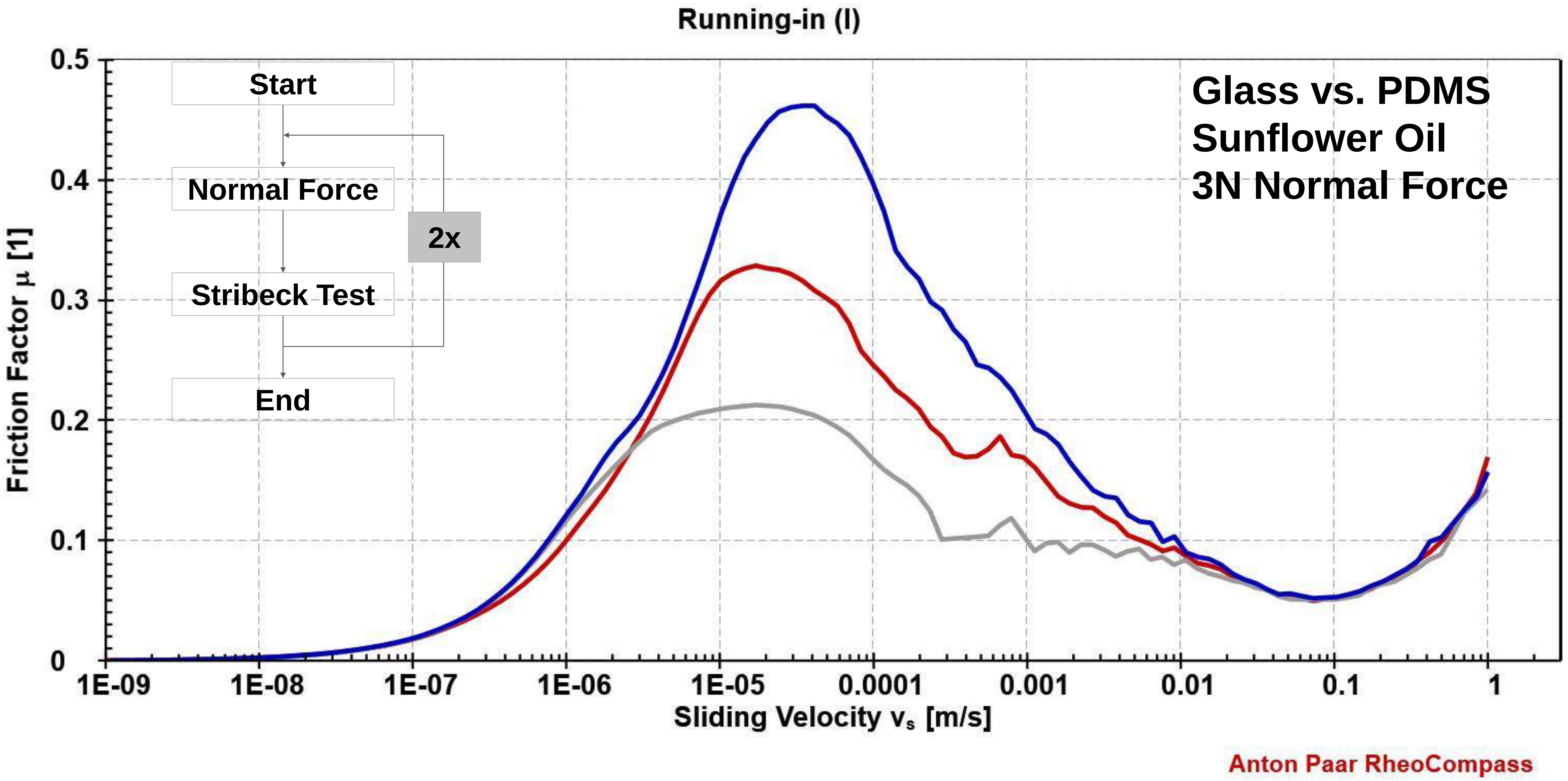
RUNNING-IN

RUNNING-IN (I)

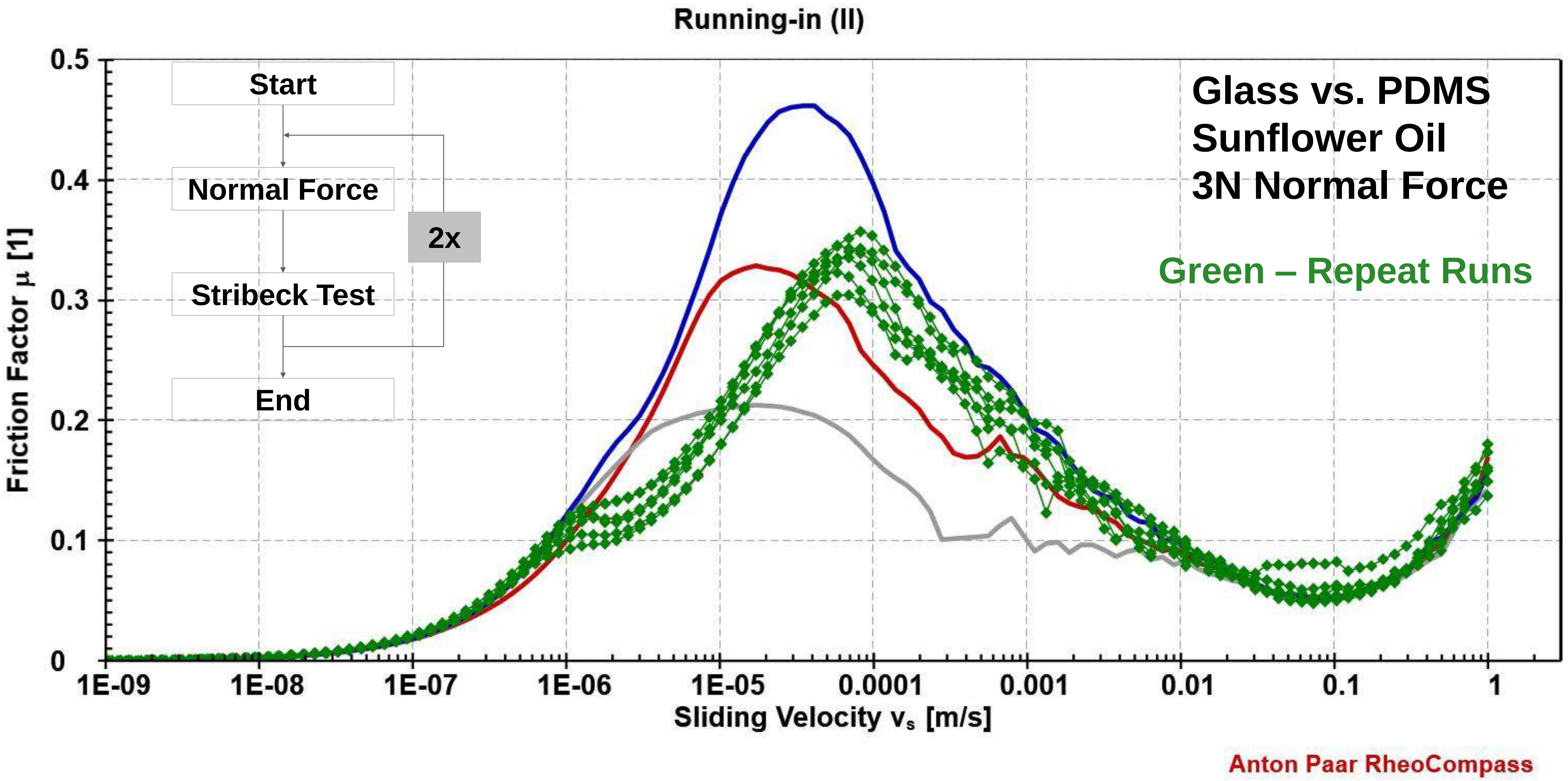
- What is Running-in?
  - It is the process of flattening/removal of surface asperities at a newly established tribocontact through a combination of wear and/or elastic/plastic deformation.

- Next Slide – (Running-in (II))
  - The three curves are from three individual tests with glass ball vs. PDMS pins with sunflower oil as a lubricant.
  - Since the fresh surfaces are not always identical due to differences in their surface properties, especially their roughness, the data from the first runs could at times not be reproducible.
- Slide After – (Running-in (III))
  - The green curves in this curve are repeat runs (2^{nd} and 3^{rd} Runs) which show decent reproducibility after the running-in process.

RUNNING-IN (II)



RUNNING-IN (III)



TEST SETUP

MODULAR COMPACT RHEOMETER

Up to 1000 bar

Pressure

Electric Field

Magnetic Field

Up to 1.3 T

Temperature

Influencing Parameters

Humidity...

-160 to 1000 °C

5 to 95% RH

DMTA

Tribology

Transforming Movement

Structural Information

Microscopy

Powder

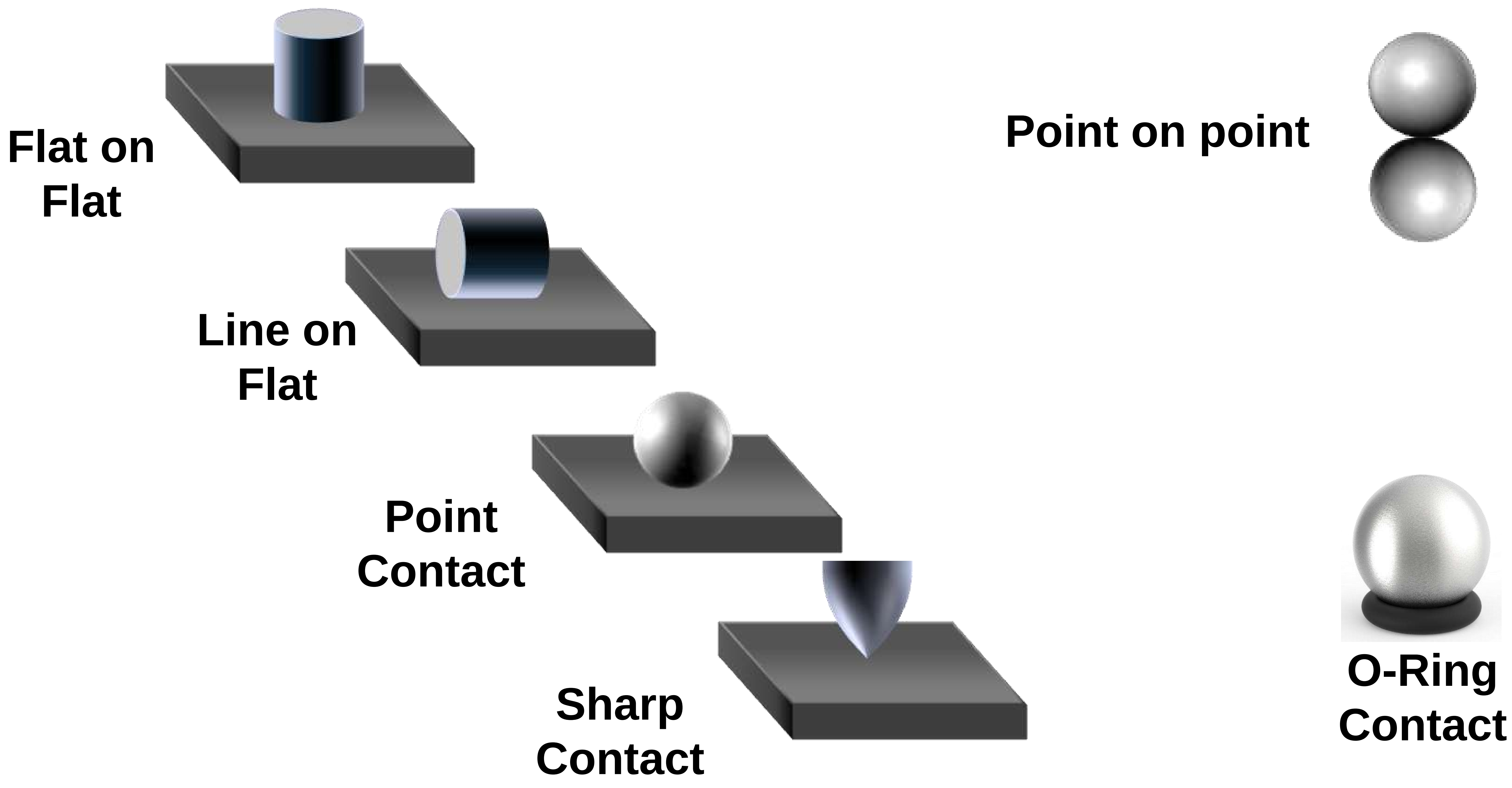
Starch...

Spectroscopy

TEST CONFIGURATIONS – MCR TRIBOLOGY

Torque	230 mN.m
Speed (RPM)	10^{-6} – 3000
Temperature	-160 – 600 °C
Normal Force	0.1 – 50 N

