THE EFFECT OF CONTAMINATION ON FRICTION MODIFICATION IN THE WHEEL-RAIL CONTACT

Šimon Skurka

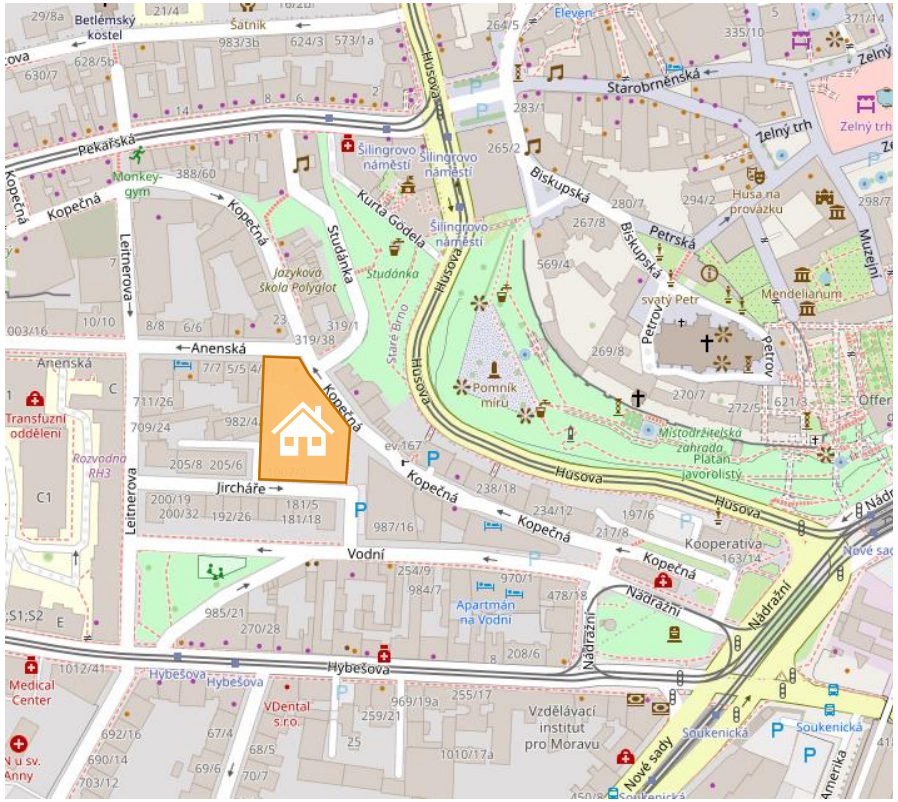
Supervisor: prof. Ing. Martin Hartl, PhD

Co-supervisor: doc. Ing. Radovan Galas, PhD

Brno, 2026

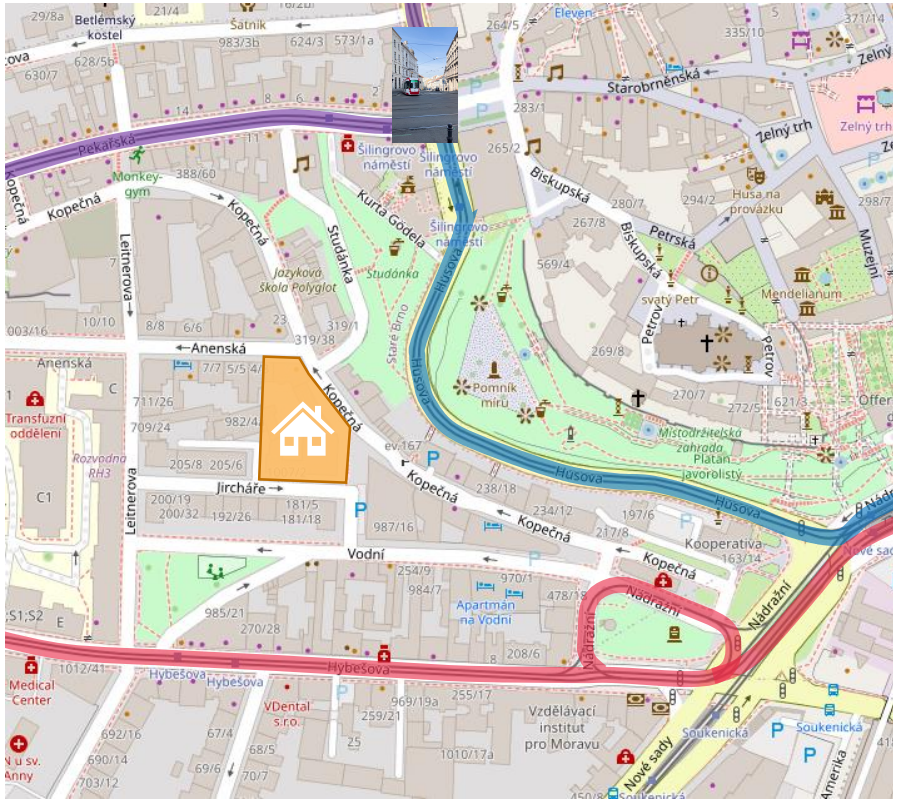
BRNO UNIVERSITY OF TECHNOLOGY

MOTIVATION


Betlémský kostel
Šatník
Husova
Eleven
Starobrněnská
Zelný trh
Pekařská
Šilingrovo náměstí
Biskupská
Petrská
Husa na provázku
Muzejní
Monkey-gym
Kopečná
Kurta Gödela
Studánka
Jazyková škola Polyglot
Leitnerova
Mendelianum
svatý Petr
Petrov
Anenská
Pomník míru
Místodržitelská zahrada
Platan javorolistý
Transfúzní oddělení
Rozvodna RH3
Jirchářa
Husova
Kooperativa
Vodní
Apartmán na Vodní
Nádražní
Hybešova
Medical Center
VDental s.r.o.
Vzdělávací institut pro Moravu
Soukenická
Nové sady

MOTIVATION

Line 6

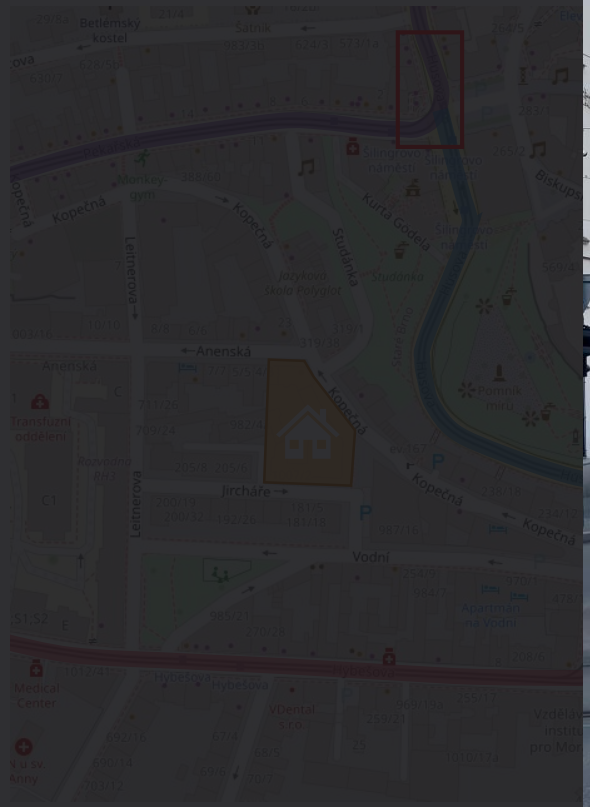


Line 1

Line 12

Trams operate daily from 5:00 AM to 11:00 PM.

Line 6



Line 1

Trams operate daily fr
to 11:00 PM

MOTIVATION

More than **22.6 million** EU residents are exposed to noise emissions from rail transport.

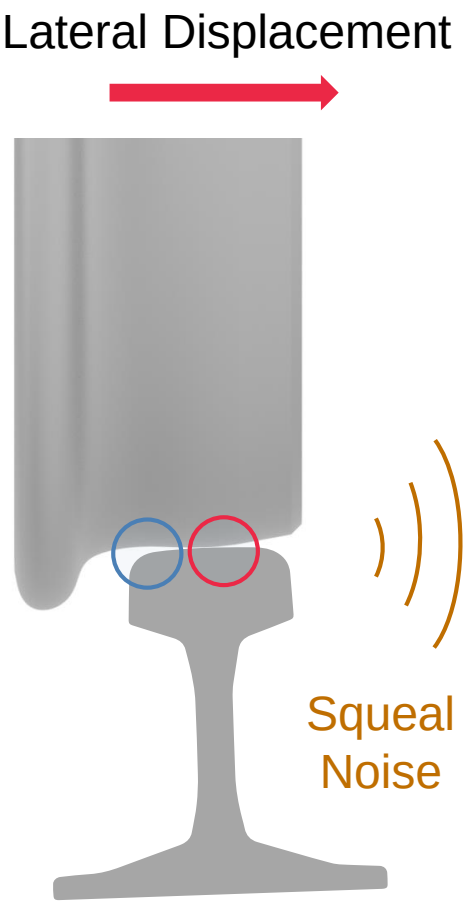
Up to **6.5 million** people living near transport corridors suffer from sleep disturbances.

Long-term exposure leads to **12,000** premature deaths and **48,000** cases of ischemic heart disease annually.

World Health Organization

European Environment Agency

MOTIVATION



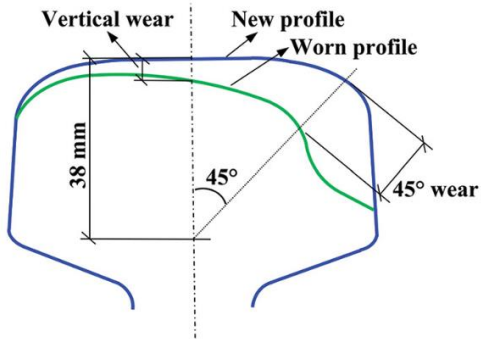
Wheel Flange Contact

- High pressure: 0.6–2.6 GPa
- High slip: < 8 %
- Target friction: f (μ) < 0.1
- Flange lubrication

Top-of-Rail Contact

- Pressure: 0.5–1.5 GPa
- Slip: < 3 %
- Target friction: f (μ) ~ 0.2–0.4
- Top-of-rail friction modification

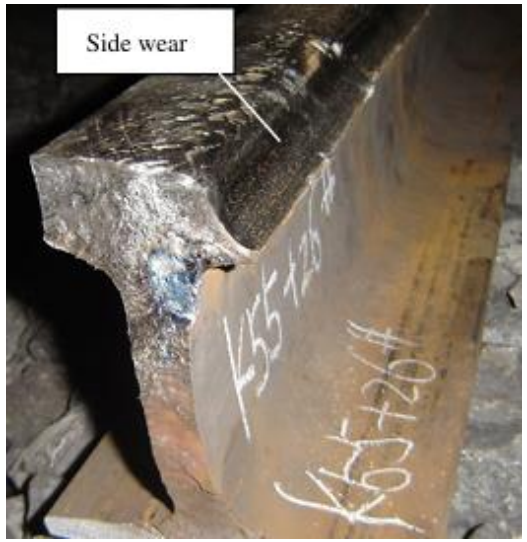
MOTIVATION



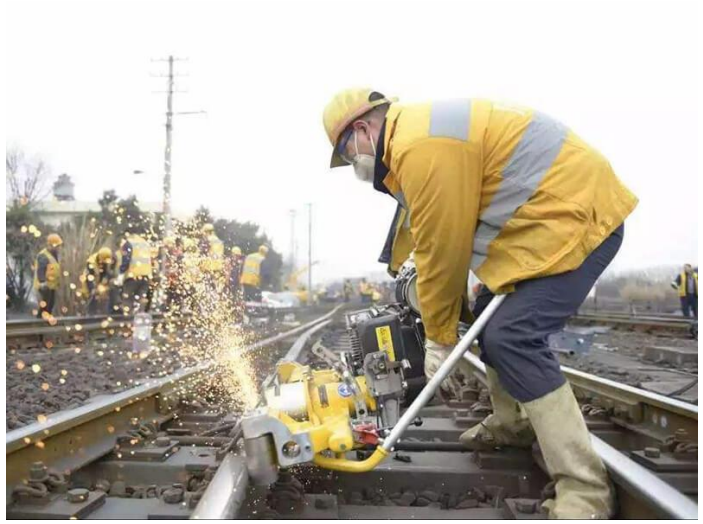
Annual Cost of Wear:

$ **2B** (USA)[1]
1.2B (China)[2]

1) The American Association of Railroads; 2) Jin et al. (2009); upper left: Vernaillen et al. (2023); lower left: Jin et al. (2009); middle left: railroadrails.com; middle right: Tsunashima et al. (2012); uppper right: Huang et al. (2018); lower right: Igwemezie Jude (2014)

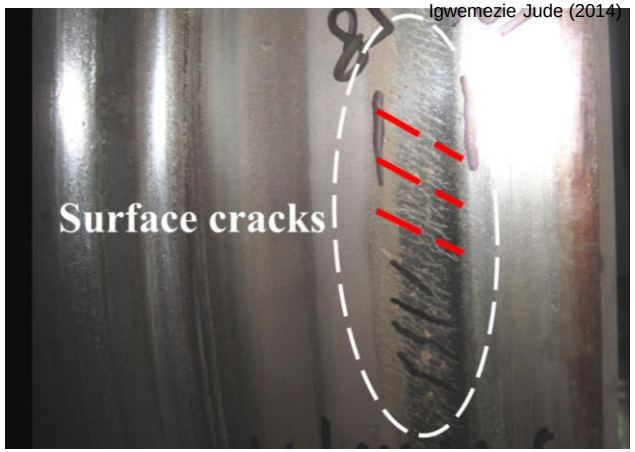


Wear Due to High Slip



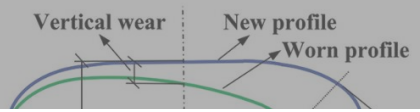
Rail Grinding

Corrugation



Rolling Contact Fatigue

MOTIVATION



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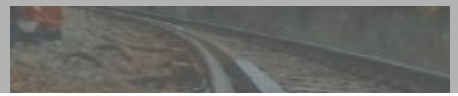
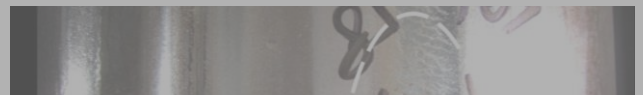


