Wear and contact fatigue properties of a novel lubricant additive

Professor Pedro Rivera[1,2]

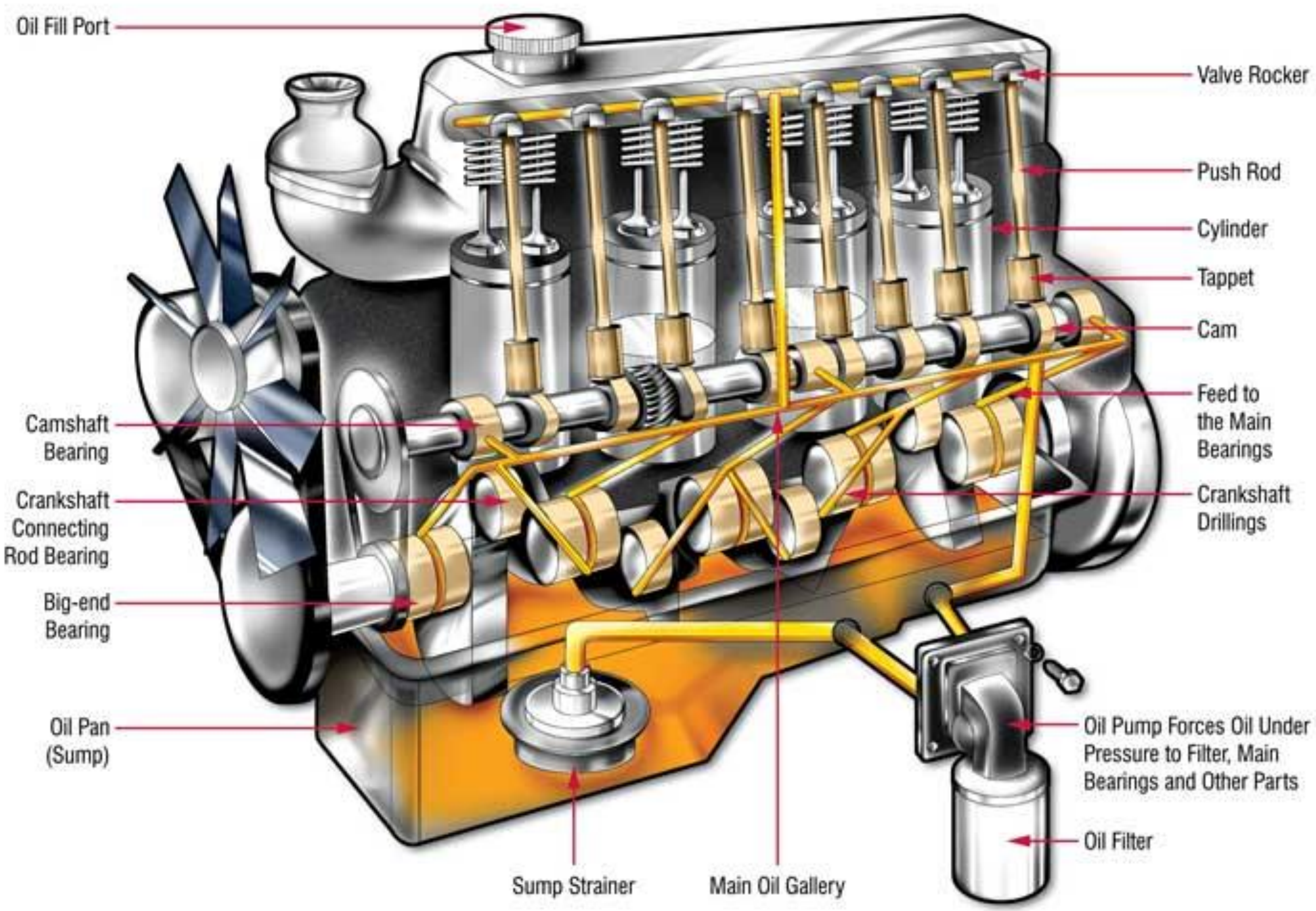
[1] Lofrix Associates Limited

[2] Lancaster University, University of Southampton

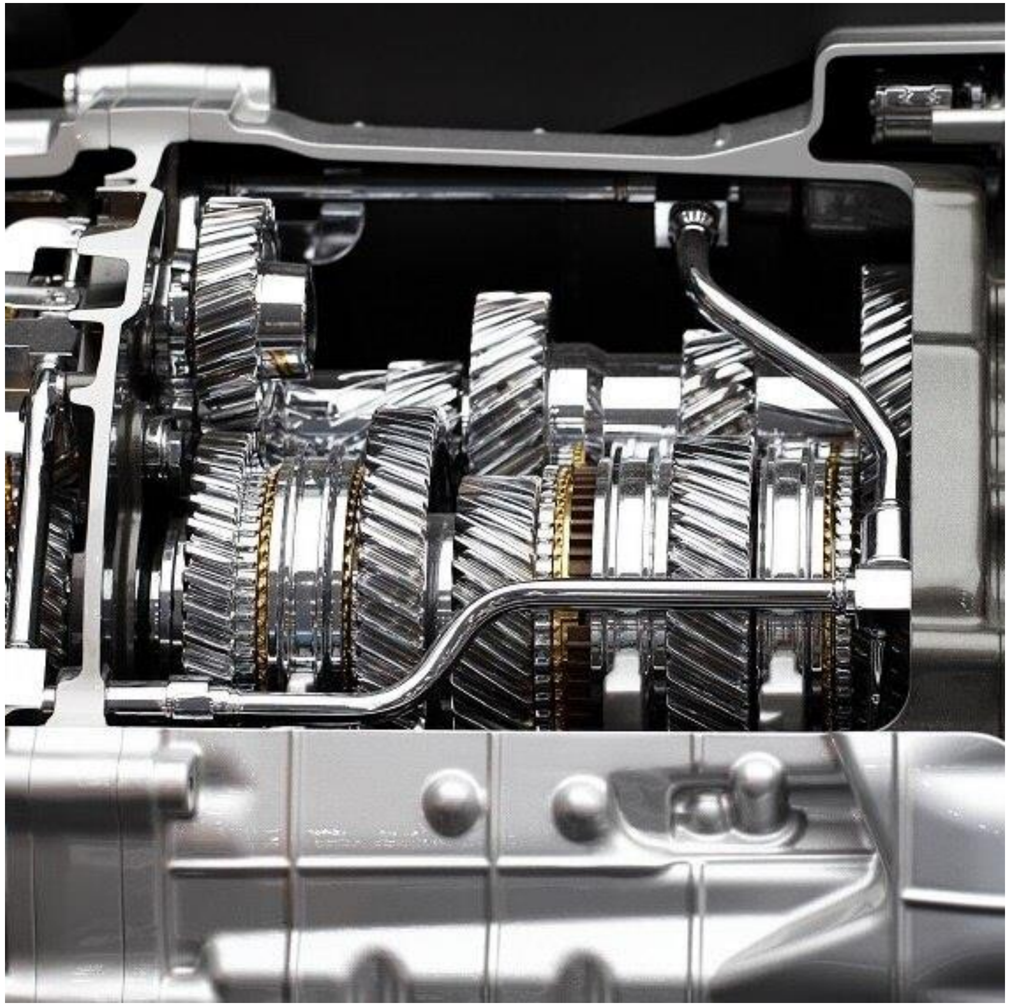
Content

1. Friction and tribofilm formation
2. Additives and dry lubrication
3. Anti-wear capabilities – roller -& spindle / shaft & break
4. Tribofilm adhesion – cutting tools
5. Evolution of coefficient of friction – rails steels
6. Nature of tribofilm – chemistry
7. Nature of tribofilm – physical properties
8. Statistical tests and future work

Wet lubrication



Contact and slide



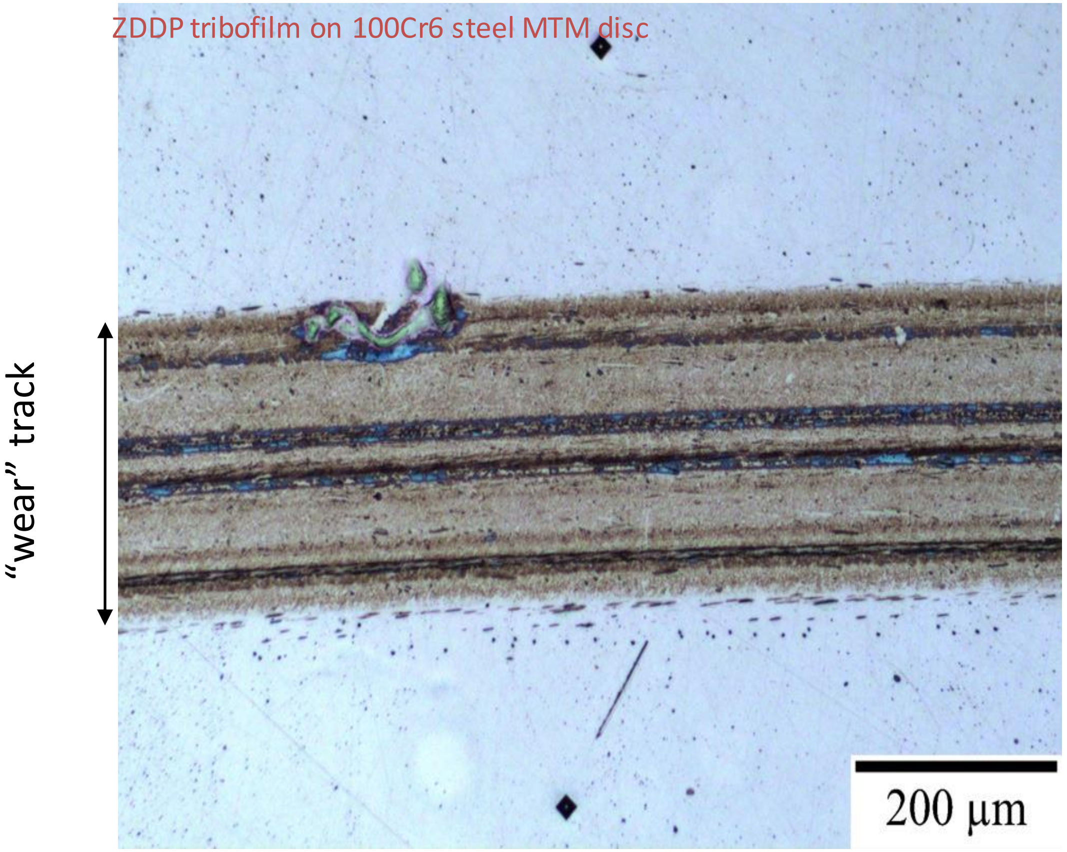
Lofrix Dry – Typhoon fighter

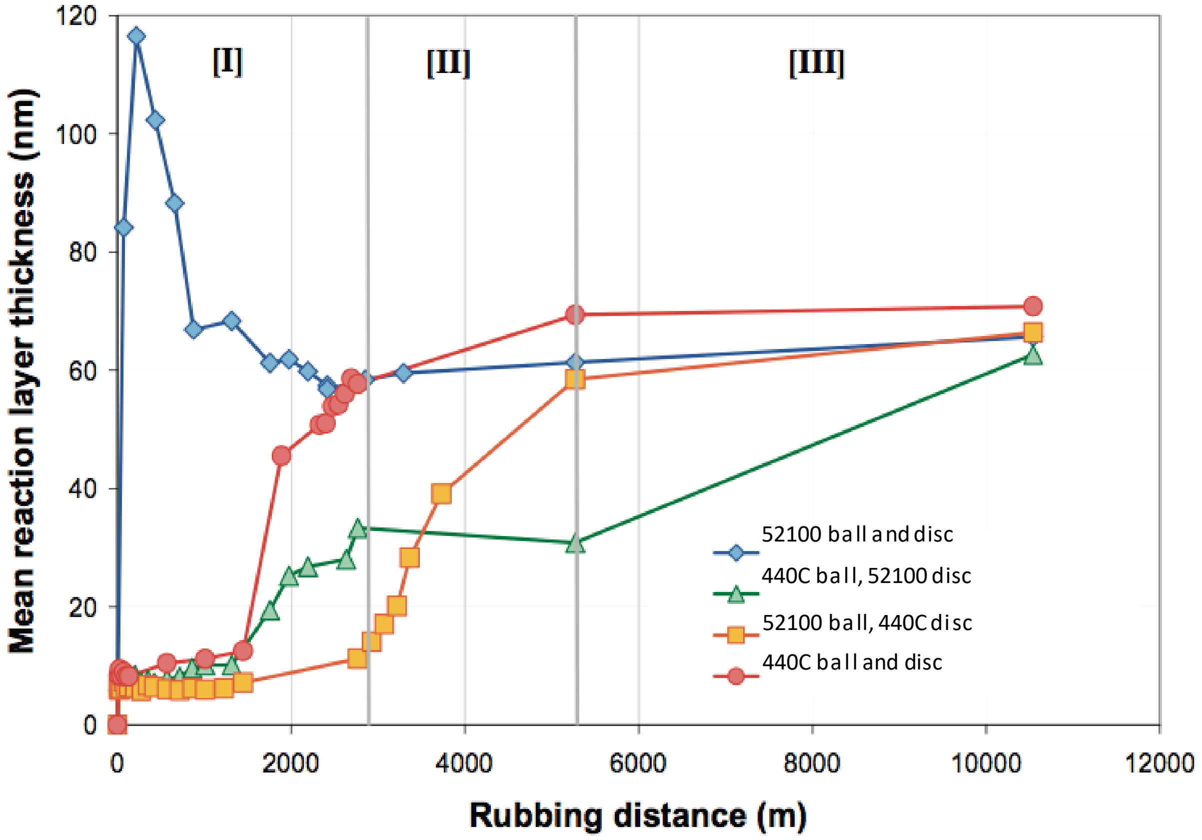
British Aerospace Military Aircraft & Structures
Tribological and tribo-chemical test results
Wear Resistance and Friction Coefficient study