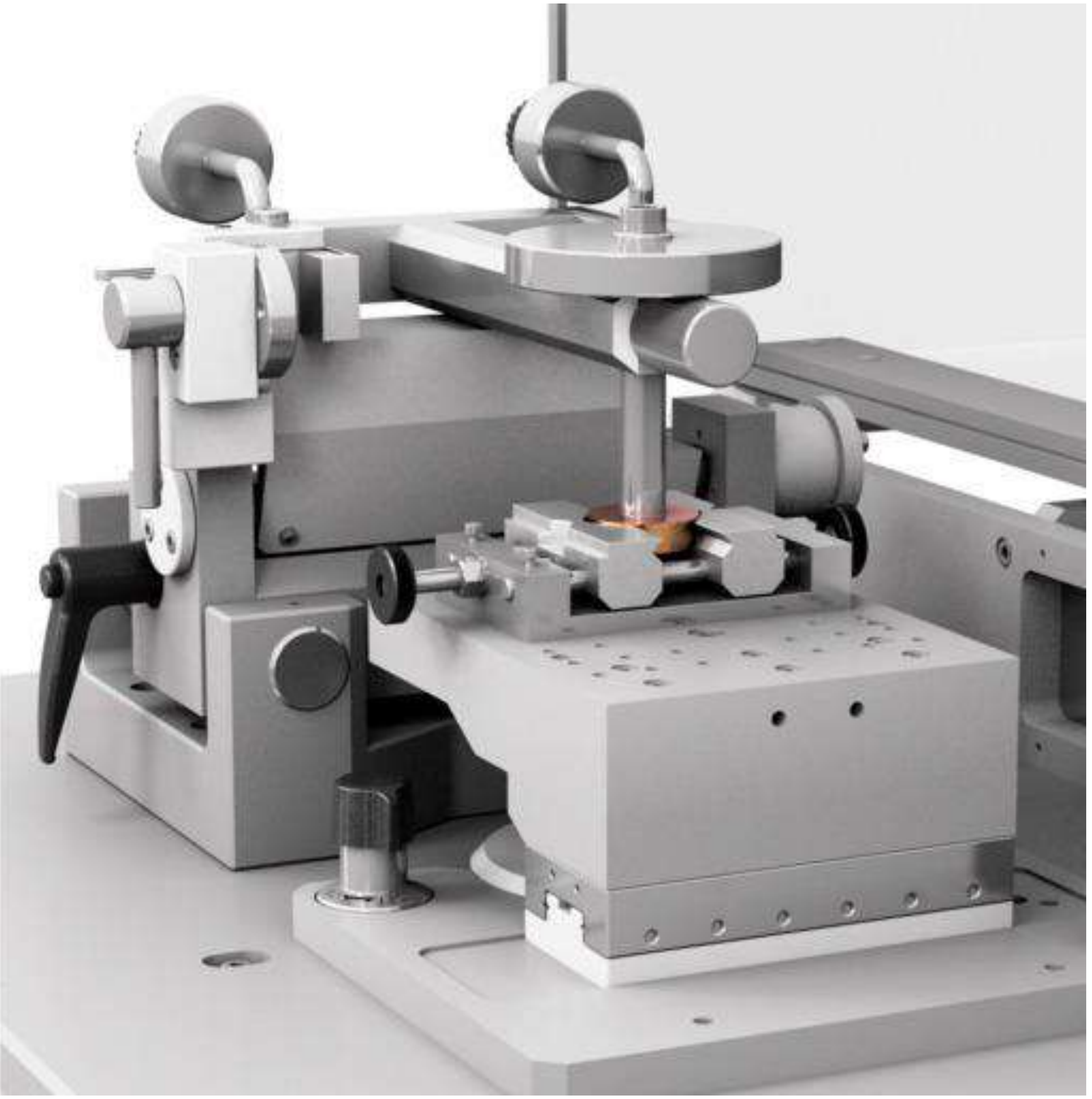
CONTACT GEOMETRIES



or: customized holder or specimen

Rotation Mode

Linear Mode



Full conformity to the standards

- ASTM G99
- G133
- DIN 50324

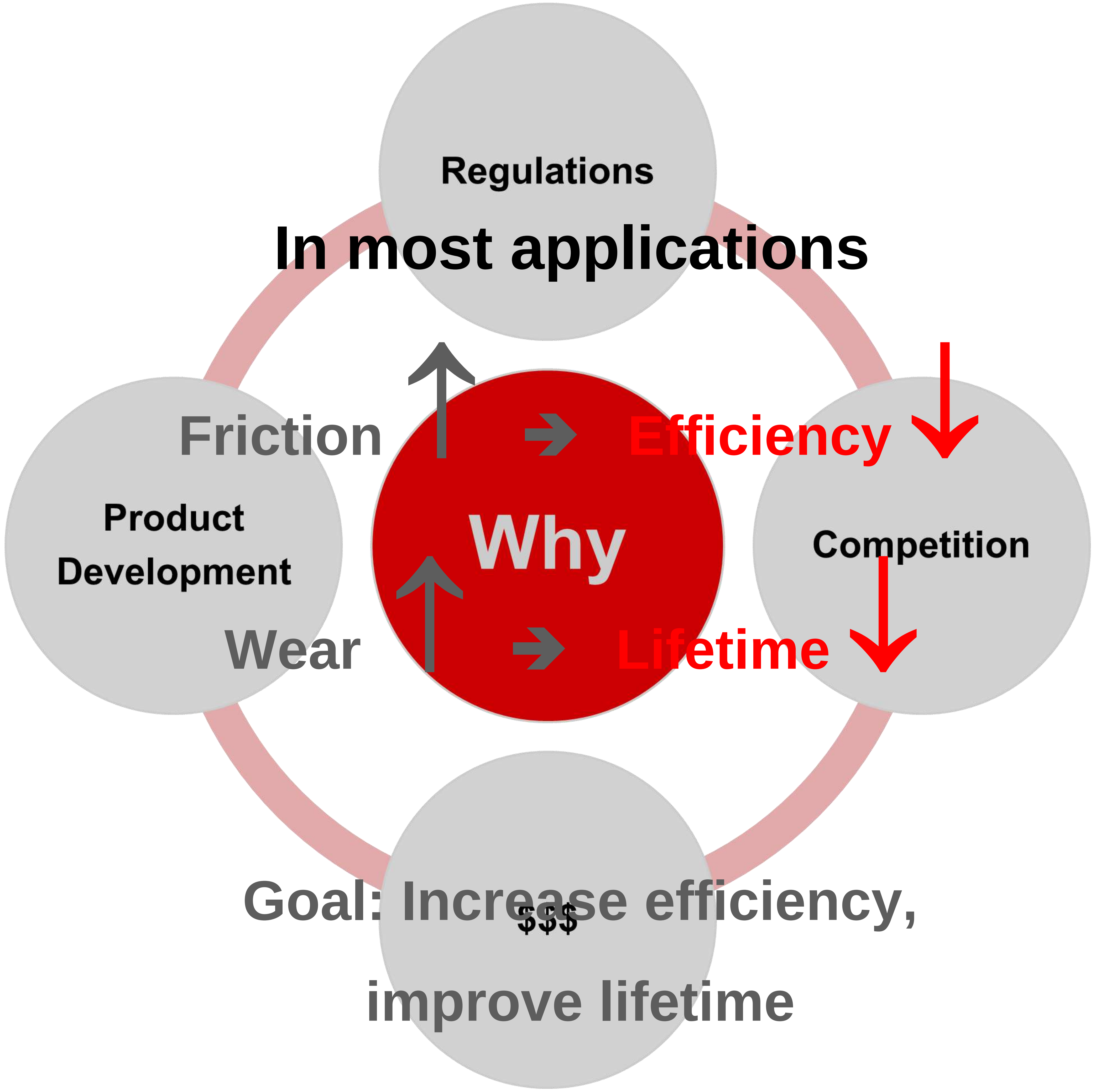
WHY TRIBOLOGY

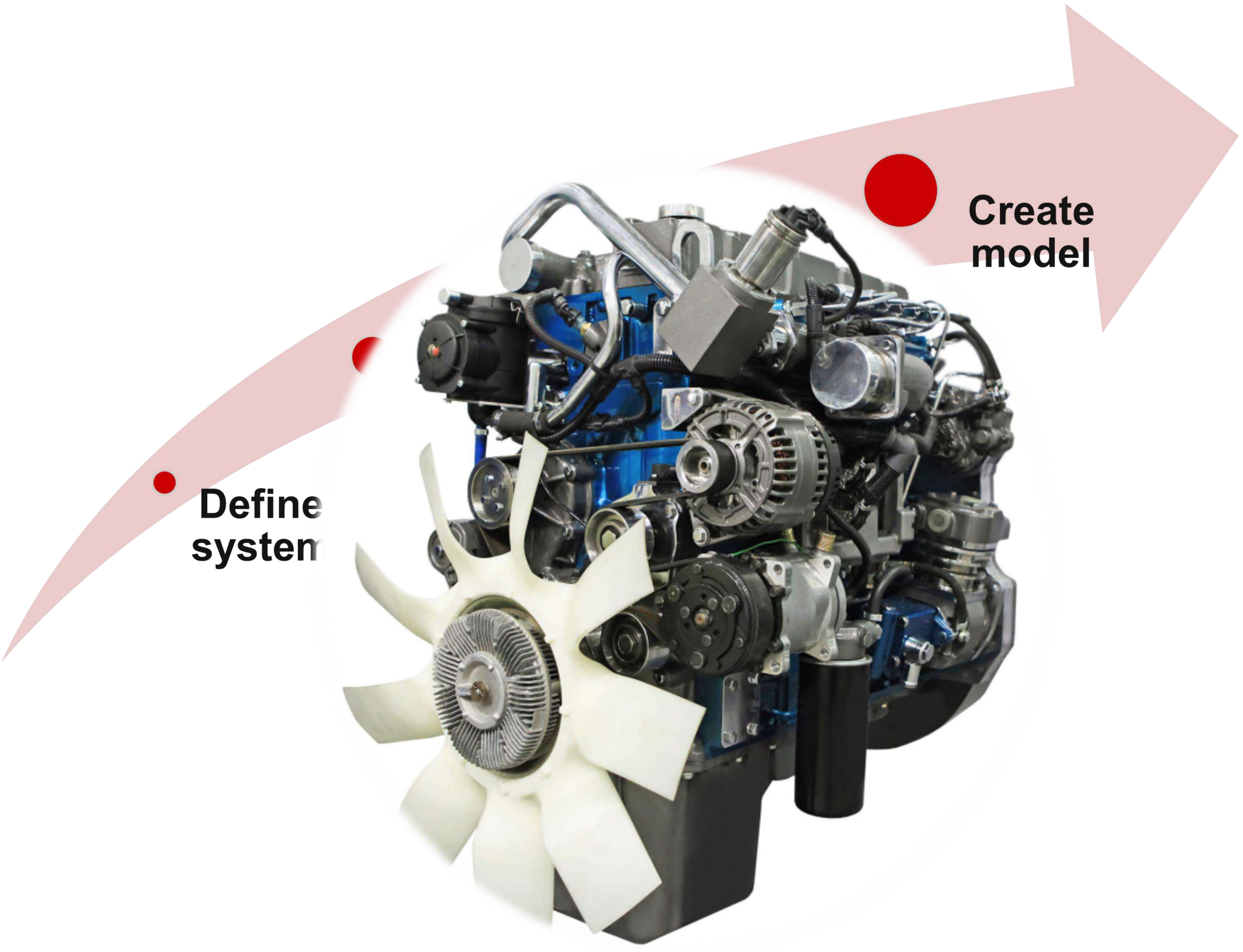
In most applications

Friction ↑ → Efficiency ↓

Wear ↑ → Lifetime ↓

Goal: Increase efficiency, improve lifetime

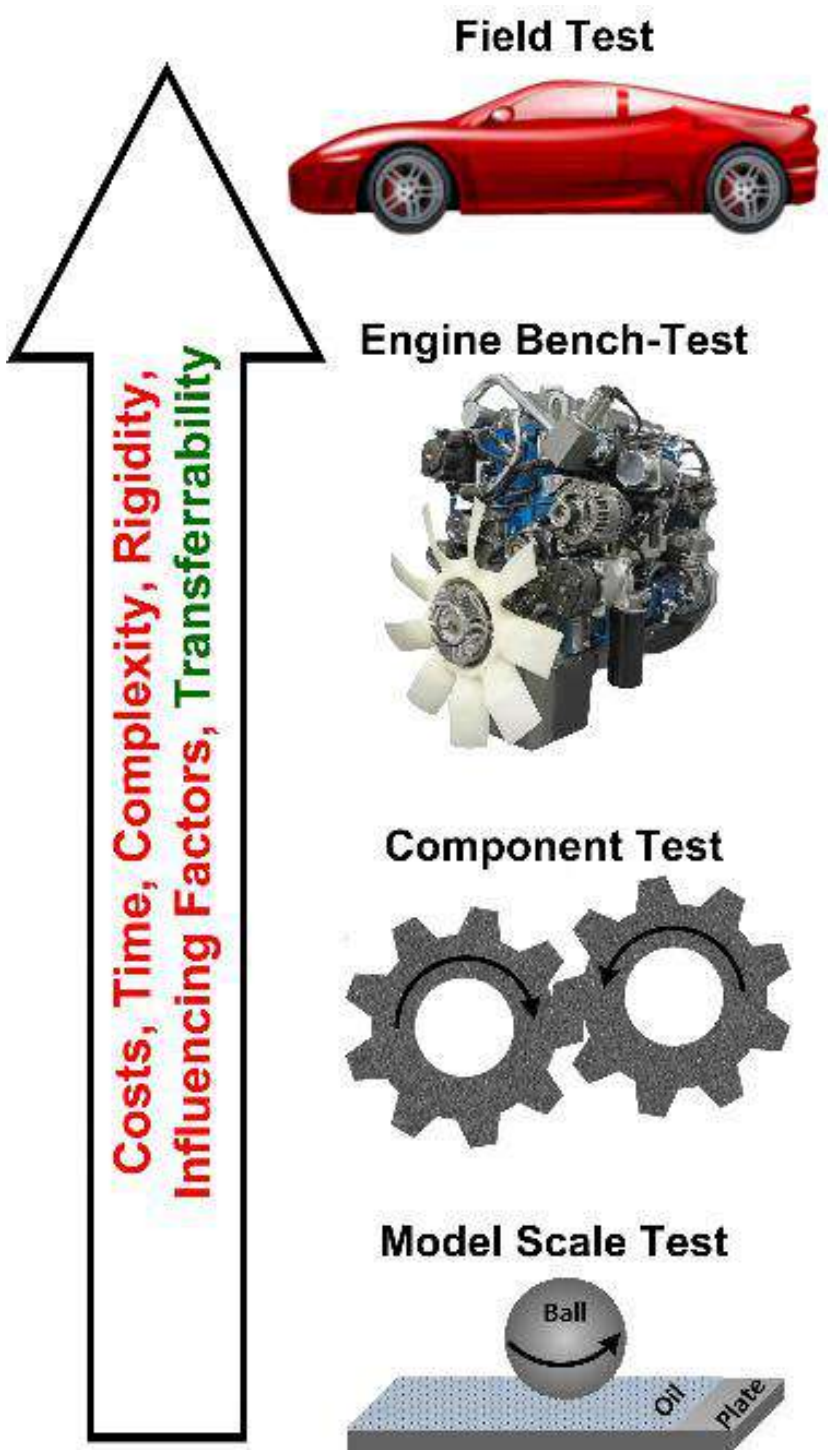




MODEL-SCALE TESTING

- Cost and time efficient
- Individual parameter study possible
- “Easier” data interpretation
- Can be used for prescreening

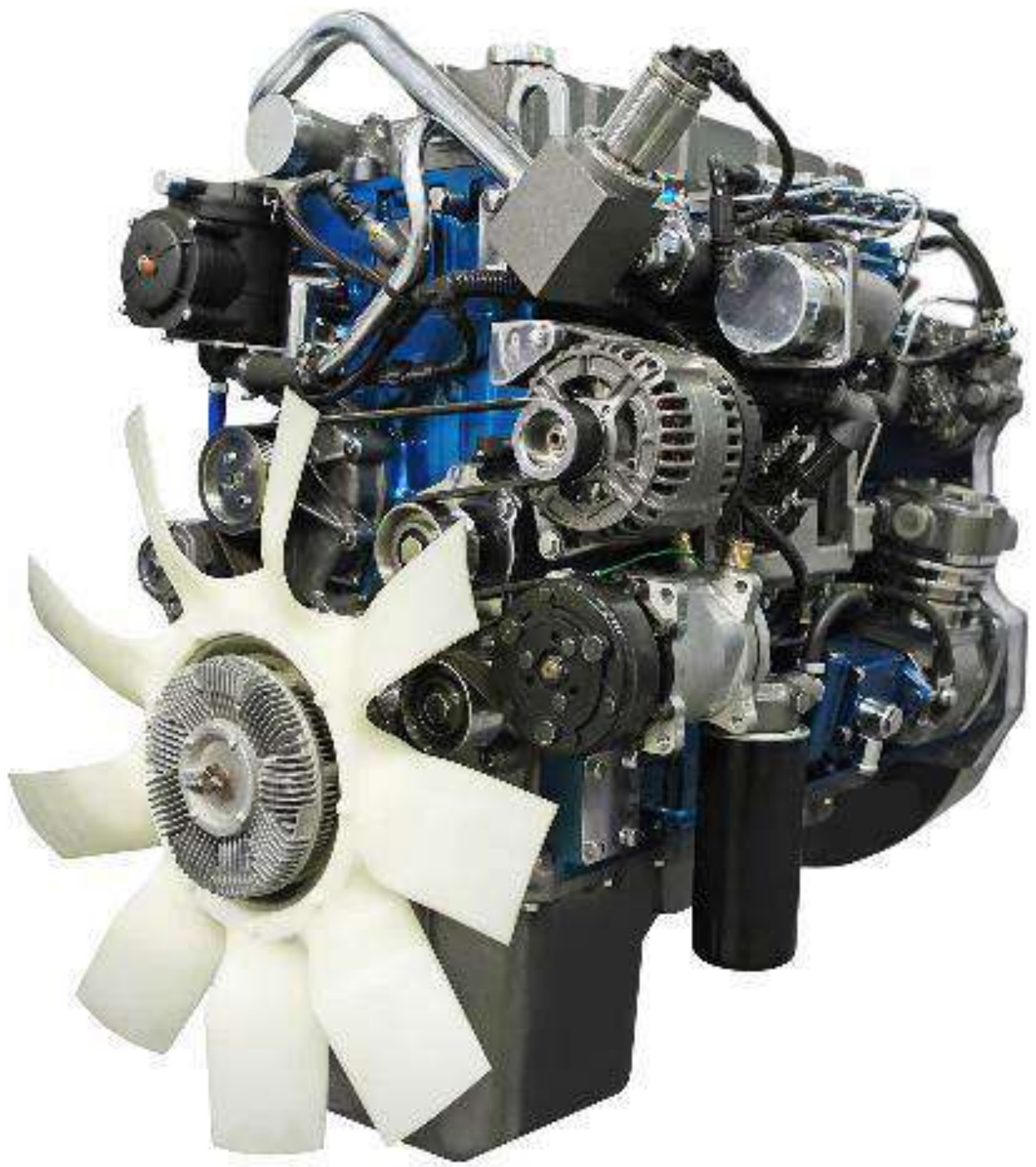
- Most often, far from real-life conditions
- Transfer of results condional

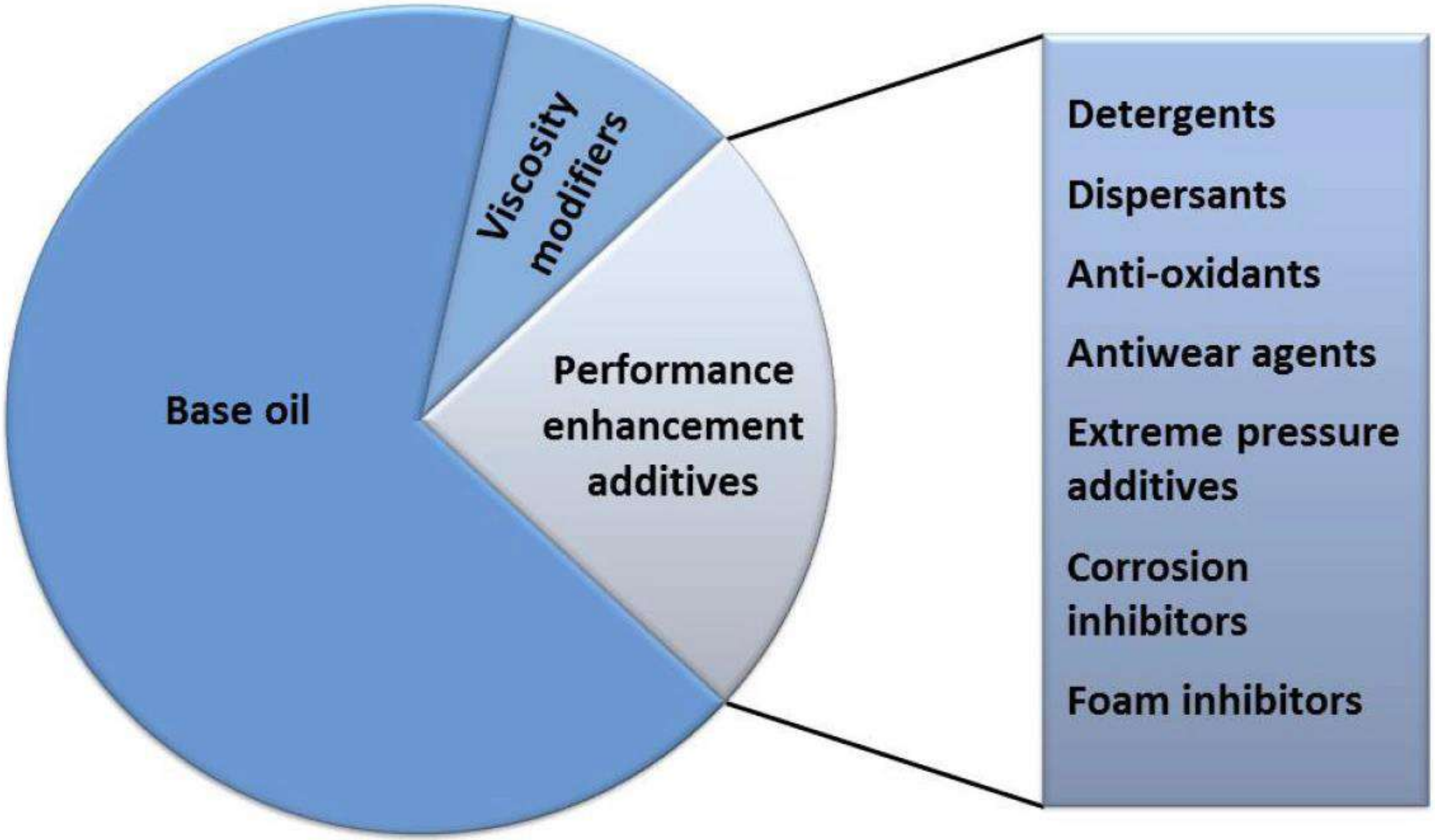


APPLICATIONS

Applications

ENGINE OILS

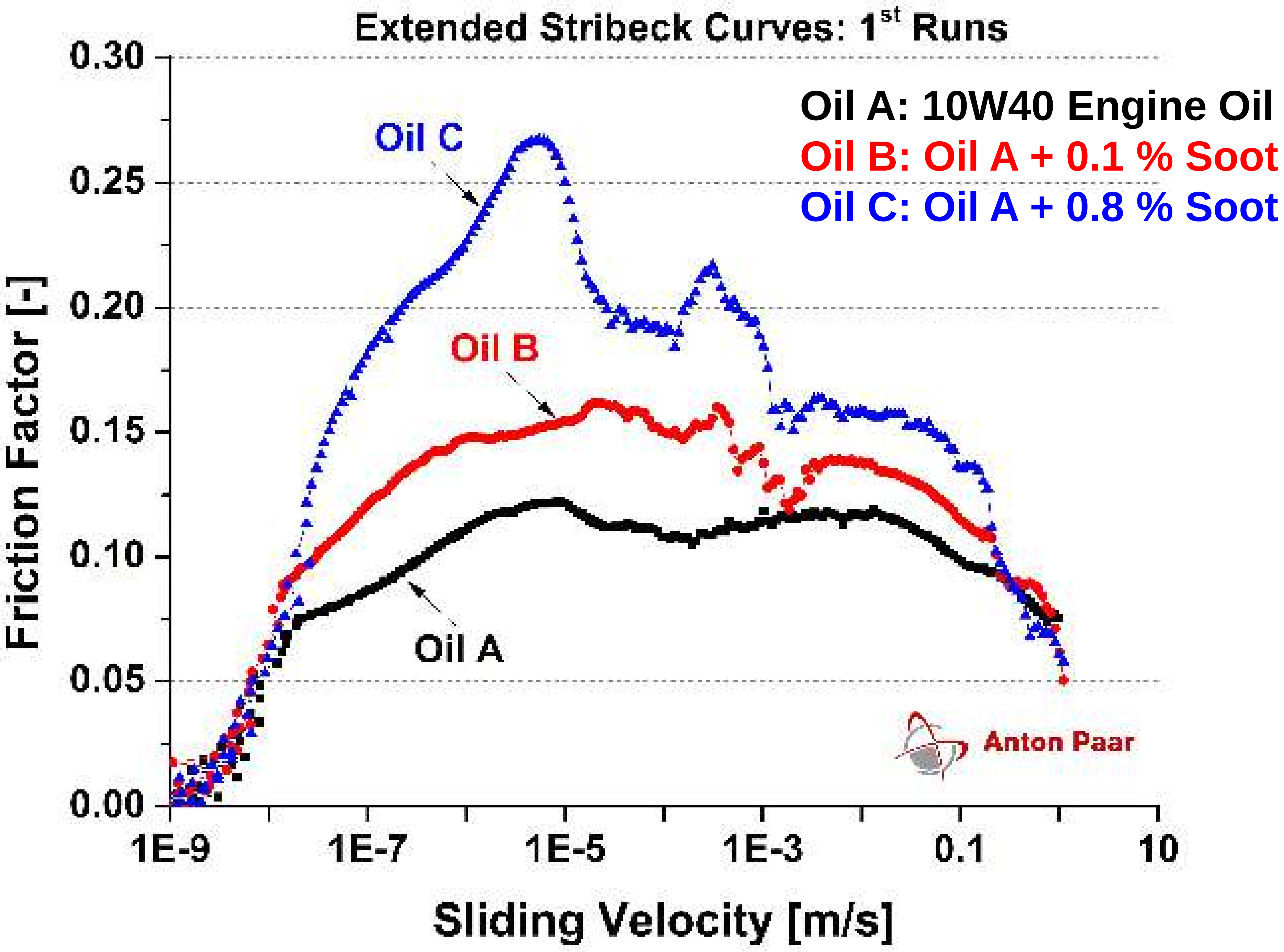


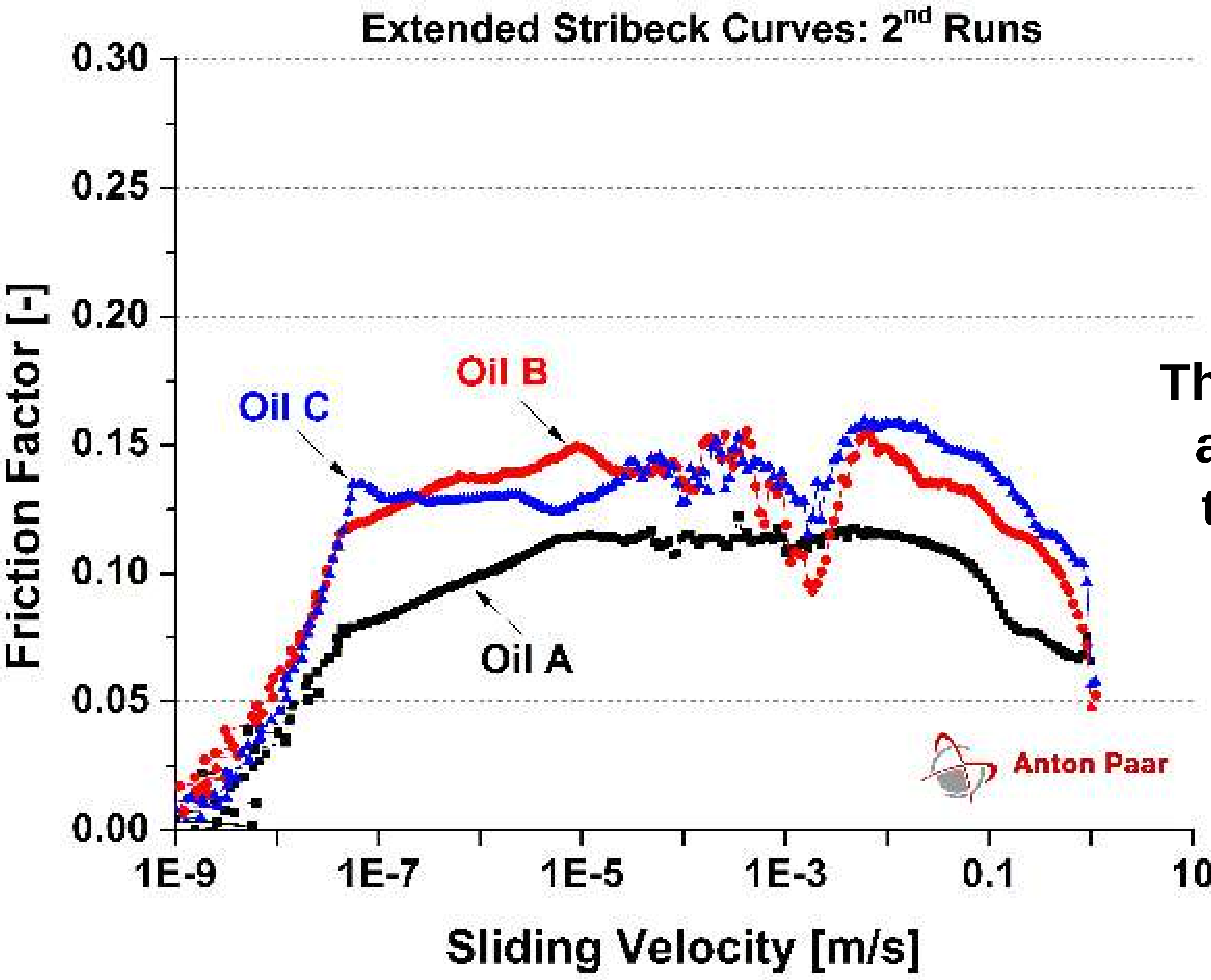


An Engine Oil comprises of multiple components which might have a synergistic or antagonistic effect among themselves.