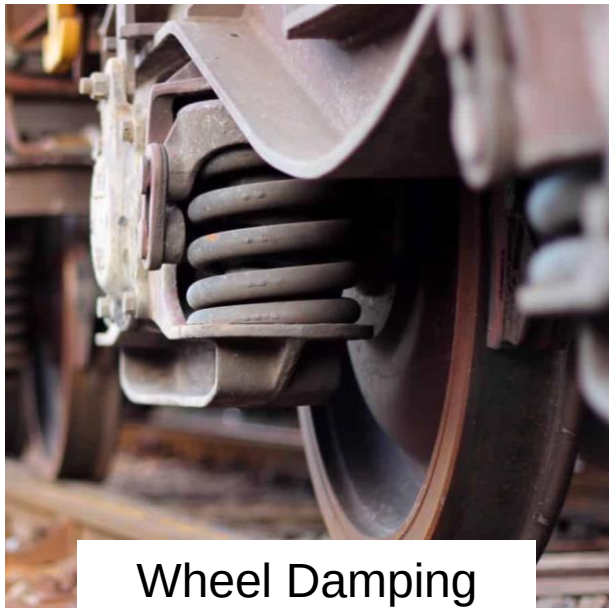


Sound Barriers

its-acoustique.fr

TOR Friction Modification

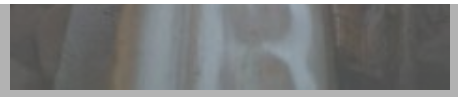
lbfoster.com



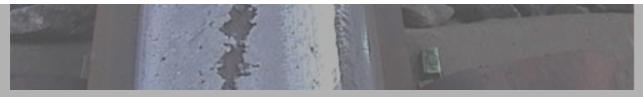
Wheel Damping

thechopal.com

Wear Due to High Slip



Corrugation



Rolling Contact Fatigue

STATE OF THE ART

STATE OF THE ART

SkyTrain

lbfoster.com

„Solid sticks“ are used to address problems with noise and corrugation on the Vancouver SkyTrain.

Early 1990s | 2000s | 2016 | 2017 | 2018 | 2021

STATE OF THE ART

Off-board Application

On-board Application

Liquid-based Friction Modifiers

Early 1990s | 2000s | 2016 | 2017 | 2018 | 2021

STATE OF THE ART

Categorisation of Top-of-Rail Products (TOR Products)

Contents lists available at ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

Material concepts for top of rail friction management – Classification, characterisation and application

Richard Stock [a,*], Louisa Stanlake [a], Chris Hardwick [b], Marcia Yu [a], Donald Eadie [a], Roger Lewis [c]

[a] LB. Foster Rail Technologies, Burnaby, Canada
[b] LB. Foster Rail Technologies, Sheffield, United Kingdom
[c] Department of Mechanical Engineering, The University of Sheffield, Sheffield, United Kingdom

Liquid Forms of TOR Products:

1) Friction Modifiers (Water-based)
2) TOR Lubricants (Oil/Grease-based)
3) TOR Hybrids (Both Water and Oil)

Early 1990s | 2000s | 2016 | 2017 | 2018 | 2021

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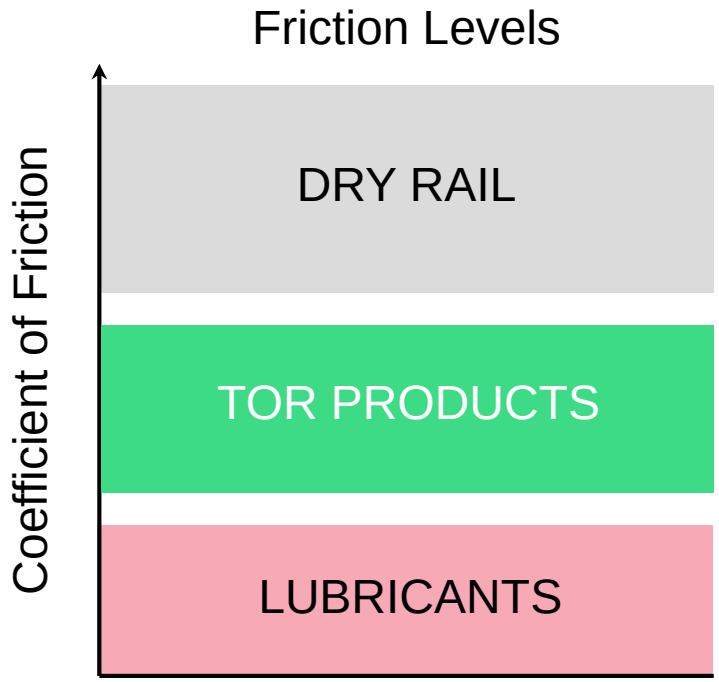

Dry Friction ($f > 0.5$)
(high wear and noise, but no problems with traction/braking)

Intermediate Friction (f ~ 0.2–0.4)
(wear and noise reduced without low adhesion problems)

Low Adhesion ($f < 0.15$)
(low wear and noise, problems with traction and braking)

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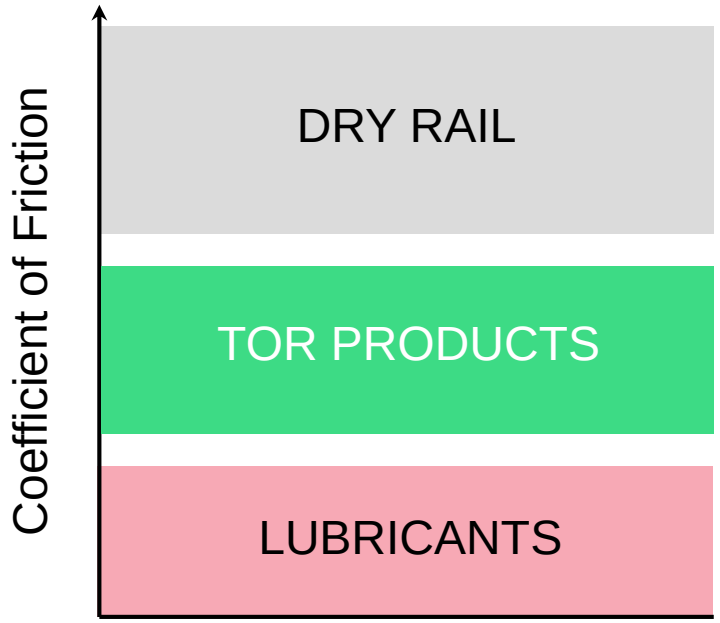
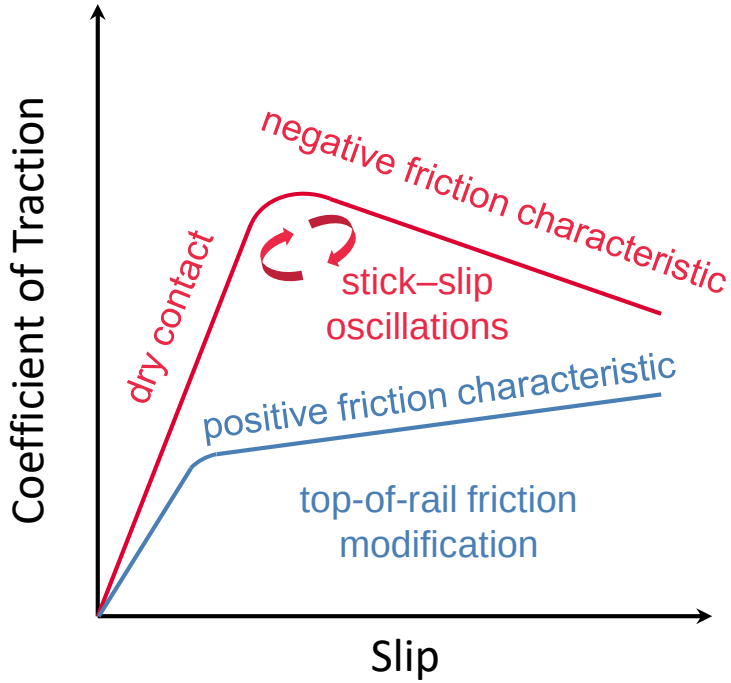
Friction Levels



Creep Curves



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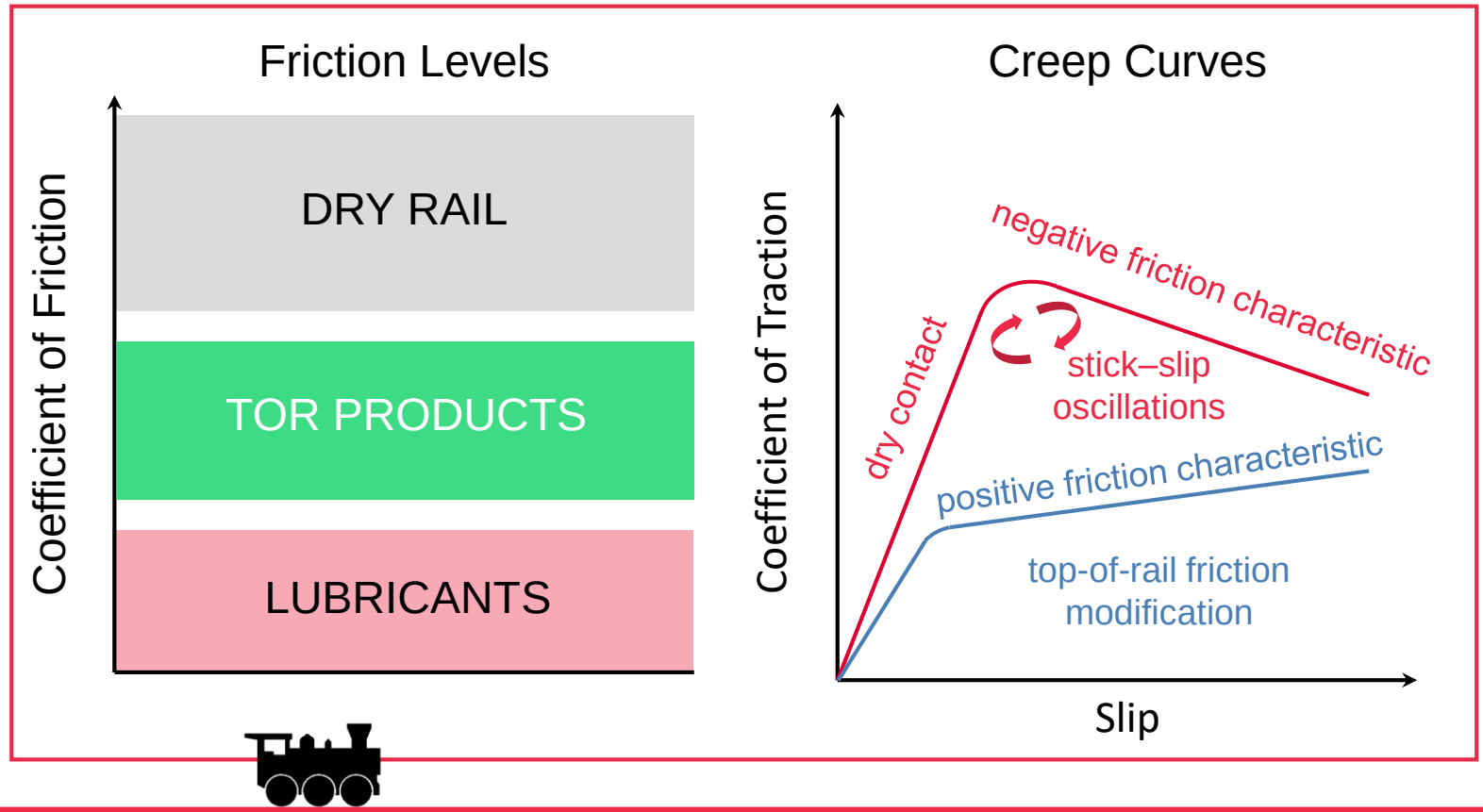
The Main Function of TOR Products