-60 to 60 ^{o}C dry lubrication

1. Friction and tribofilm formation

1. Mechanical contact is necessary to form the tribofilm.

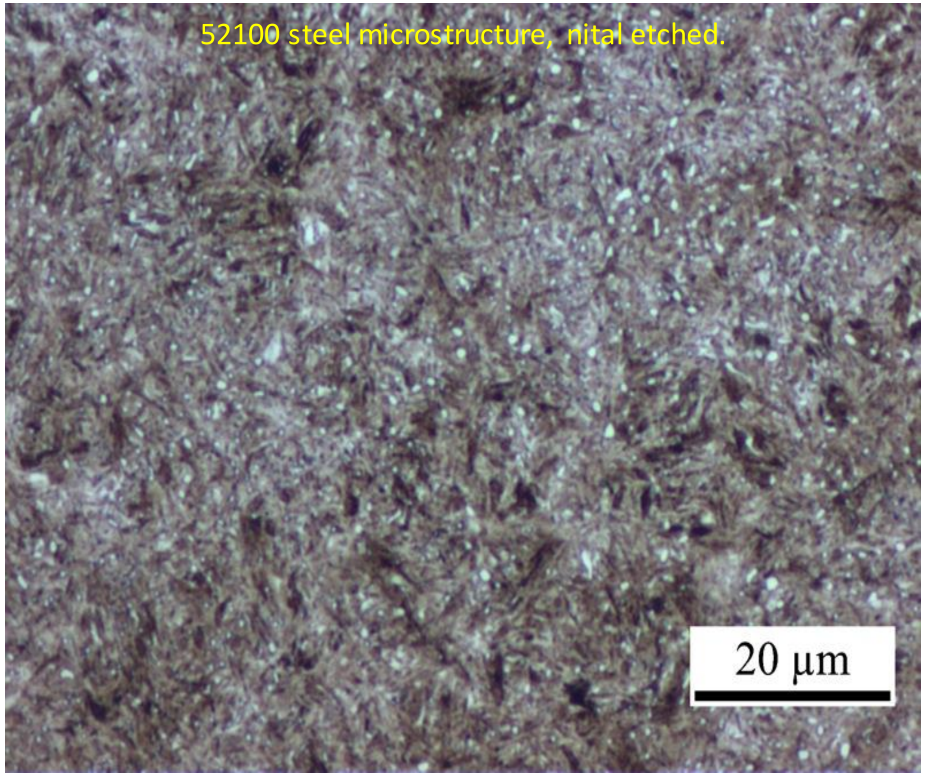


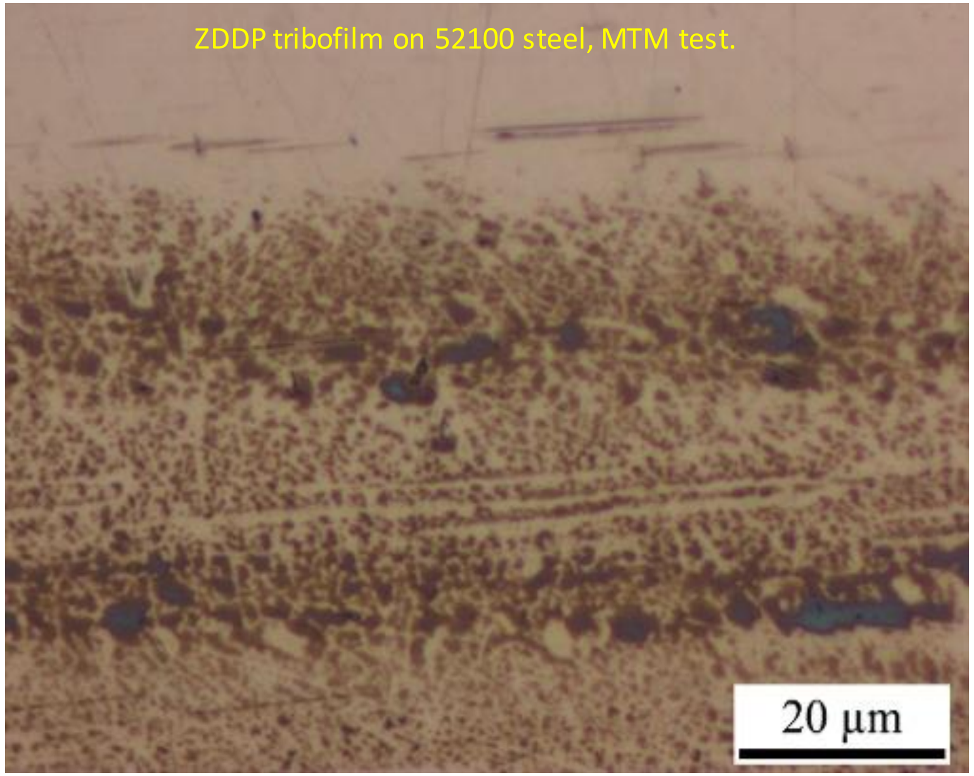


2. Behaviour of the anti-wear additives depends on the steel grade used.

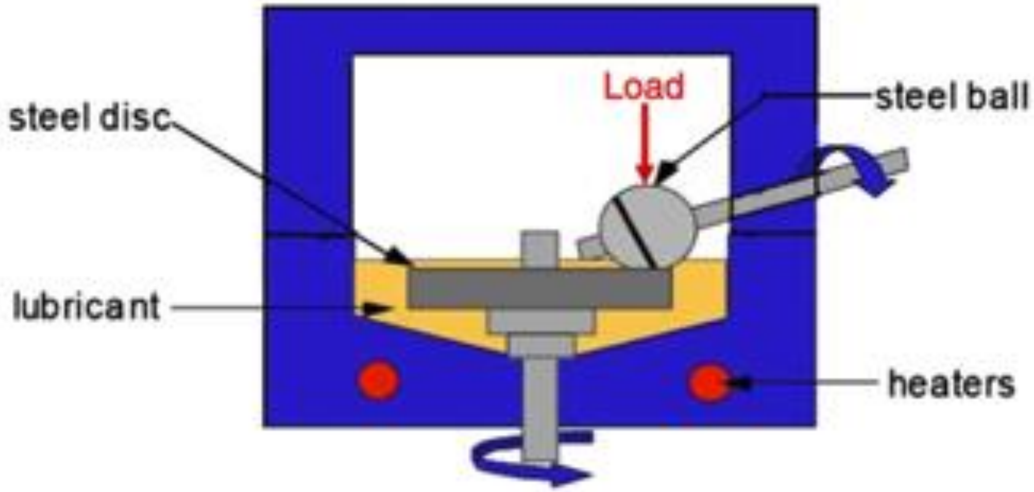
1. Friction and tribofilm formation

3. Anti-wear additives form patches of the tribofilm on the surface. Scale is similar to that of the microstructure.





1. Friction and tribofilm formation



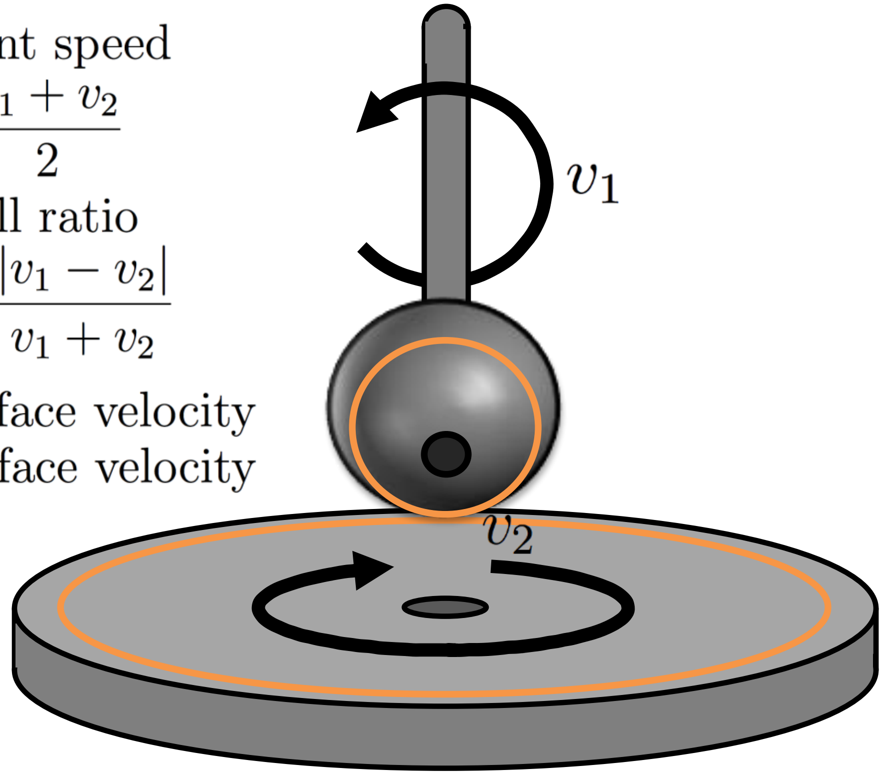
Entrainment speed

$$v_{entr} = \frac{v_1 + v_2}{2}$$

Slide-roll ratio

$$SRR = 2\frac{|v_1 - v_2|}{v_1 + v_2}$$

v_1 is ball surface velocity
v_2 is disc surface velocity



Controlled parameters:

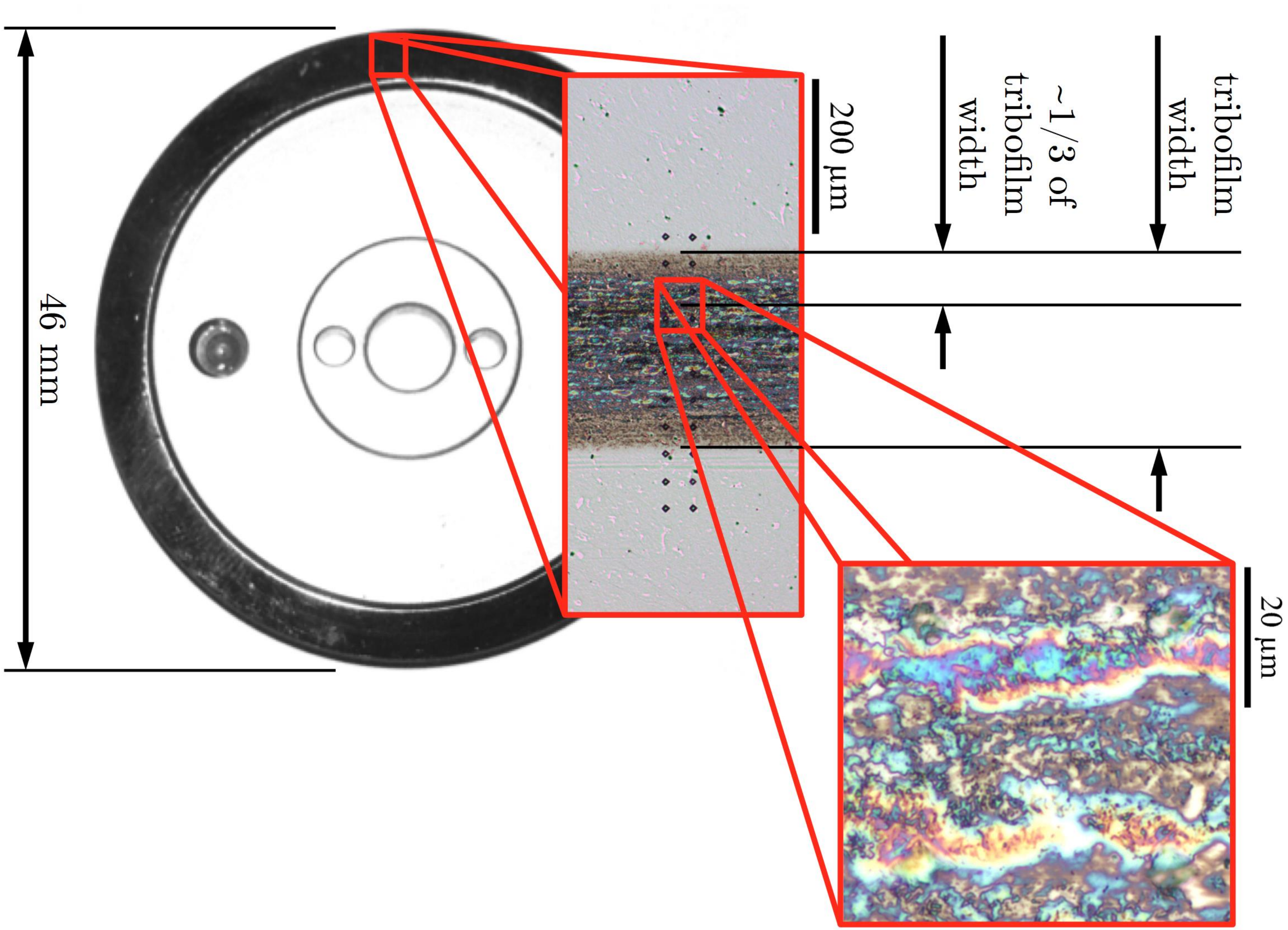
- **Load**
- Disc and ball **speed**
- **Temperature**

Measured:

- **Tribofilm thickness** vs **time** (interrupt test)
- **Coefficient of friction** vs **time**
- “Striebeck” curves: **COF** vs **rolling speed** (interrupt test)

In “timed step” (normal operating mode) disc moves faster than the ball.
In “Striebeck step” two measurements are done; one with ball moving faster and one with disc moving faster.

2. Additives and dry lubrication

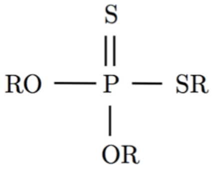
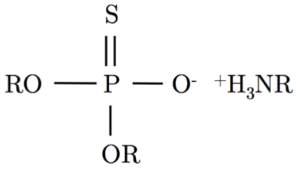
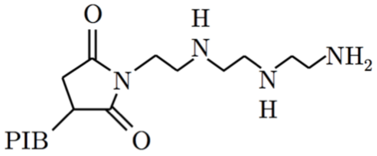
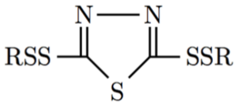
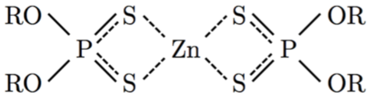


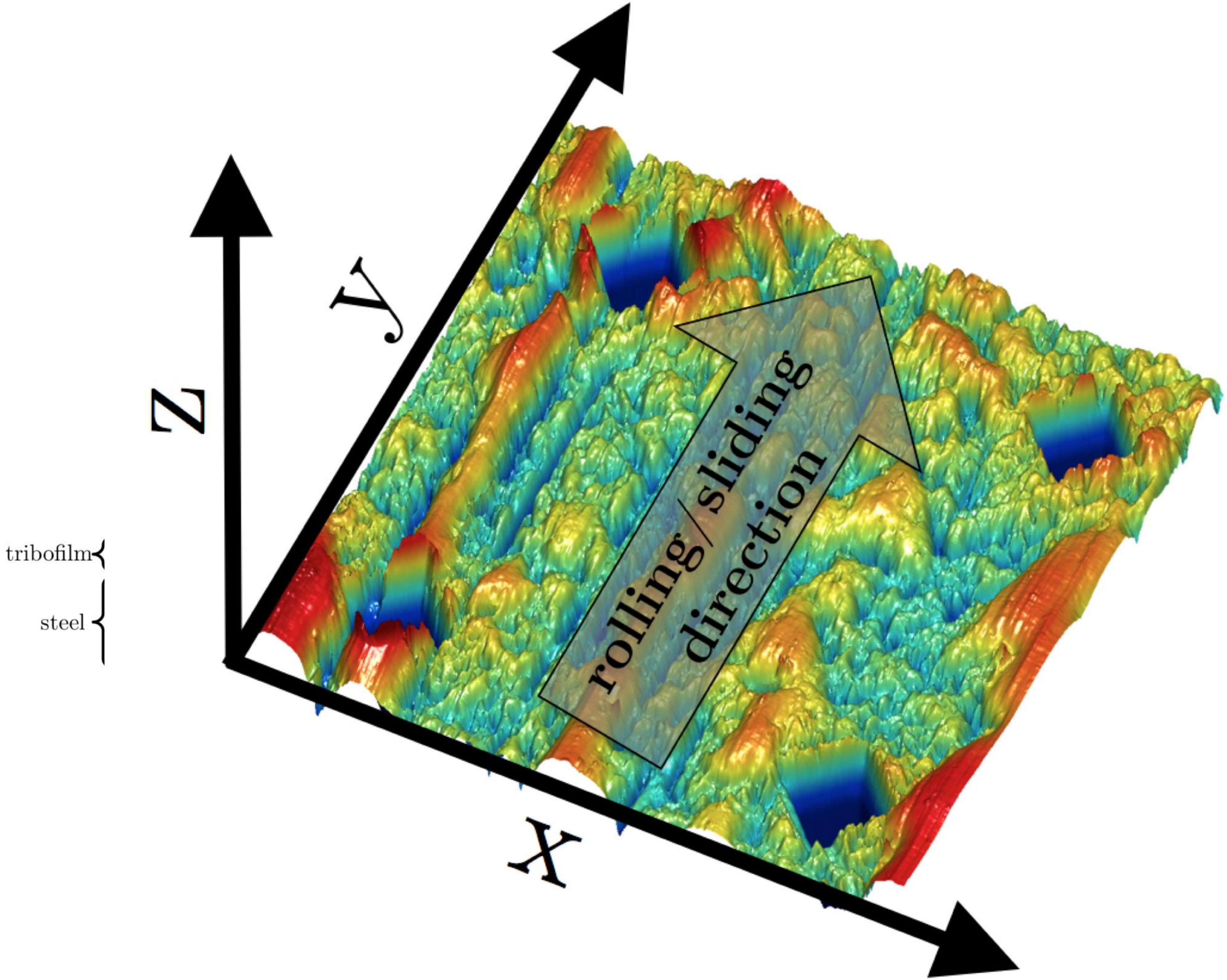
9

2. Additives and dry lubrication

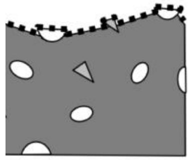
Grade	C	Mn	Si	Cr	Ni	Mo	V	W
100Cr6	0.98-1.1	0.25-0.45	0.15-0.35	1.3-1.6				
440C	0.95-1.2	1	1	16-18	$\leq$0.75	$\leq$0.75		
M2	0.78-1.05	0.15-0.4	0.20-0.45	3.75-4.50	0.3	4.5-5.5	1.75-2.20	5.5-6.75
16MnCr5[a]	0.14-0.19	1-1.3	0.15-0.4	0.8-1.1				

[a] Bulk composition.