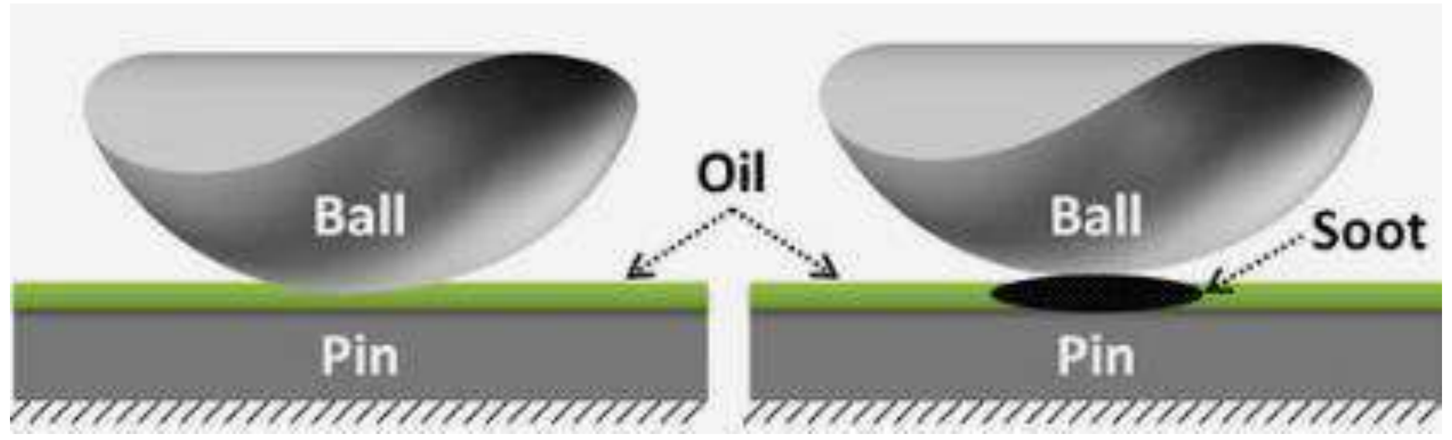
Normal Force: 10 N
100Cr6 Ball on 100Cr6 Flats

CONTAMINATION OF ENGINE OIL (SOOT)



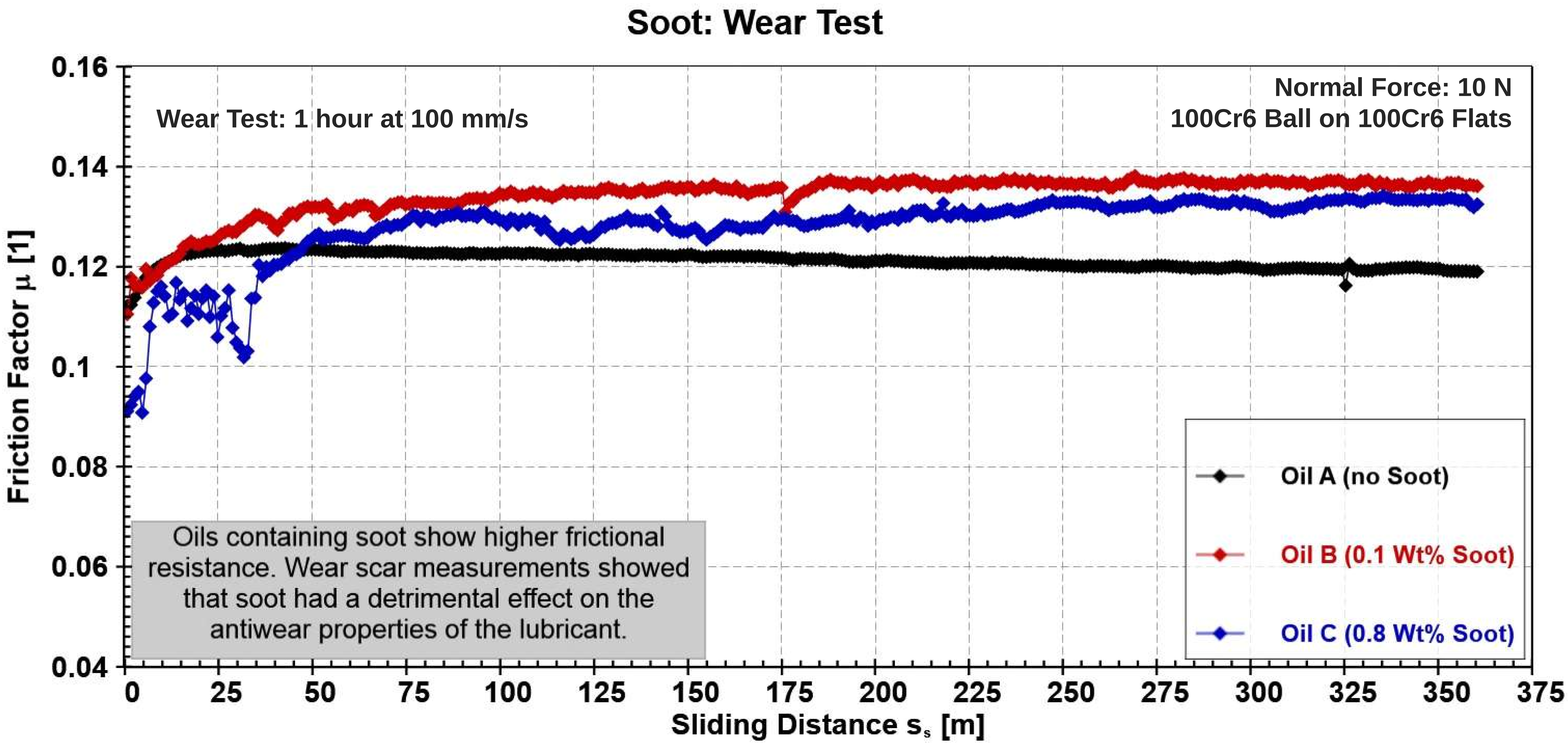


The effect of soot is already visible in the 1st run of the tests



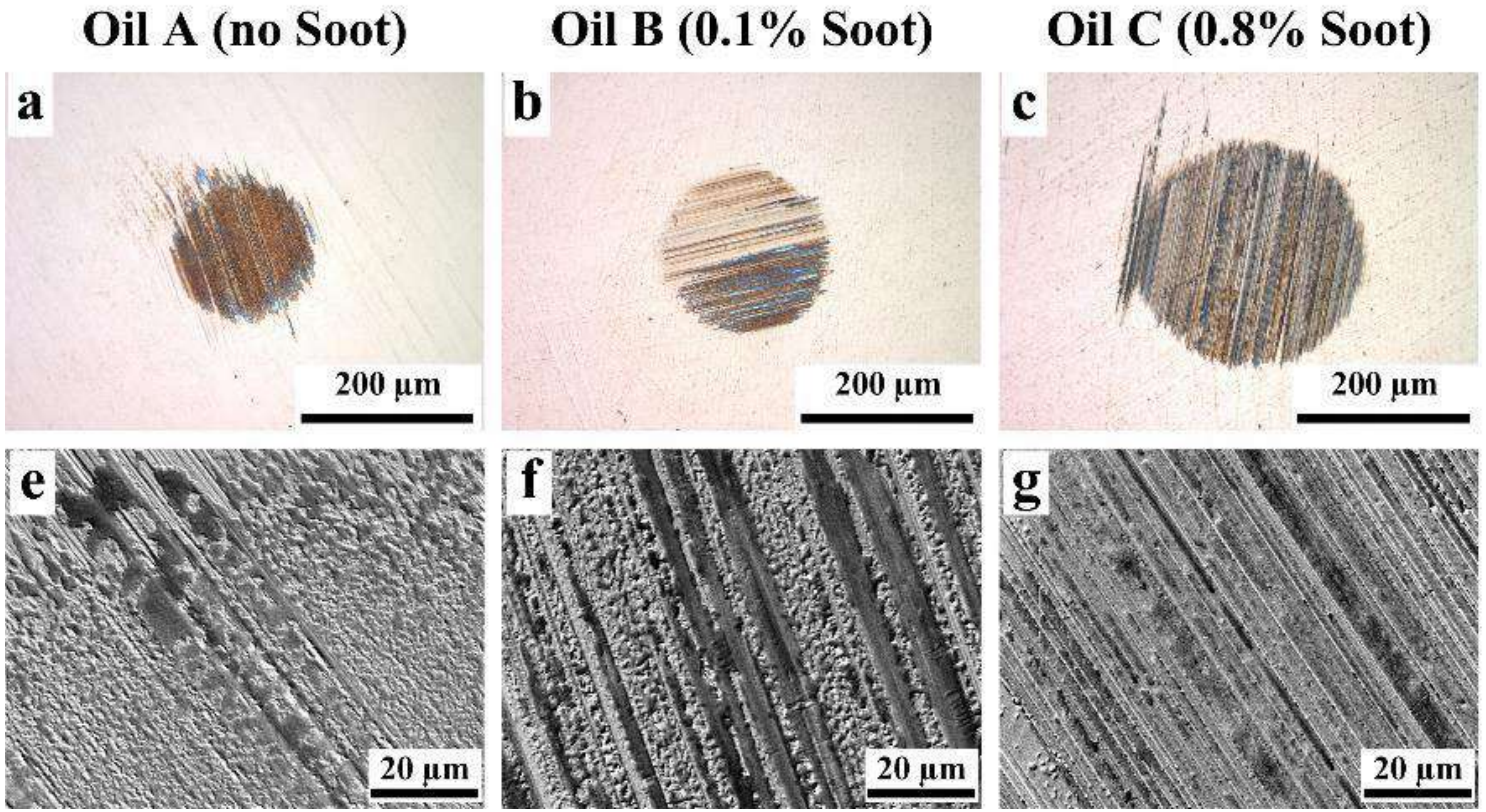
Soot particles at the contact interface are harder to shear, as compared to oil, which would explain the higher frictional resistance for oils with soot.

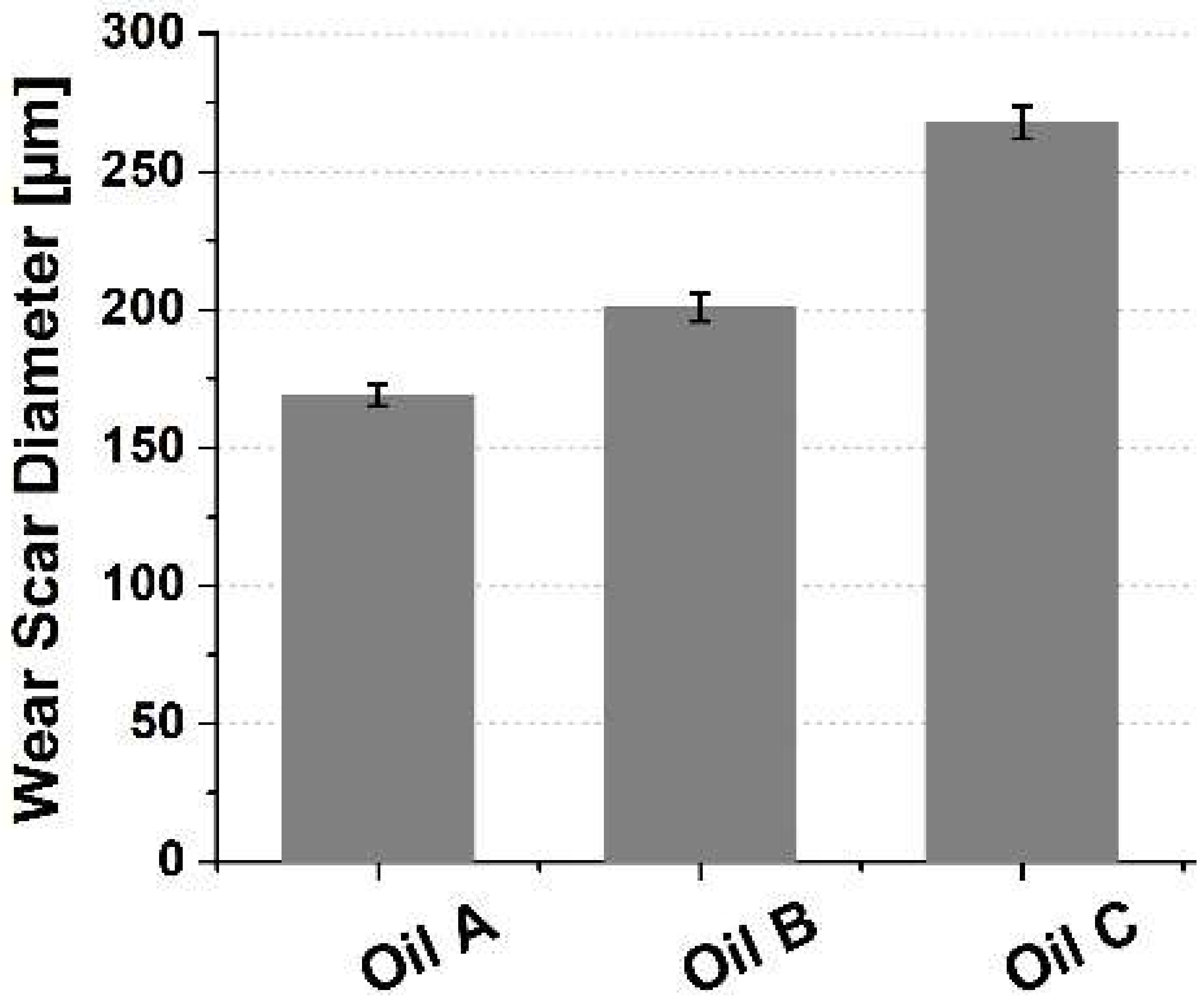
CONTAMINATION OF ENGINE OIL (SOOT) – WEAR TEST



Anton Paar RheoCompass

LIGHT AND SEM MICROGRAPHS



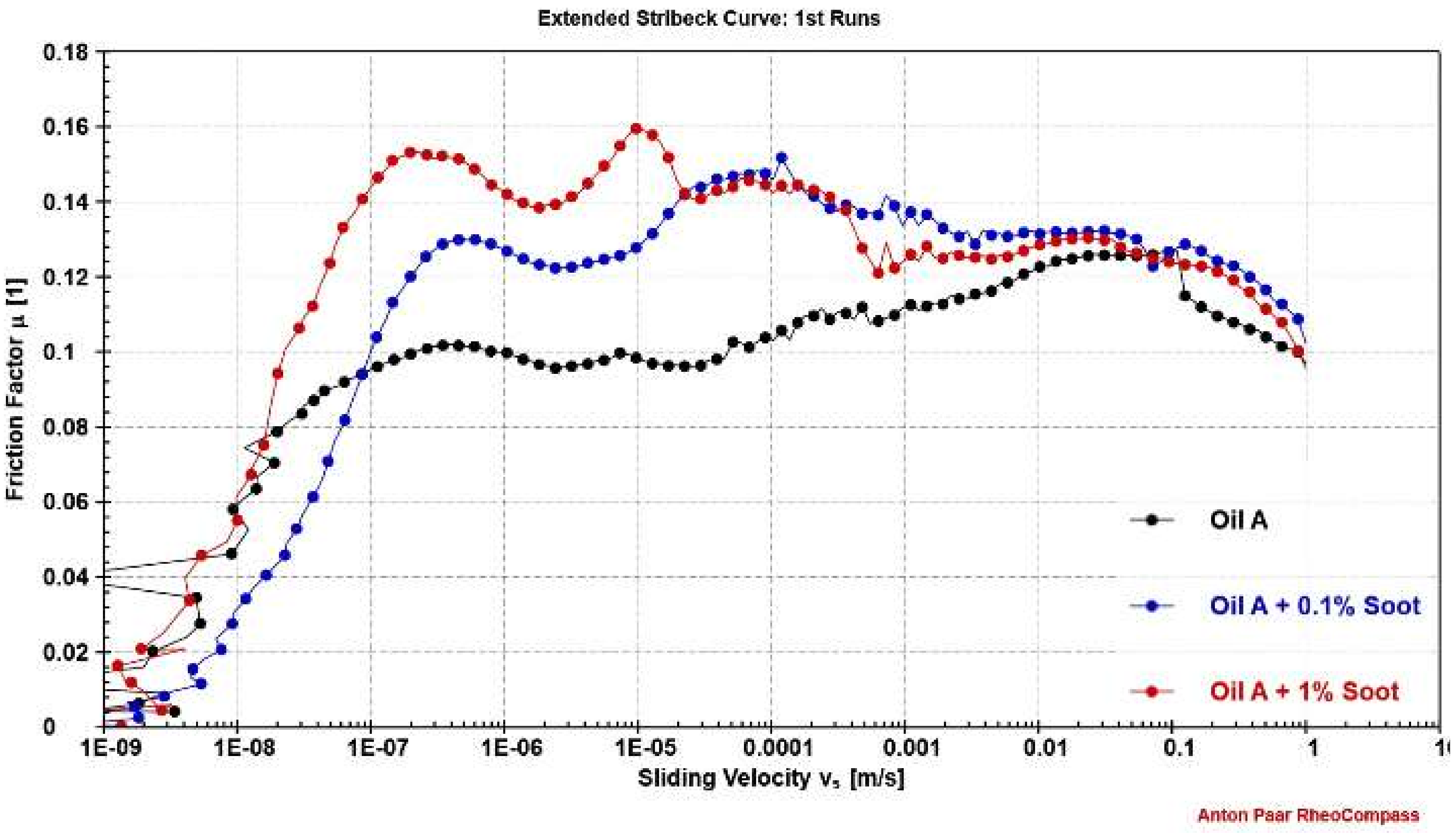
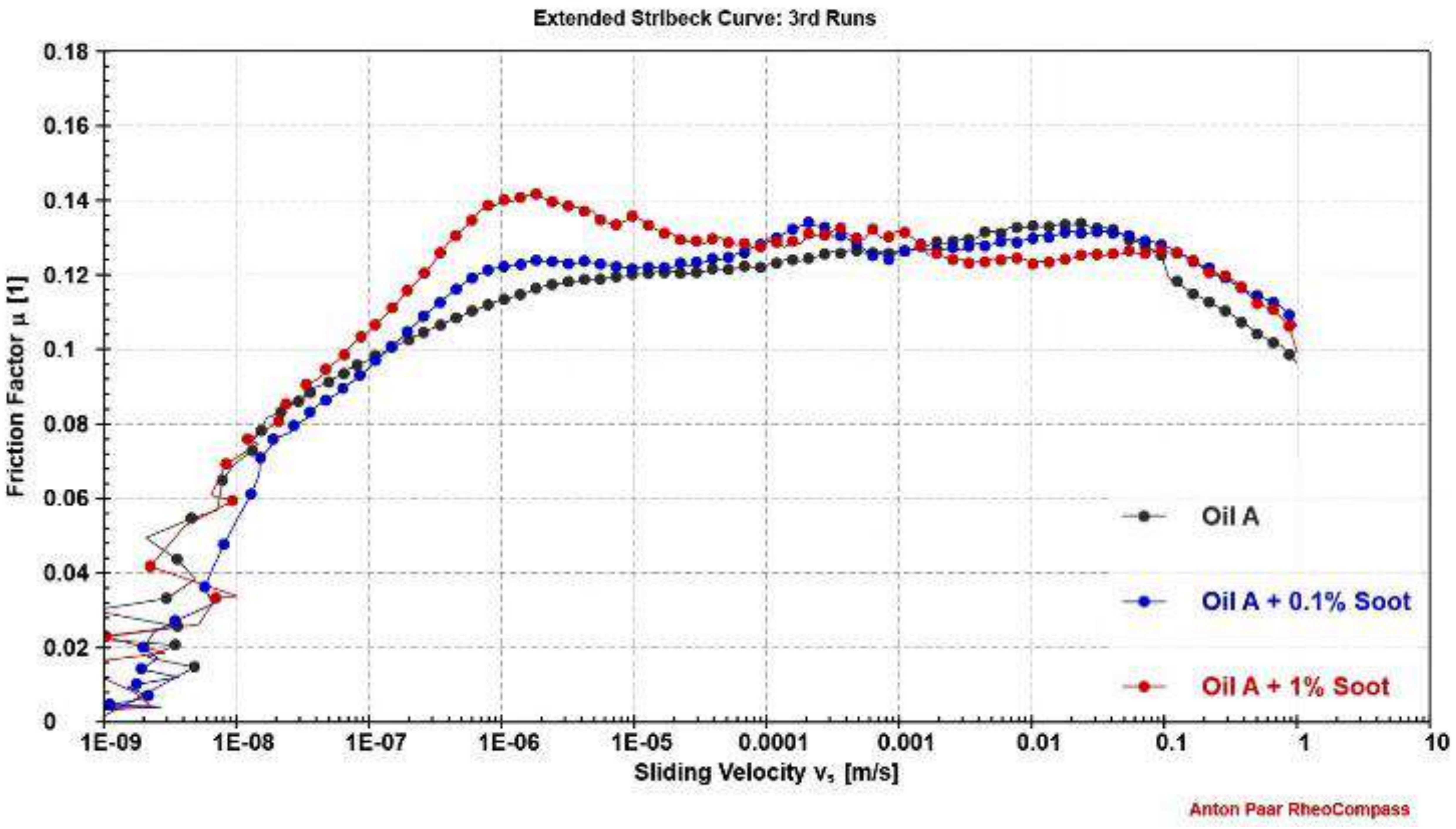


Tribofilms help increase wear resistance of the surfaces

Engine Oil - Soot

PART II

EFFECT OF SOOT (PART II)

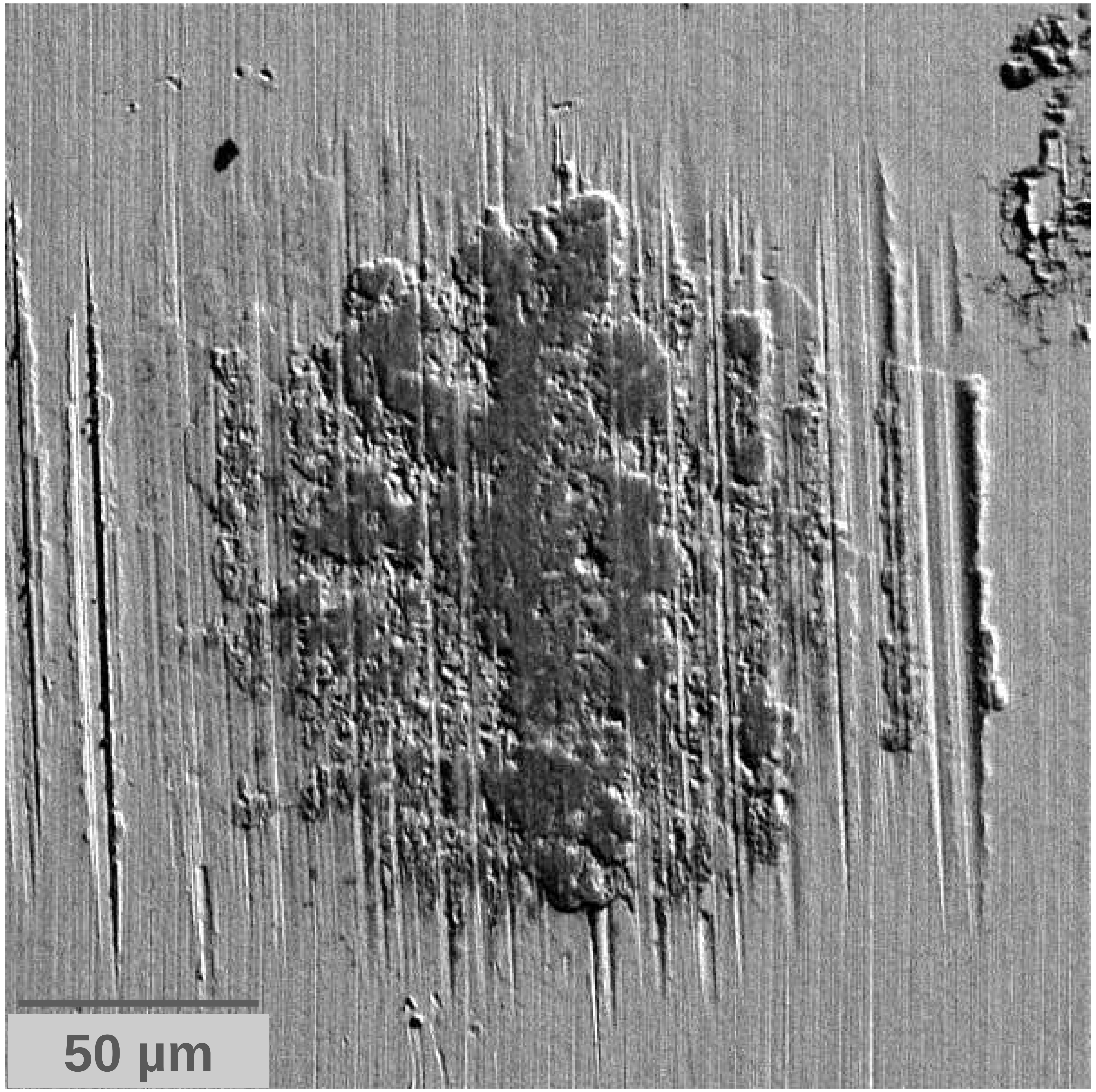
1st Runs	3rd Runs
	

Boundary and Mixed regimes are of primary concern

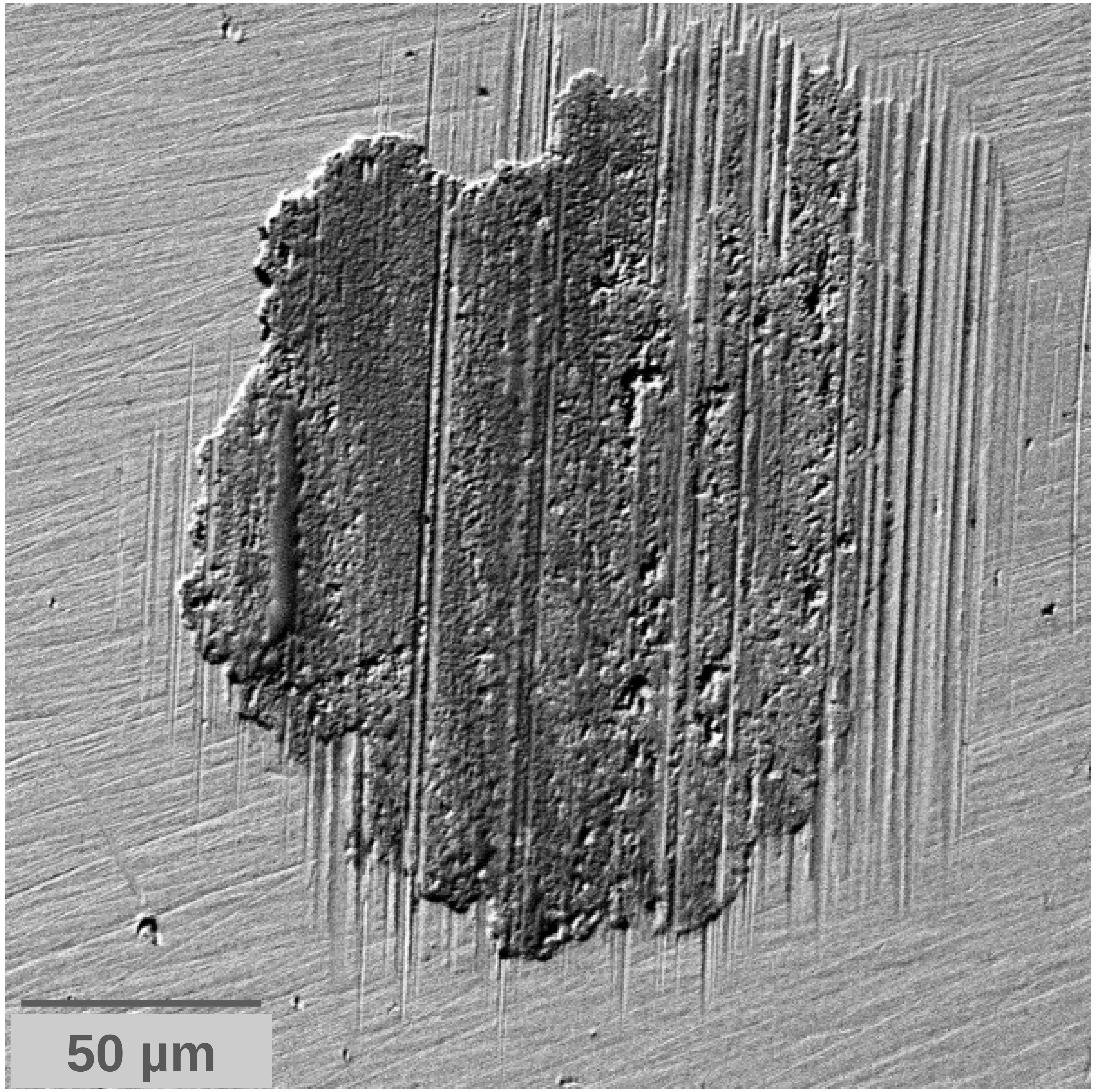
So… again… why the 3rd Runs???