Early 1990s | **2000s** | **2016** | **2017** | **2018** | **2021**

STATE OF THE ART

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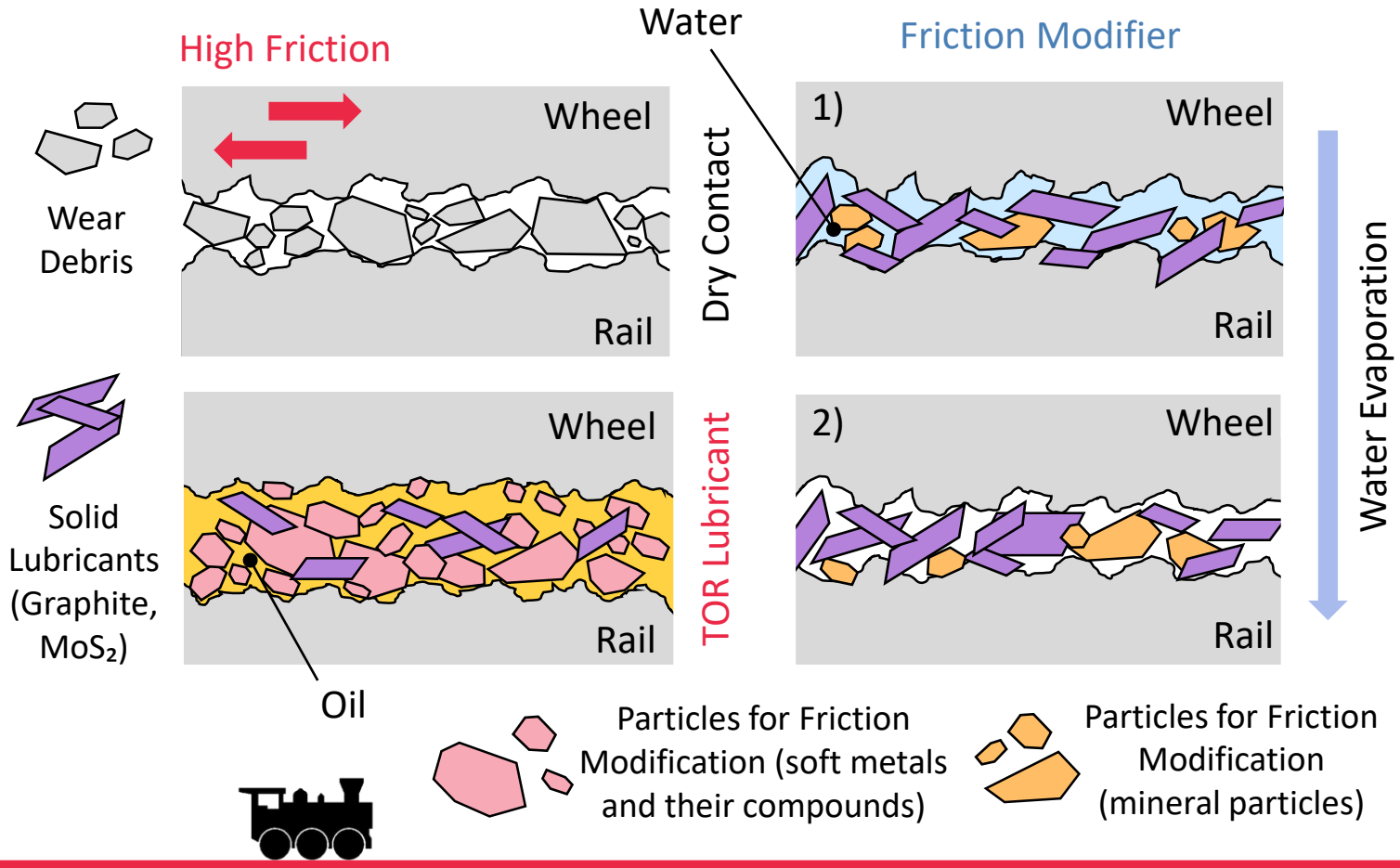
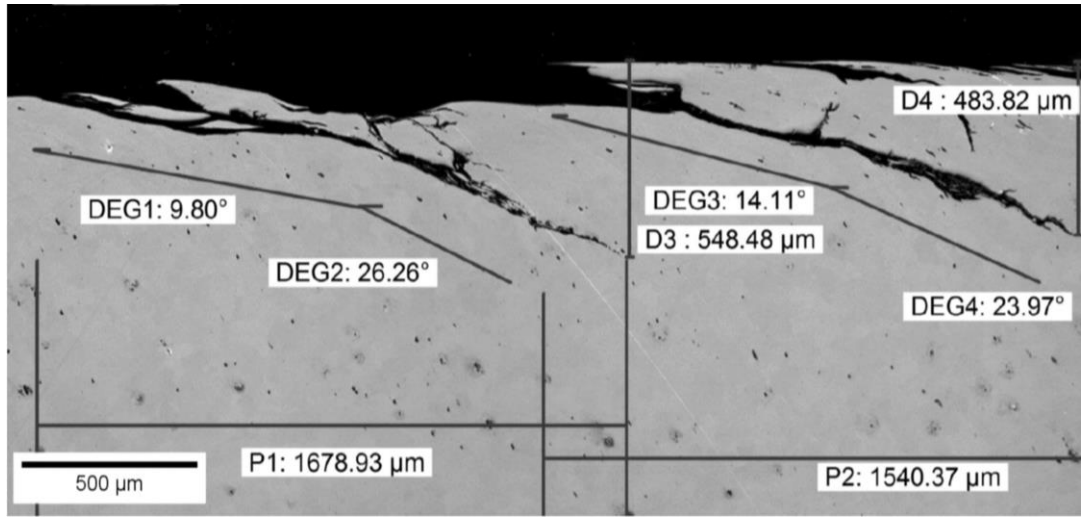


Early 1990s | 2000s | 2016 | 2017 | 2018 | 2021

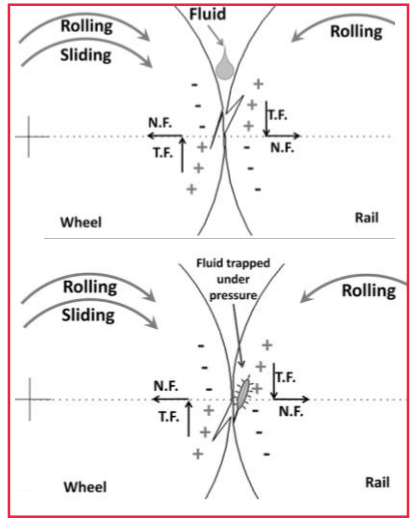
STATE OF THE ART

Possible drawbacks of TOR products

State of the Surface after the use of the TOR Lubricant



Liquid-assisted Crack Propagation

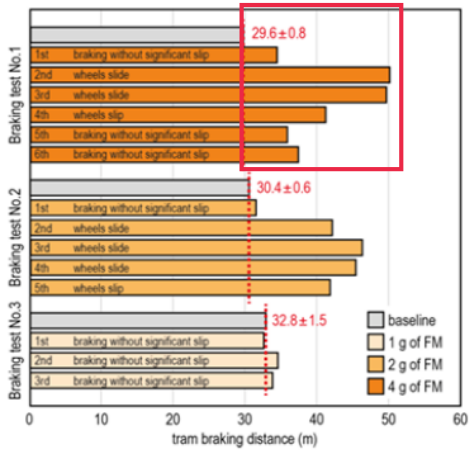


left: Hardwick et al. (2017); right: Maya-Johnson et al. (2017)

Early 1990s | 2000s | 2016 | 2017 | 2018 | 2021

STATE OF THE ART

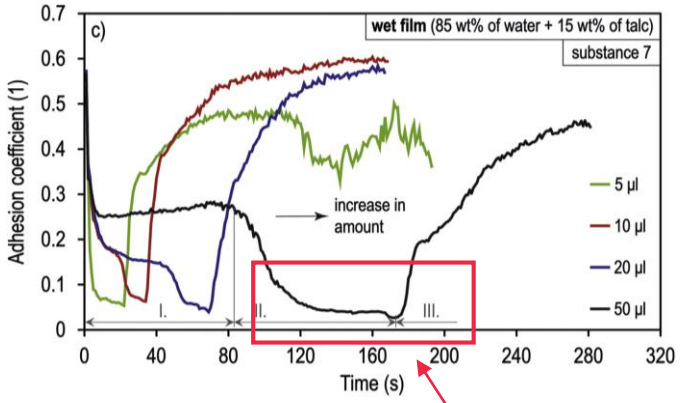
Braking Distance Extended for up to 20 m



Oil-based TOR Lubricants

left and middle: Galas et al. (2017); right: Galas et al. (2018)

Water-based Friction Modifiers



Low Adhesion

Possible drawbacks of TOR products

Early 1990s | 2000s | 2016 | 2017 | 2018 | 2021

STATE OF THE ART

„Start of my PhD Journey“

Original topic: Reducing Noise Emissions in Railway Transport

Early 1990s | 2000s | 2016 | 2017 | 2018 | 2021

STATE OF THE ART

Interval-based application

- The TOR product is applied after every N vehicle passes
- The TOR product is then carried by the wheel of the vehicle

Application Bar

TOR Product Tank

STATE OF THE ART

Interval-based application

- The TOR product is applied after every N vehicle passes
- The TOR product is then carried by the wheel of the vehicle

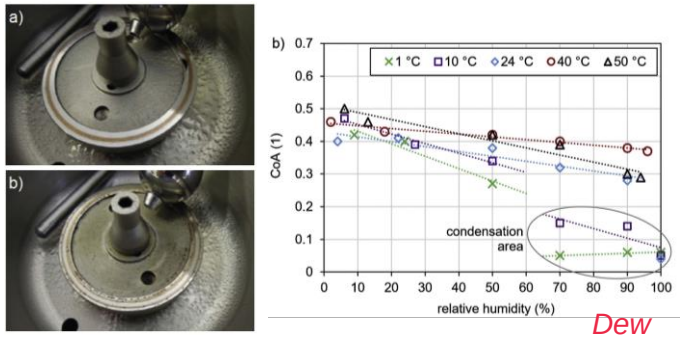
An interval-based application does not account for current track conditions or environmental factors.

Application Bar

TOR Product Tank

STATE OF THE ART

The effect of Humidity and Dew

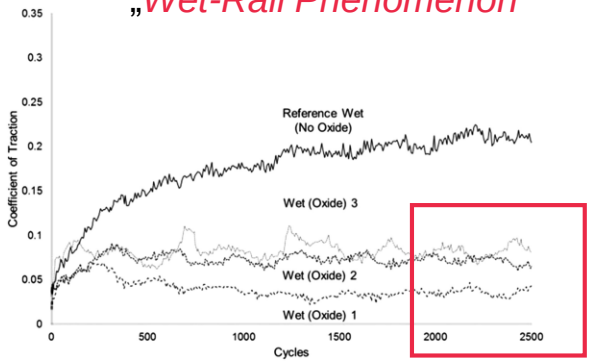


Galas et al. (2020)

Dew Conditions

The effect of Dew and Iron Oxides

„*Wet-Rail Phenomenon*“

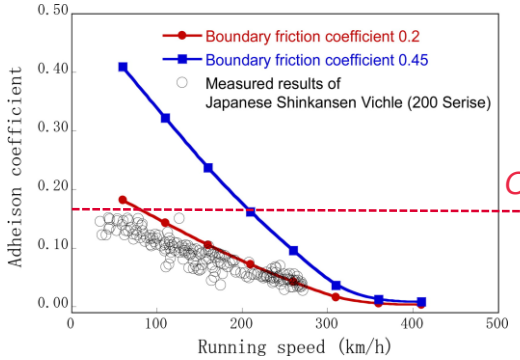


Hardwick et al. (2014)

Low Adhesion

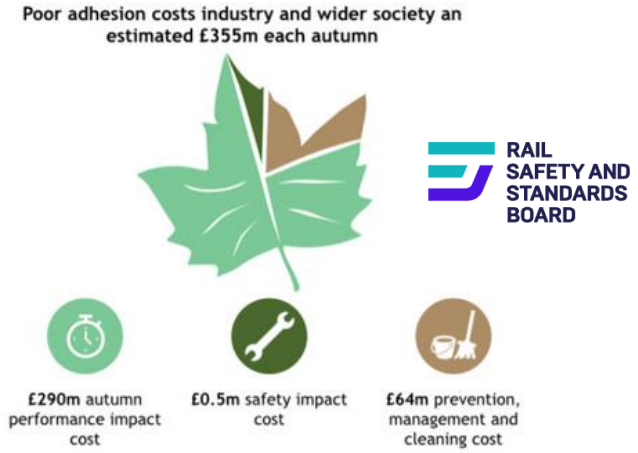
TOR Contact Is an Open Interface

The effect of Water (Precipitation)



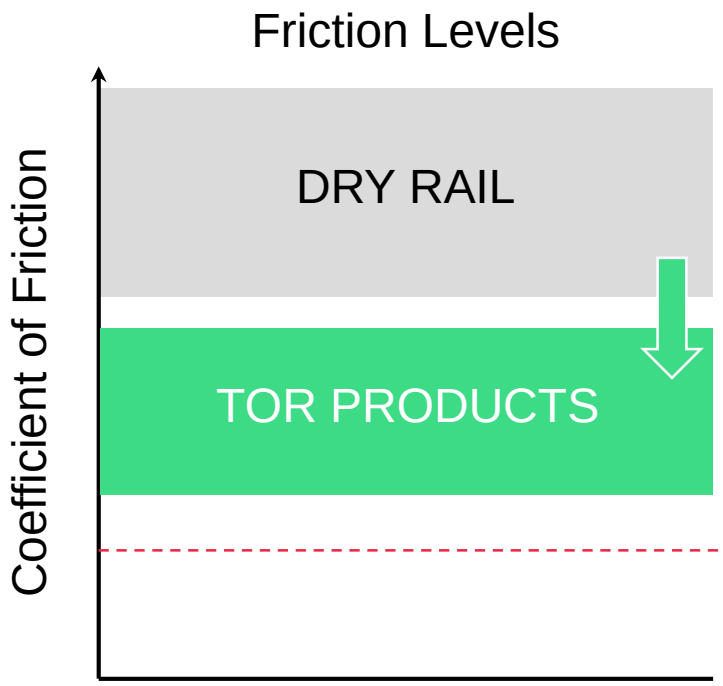
CoA < 0.15

Chen et al. (2011)



Humidity Dew Precipitation Iron Oxides Leaves

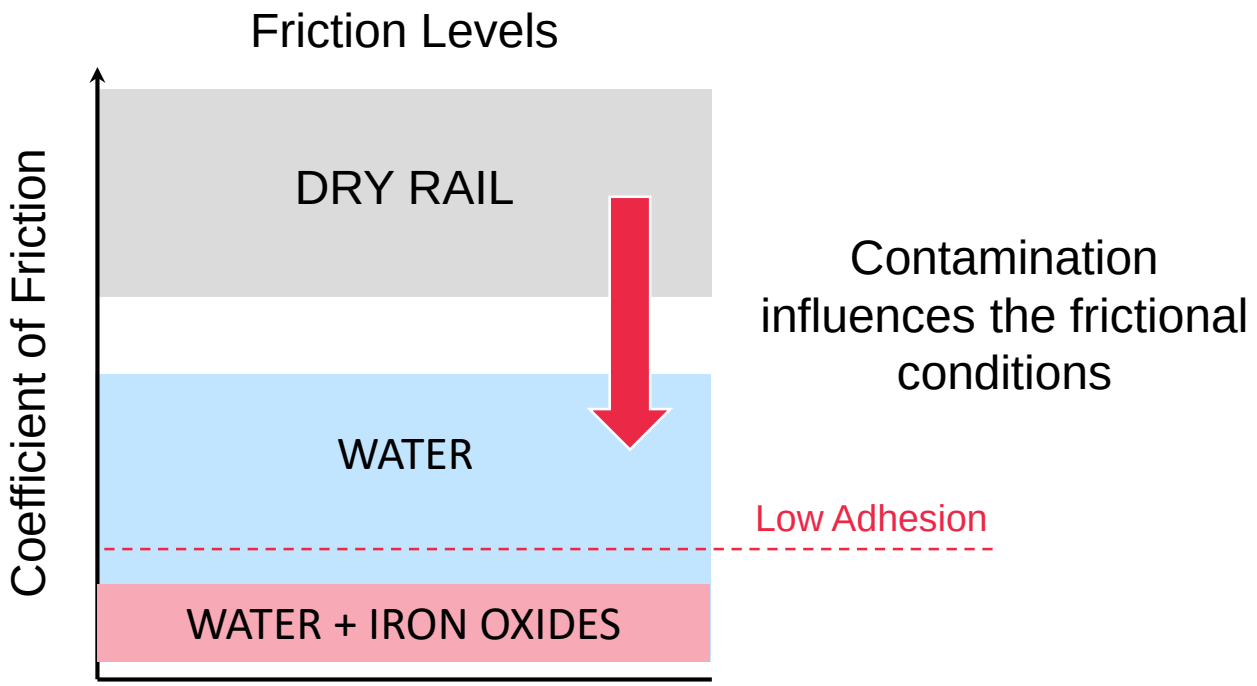
STATE OF THE ART



On dry and clean rail, TOR products reduce friction but ensure sufficient adhesion.