Structure	Name
	Dithiophosphate (DTP)
	Amine thiophosphate (ATP)
	Succinimide
	Thiadiazole
	Zinc dialkyl dithiophosphate (ZDDP)

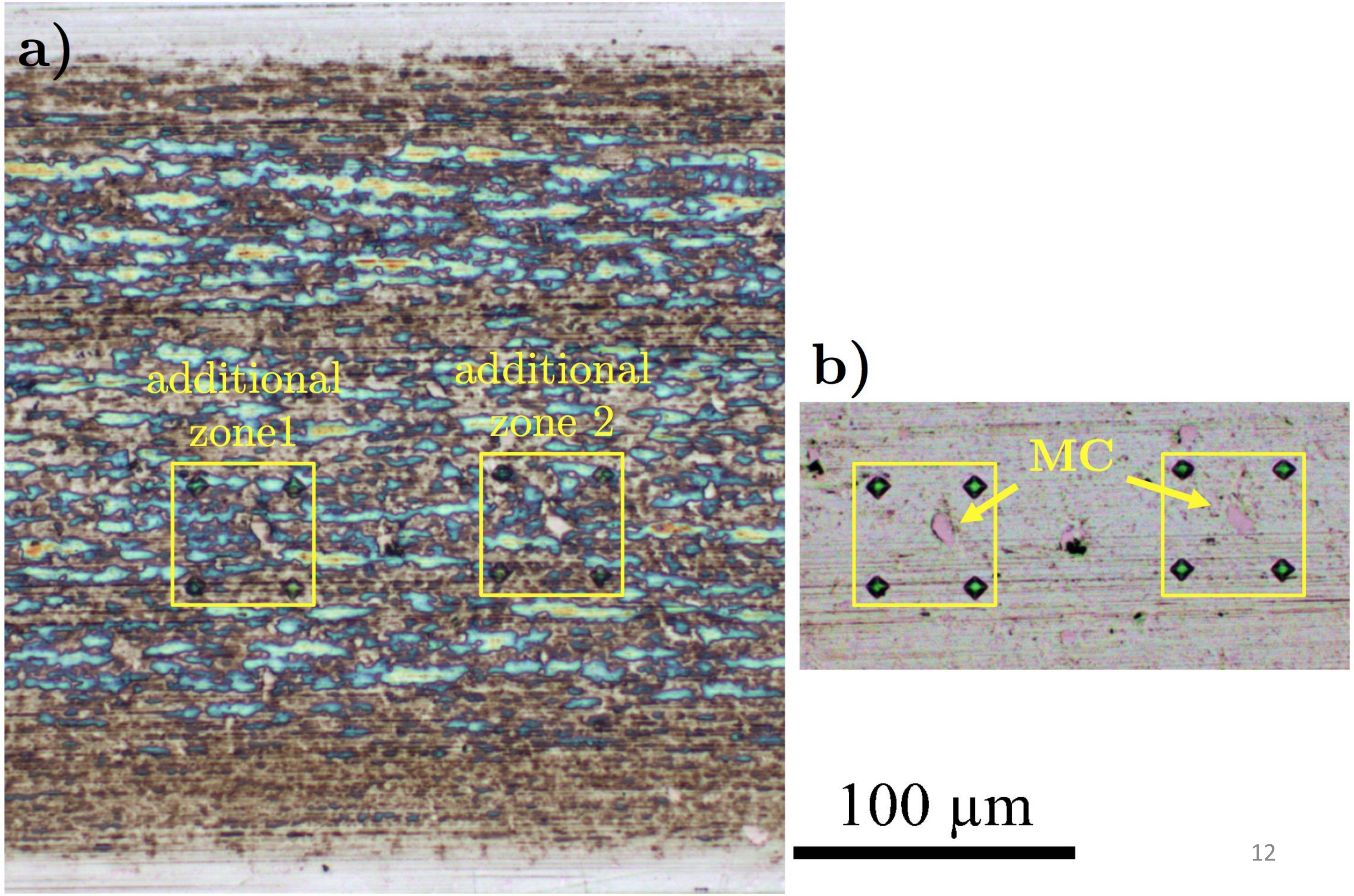


Z
y
X
rolling/sliding
direction
tribofilm
steel



2. Additives and dry lubrication

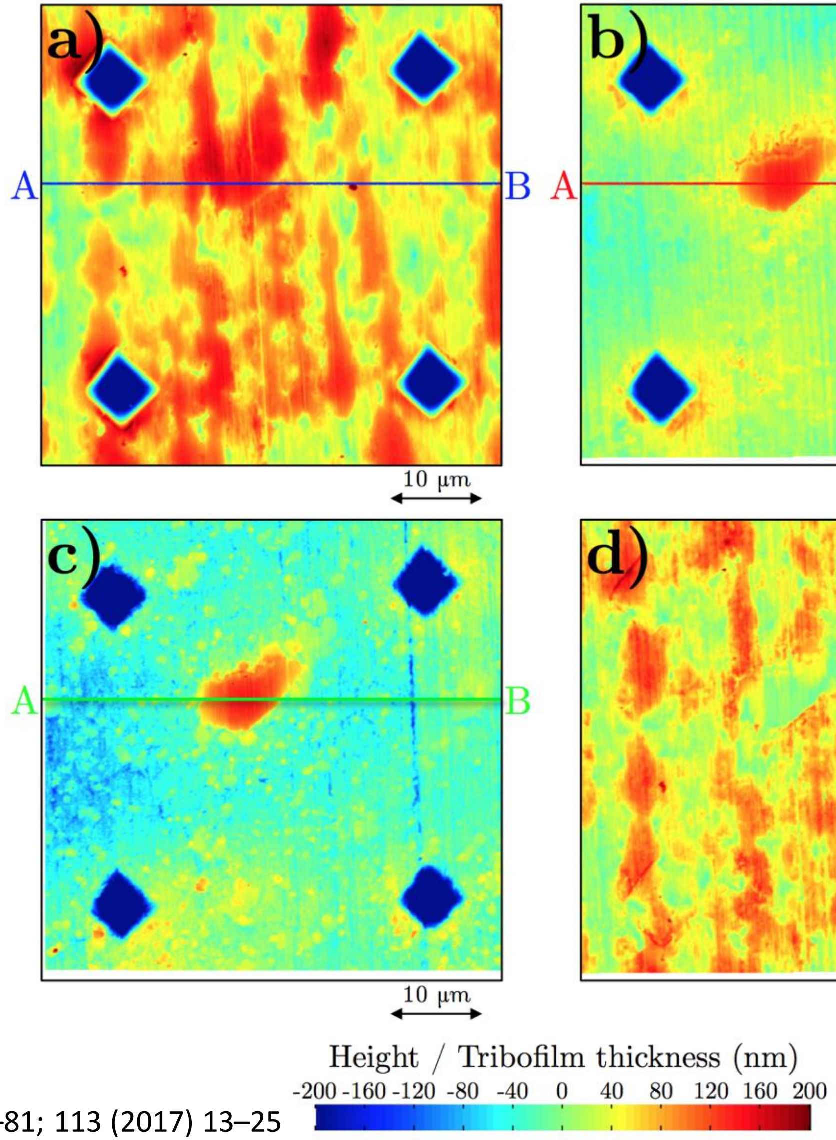
Tribofilm-microstructure correlation (**M2/ZDDP**-large residual carbides)



12

2. Additives and dry lubrication

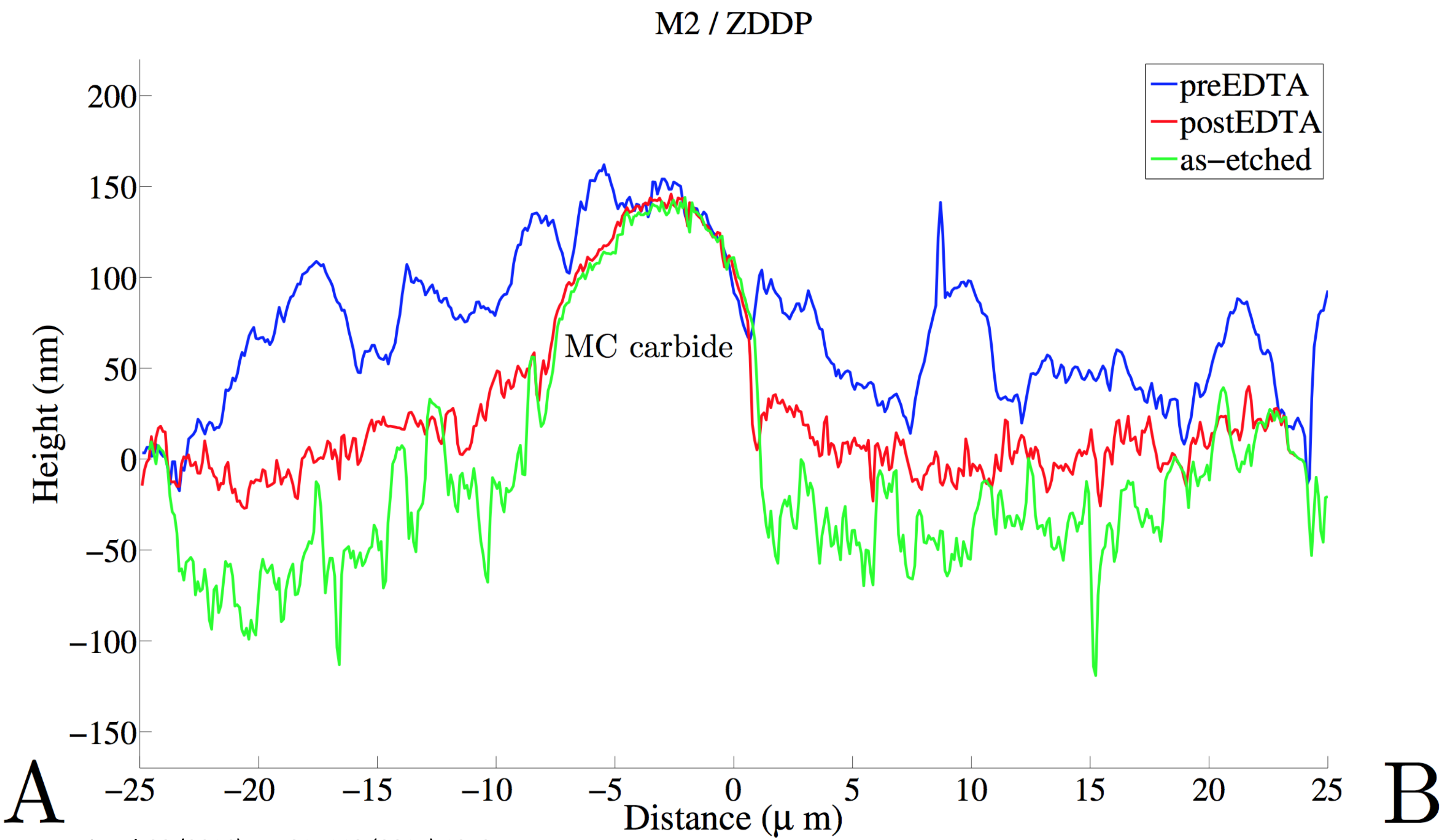
Tribofilm-microstructure correlation (**M2/ZDDP**-large residual carbides)



Jelitay Rydel *et al.* Tribology International 98 (2016) 74–81; 113 (2017) 13–25

2. Additives and dry lubrication

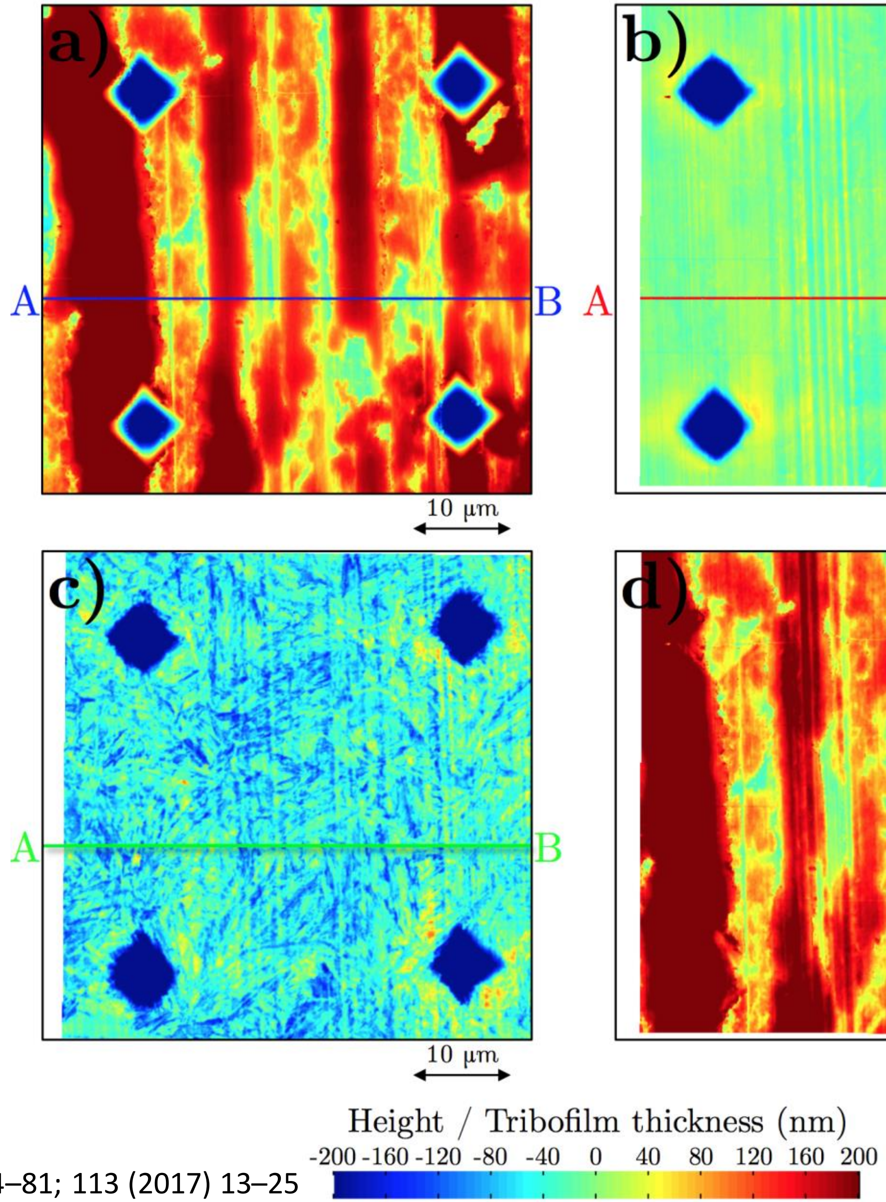
Tribofilm-microstructure correlation (**M2/ZDDP**-large residual carbides)