EFFECT OF RUNNING-IN

After 1x Stribeck Run

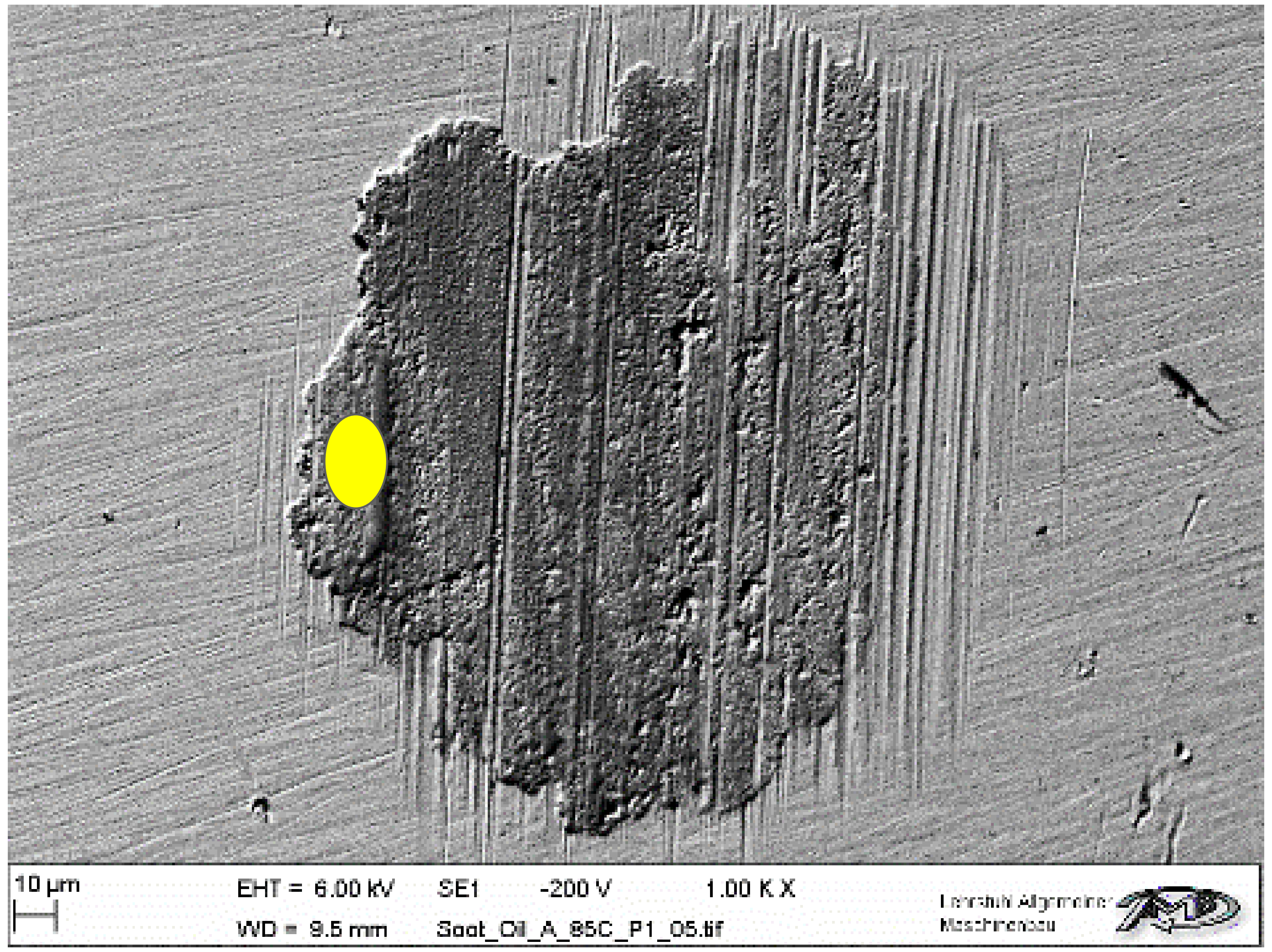


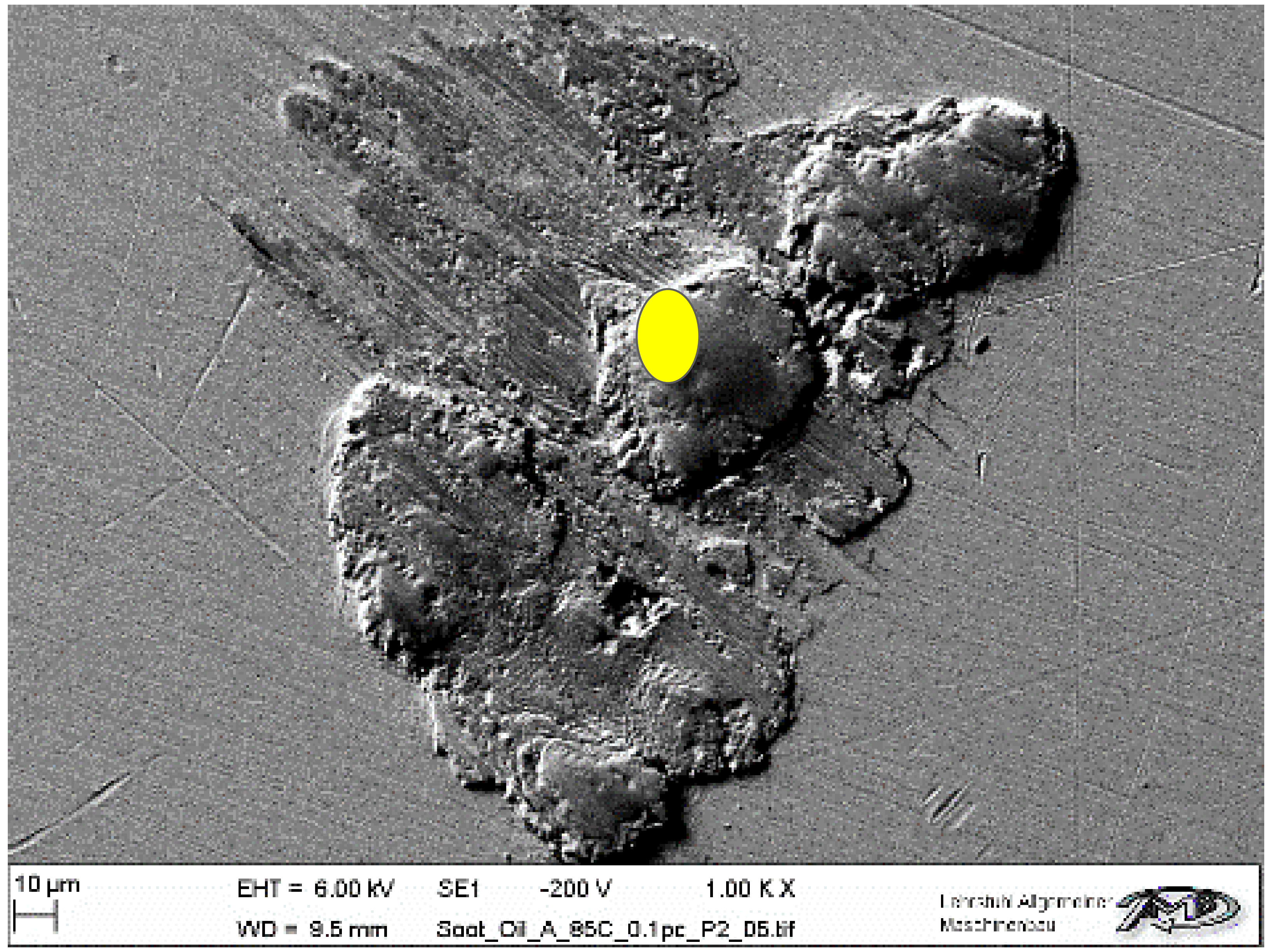
Test End (3x Stribeck + Wear Test)

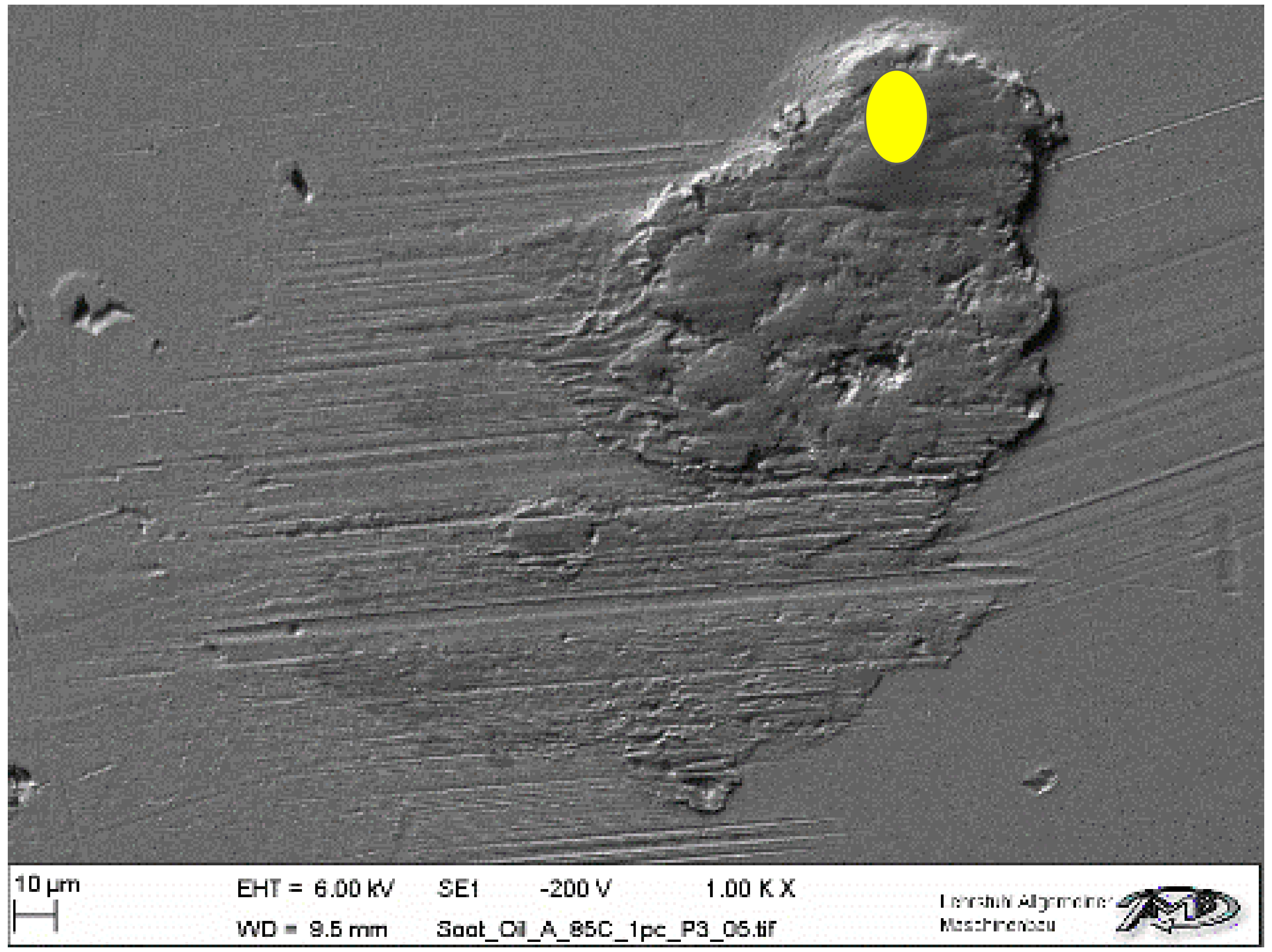


SEM IMAGES

Oil A	Oil A + 0.1% Soot	Oil A + 1% Soot



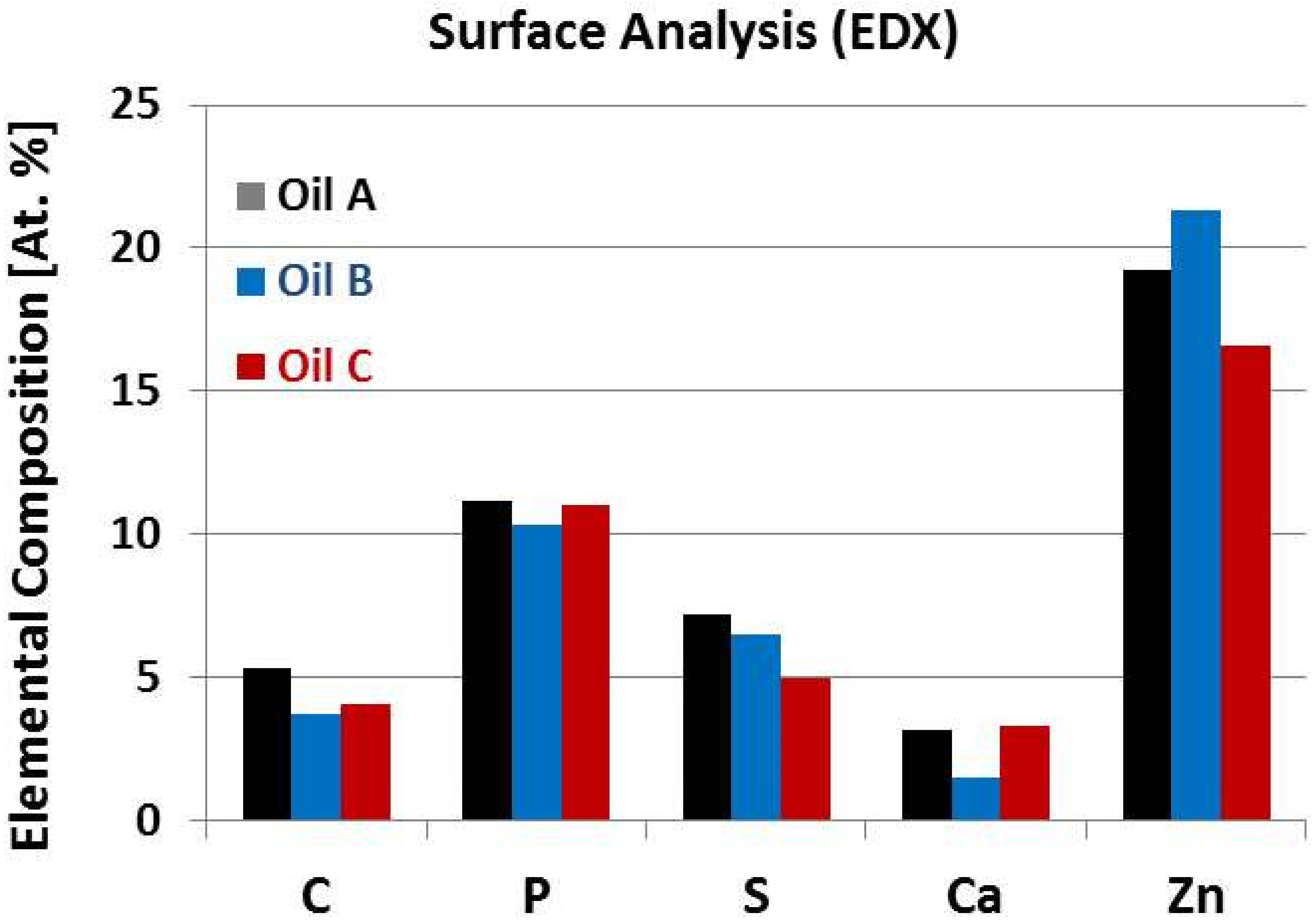




- Soot competes with the additives in the oil – surface activity
- Presence of soot hinders proper adhesion of the tribofilms at the surface

  → Lower wear protection

EDX ANALYSIS



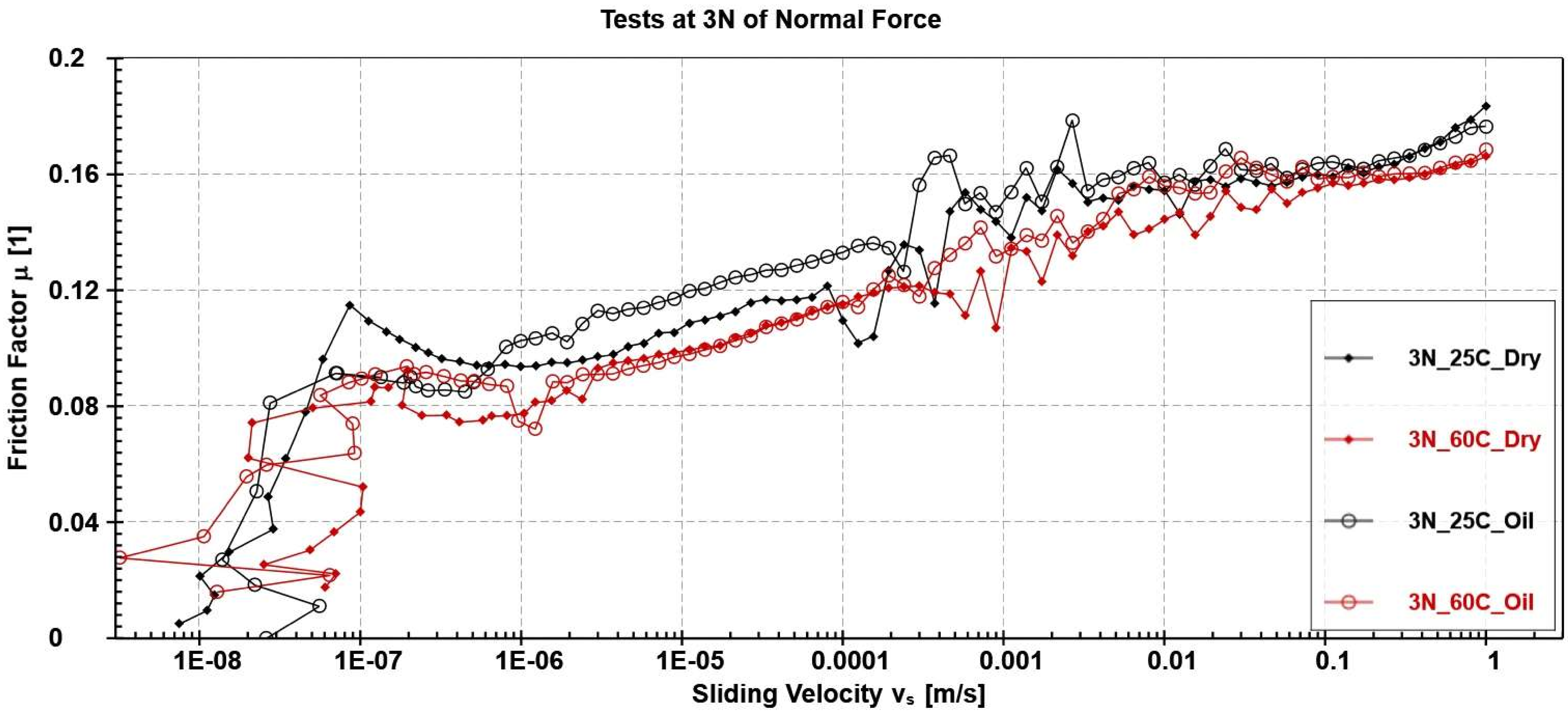
Composition of tribofilms did not change with the presence of soot