STATE OF THE ART

In reality, the rail is rarely dry and clean…



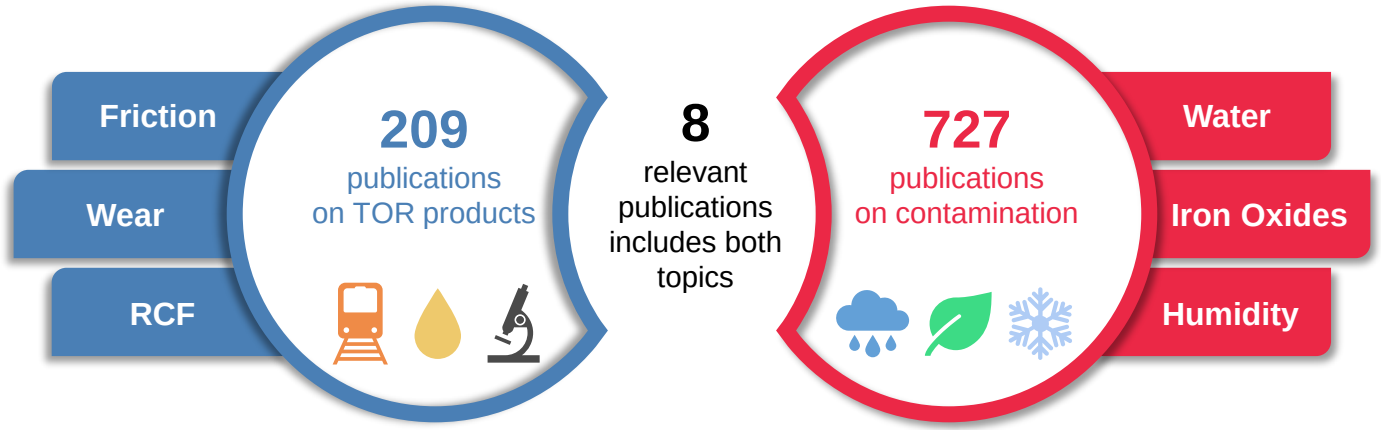
Contamination influences the frictional conditions

Are TOR products able to provide sufficient adhesion even under contaminated conditions?

THE RESEARCH GAP

RESEARCH GAP

Are TOR products able to provide sufficient adhesion even under contaminated conditions?



Existing studies rarely address these two topics together. TOR products are tested under laboratory-clean conditions or in the field, but typically on sunny days, and the effect of contamination is not taken into account.

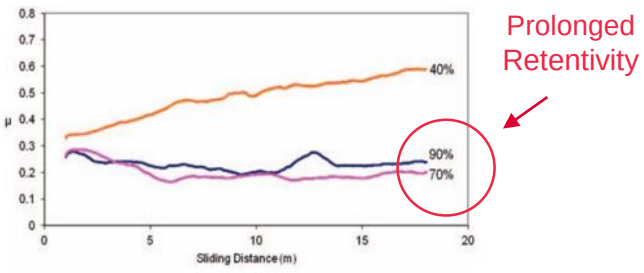
RESEARCH GAP

Lewis et al. (2012)

- Conditions: humidity, temperature and iron oxides
- TOR product: water-based friction modifier
- Setup: pin-on-disc tribometer, climate chamber

Main Findings:

1) In a humid environment, evaporation of the base medium is slowed down and retentivity increases
2) Iron oxides disrupt the FM film and increase friction



Prolonged Retentivity

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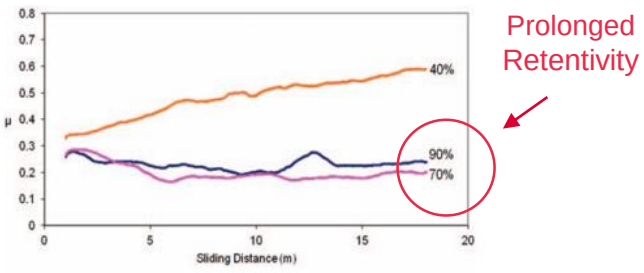


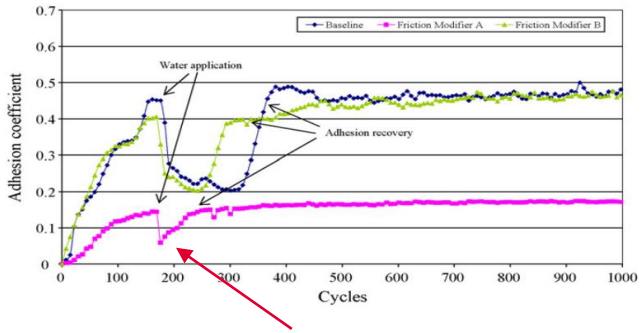
Prolonged Retentivity

Arias-Cuevas et al. (2010)

- Conditions: direct water application
- TOR product: two commercial water-based FMs
- Setup: a twin-disc machine

Main Findings:

1) Direct water application caused a drop of CoA below 0.1
2) However, the tested products contained particles for traction enhancement, which is not typical for FMs



Water Caused a Drop of CoA

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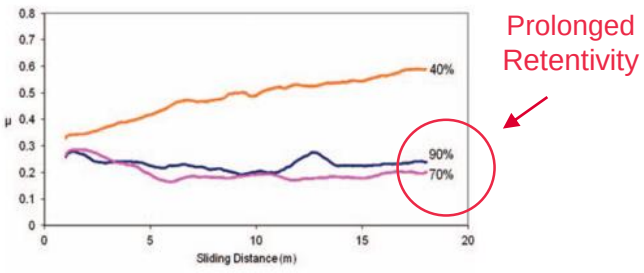

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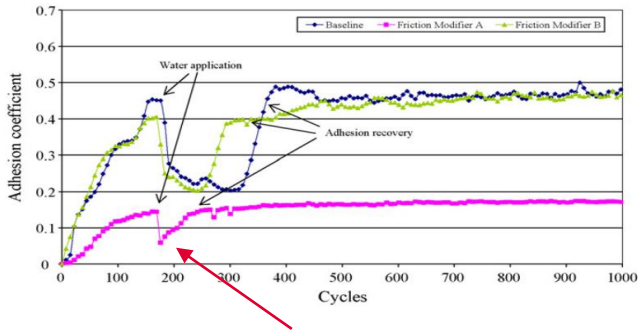

Water Caused a Drop of CoA

Seo et al. (2018)

- RCF Test
- TOR product: TOR hybrid (both water and oil)
- Setup: a twin-disc machine

Main Findings:

TOR hybrid caused severe RCF as a result of the combination of high tangential forces and liquid-assisted crack propagation.

Surface after 200 000 cycles, Severe Spalling

RESEARCH GAP

The performance of TOR products under contaminated conditions has barely been investigated, and the few studies that exist focus almost exclusively on water-based products and adhesion.

AIM OF THE THESIS

The thesis aims to explore the effect of environmental contamination on the performance of TOR products, with scope and conditions defined by the three scientific questions.

SCIENTIFIC QUESTIONS

SCIENTIFIC QUESTIONS

CONDITIONS	TOR PRODUCT	BEHAVIOUR
Water Humidity/Dew Iron Oxides	Friction Modifier TOR Lubricant	Adhesion Wear Rolling Contact Fatigue

SCIENTIFIC QUESTIONS

CONDITIONS	TOR PRODUCT	BEHAVIOUR
Water	**Friction Modifier**	**Adhesion**
Humidity/Dew	**TOR Lubricant**	Wear
Iron Oxides		Rolling Contact Fatigue

Q1: How does water contamination influence the ability of TOR products to modify friction?

SCIENTIFIC QUESTIONS

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Q1: How does water contamination influence the ability of TOR products to modify friction?

Q2: How does the performance of TOR lubricants change with increasing ambient humidity and under dew conditions?

SCIENTIFIC QUESTIONS

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Iron Oxides		**Rolling Contact Fatigue**

Q1: How does water contamination influence the ability of TOR products to modify friction?

Q2: How does the performance of TOR lubricants change with increasing ambient humidity and under dew conditions?

Q3: How do TOR products affect wear and rolling contact fatigue in the presence of oxide layers under wet conditions?

THE EFFECT OF WATER CONTAMIANTION

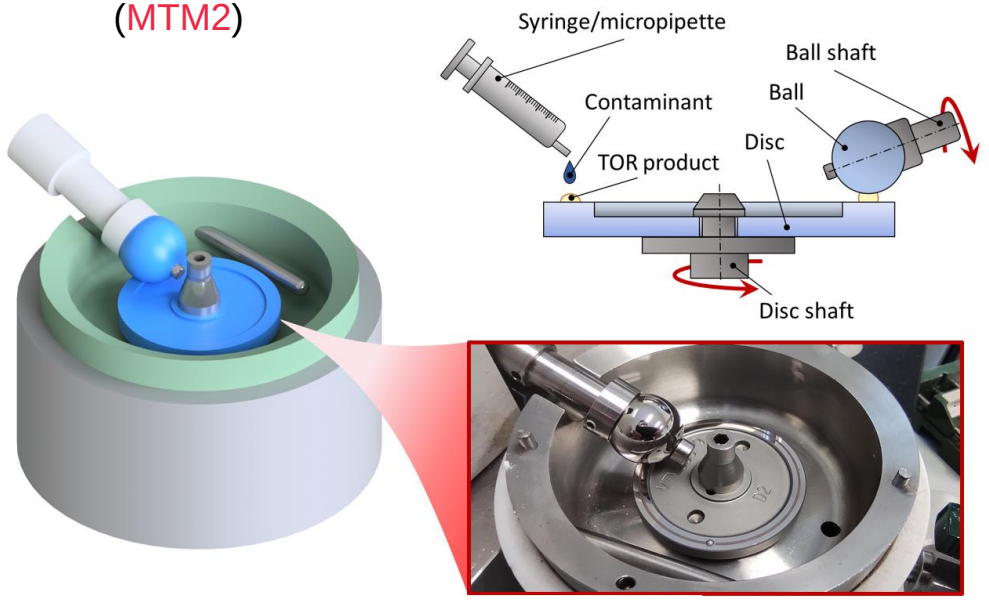
THE FIRST SCIENTIFIC QUESTION

THE EFFECT OF WATER CONTAMINATION

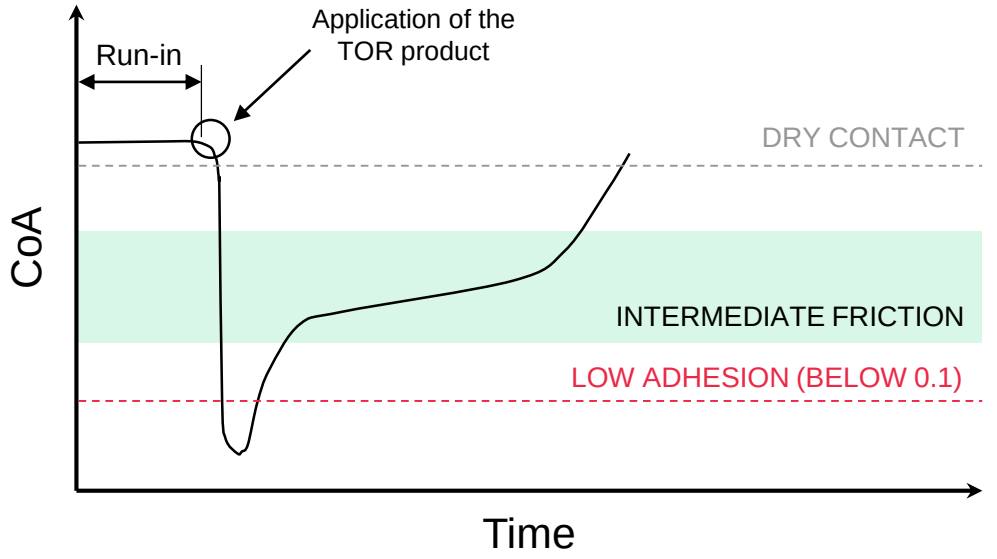
MATERIALS AND METHODS

Tested hypothesis: *Water will shift the balance between the solid and liquid phases of TOR products in favour of a stronger lubricating effect.*

Mini-Traction Machine
(MTM2)