Jelitay Rydel *et al.* Tribology International 98 (2016) 74–81; 113 (2017) 13–25

2. Additives and dry lubrication

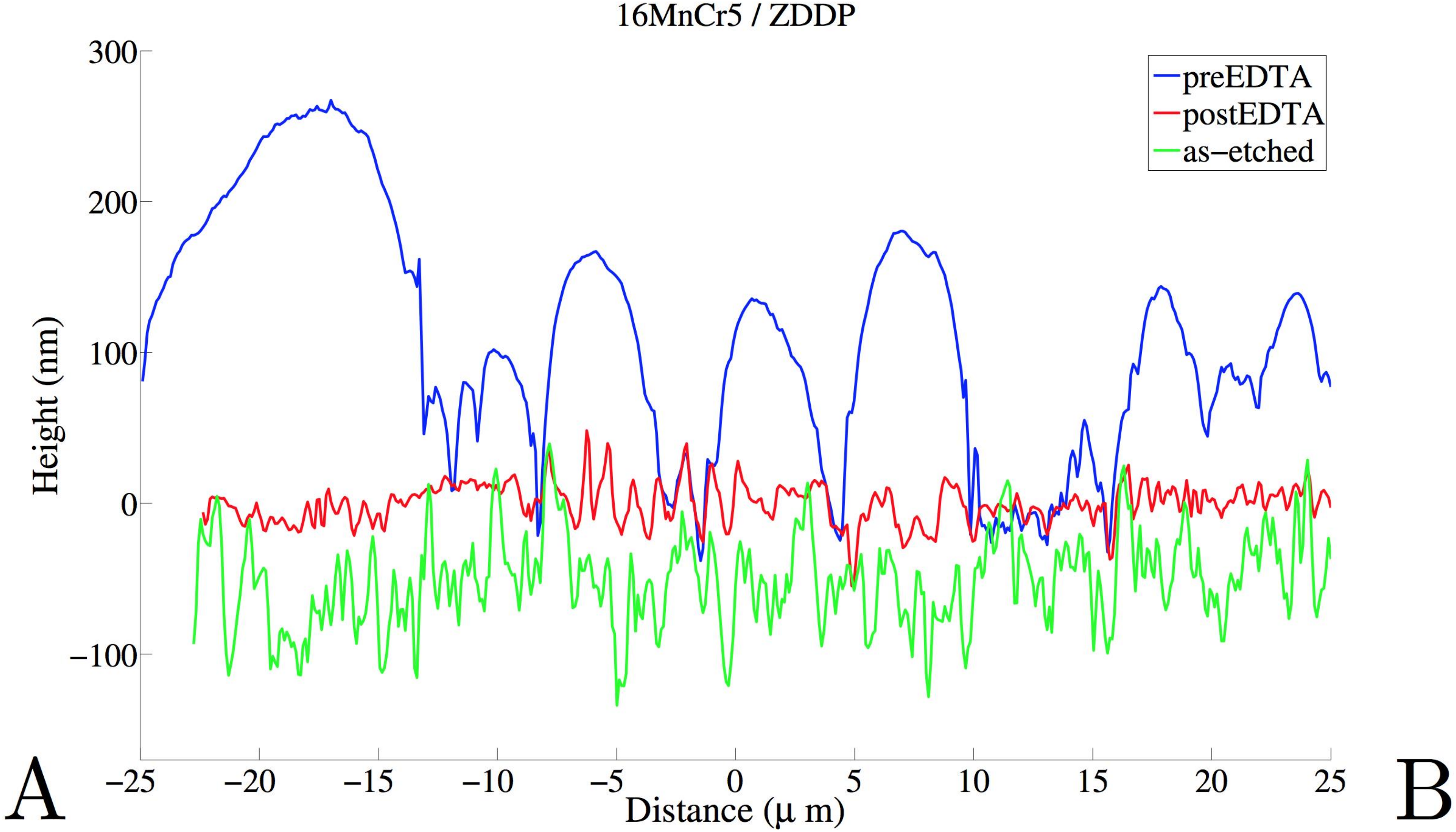
Tribofilm-microstructure correlation (**16MnCr5/ZDDP**)



Jelitay Rydel *et al.* Tribology International 98 (2016) 74–81; 113 (2017) 13–25

2. Additives and dry lubrication

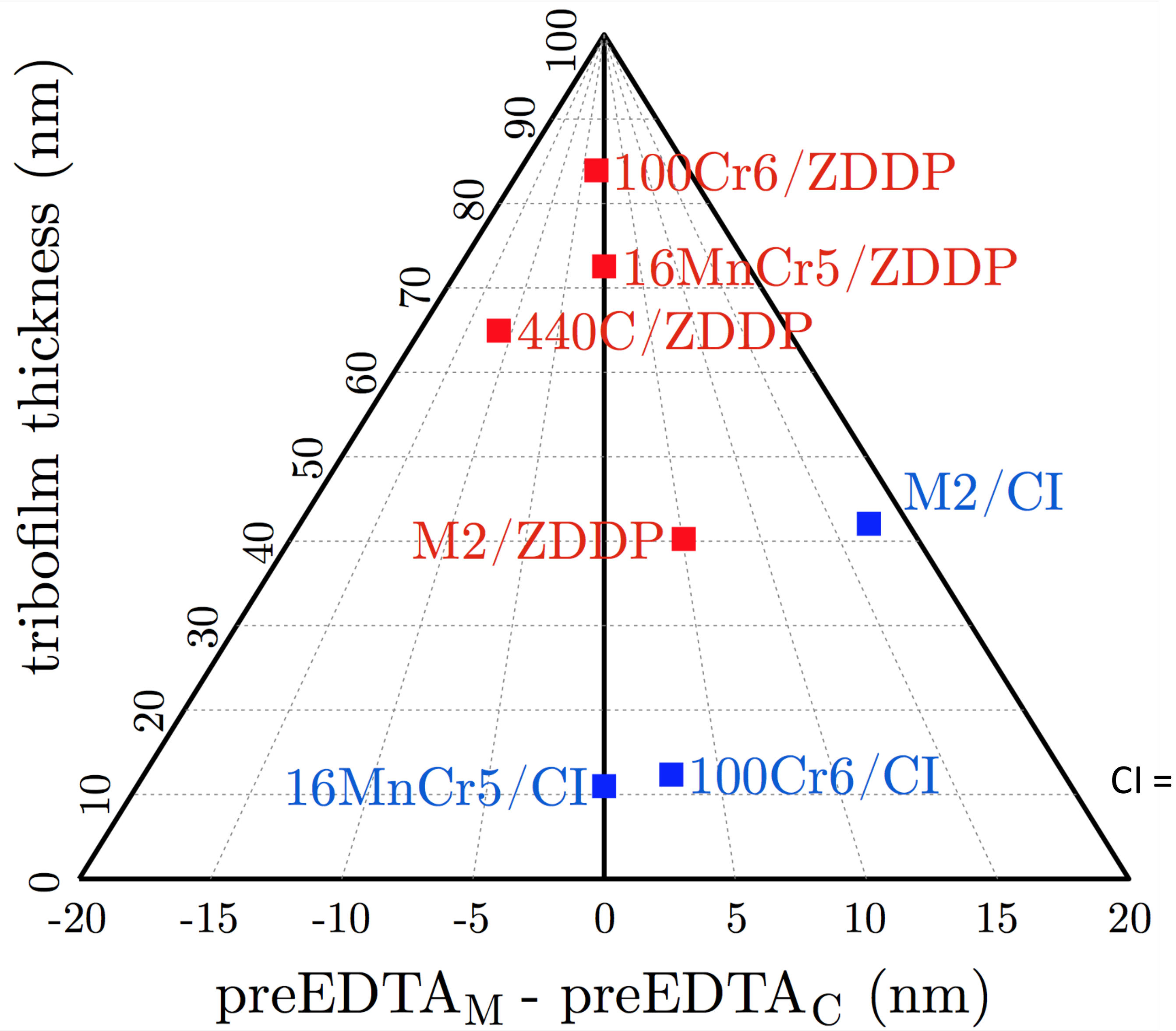
Tribofilm-microstructure correlation (**16MnCr5/ZDDP**)



Jelitay Rydel *et al.* Tribology International 98 (2016) 74–81; 113 (2017) 13–25

2. Additives and dry lubrication

Tribofilm-microstructure correlation (**summary**)



CI = Corrosion inhibitor

Jelitay Rydel *et al.* Tribology International 98 (2016) 74–81; 113 (2017) 13–25

What is the tribofilm structure in dry lubricants?

Can pressure be avoided?

Is a wet lubricant required?

3. Anti-wear capabilities – roller -& spindle / shaft & break

Figure 1 Oil Bath

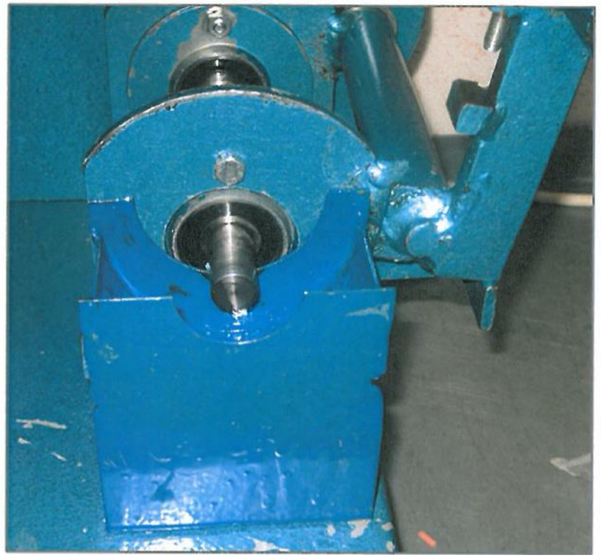


Figure 2 Roller clamped to arm

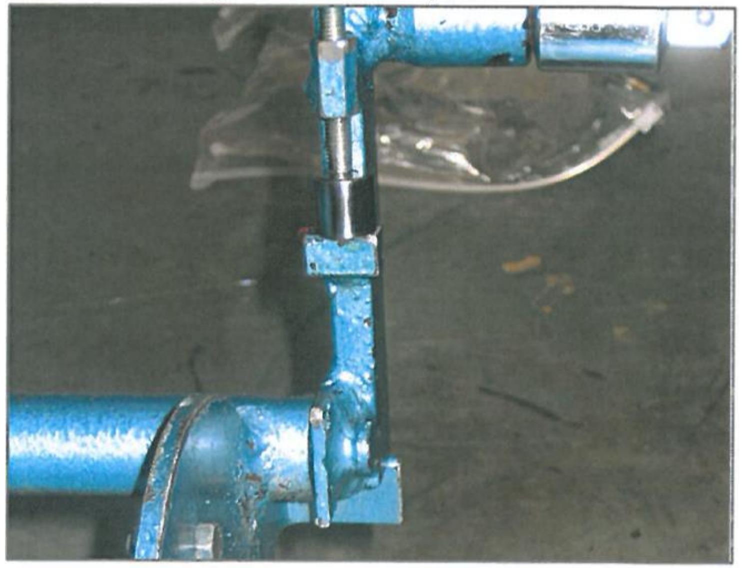


Figure 3 Roller and spindle in contact

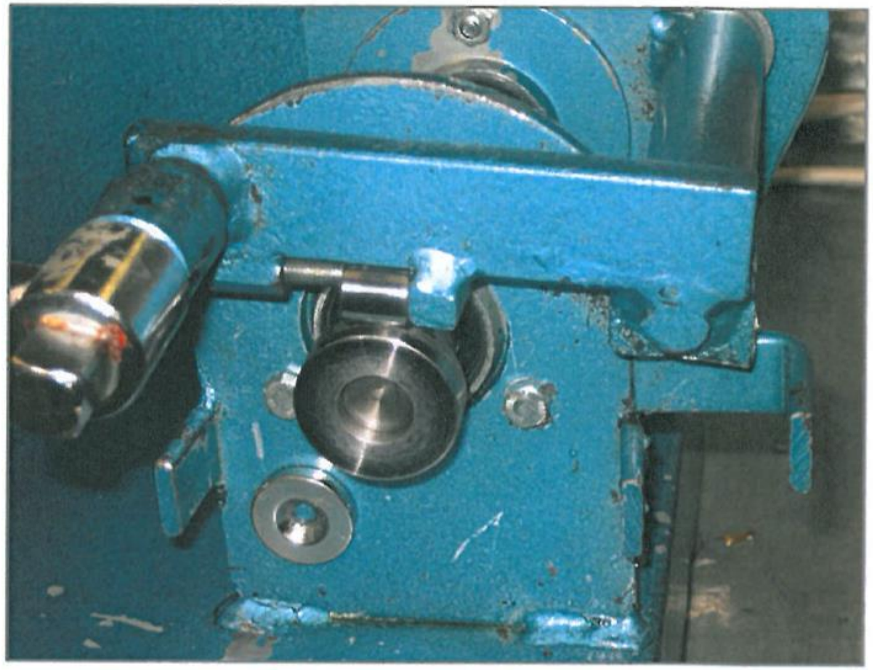
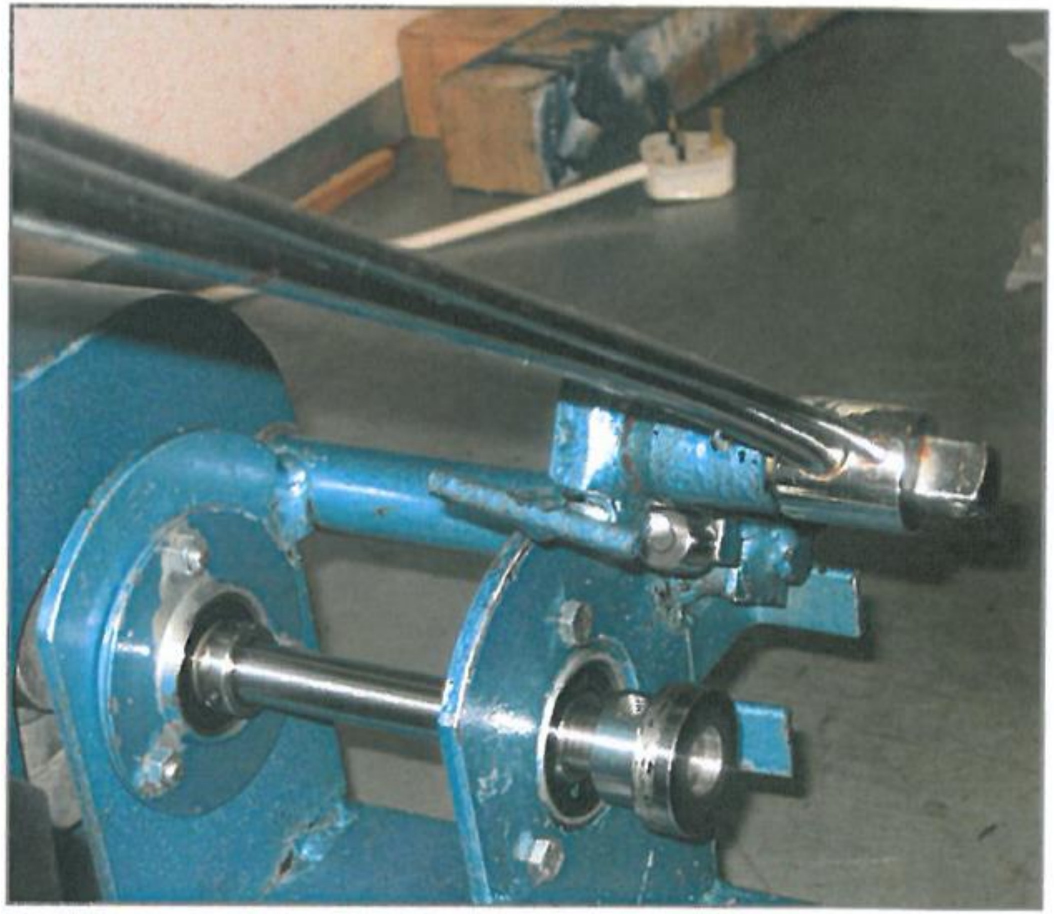
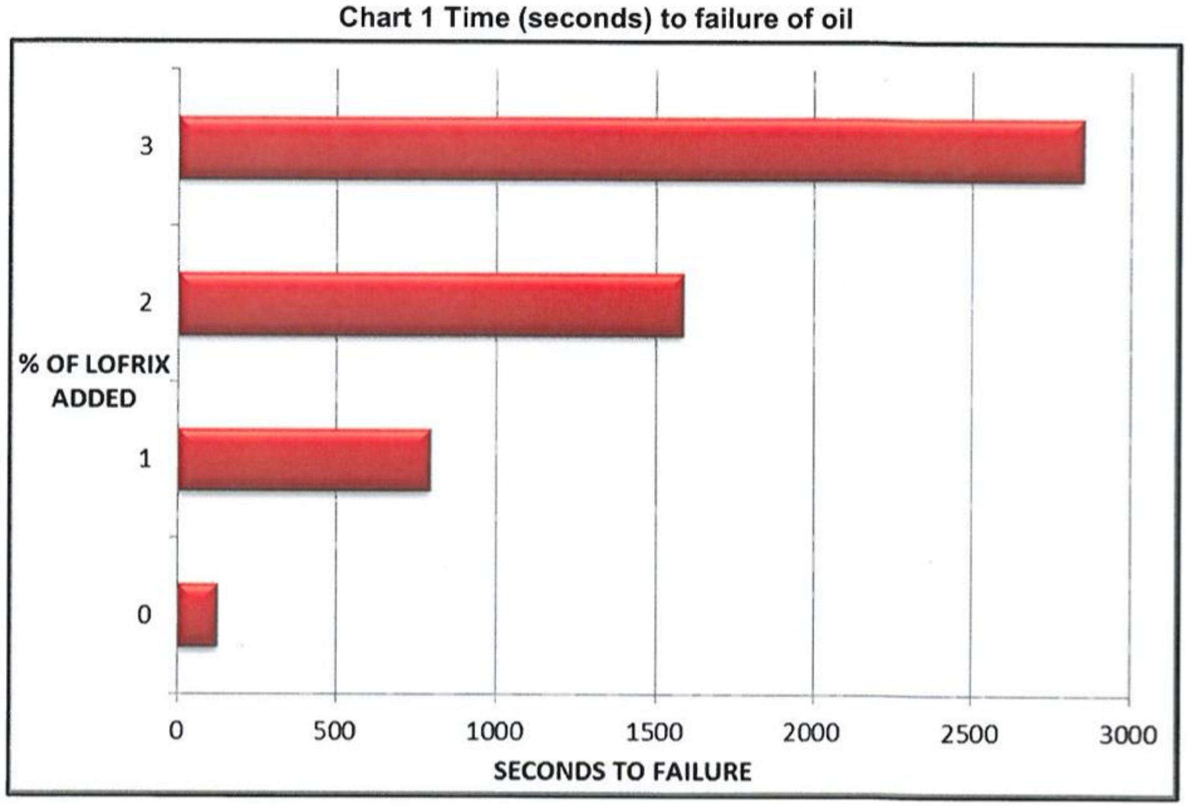