Applications

CLUTCH

MODEL-SCALE – OPTION I

CLUTCHES – TEST DATA



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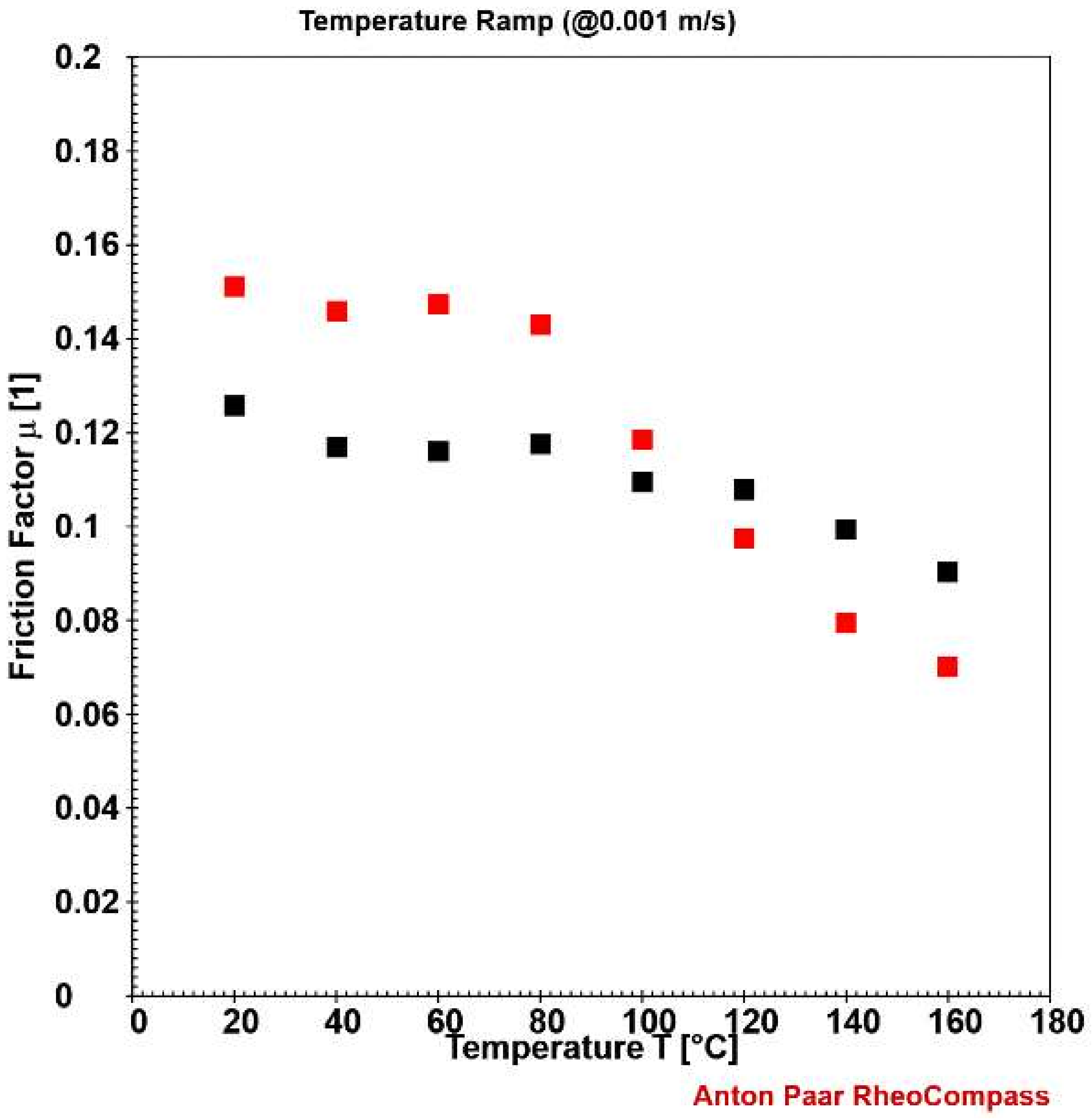
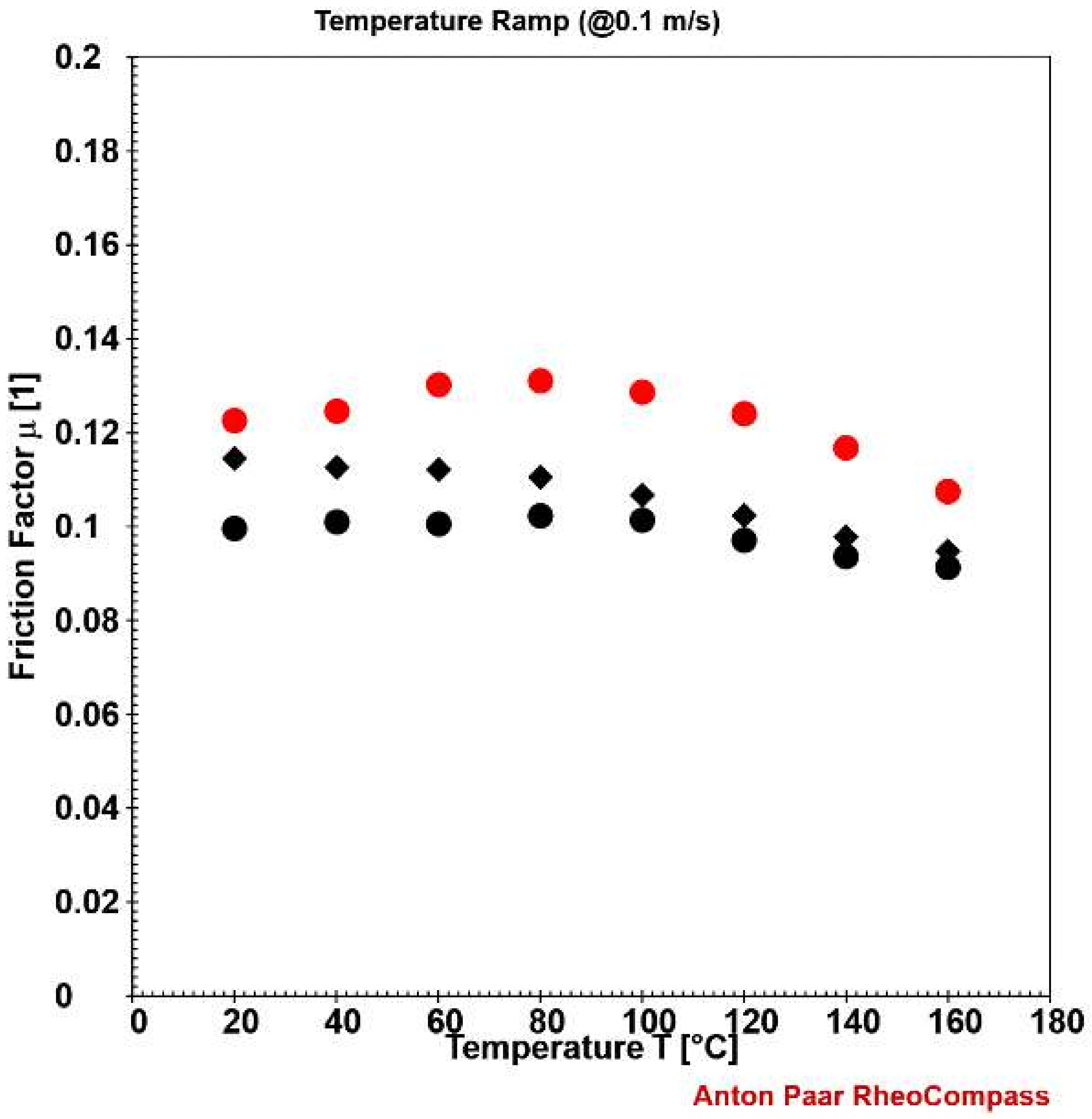
MODEL-SCALE – OPTION II

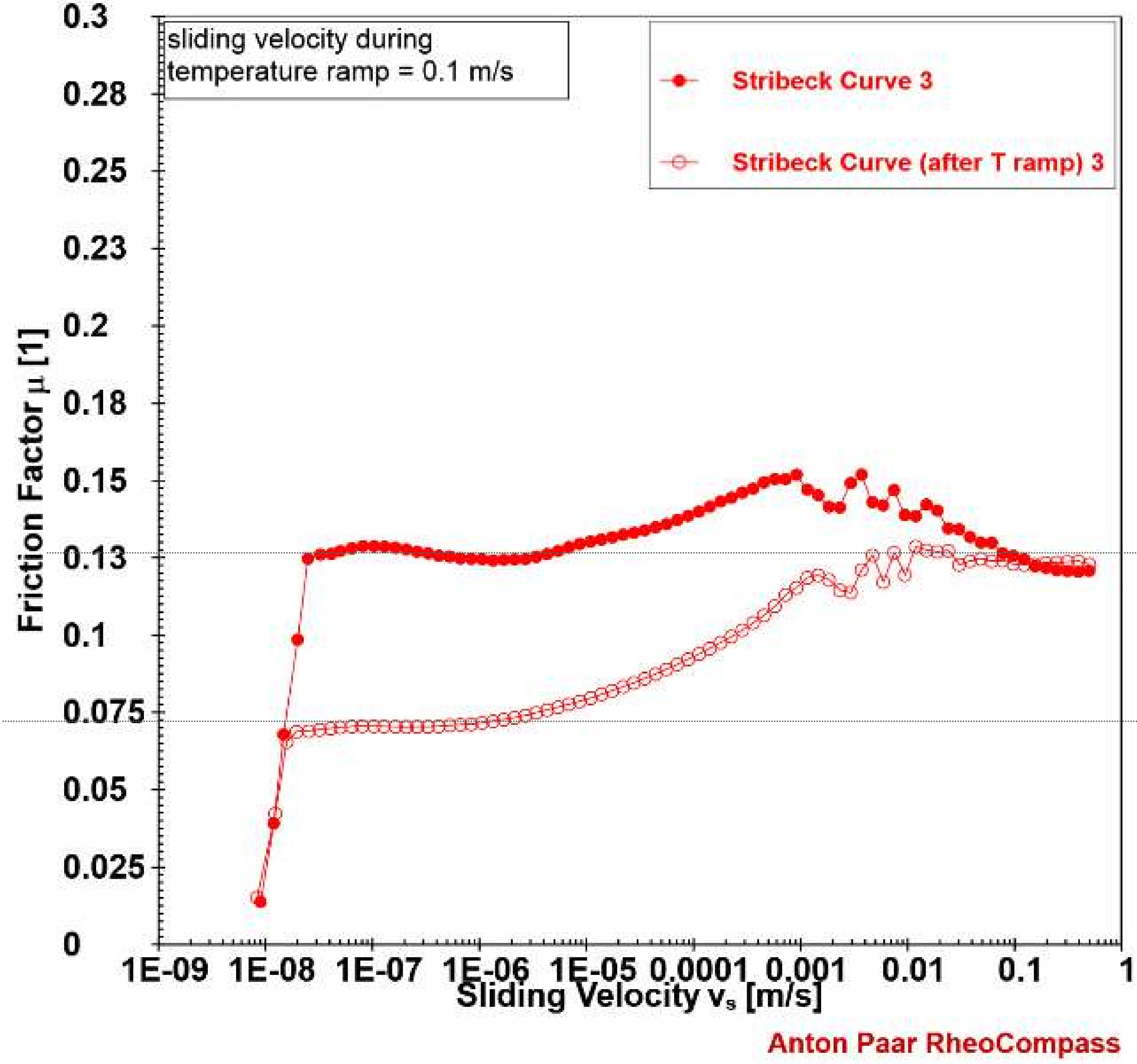
TEMPERATURE TESTS



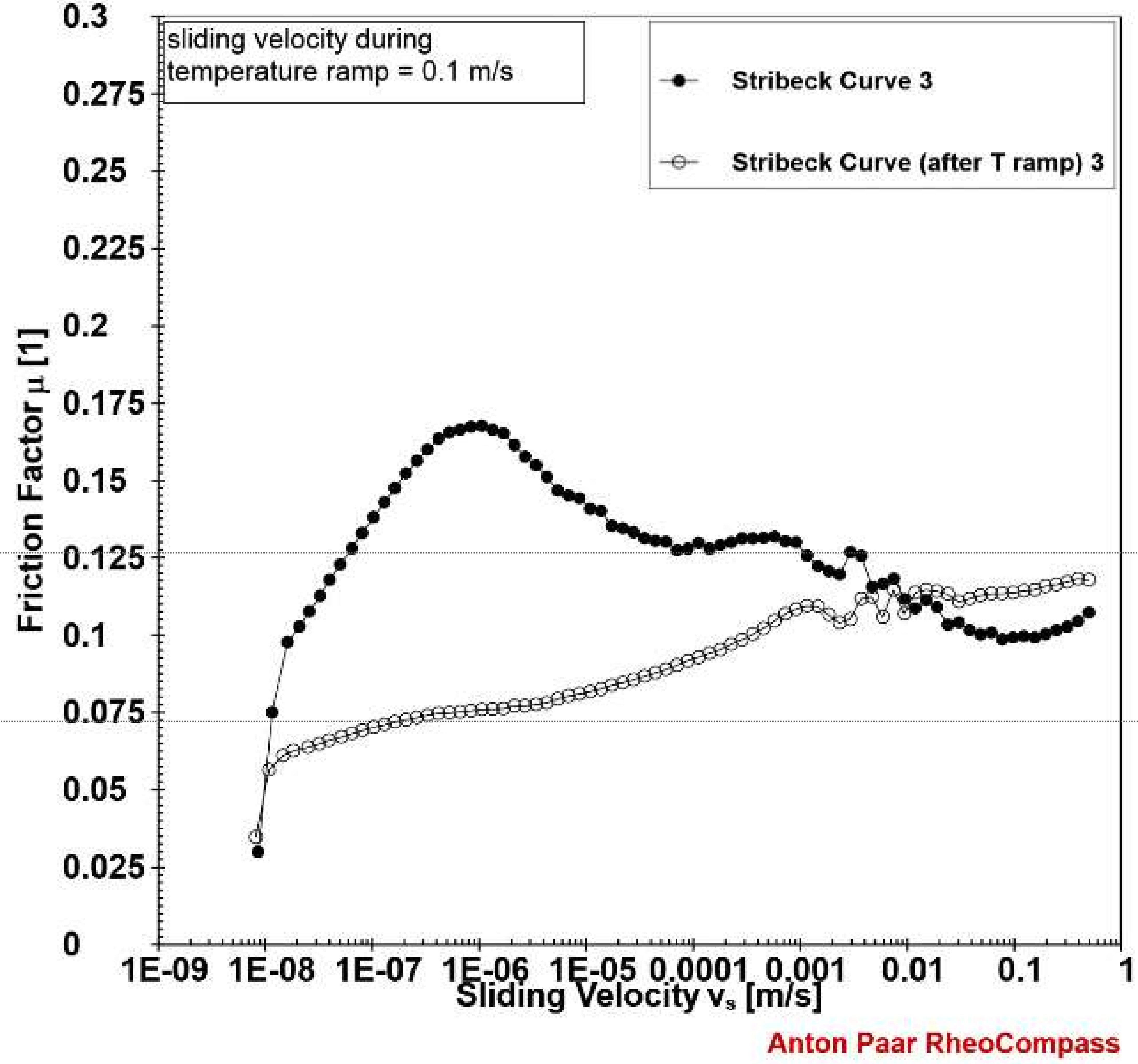


CLUTCH – STRIBECK CURVES

Clutch 1



Clutch 2

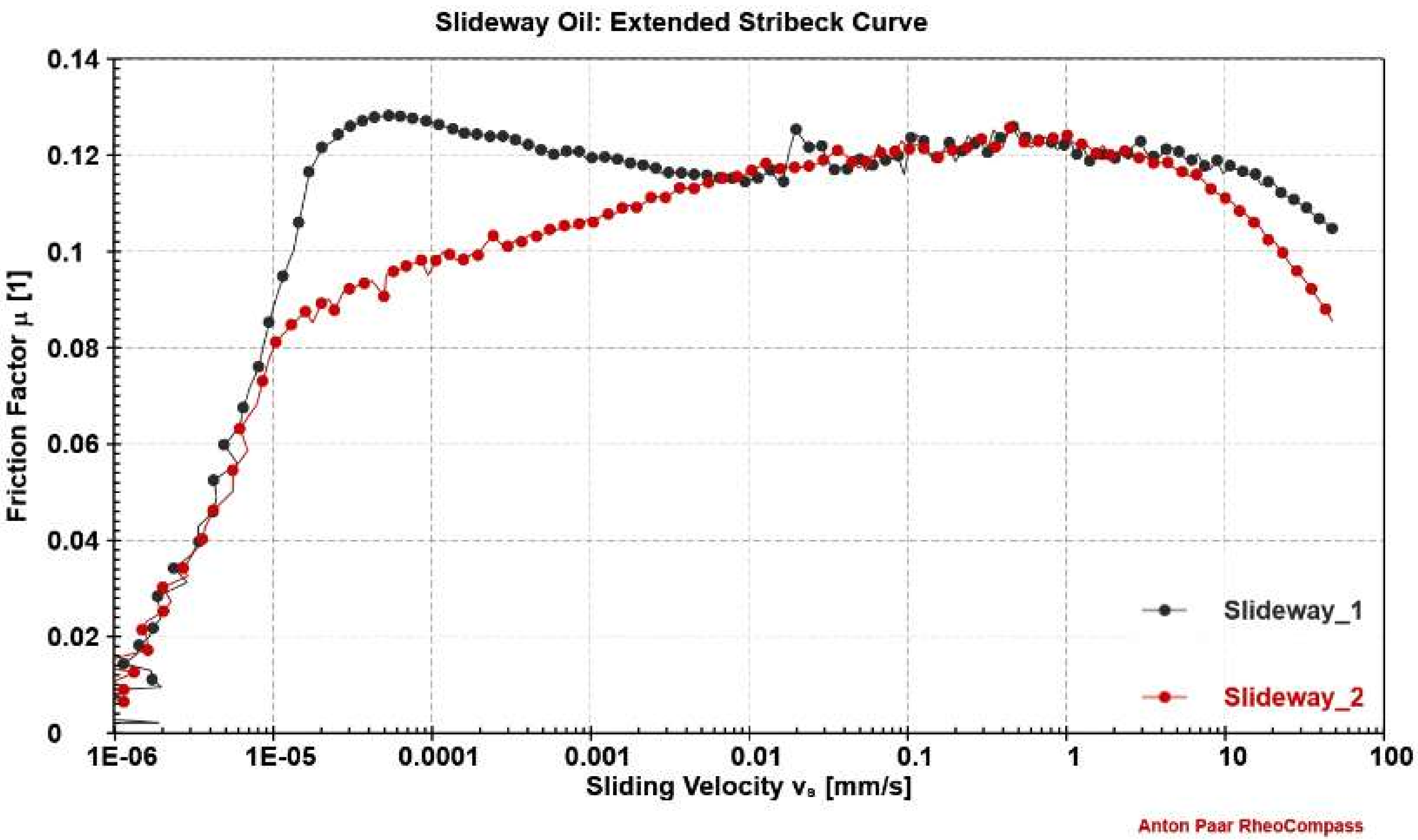


SLIDEWAY OIL


Vactra 2

SLIDEWAY OIL – TEST DATA

- Used for rails and guides in machines
- In addition to providing lubrication, corrosion protection, etc., they must **overcome stick-slip**



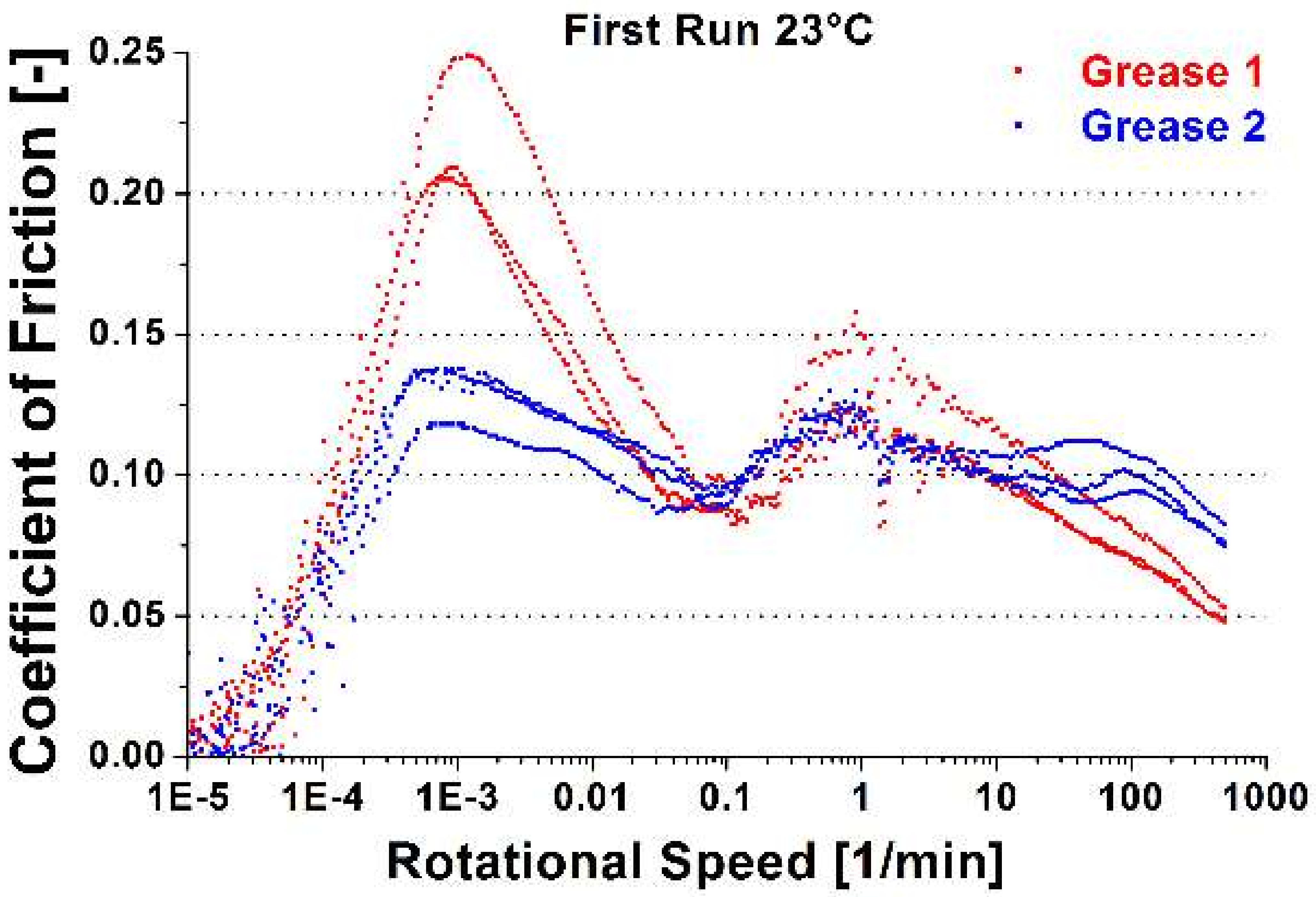
One way to avoid stick-slip

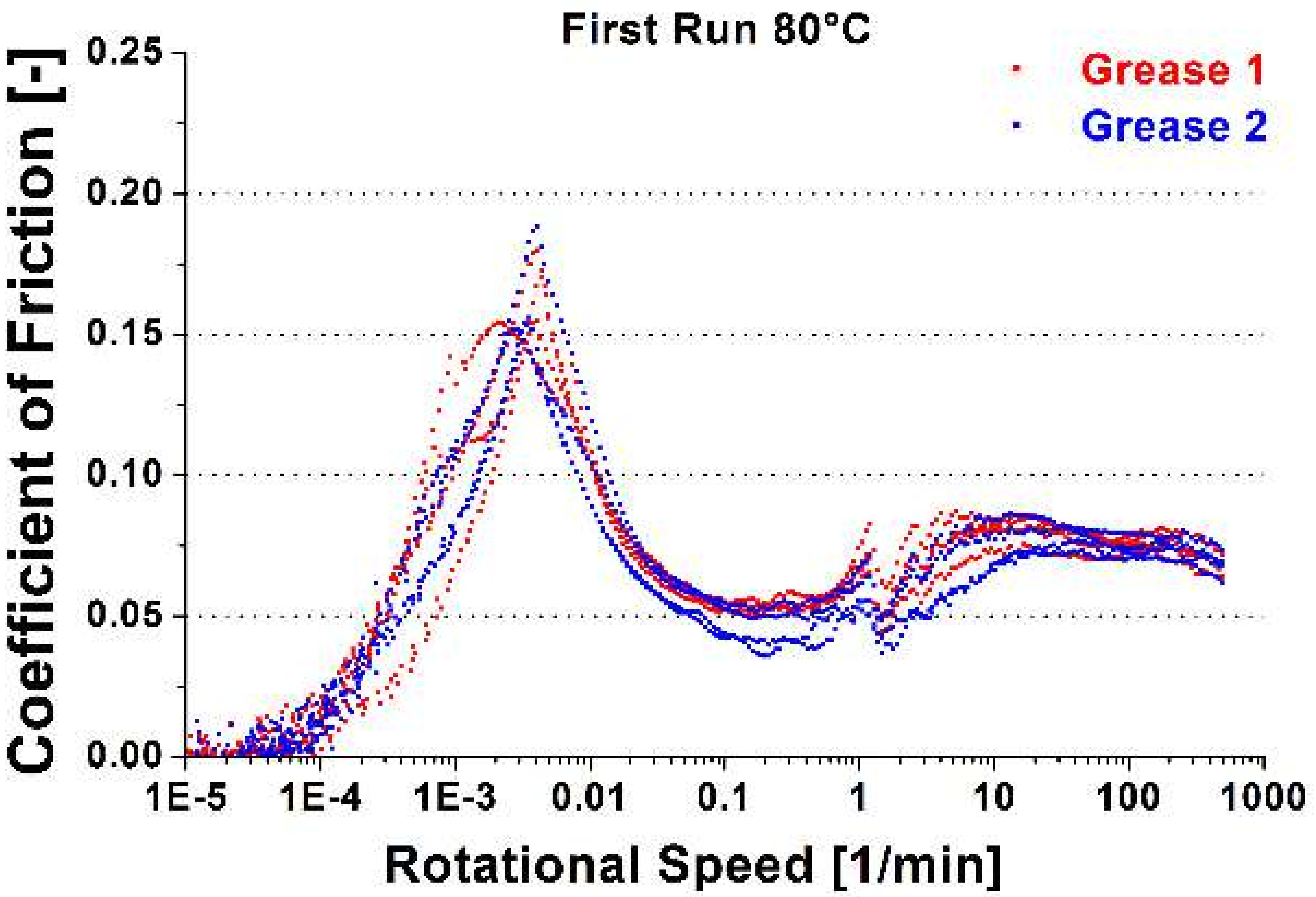
$$\mu_k > \mu_s$$

Applications

GREASE (I)