A typical friction curve for the TOR product



AISI 52100 0.8 GPa 1 m/s SRR 2% 1x FM 2x TOR Lubricant

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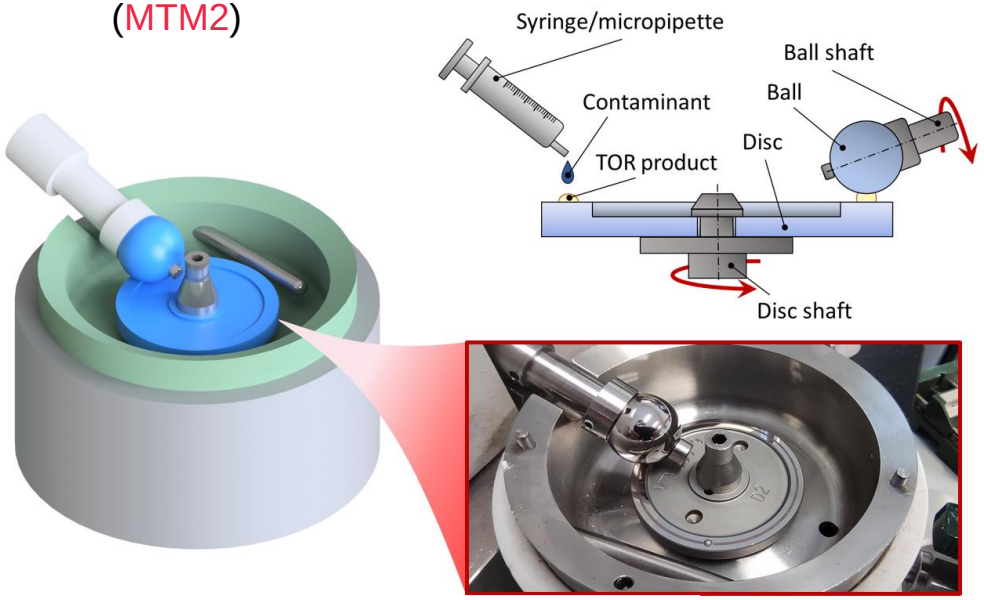
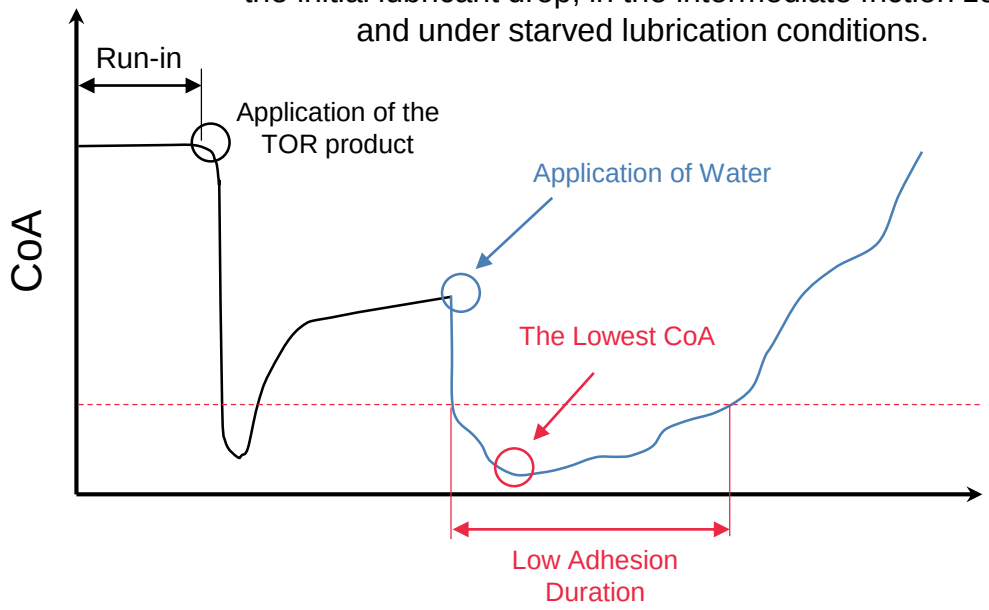


Water was applied at three distinct time points: during the initial lubricant drop, in the intermediate friction zone, and under starved lubrication conditions.



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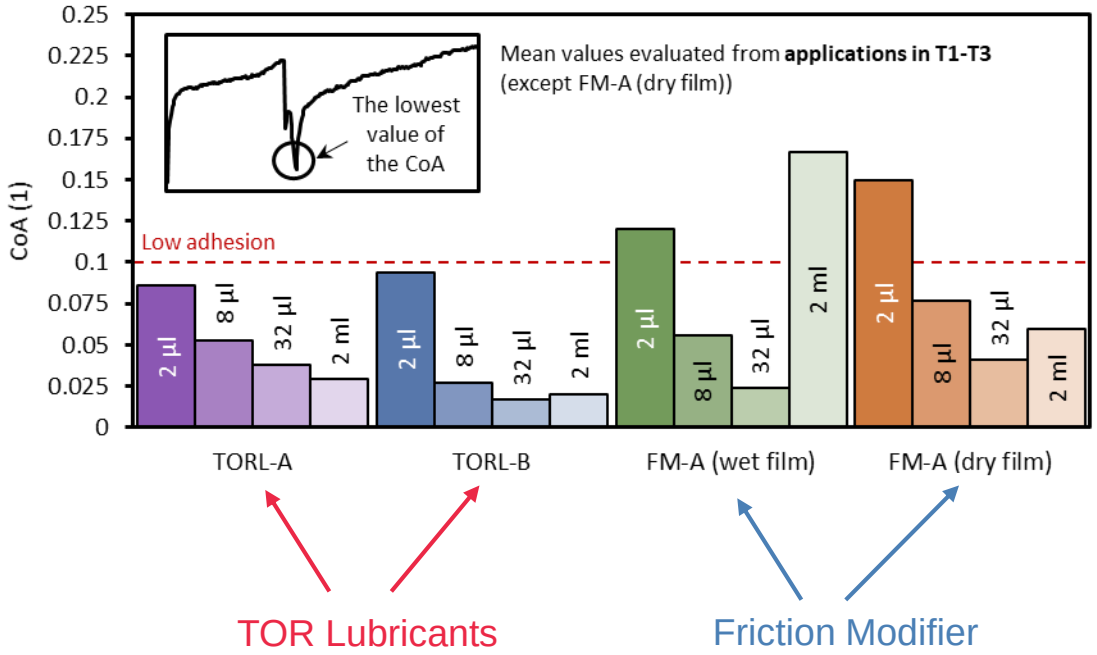
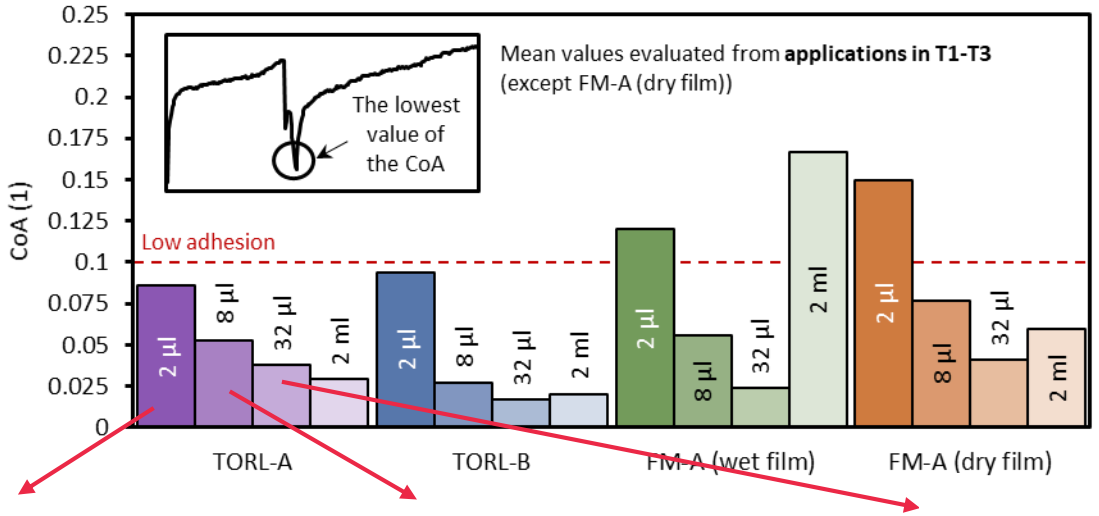
THE EFFECT OF WATER CONTAMINATION

RESULTS

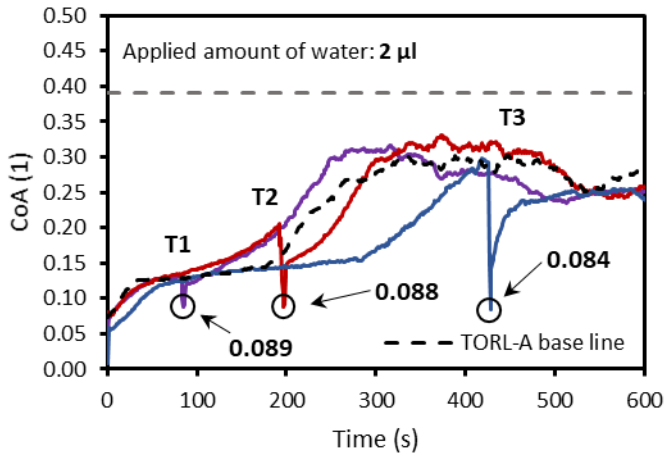


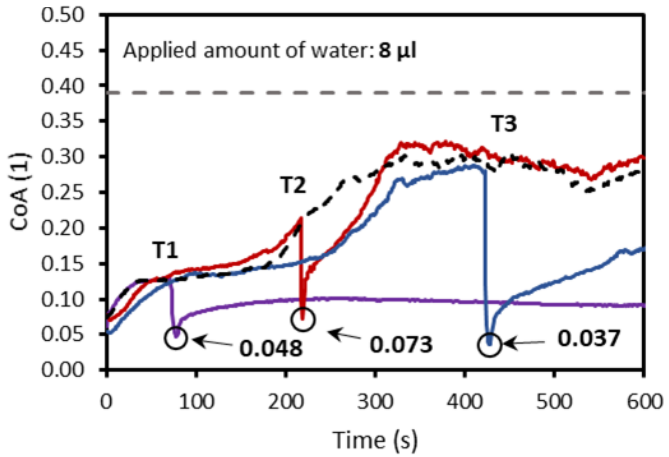
THE EFFECT OF WATER CONTAMINATION

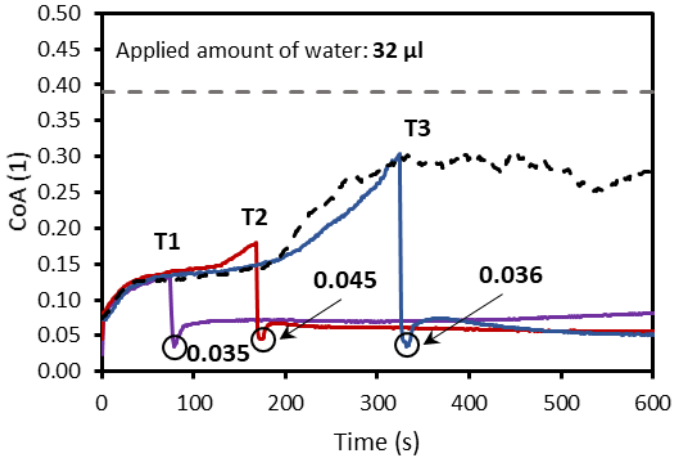
RESULTS



With the increase in the water amount, the CoA reaches a lower minimum.

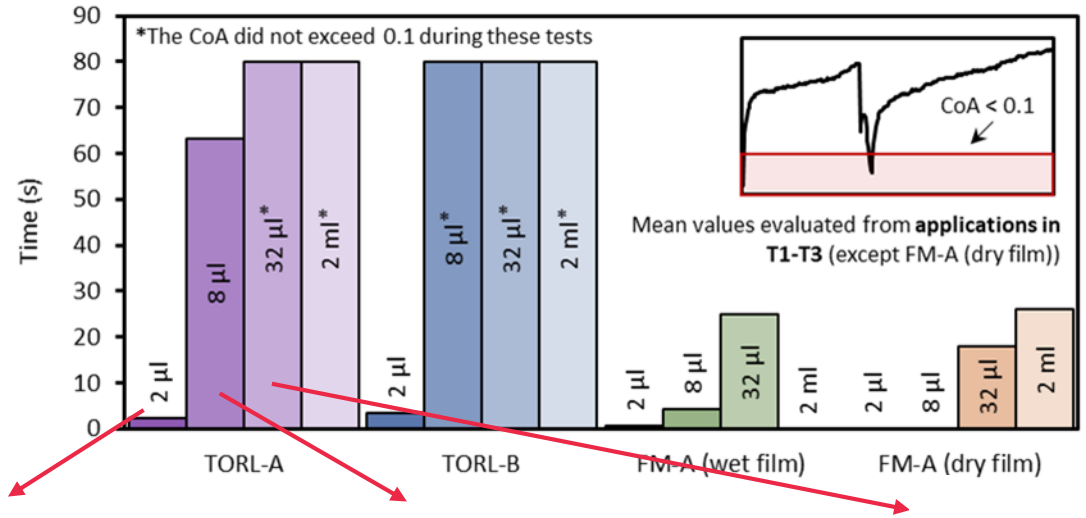




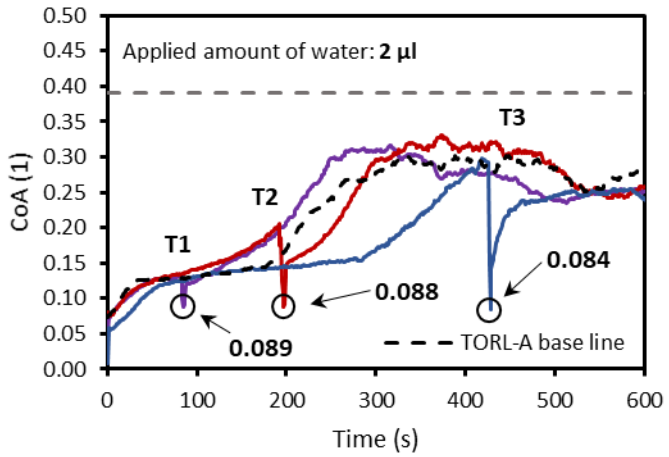


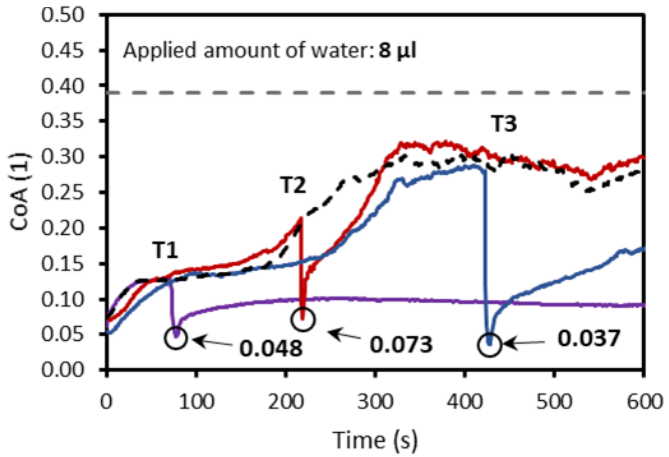
THE EFFECT OF WATER CONTAMINATION

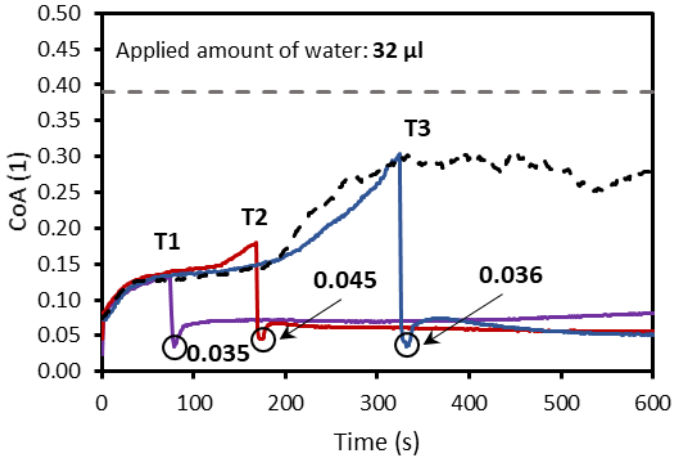
RESULTS



Contamination of TOR lubricants by a large amount of water resulted in a long-lasting period of low adhesion.