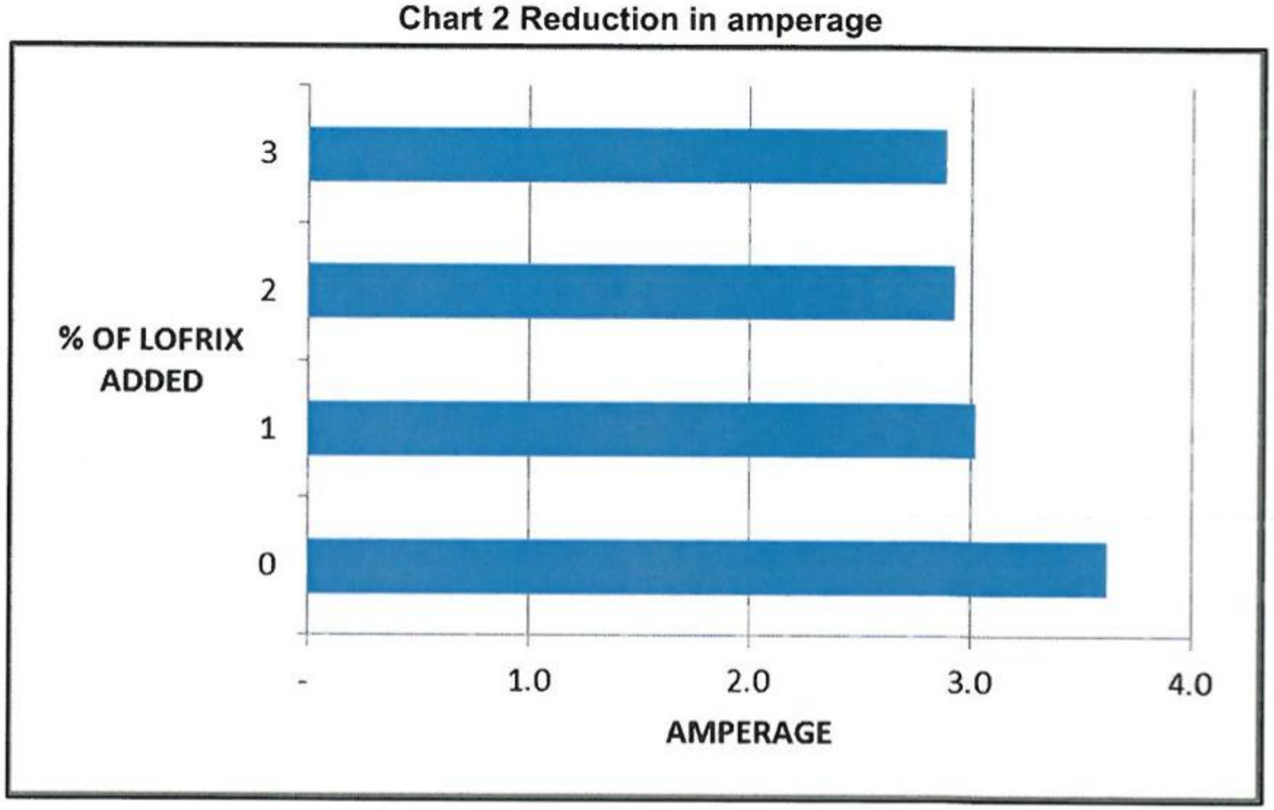
Figure 4 Pressure applied via a lever



Courtesy: Professor Andrew Ball, University of Huddresfield

3. Anti-wear capabilities – roller -& spindle / shaft & break





Courtesy: Professor Andrew Ball, University of Huddersfield

3. Anti-wear capabilities – roller -& spindle / shaft & break

Figure 5 Wear scar at 0% Lofrix

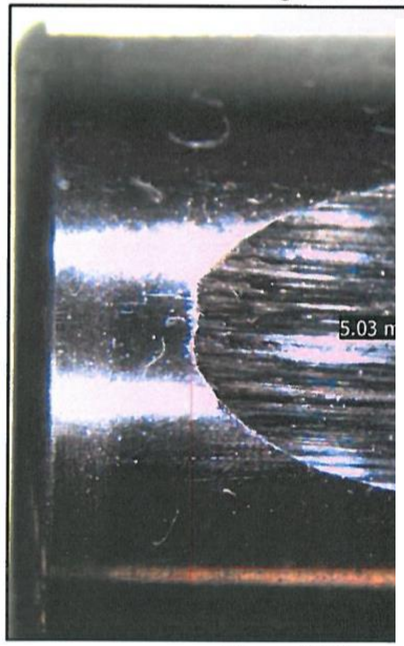


Figure 6 Wear scar at 1% Lofrix

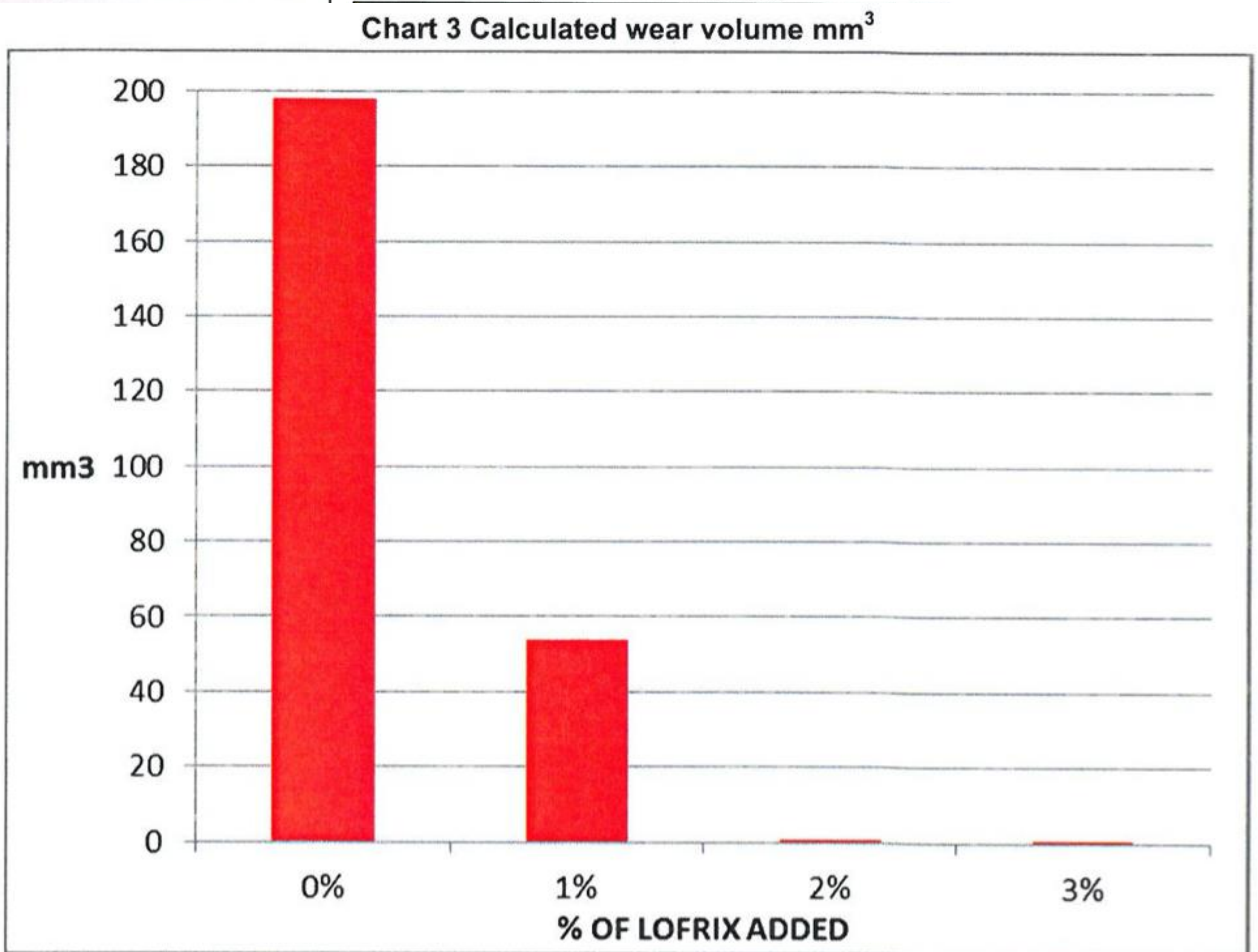
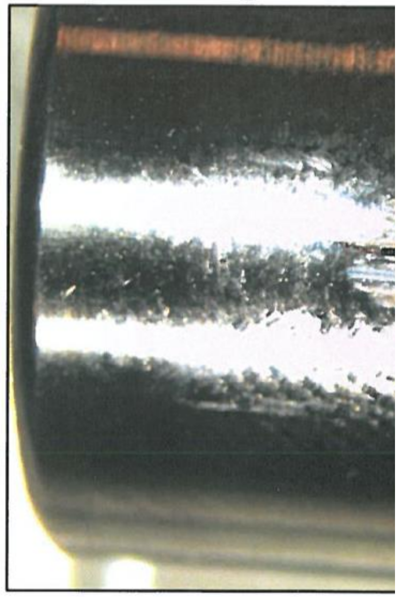