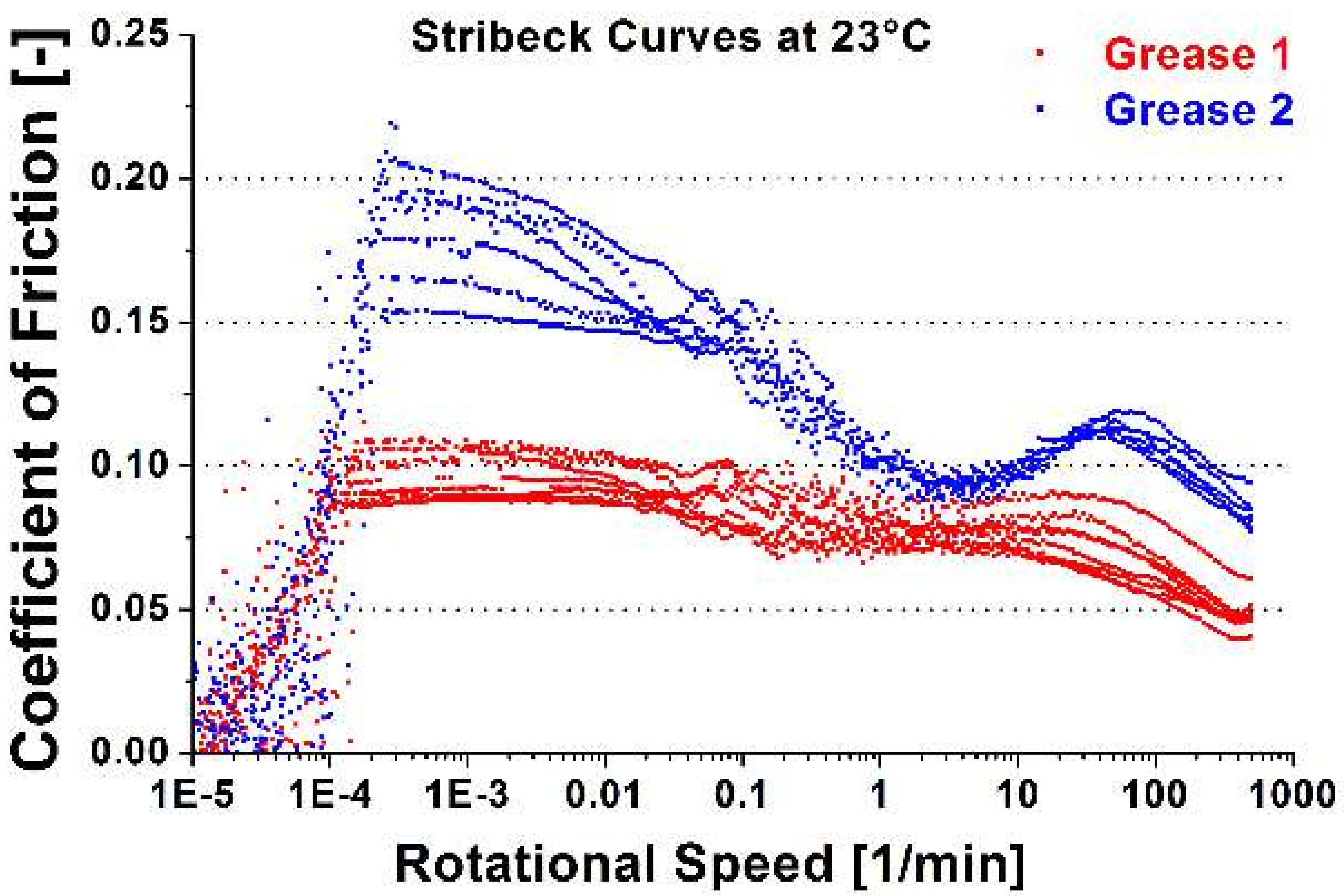
STRIBECK CURVE – 1ST RUNS

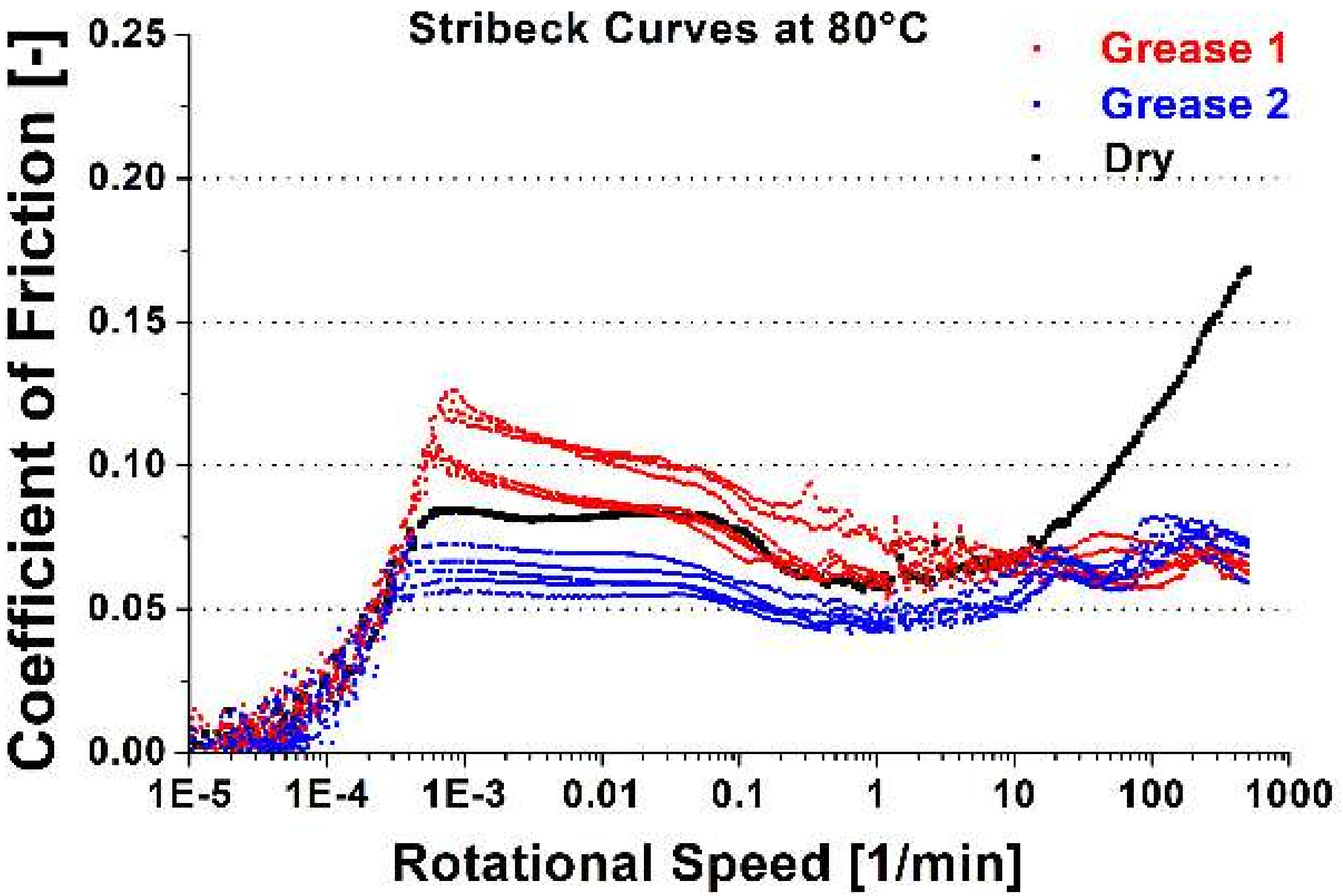




- At 23 °C, **grease 1** has higher limiting friction
- At 80 °C, there is no difference between **grease 1** and **grease 2**

STRIBECK CURVE –2ND, 3RD RUNS

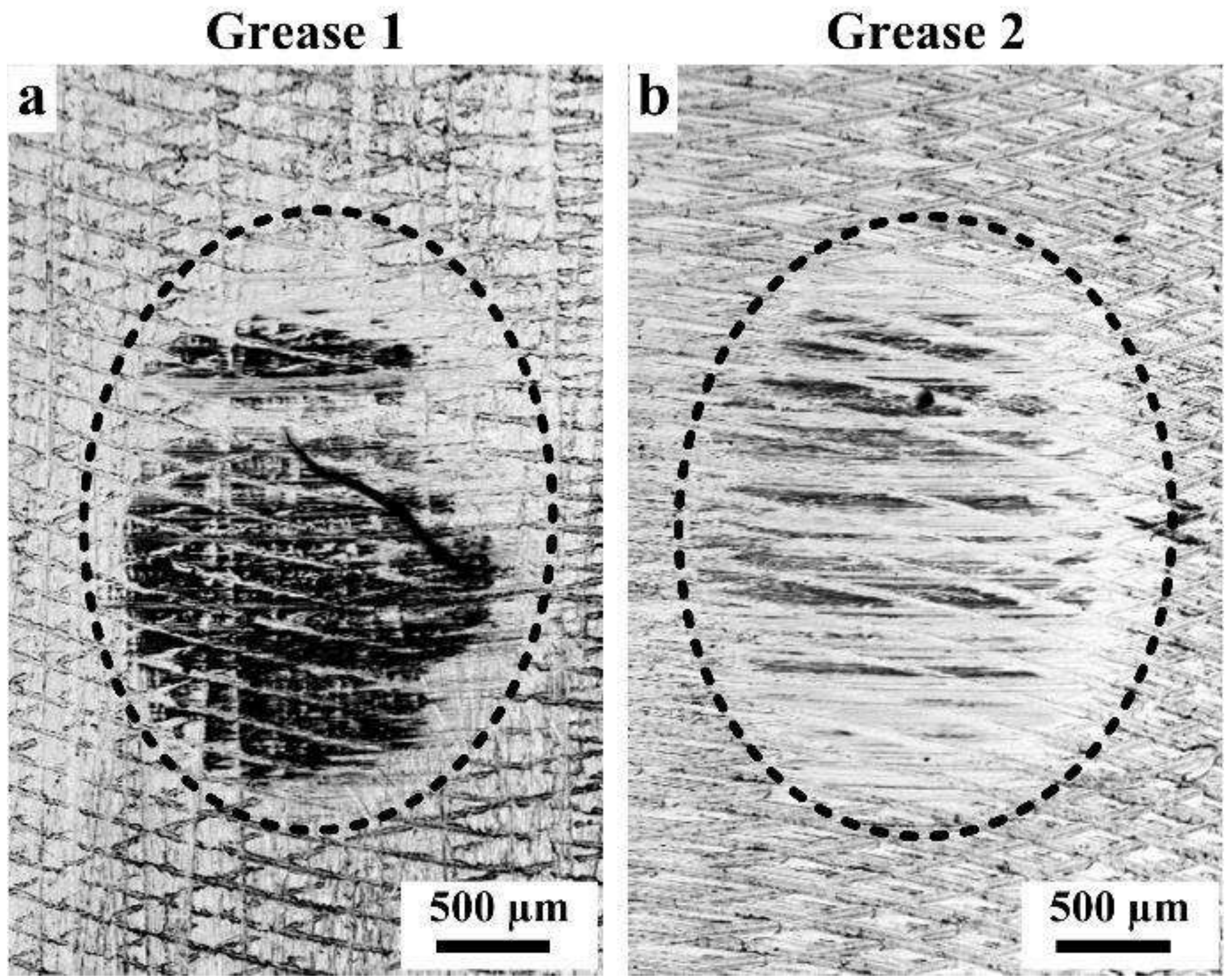




- **Grease 1** maintains its frictional resistance over the temperature range
- **Grease 2** is affected greatly by increase in temperature (formation of reactive films at the contact interface – see next slide)

SEM MICROGRAPHS

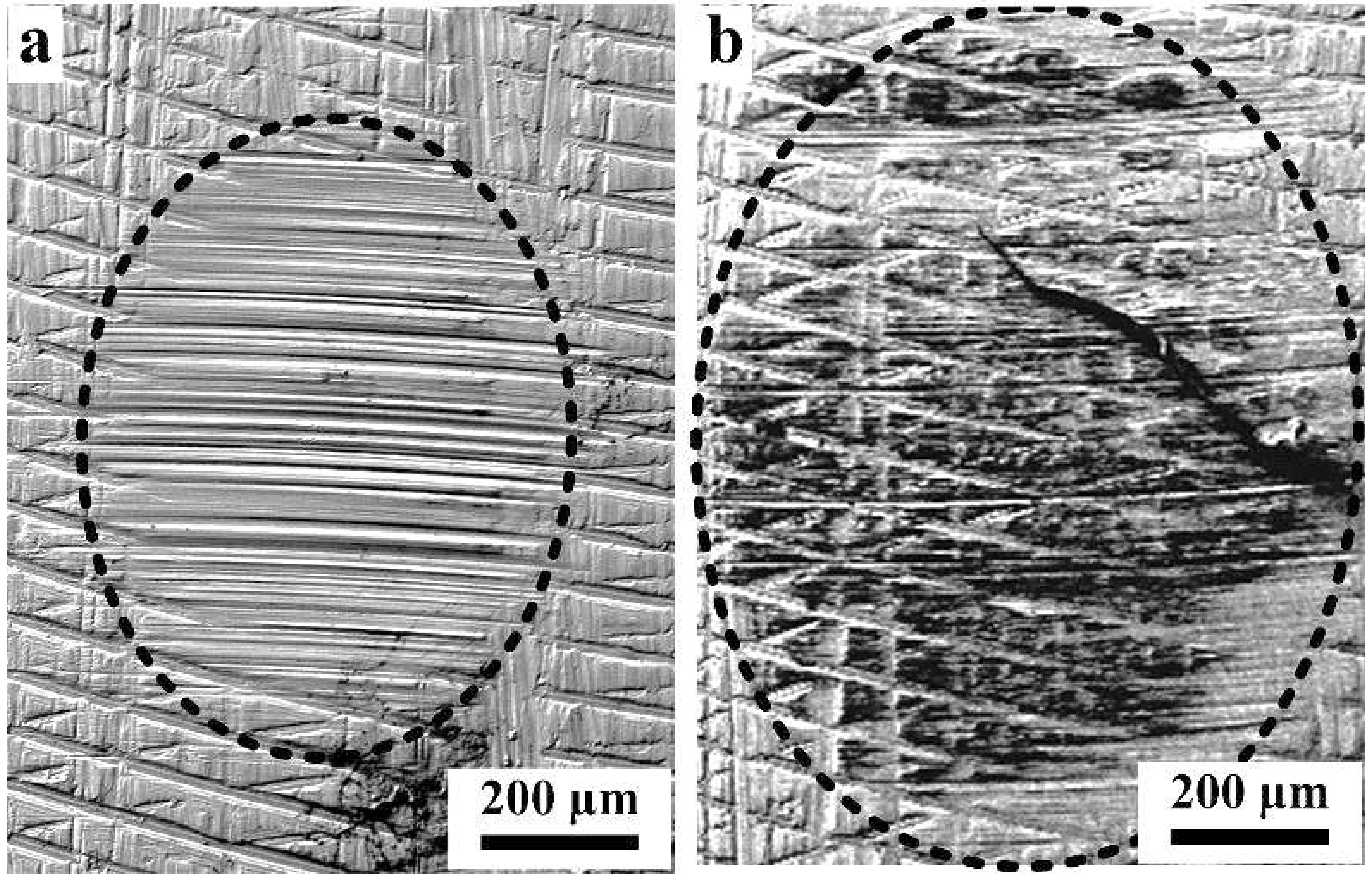
Tests at 80°C



Only Grease 2

Grease 2 at 23°C

Grease 2 at 80°C



Formation of carbonatious layer at 80°C causes drop in the breakaway friction of Grease 2.

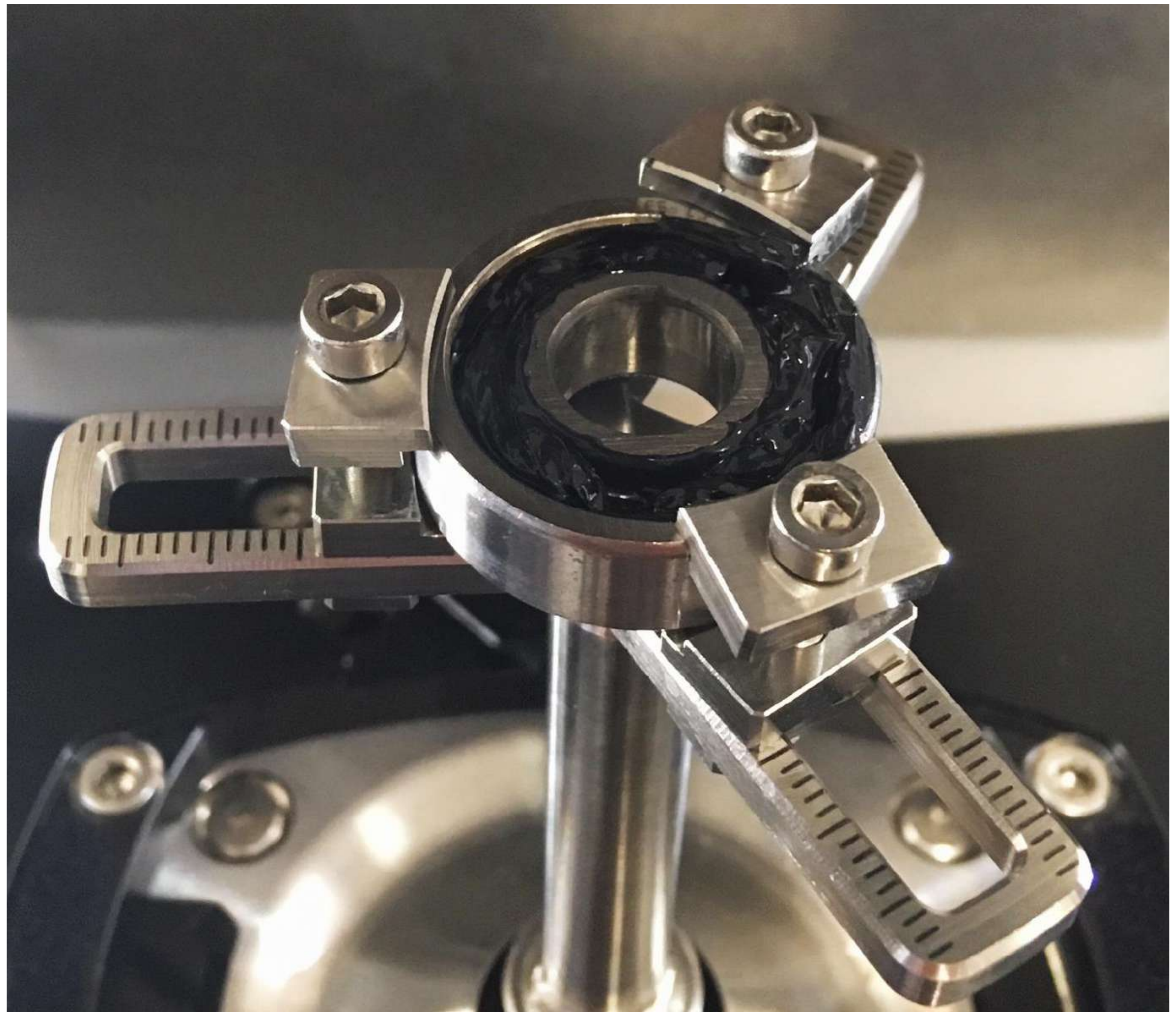
Applications

GREASE – LOW TEMPERATURE

LOW-TEMPERATURE TESTING – SETUP (I)