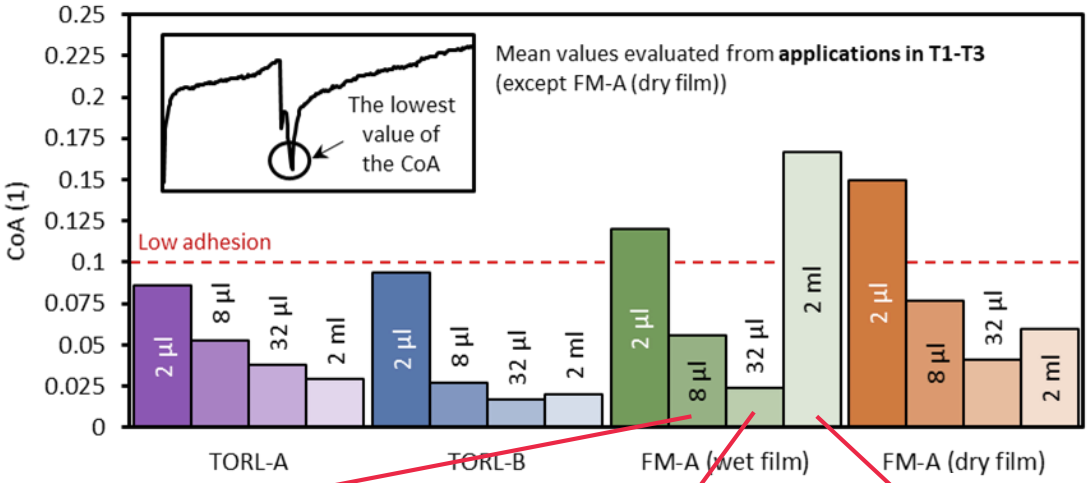


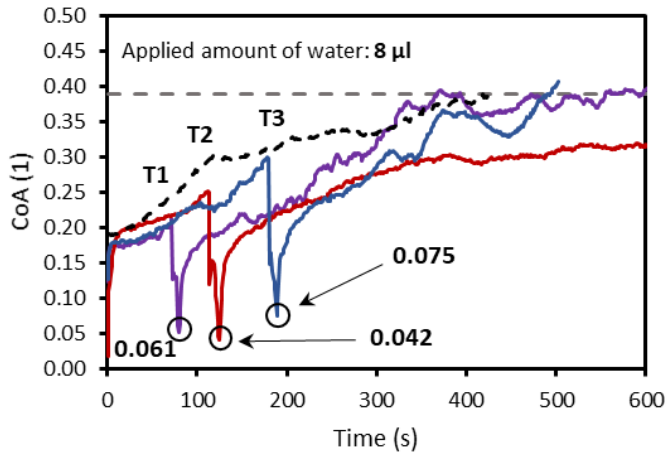


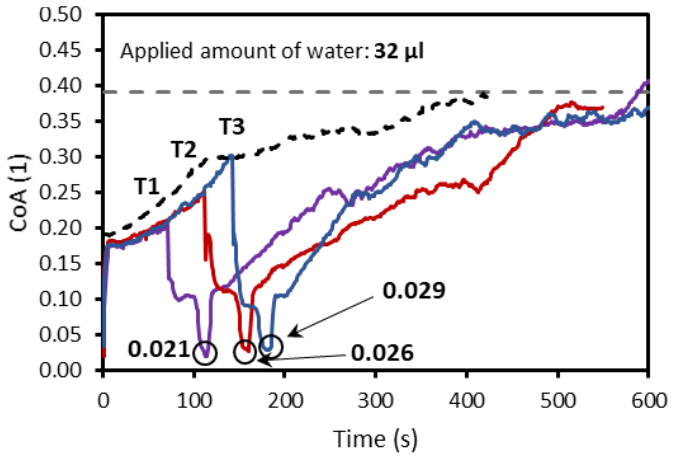
THE EFFECT OF WATER CONTAMINATION

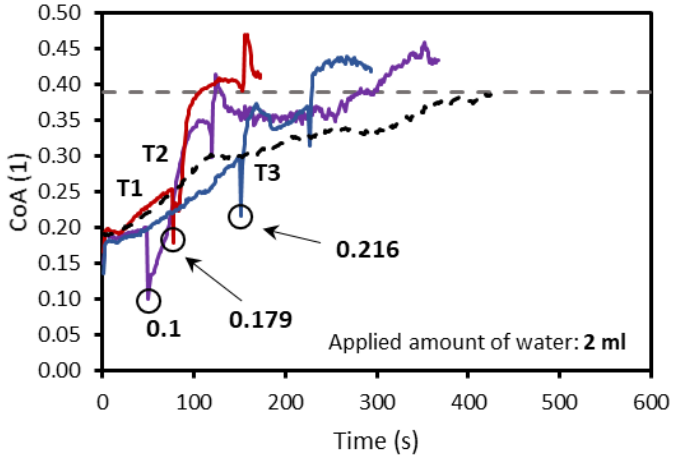
RESULTS

With the increase in the water amounts (to some extent), the CoA reaches a lower minimum.









However, contamination by a large amount of water leads to an immediate increase in CoA to dry levels.

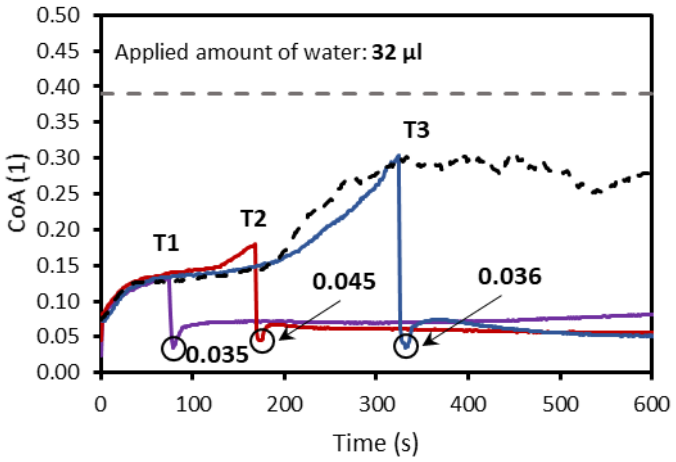
THE EFFECT OF WATER CONTAMINATION

RESULTS

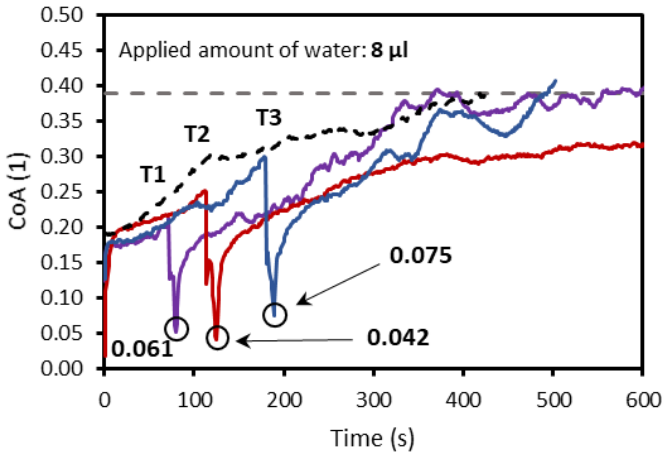
Quick Summary and Conclusions

- TOR Lubricant on „wet rail“ → most likely results in low adhesion problems
- FMs on „wet rail“ → decrease in friction, wet-rail phenomenon
- FMs under „rain conditions“ → unable to control friction, any effect is lost

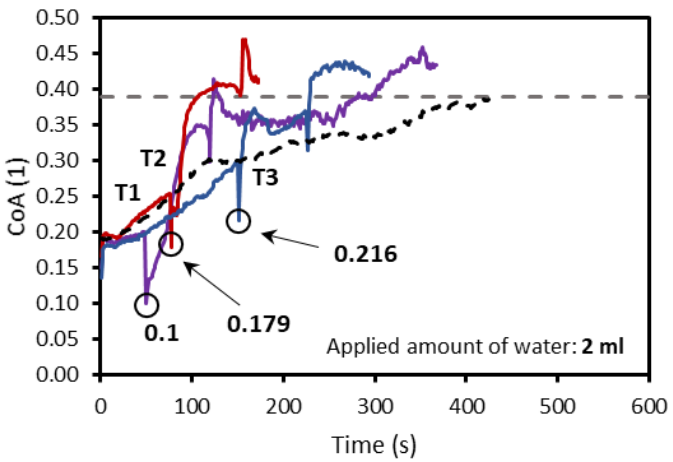
TOR Lubricant on „wet rail“



FM on „wet rail“



FM under „rain conditions“



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Based on the monitoring of CoA

But the thesis aims to describe changes in the performance, so…

How to assess the performance of TOR products?

METHODOLOGIES AND STANDARDS

„Start of my PhD Journey“

Early 1990s | 2000s | 2016 | 2017 | 2018 | 2021

METHODOLOGIES AND STANDARDS

Also, the first standard on the TOR product testing was published:

CEN/TS 15427–2-2
Railway applications - Wheel/Rail friction management - Part 2–2: Properties and Characteristics Top of Rail materials
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A Benchmarking Methodology for Top-of-Rail Products


Tribology International 189 (2023) 108910

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A benchmarking methodology for top-of-rail products

Radovan Galas [a,*], Simon Skurka [a], Martin Valena [a], Daniel Kvarda [a], Milan Omasta [a], Haohao Ding [b], Qiang Lin [b], Wen-jian Wang [b], Ivan Krupka [a], Martin Hartl [a]

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ARTICLE INFO

Keywords:
Rail-wheel tribology
Rolling-sliding
Friction modifier
Top-of-rail lubricants

ABSTRACT

Top-of-rail (TOR) products are designed to optimize adhesion, reduce wear and mitigate noise from the wheel-rail interface. Prior to testing these products in field conditions, a laboratory approach is suitable because it is not time-consuming and expensive. This study aims to design a benchmarking methodology to investigate the performance of TOR products using a standard tribometer in a ball-on-disc configuration. The resulting methodology is based on a multi-parameter approach enabling the assessment of TOR products from multiple perspectives. The core of the methodology is formed by traction tests and a robust evaluation phase resulting in a performance map dividing TOR products into four performance classes, Q1-Q4, based on which a suitable TOR product can be chosen for further testing.

1. Introduction

TOR products represent a progressive approach to modification of friction between the wheel tread and the rail head. In contrast with other conventional methods, such as sanding and flange lubrication, TOR products are designed to control friction at a desired level, referred to as an intermediate level of friction [1]. Besides that, the presence of TOR product in the contact should avoid a negative slope of the creep curve occurring in untreated contact [2]. According to the state of matter, TOR products are classified into solid and liquid. Solid TOR products are usually called "solid sticks" or "HPF solid sticks", while there are different, sometimes confusing, terms for liquid products. Water-based products (drying products) are called friction modifiers (FMs), while oil- or grease-based products (non-drying products) are called TOR lubricants (TORLs). There is also a third category of TOR products containing both water and oil/grease. These products are called TOR hybrids [1,2].

The possible benefits of TOR products have been intensively studied since 1992, when Eadie et al. [3] published a pilot study on railway friction management. This study was conducted on the Vancouver mass transit system line, where severe short pitch wheel and rail corrugation developed only a few months after its opening. This investigation showed that applying a solid stick to the wheel tread prevented corrugation formation as roll-slip oscillations were eliminated due to a positive creep curve. The ability to reduce or completely avoid the corrugation growth for different mass transit systems was later confirmed for FMs [4–7]. Other field studies [7–11] showed that suppression of roll-slip oscillations

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Available online 29 August 2023
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Although field studies have proved many benefits of TOR products, some negative effects related to their application have been revealed as well. One of the most severe drawbacks is the risk of a very low CoT compromising traction and braking. This undesirable phenomenon was observed for both FM [17] and TOR lubricants [15–20]. FMs may cause a very low CoT immediately after their application when a high amount of FM enters the contact [21]. In addition, a significant drop in the CoT was observed during the drying of FM when a viscous film was formed between the contacting surfaces [22]. In the case of TOR lubricants as oil or grease-based products, the applied amount strongly affects product performance [23,24]. A high amount of these non-drying products (TORLs and TORHs) in the contact can lead to the extension of braking distance and can promote the growth of pre-existing cracks and spalling formation [18,25]. Besides these security risks, recently published studies [26–28] showed that the expected benefits of TOR products, such as squeal noise reduction and long carry distance, cannot be

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A Comparison of both Methodologies:

	Wear-in[1] parameters	Run-in parameters	Test parameters	# of sets	Total time[2]	Performance parameters	Overall assessment
Article II	0.8 GPa 1 m/s 2% SRR 60 min	0.8 GPa, 1 m/s, 2% SRR, 30 min	0.8 GPa 1 m/s 0–20% SRR 20–40 min	5	5–8h	I, OLF	Performance map (Q1–Q4)
CEN/TS standard	1 GPa 0.1 m/s 50% SRR 30 min	–	1 GPa 1, 3.8 m/s 0.25–10% SRR 22 min	1	1h	CoT at 10% SRR	Good/bad

1) CEN/TS standard uses run-in in the same way as wear-in in the proposed methodology.
2) Estimation, the exact time is dependent on the number of creep curves.