Figure 7 Wear s



Courtesy: Professor Andrew Ball, University of Huddrersfield

4. Tribofilm adhesion – cutting tools

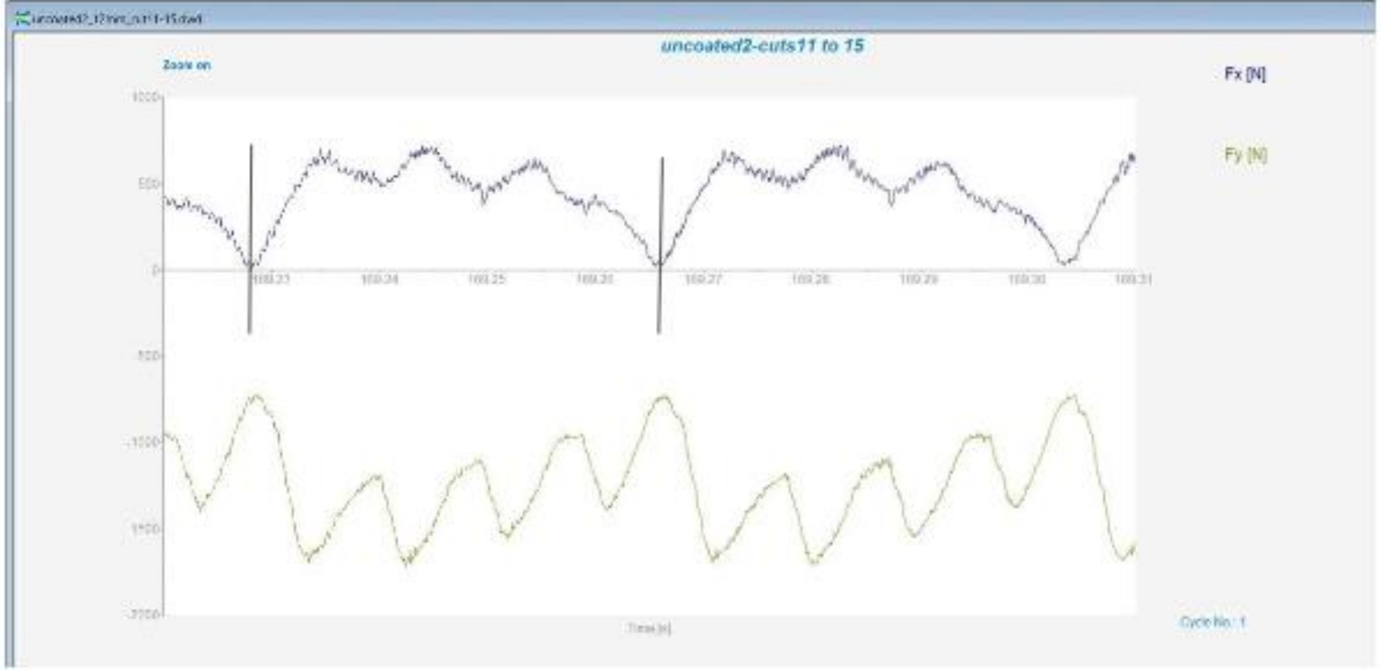
DMG Mori NVX5080

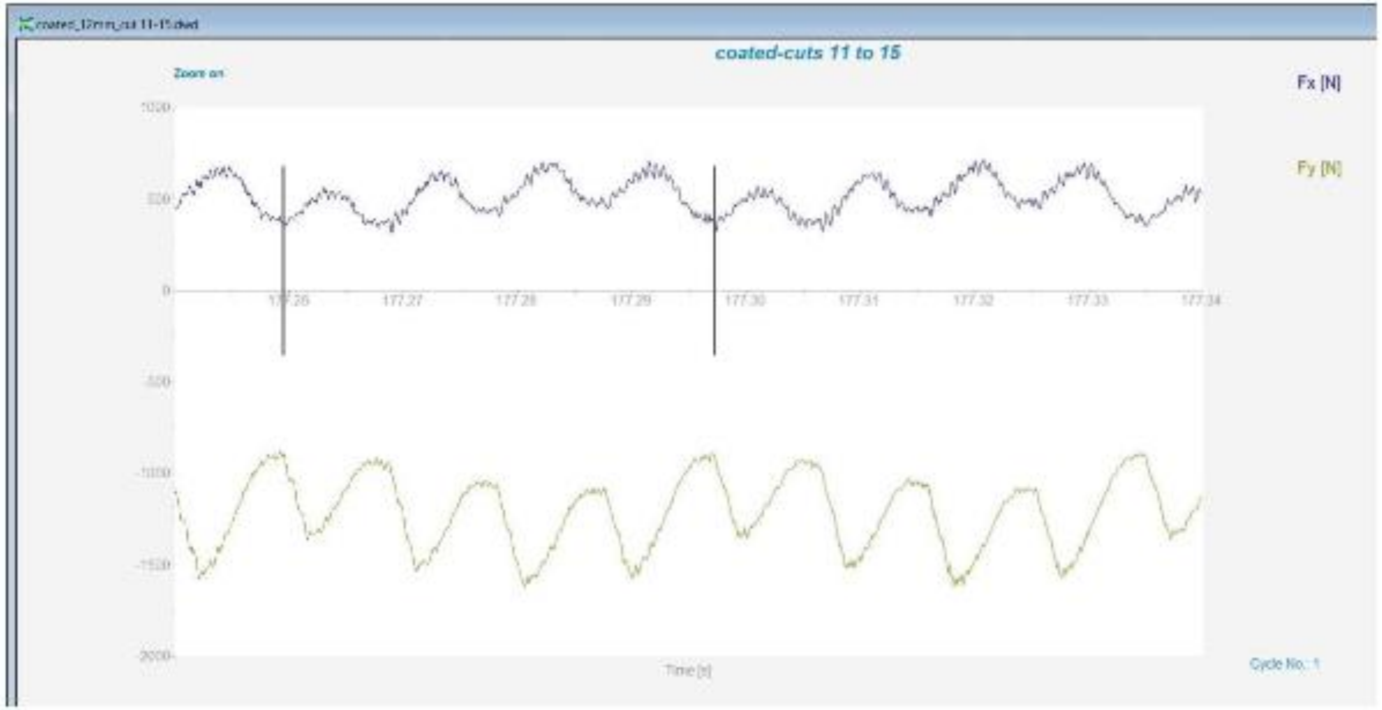
2off Nikken-
NBT40-C20-70
tool holders
with (OSG)
cutter

Kistler Dyno
Type 9255C

Steve Townley, Advanced Manufacturing and Research Centre, University of Sheffield

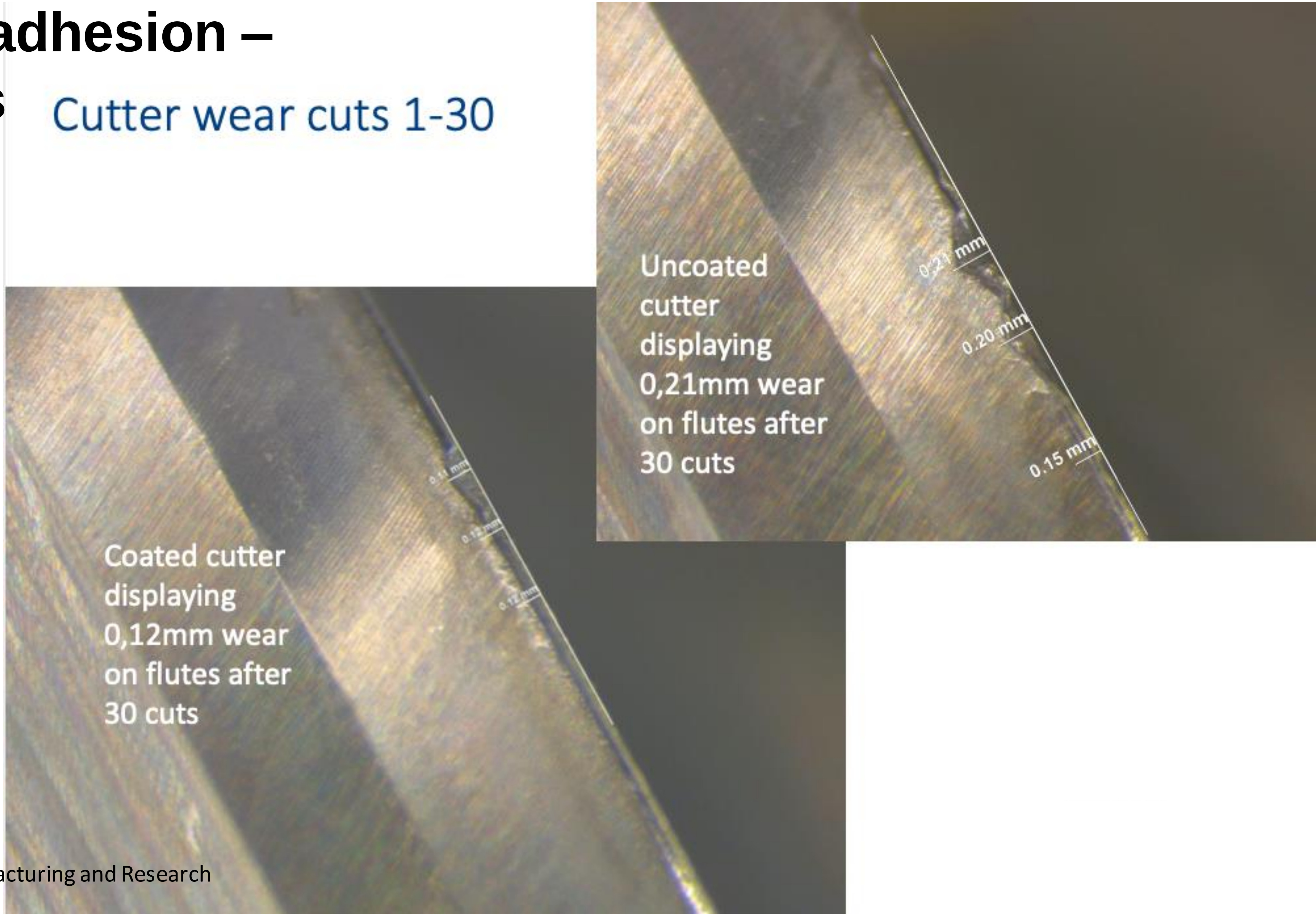
4. Tribofilm adhesion – cutting tools





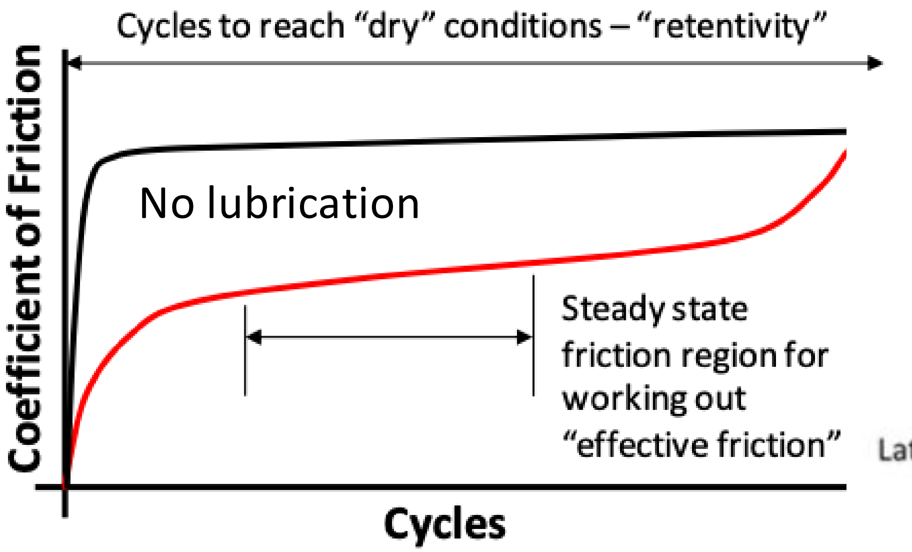
Steve Townley, Advanced Manufacturing and Research Centre, University of Sheffield

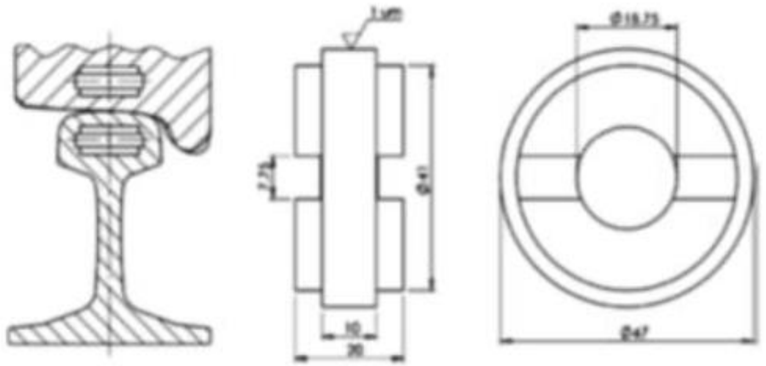
4. Tribofilm adhesion – cutting tools

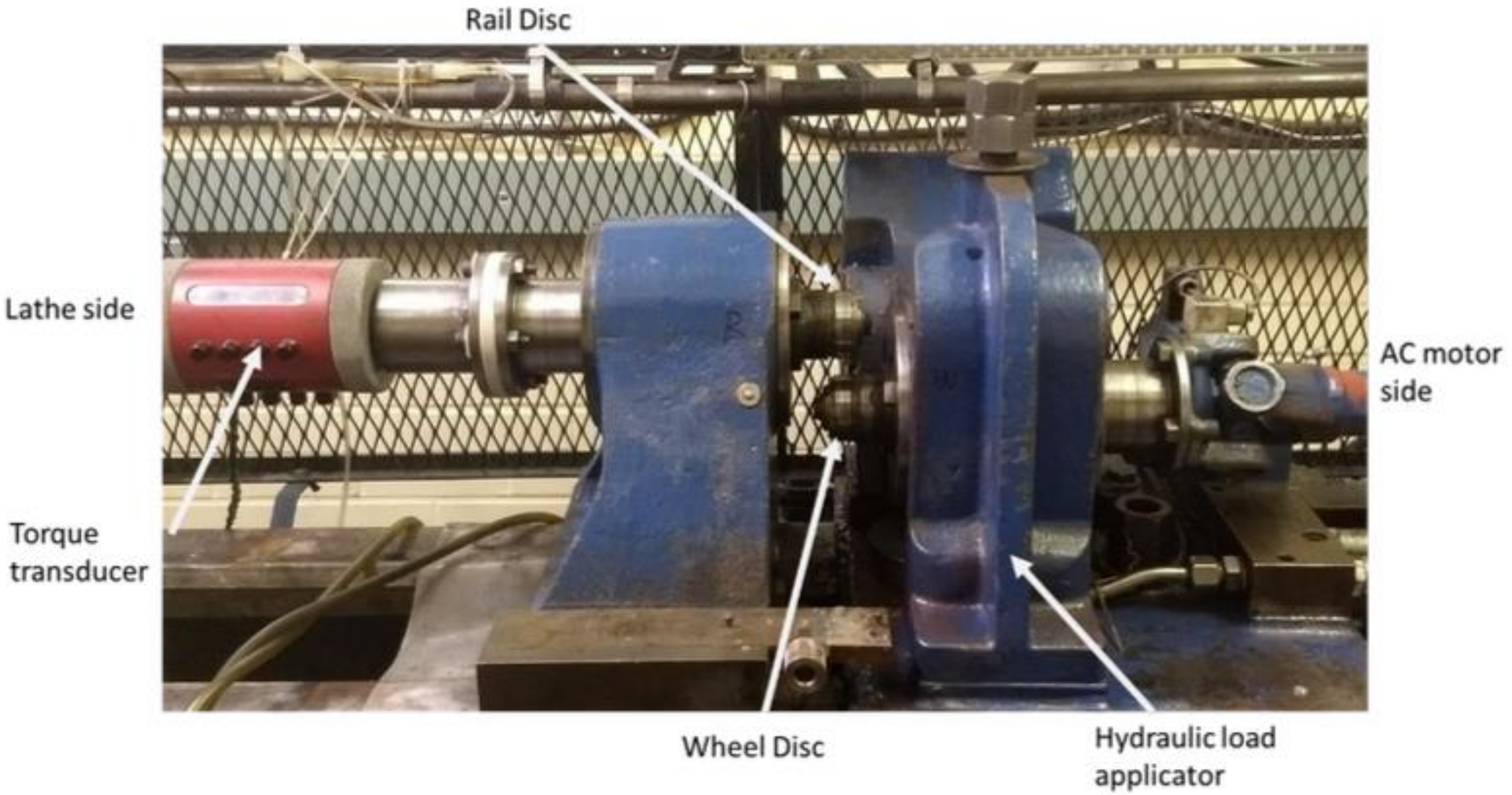


Steve Townley, Advanced Manufacturing and Research Centre, University of Sheffield