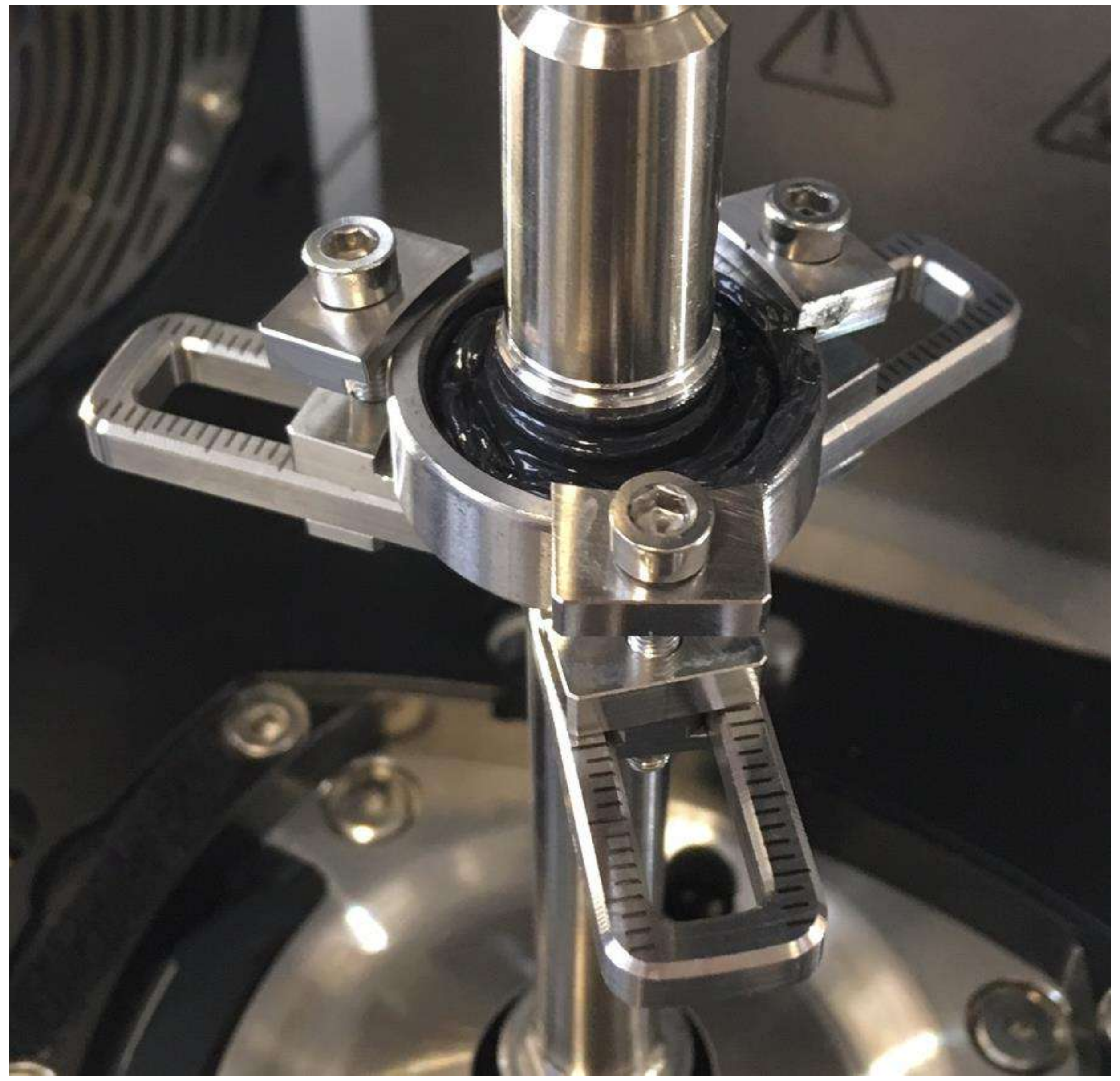
MCR Tribometer

Bearing Adapter

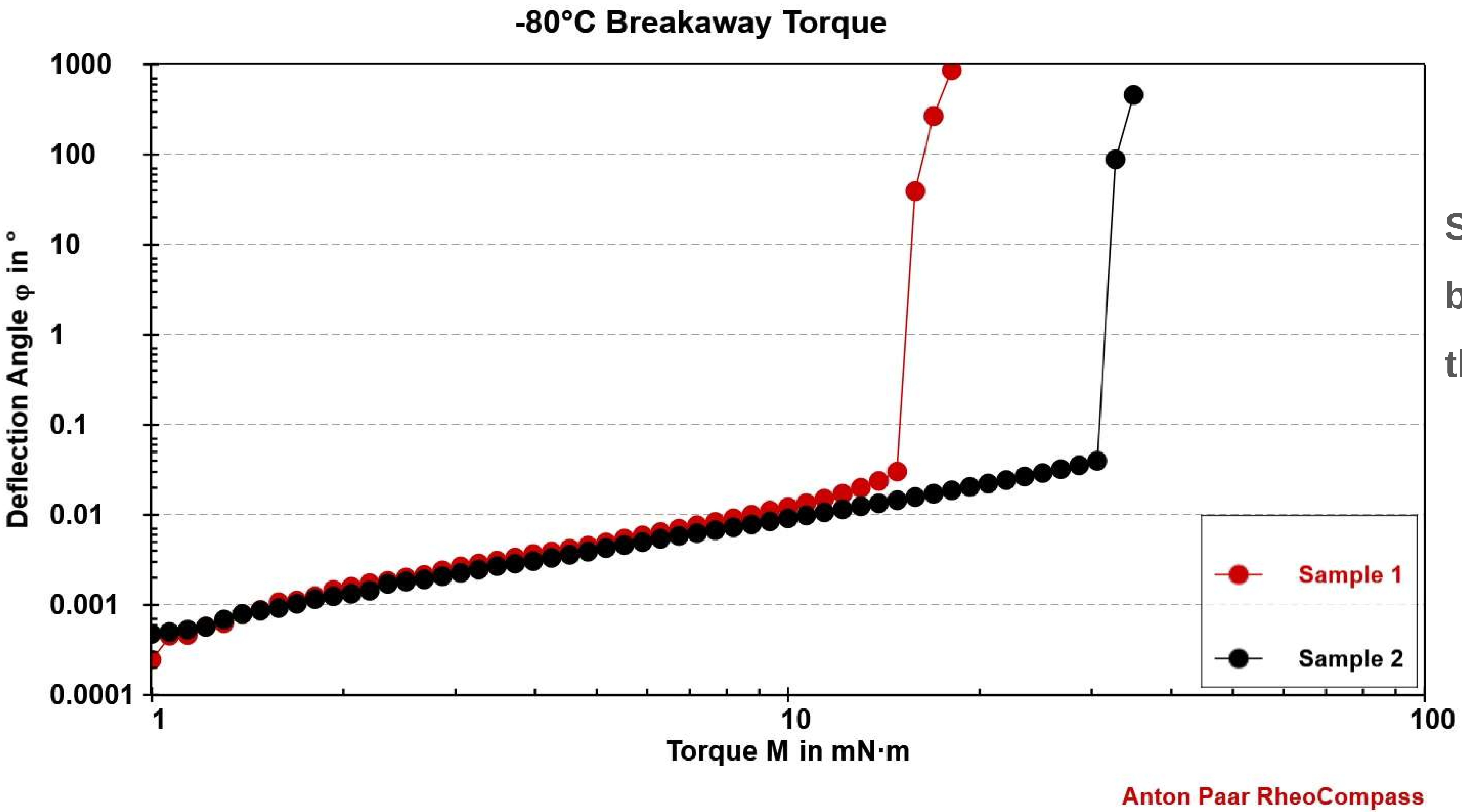


The Tribosystem

LOW-TEMPERATURE TESTING – SETUP (II)

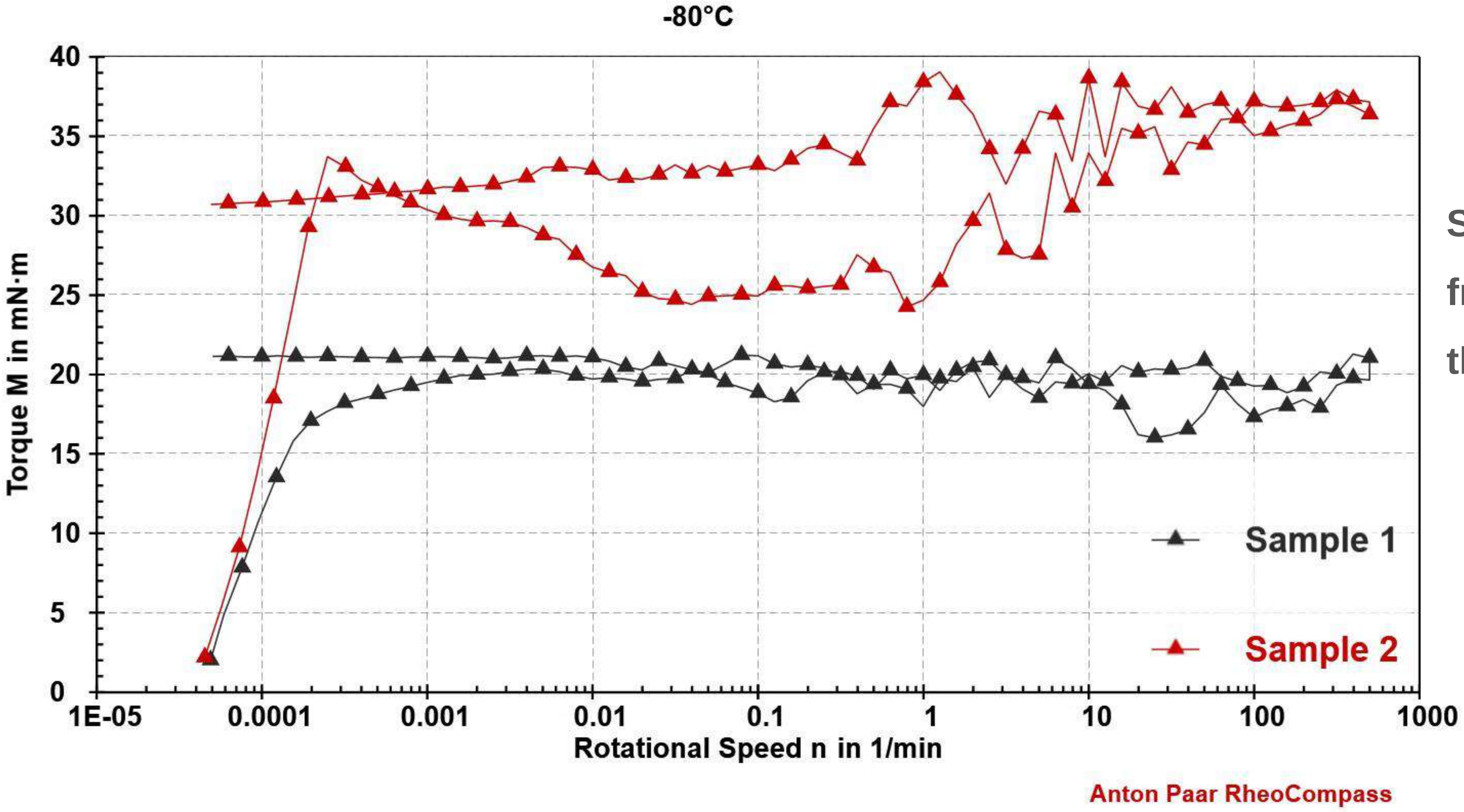


BREAKAWAY TORQUE (–80°C)



Sample 1 has lower breakaway torque over the entire speed range

STRIBECK CURVES (-80°C)

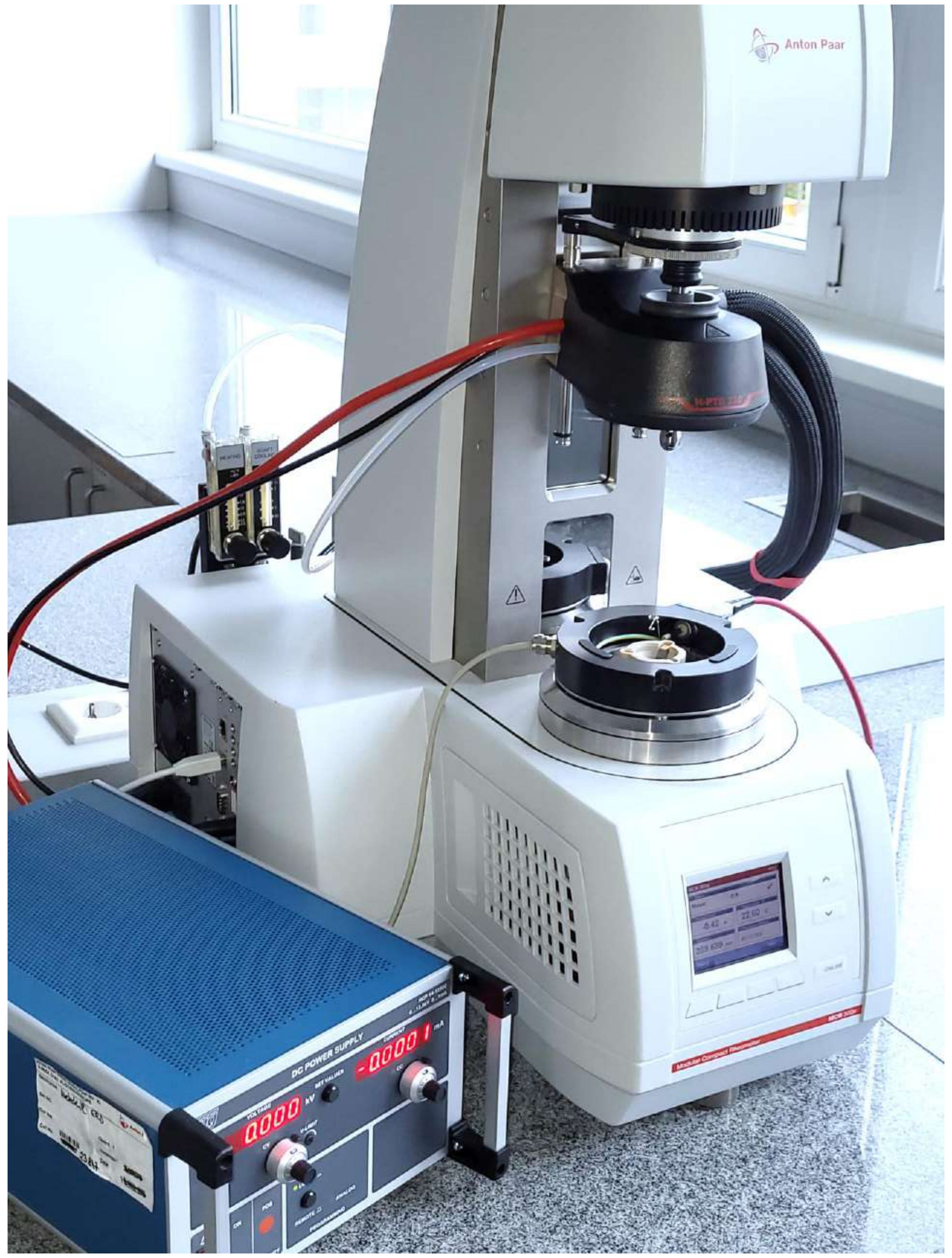


Sample 1 has lower frictional torque over the entire speed range

Applications

ELECTRO-TRIBOLOGY

SSTUP



MCR 302e

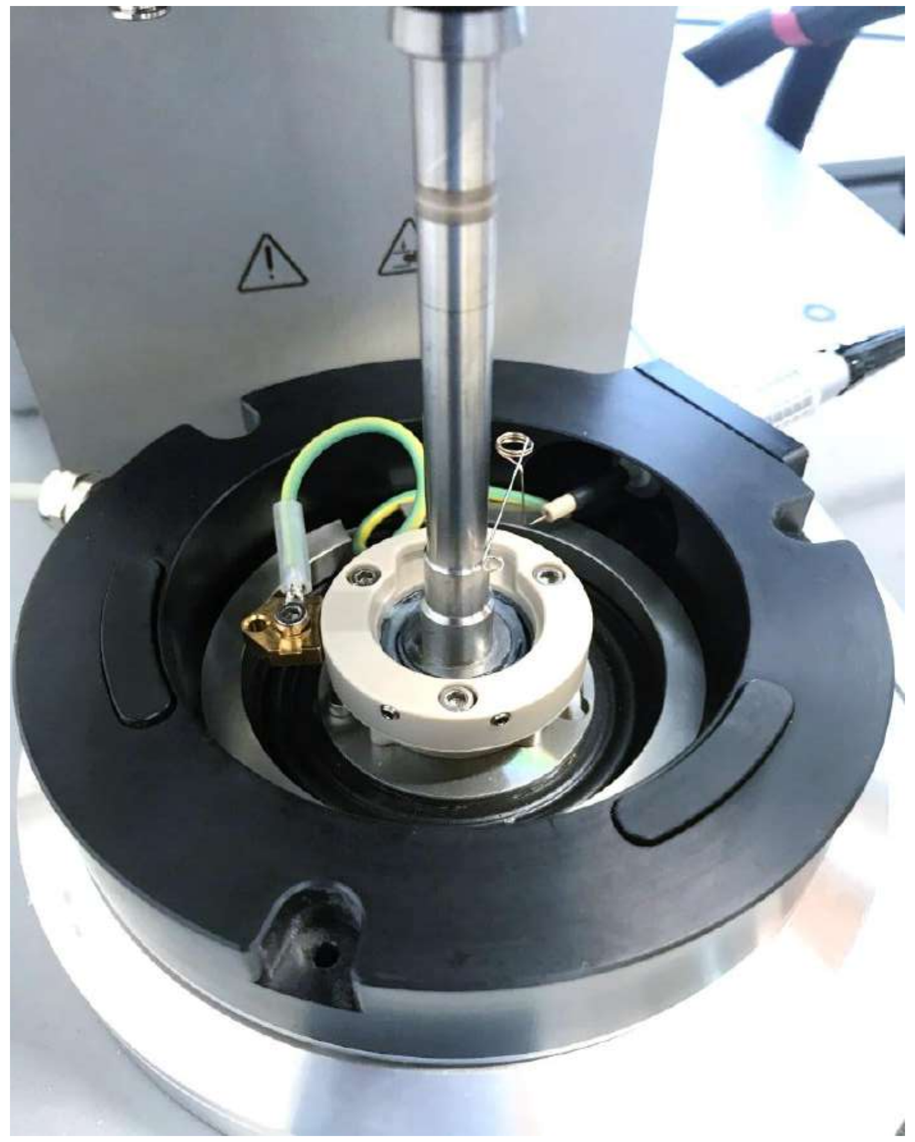
+ High voltage power supply 12.7 kV DC

T-PTD200 +
H-PTD220 +
Spacer ring
with HV
connector,
spring
contact,
safety
switches

Ball on 3 flats

OR

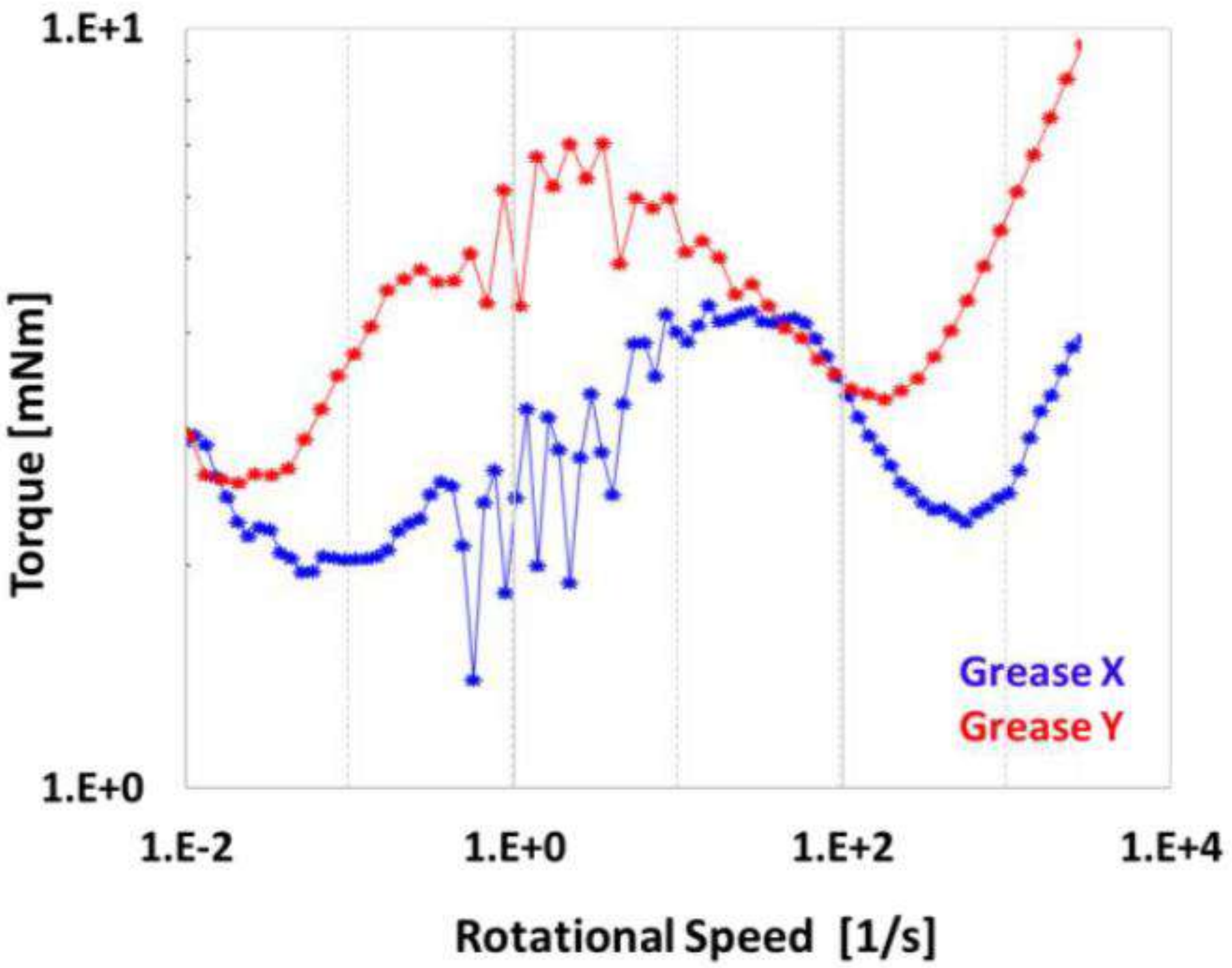
Rolling bearing option



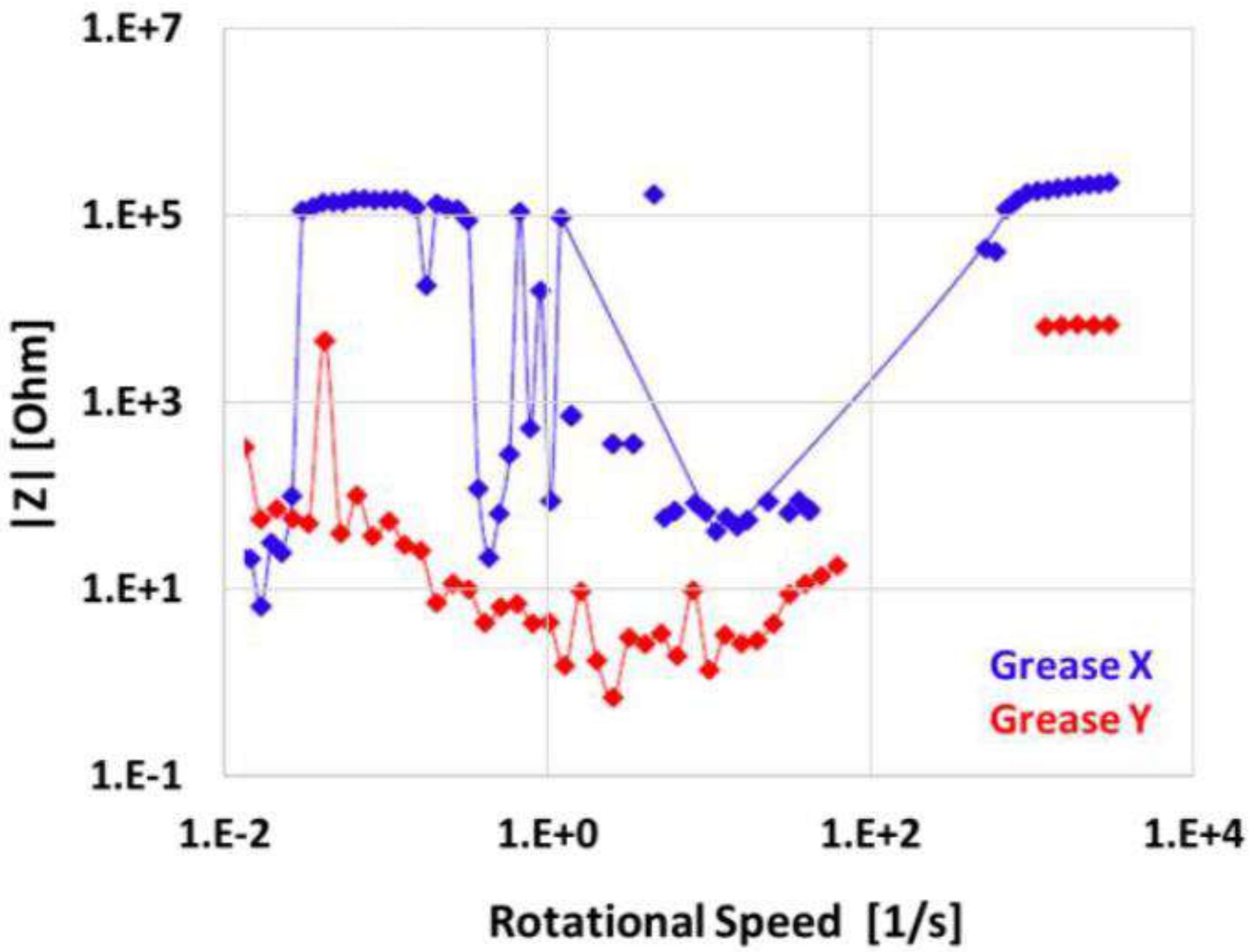
The Tribo ERD uses a H-PTD220 instead of a separate ERD hood. As a consequence the Setup is limited to 4 kV.