\+ A robust multi-parameter approach

\- Time-consuming

Early 1990s | 2000s | 2016 | 2017 | 2018 | 2021

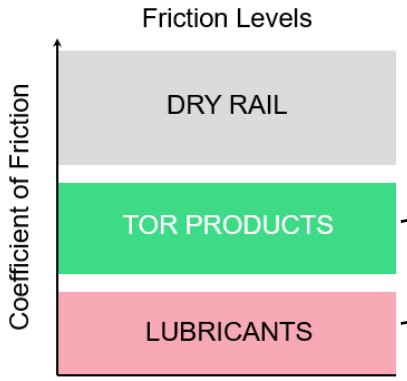
METHODOLOGIES AND STANDARDS

THE DEVELOPED METHODOLOGY

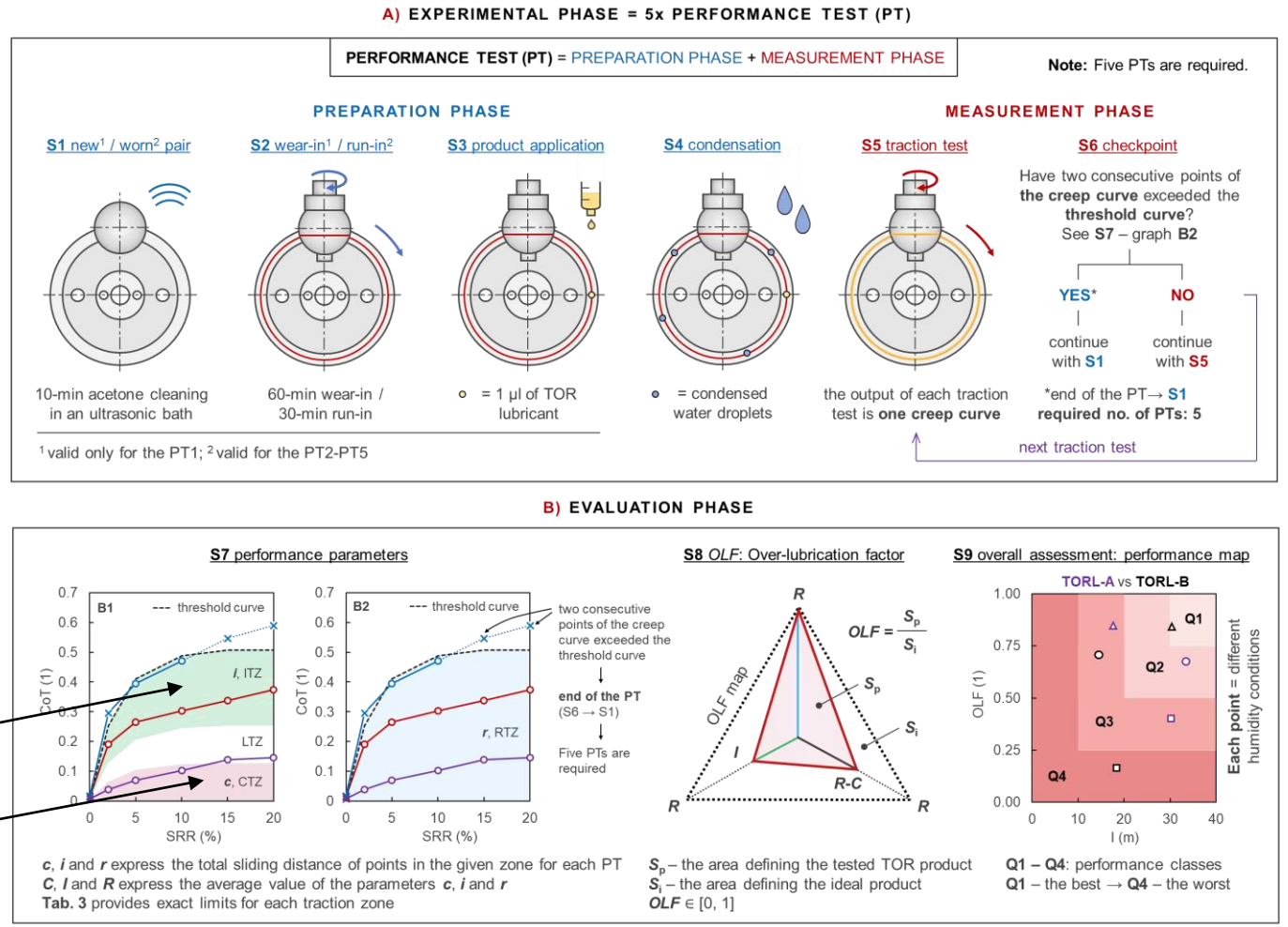
Performance parameters:

C – Critical Traction
I – Intermediate Traction
R – Retentivity

Based on these parameters, the over-lubrication factor (**OLF**) is calculated.



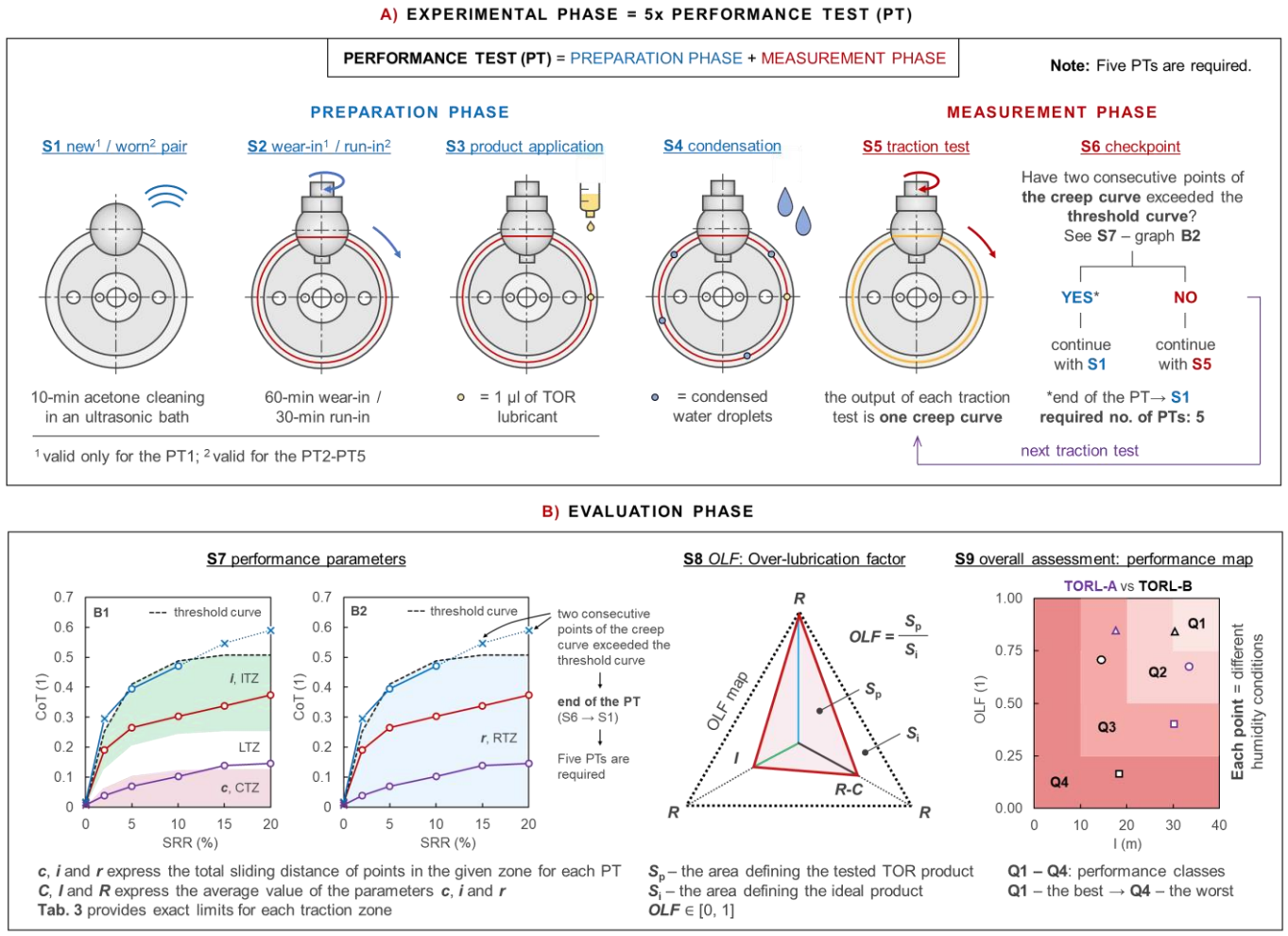
Stock et al. (2016)



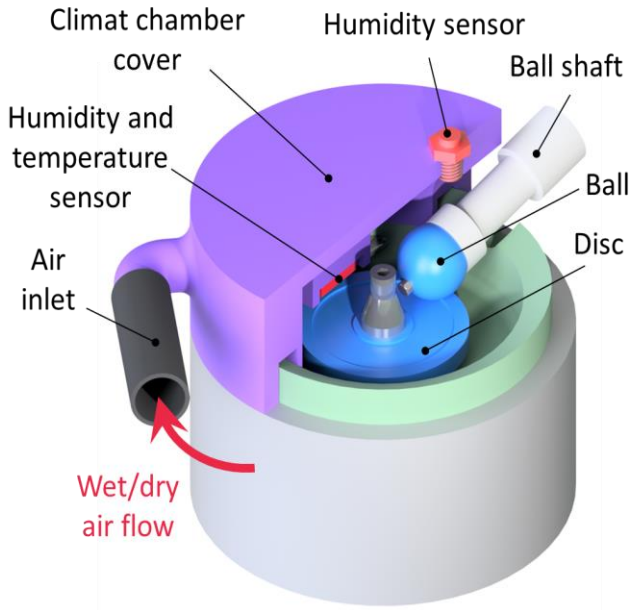
OLF and **I** are used to construct a performance map divided into four performance classes, Q1-Q4

METHODOLOGIES AND STANDARDS

THE DEVELOPED METHODOLOGY



Tested Hypothesis: Humidity has a negligible effect until the dew point is reached.



AISI 52100 0.8 GPa 1 m/s SRR 0–20%

2x TOR Lubricant RH levels: 34%; 70%; 100%

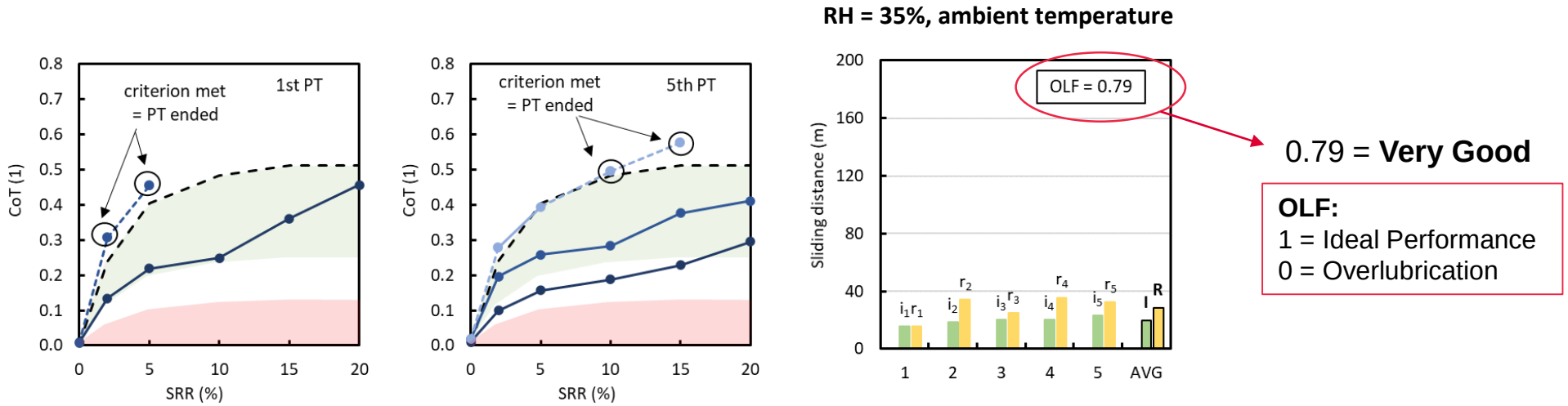
THE EFFECT OF HUMIDITY AND DEW

THE SECOND SCIENTIFIC QUESTION

THE EFFECT OF HUMIDITY AND DEW

RESULTS

Standard performance of TORL-A



Per one dosage, 2-3 creep curves were measured without any risk of low adhesion.