5. Evolution of coefficient of friction – rails steels







Courtesy Professor Roger Lewis, University of Sheffield

5. Evolution of coefficient of friction – rails steels

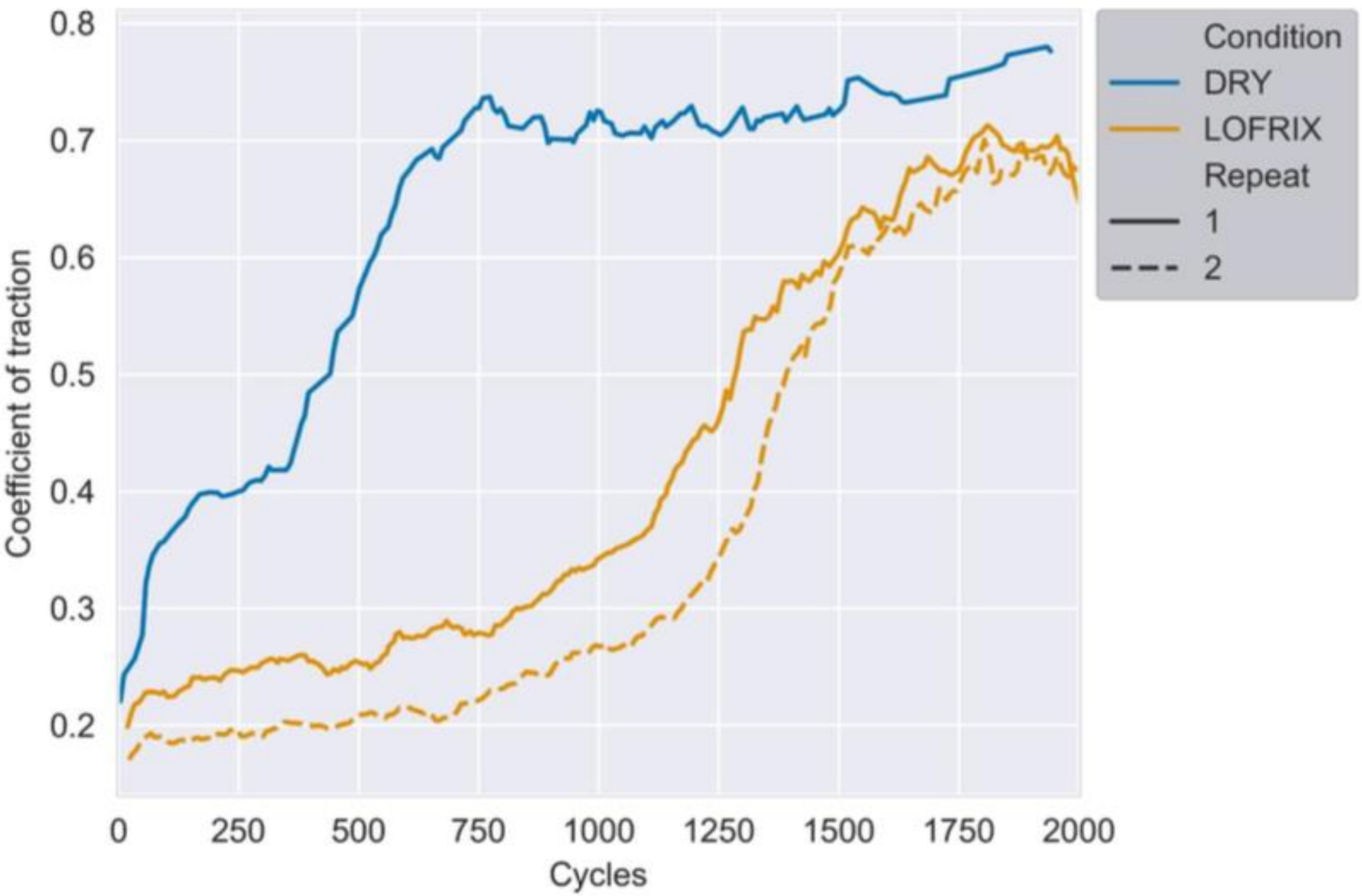
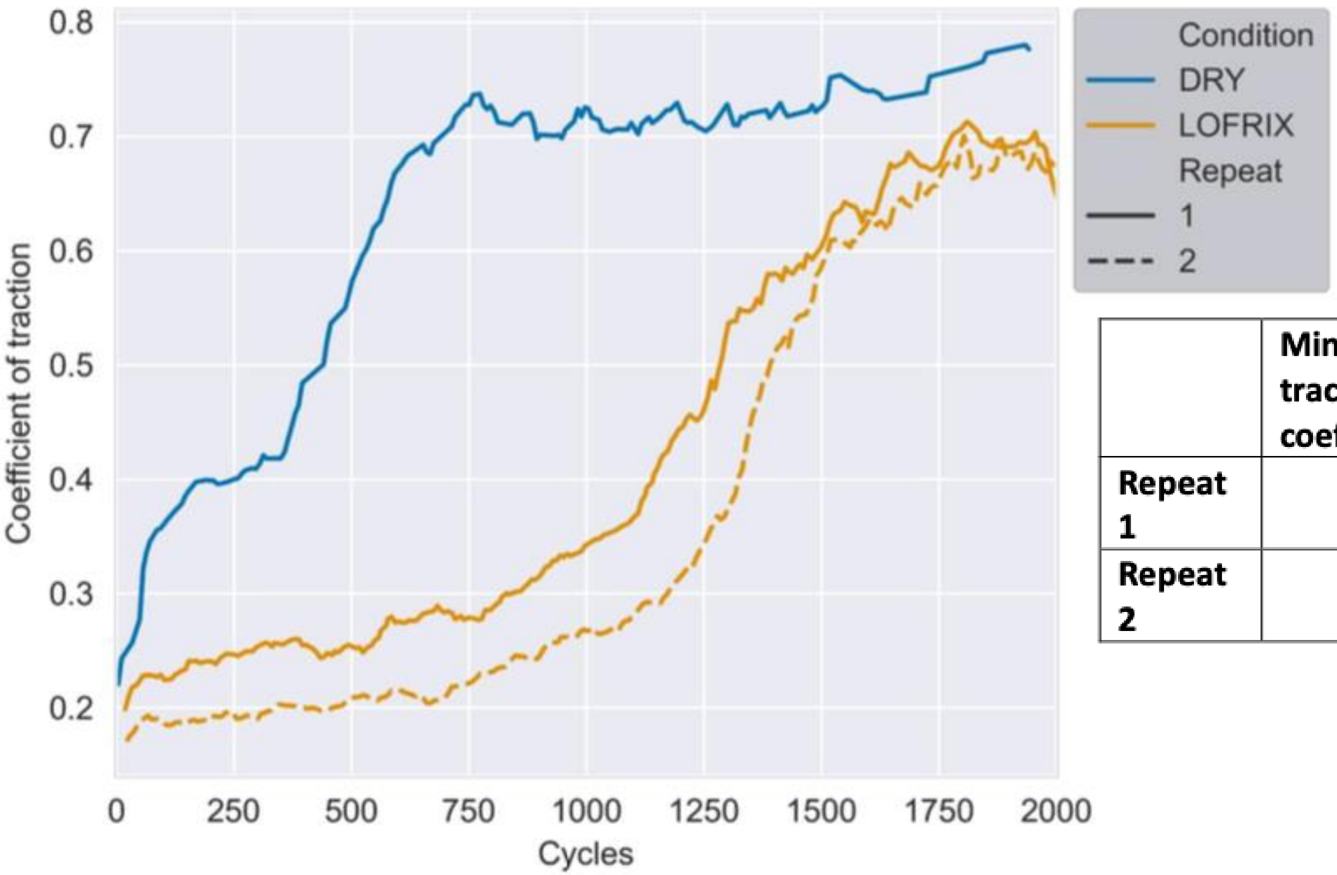


Figure 7 Repeat 2 Rail disc before (L) after (R)

Courtesy Professor Roger Lewis, University of Sheffield

5. Evolution of coefficient of friction – rails steels



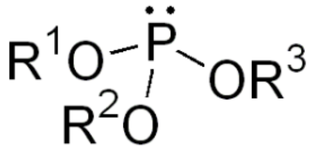
	Minimum traction coefficient	Average traction coefficient for first 1000 cycles ("effective friction")	Cycles to reach a traction coefficient of 0.4 ("retentivity")
Repeat 1	0.15	0.26	1140
Repeat 2	0.15	0.20	1324

Table 3 Coating performance criteria

Courtesy Professor Roger Lewis, University of Sheffield

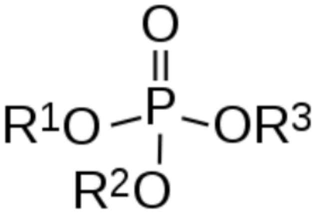
6. Nature of tribolayer – chemistry

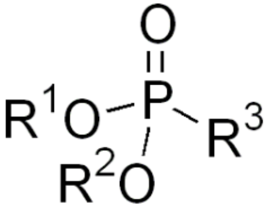
Three classes of ashless antiwear additives studied
R groups were also varied



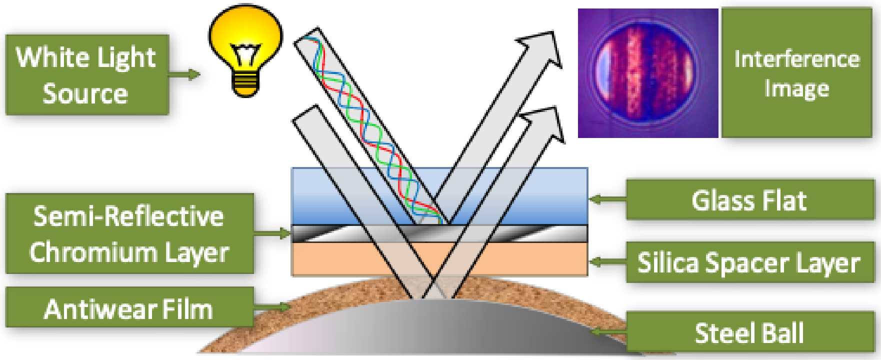
Phosphite

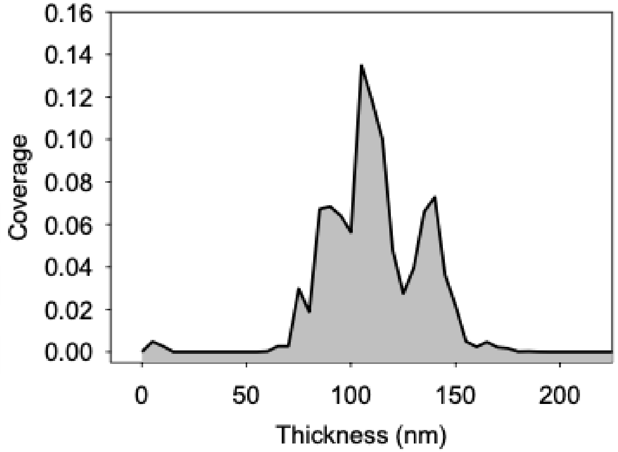
Phosphate

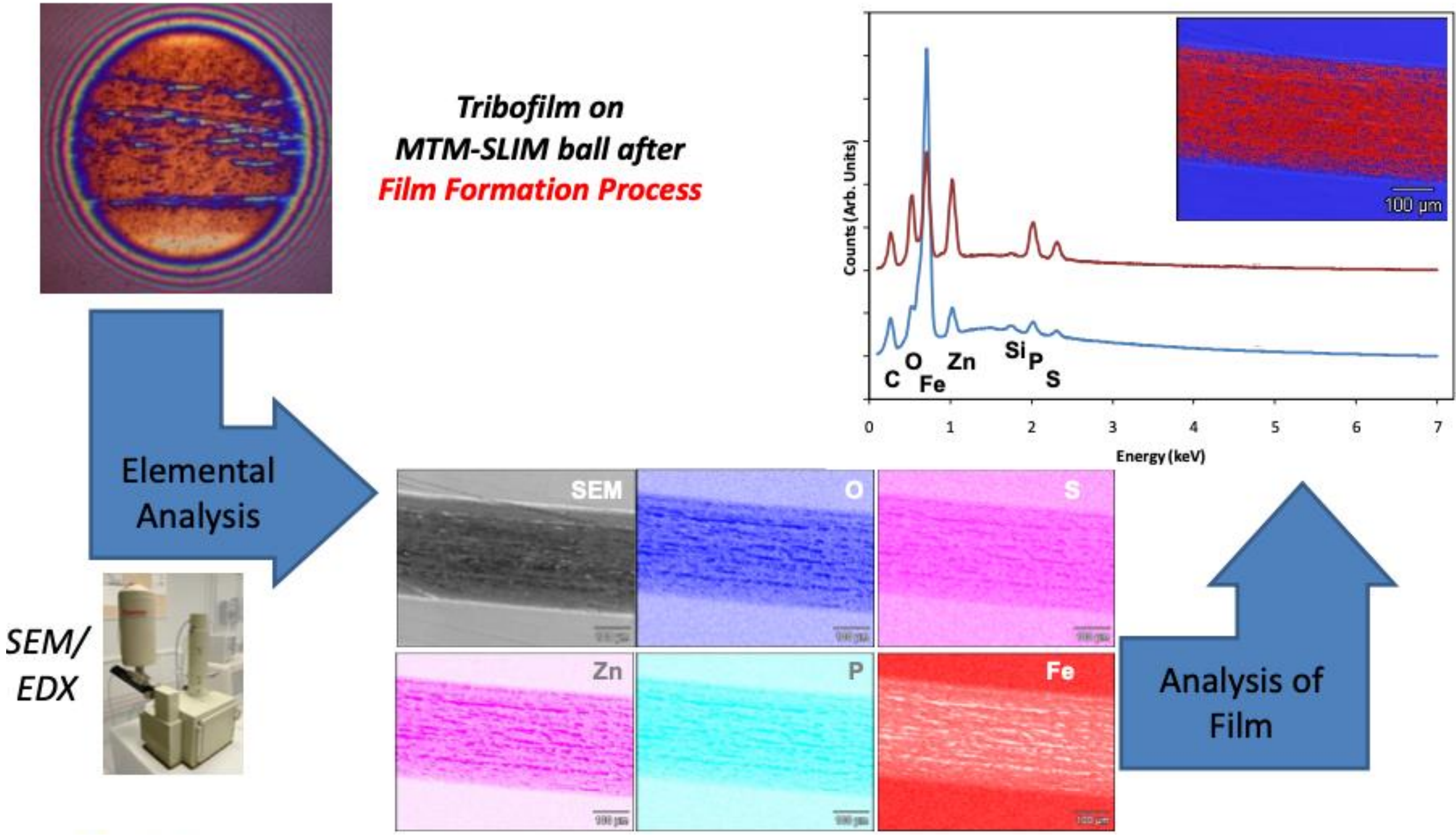




Phosphonate



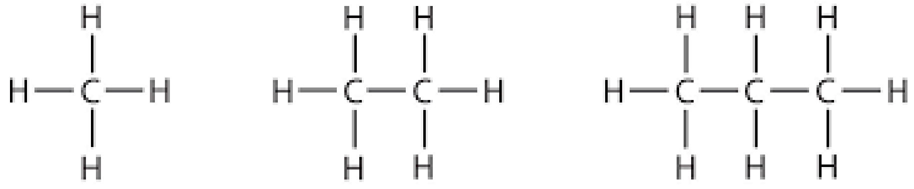




Courtesy of Jeffrey M. Guevremont, Afton Chemicals

6. Nature of tribolayer – Lofrix chemistry

Alkanes



Methane Ethane Propane

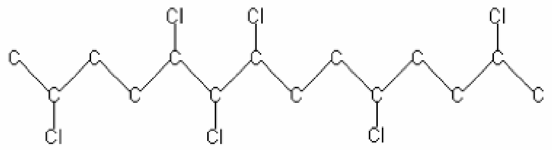
* IUPAC Name: alkanes, C_{14-17}, chloro

Synonyms: chlorinated paraffin (C_{14-17}); chloroalkanes, C_{14-17}; chloroparaffin; chloroparaffine, C_{14-17}; medium-chain chlorinated paraffins; paraffine clorurate (C_{14-17}); paraffine clorurate a catena media.