ELECTRO-TRIBOLOGICAL DATA

Torque Data



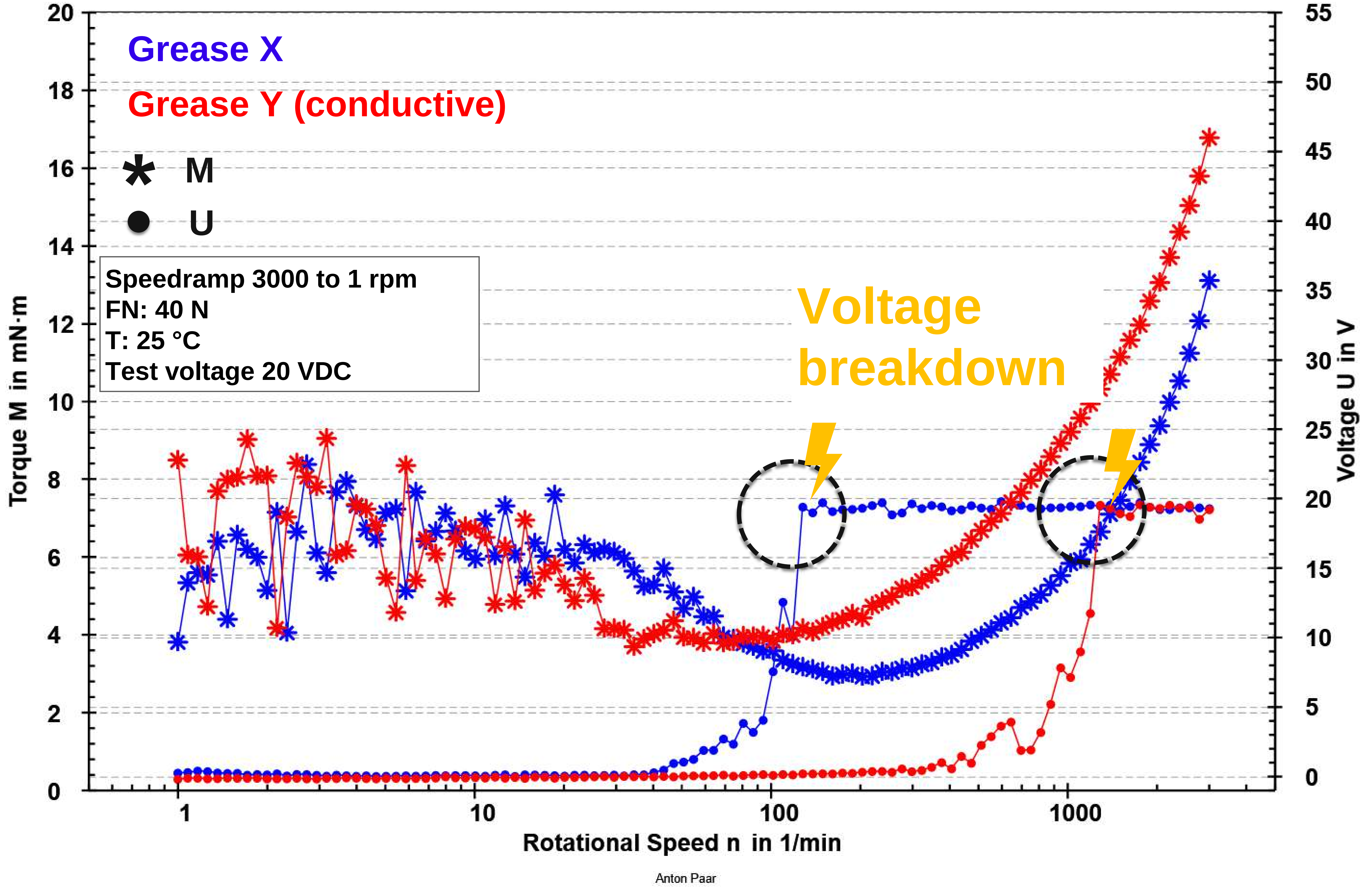
Impedance Data

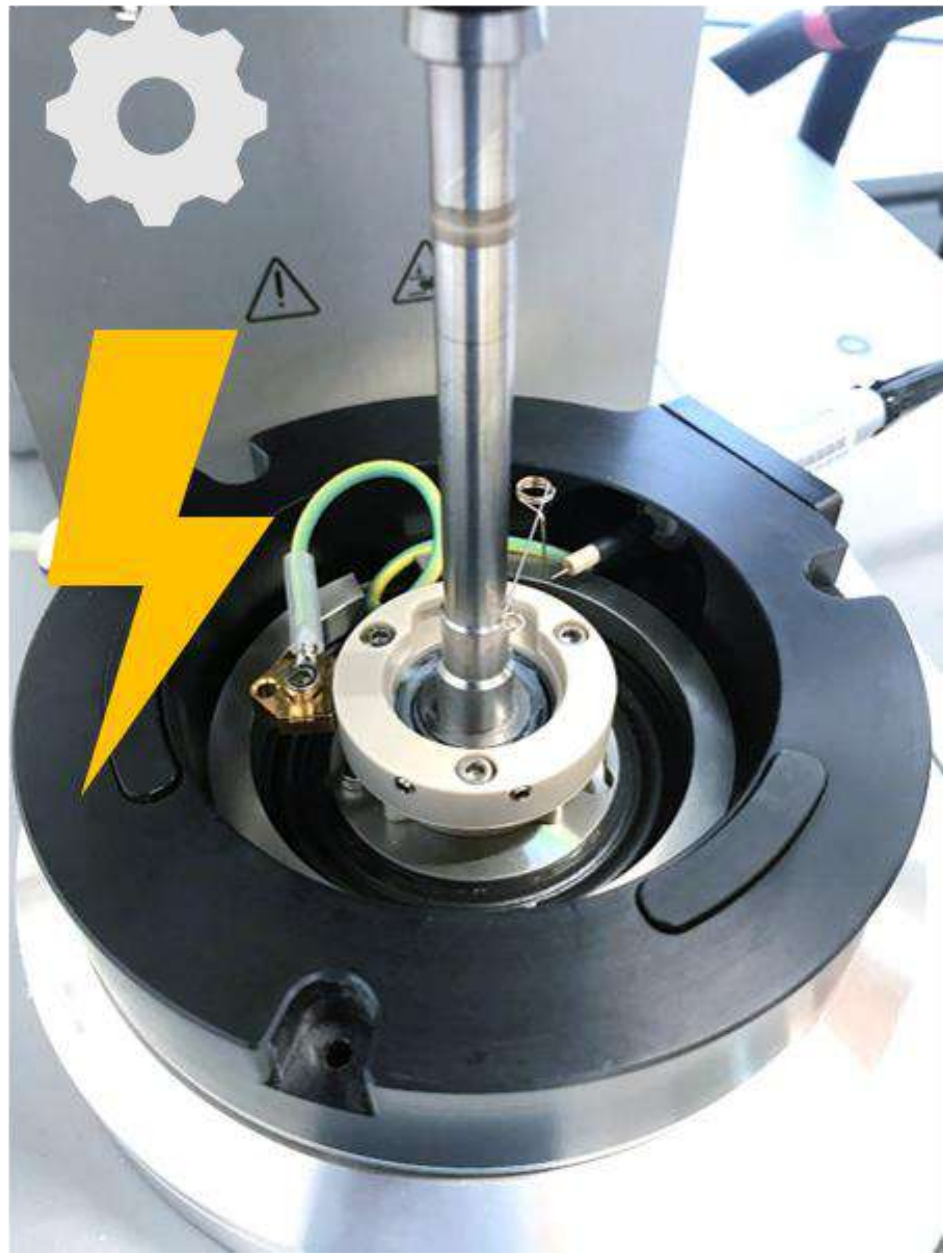


- The Ionic liquid present in Grease Y is the reason for the lower impedance recorded during the test

BREAK DOWN VOLTAGE

Tribo ERD Setup with rolling bearing option.





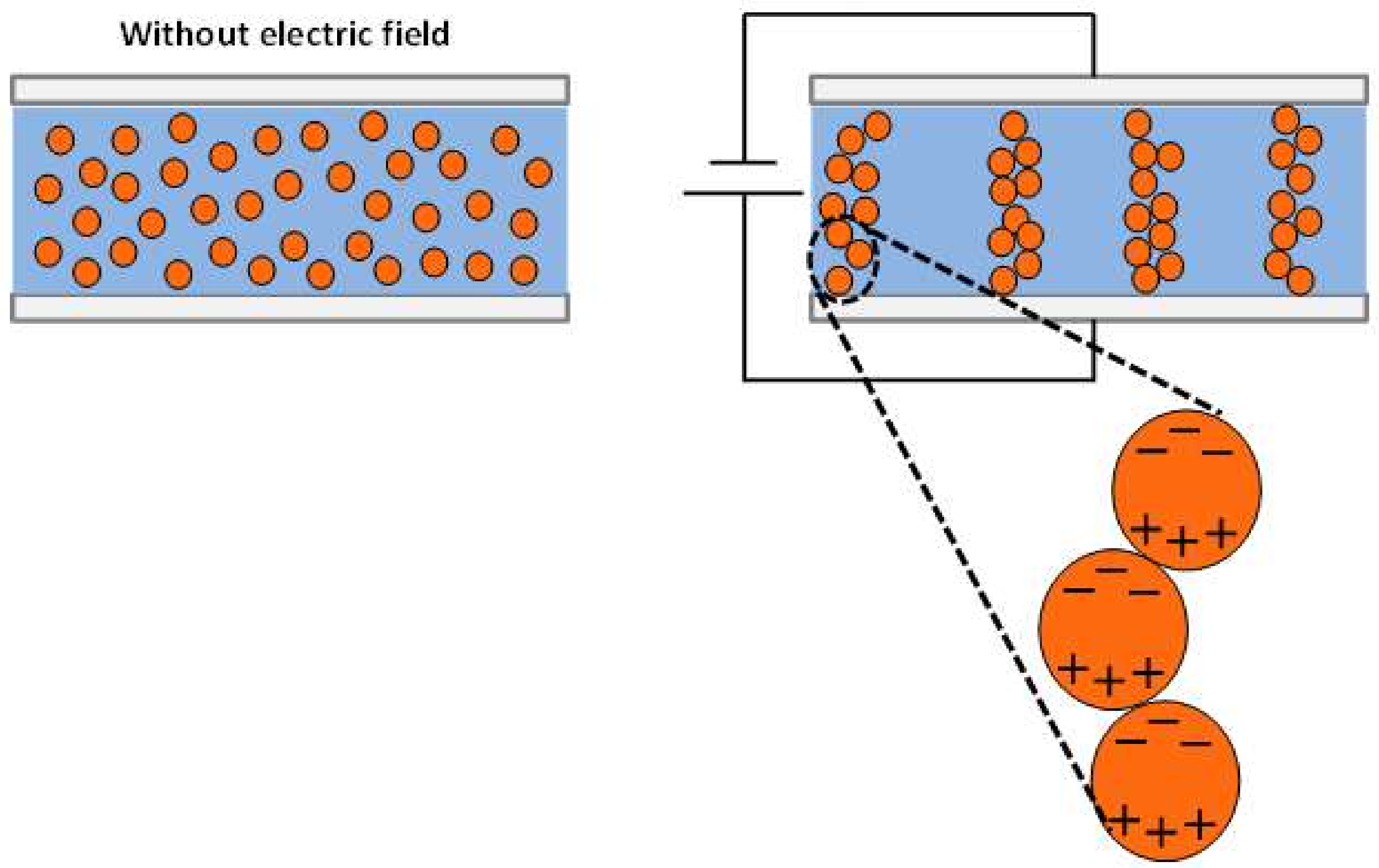
Rotational speed ramp with decreasing speed at a constant voltage of 20 V.

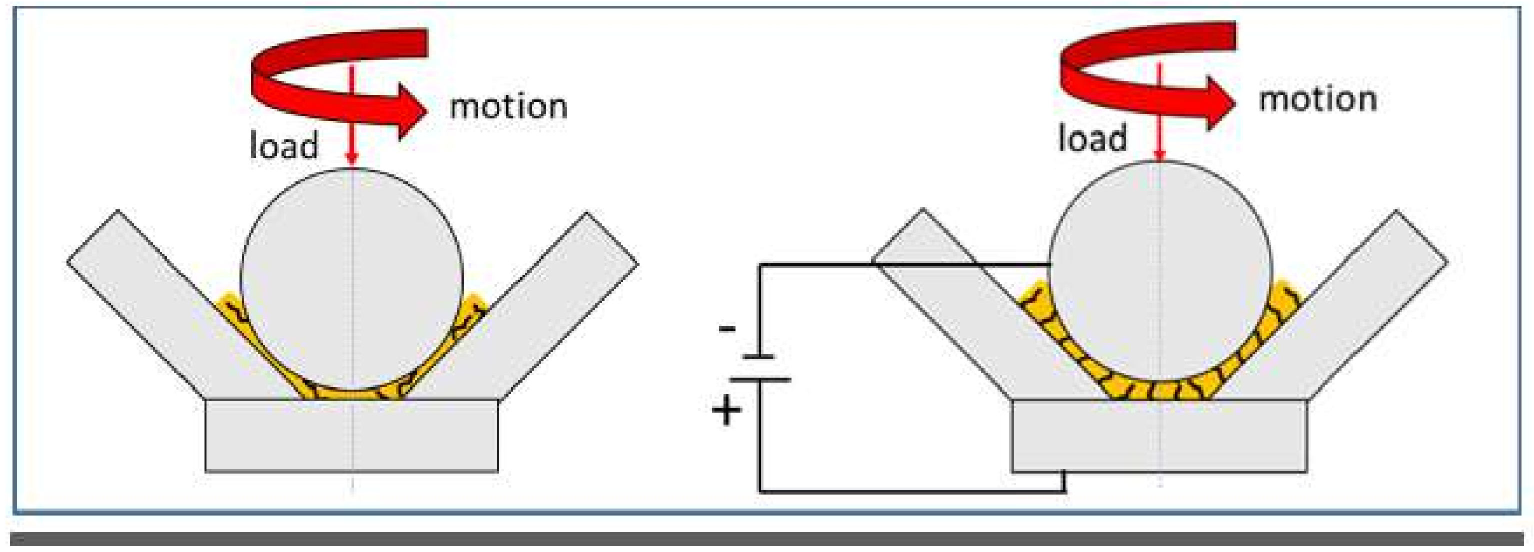
Voltage break down

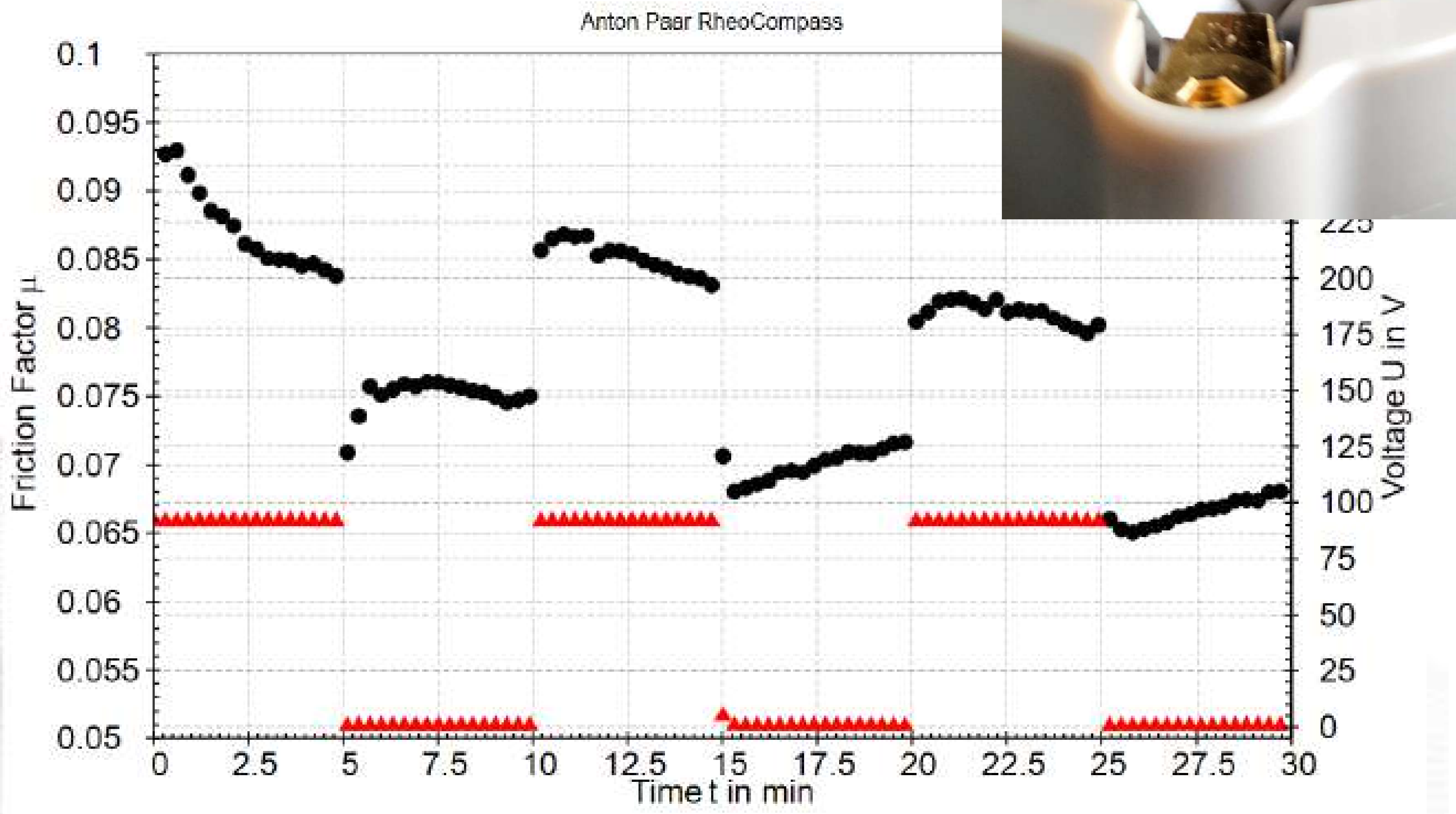
Grease X: 105 rpm

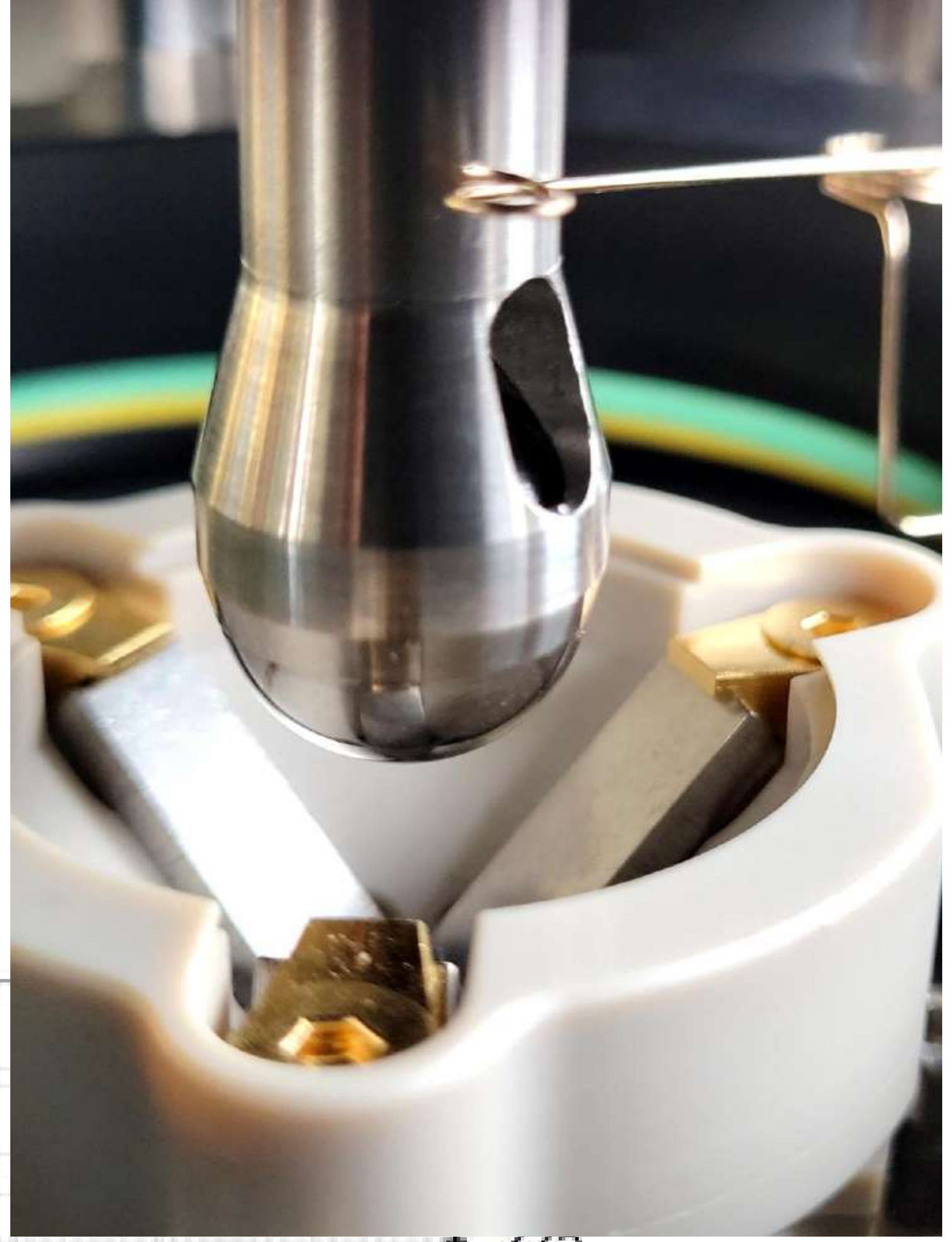
Grease Y: 1010 rpm

SMART FLUID









Tribo ERD Setup with ball on 3 plates measurement (dispersion of polarizable nanoparticles in vegetable oil).

See Application Report: Active Control of Friction Coefficient with Electro-sensitive Biolubricants.

Anton Paar

Thank You!

Questions?

www.anton-paar.com