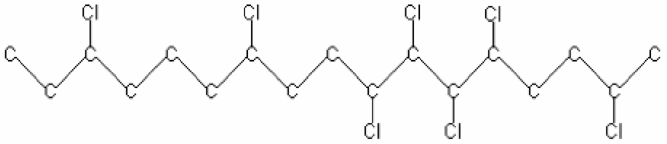
Molecular weight: 233-827 g/mole

Molecular formula: $C_xH_{(2x-y+2)}Cl_y$, where x = 14-17 and y = 1-17

Structural formula:



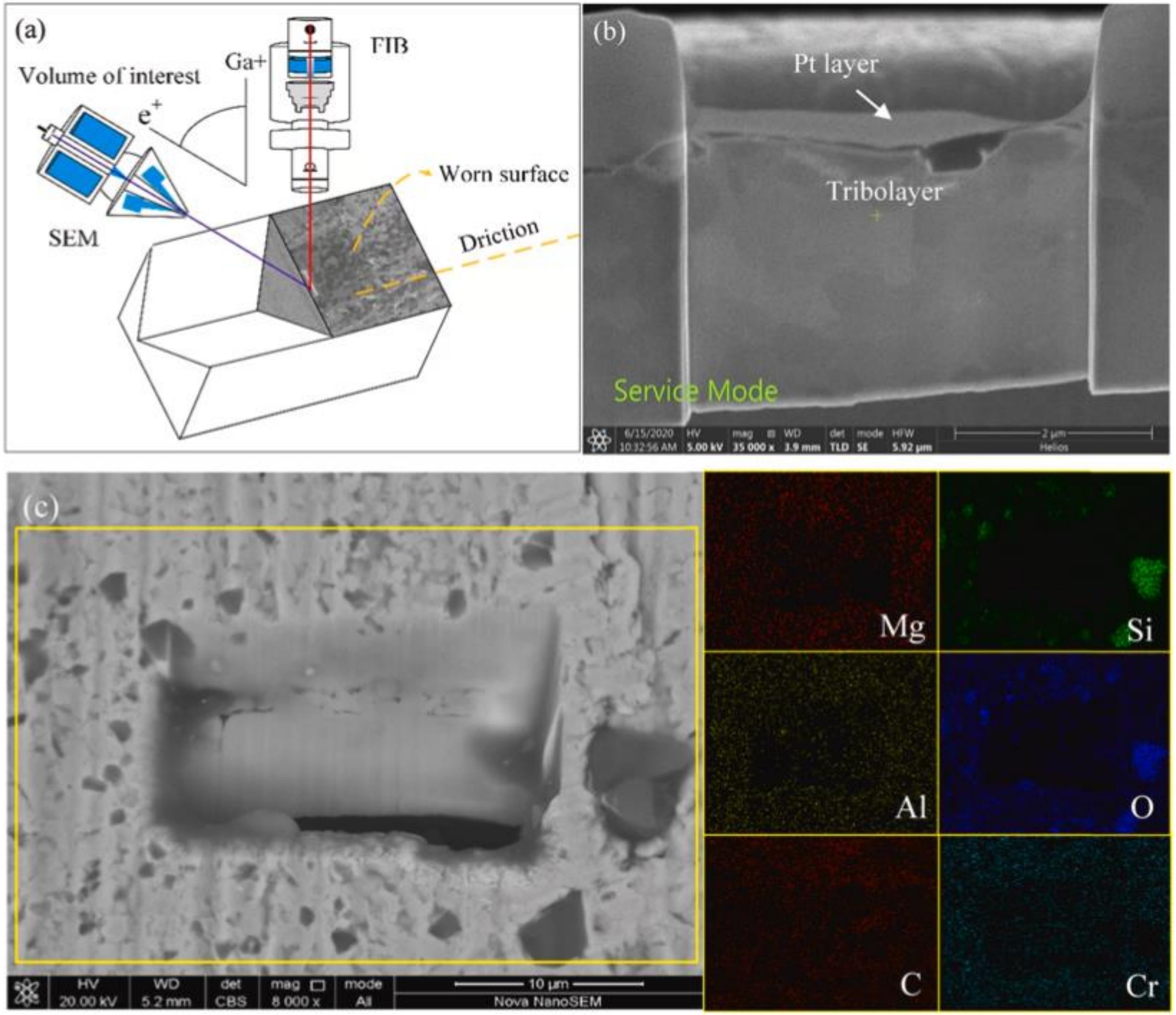
$C_{14}H_{24}Cl_6$

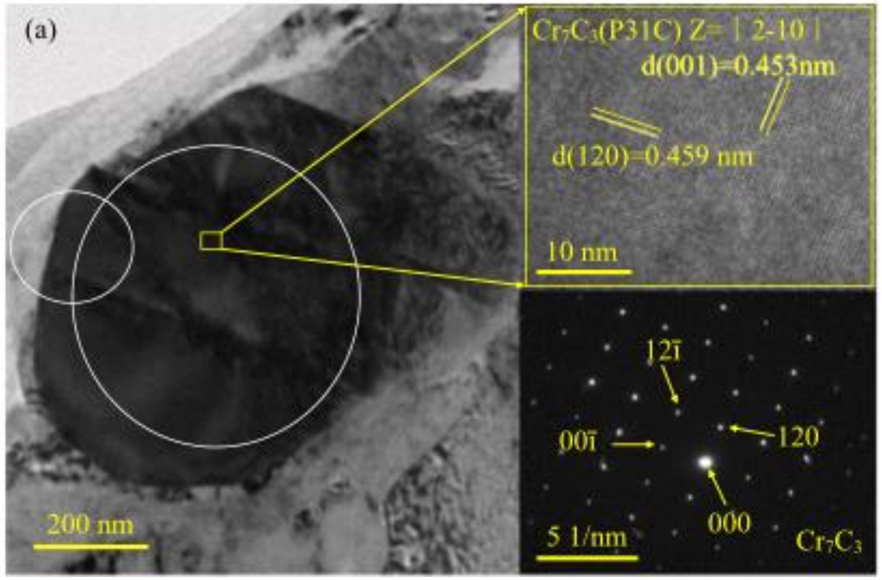


$C_{17}H_{29}Cl_7$

* Institute for Health and Consumer Protection European Chemicals Bureau, I-21020 Ispra (VA) Italy

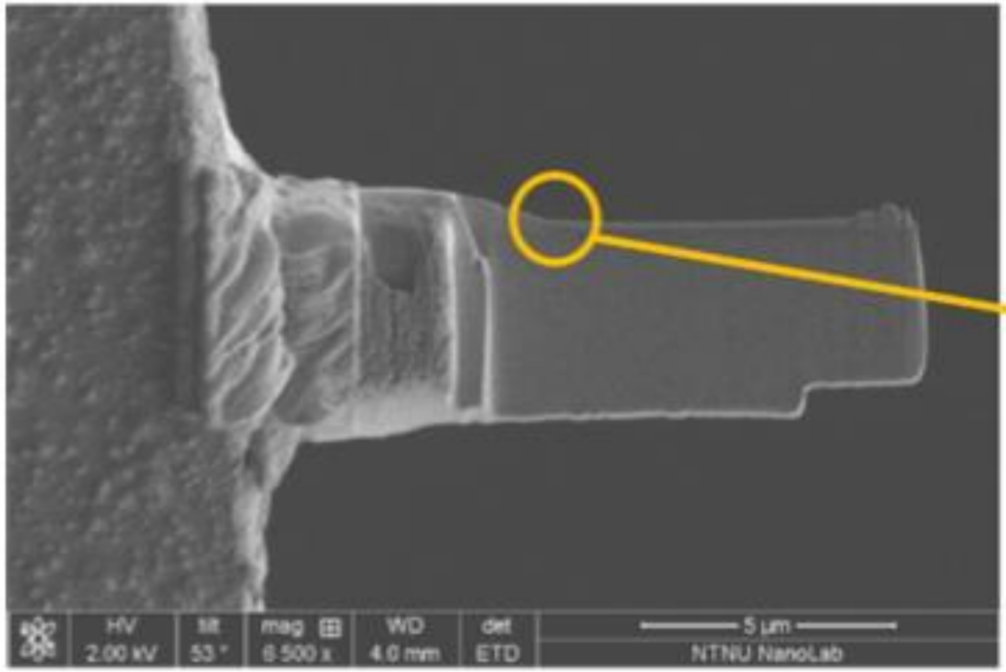
7. Nature of tribolayer – physical properties

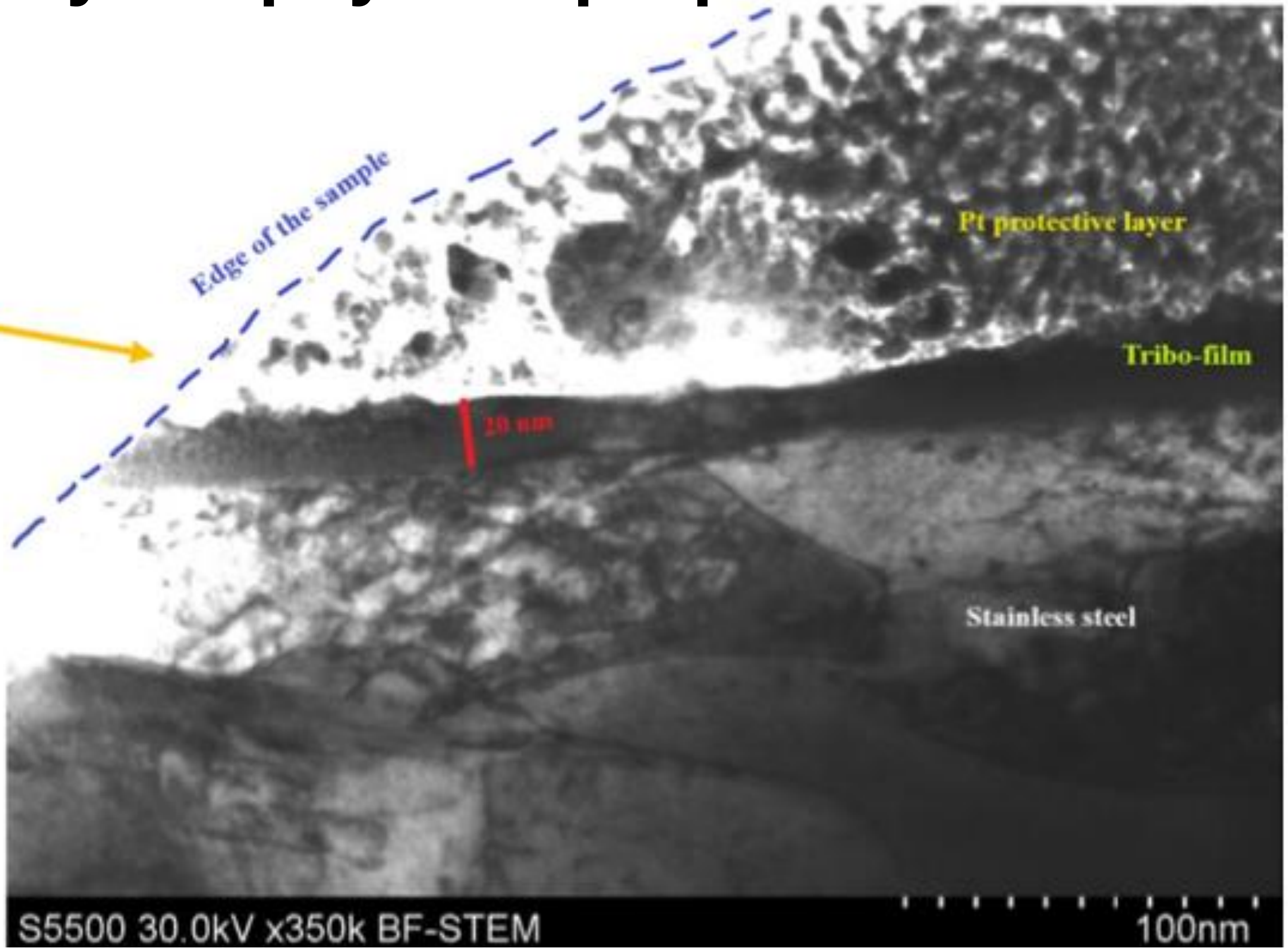


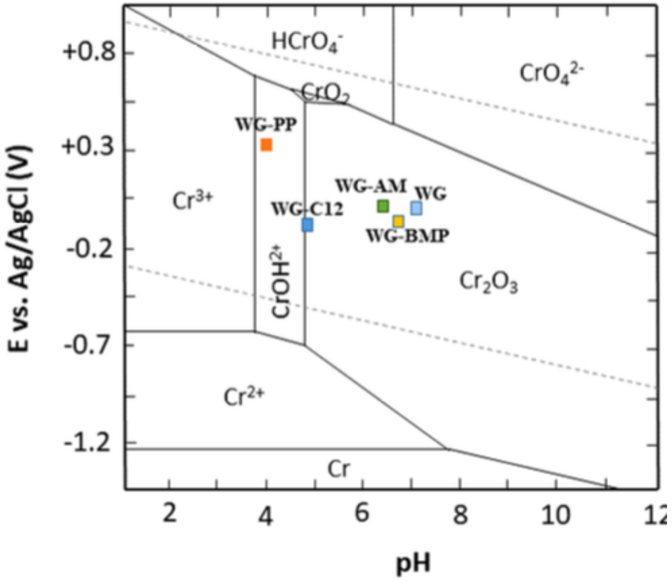


Courtesy: Zhang *et al.* Tribology International 173 (2022) 107637

7. Nature of tribolayer – physical properties



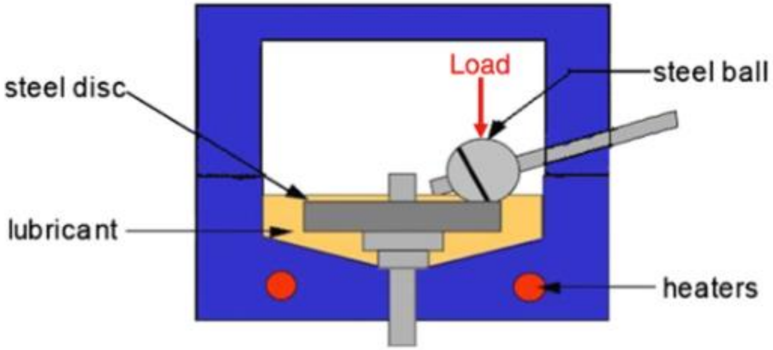




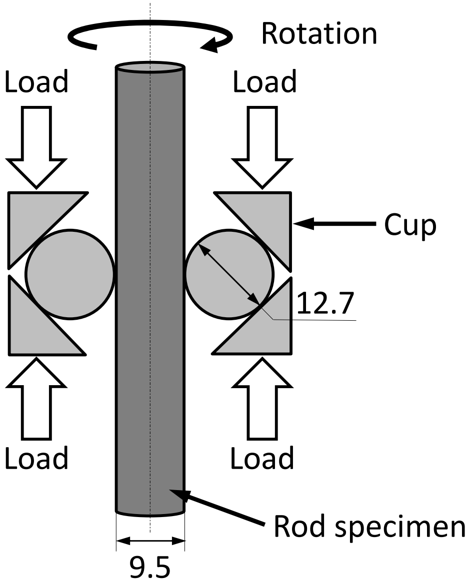
Courtesy: Khanmohammadi *et al. Tribology Letters (2020) 68:130*

8. Statistical tests and future work

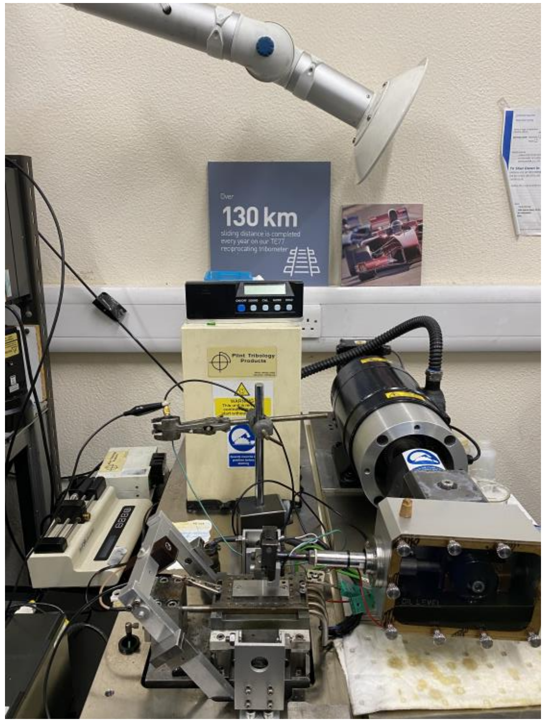
Flat washer – ball testing (MTM machine)



Three ball on rod



Friction measurements (TE77)



8. Statistical tests and future work

1. Focused ion beam and production of lamellae
2. TEM observation of tribofilm
3. Characterisation of friction compounds
4. Comparison with Pourbaix diagrams (Thermocalc)
5. Comparison with literature reports

Contact

http://www.lofrix.com/products/lofrix-dry.html

p.rivera1@Lancaster.ac.uk

Thank you!