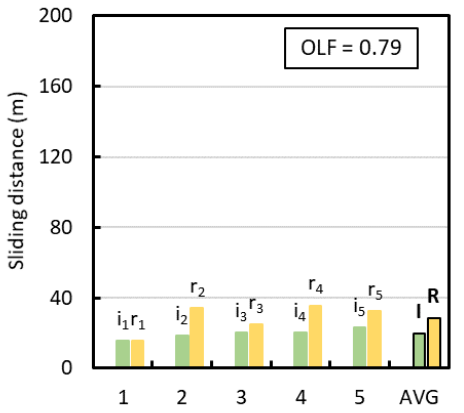
THE EFFECT OF HUMIDITY AND DEW

RESULTS

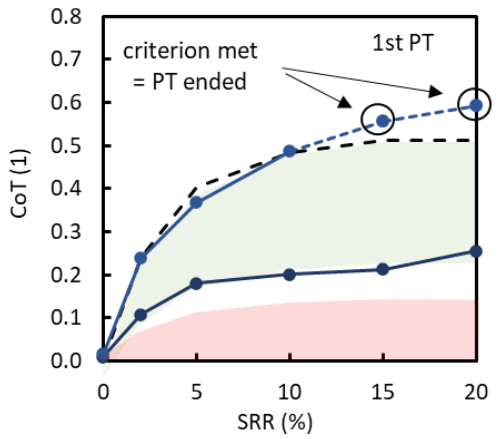
OLF:
1 = Ideal Performance
0 = Overlubrication

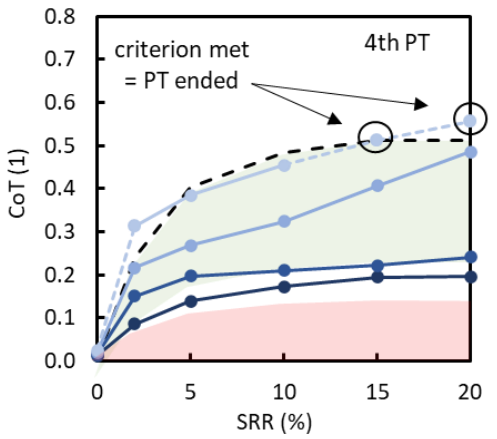
Performance of TORL-A in Humid Environment

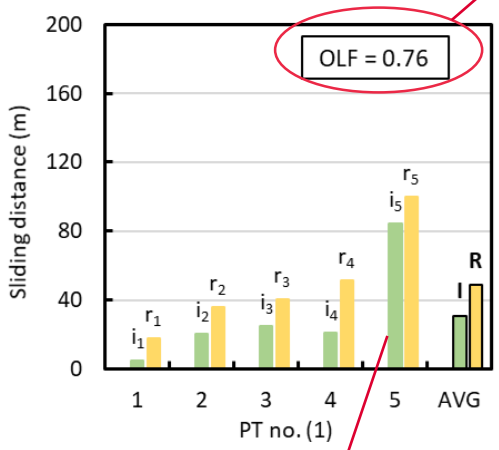
RH = 35%, ambient temperature



70% RH, ambient temperature







0.76 = **Very Good**

A slight positive effect of humidity was observed, but with reduced repeatability.

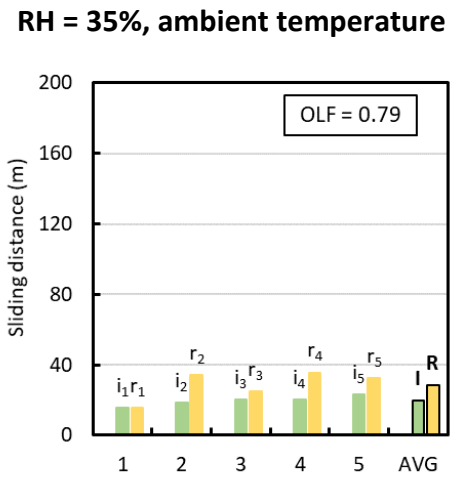
Prolonged Period of Intermediate Friction

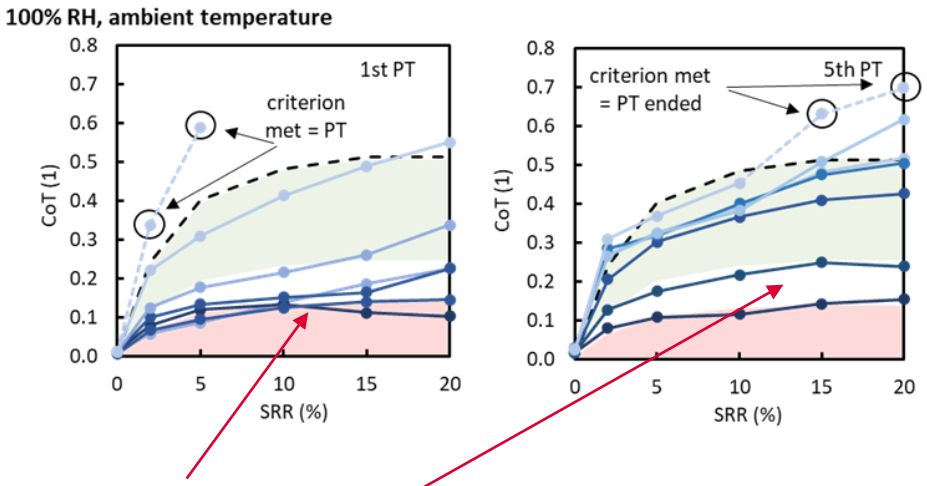
THE EFFECT OF HUMIDITY AND DEW

RESULTS

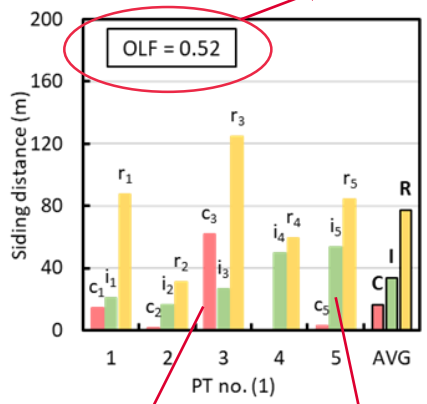
OLF:
1 = Ideal Performance
0 = Overlubrication

Performance of TORL-A under Dew Conditions





Water changed the trend of some creep curves to negative.



0.52 = **Sufficient**

Period of Low Adhesion

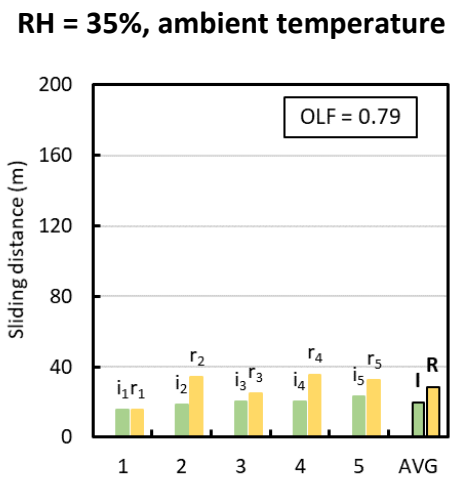
Prolonged Period of Intermediate Friction

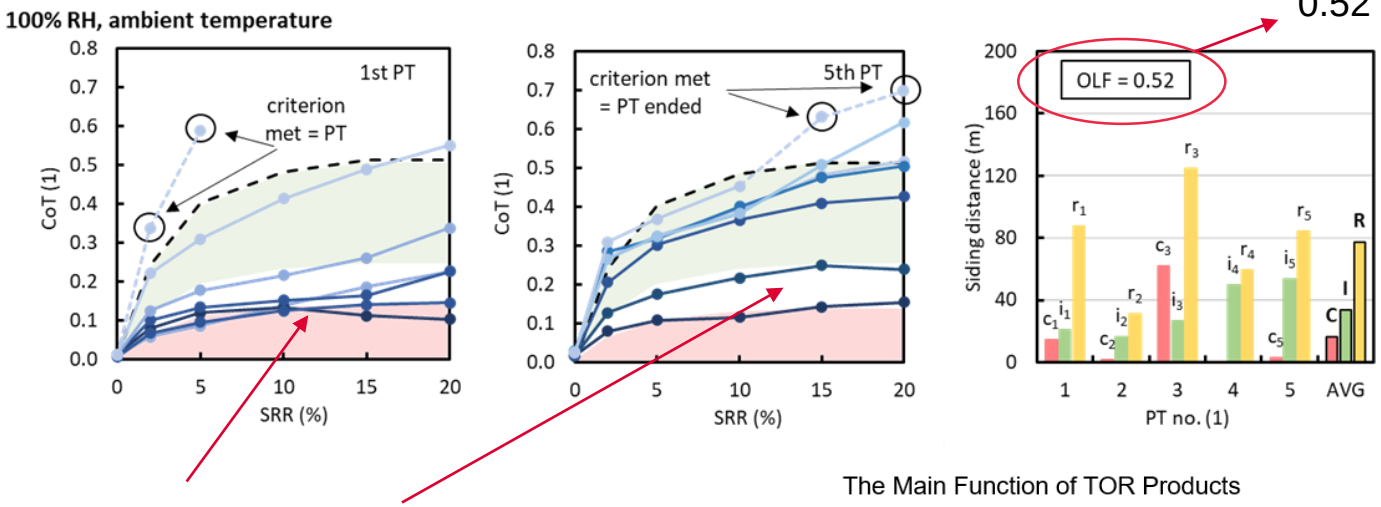
THE EFFECT OF HUMIDITY AND DEW

RESULTS

OLF:
1 = Ideal Performance
0 = Overlubrication

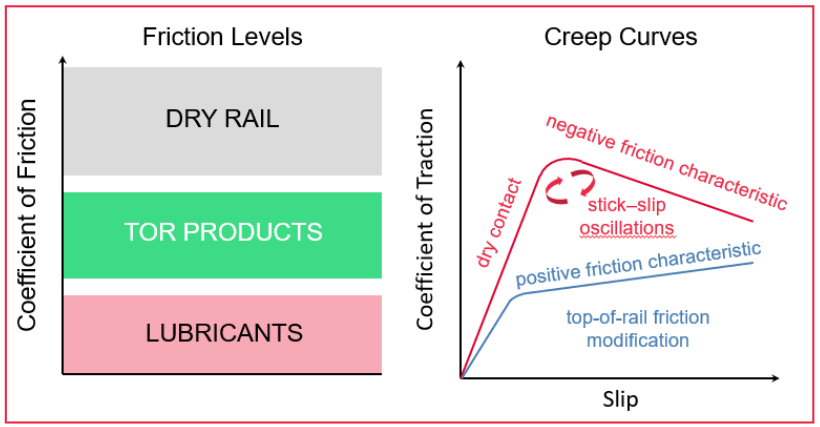
Performance of TORL-A under Dew Conditions





Water changed the trend of some creep curves to negative.

The Main Function of TOR Products



Stock et al. (2016)

THE EFFECT OF HUMIDITY AND DEW

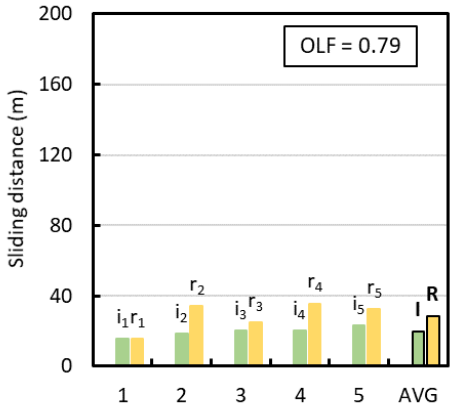
RESULTS

OLF:
1 = Ideal Performance
0 = Overlubrication

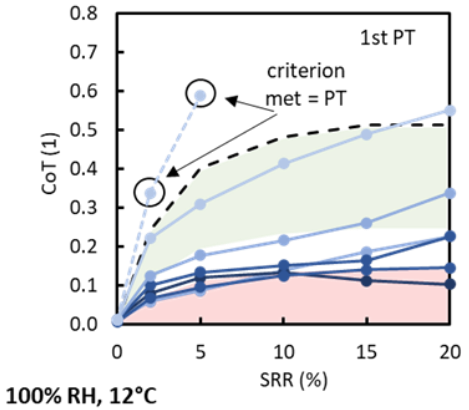
0.29 = **Very Bad**

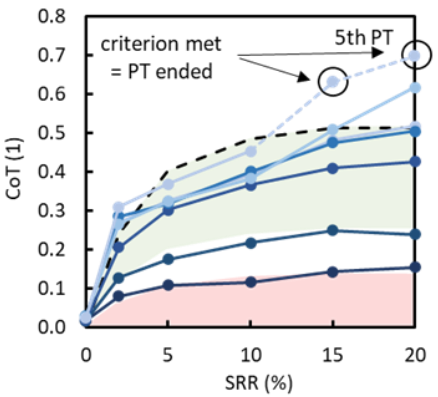
Performance of TORL-A under Dew Conditions

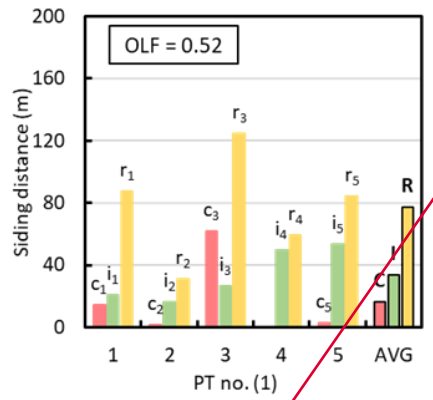
RH = 35%, ambient temperature



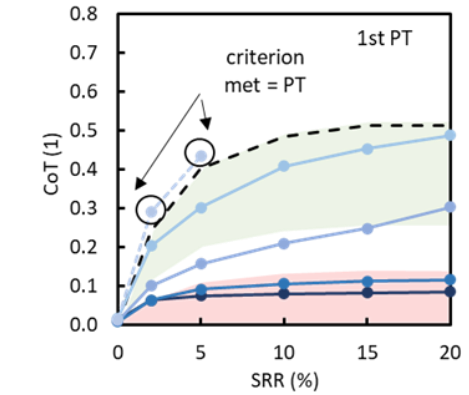
100% RH, ambient temperature

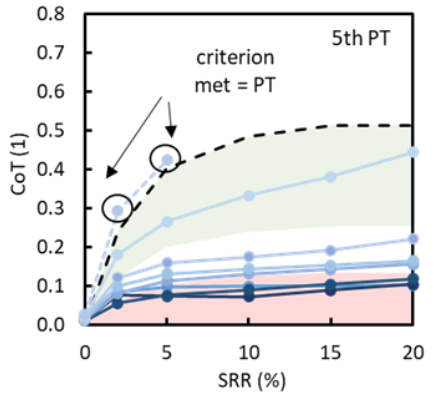


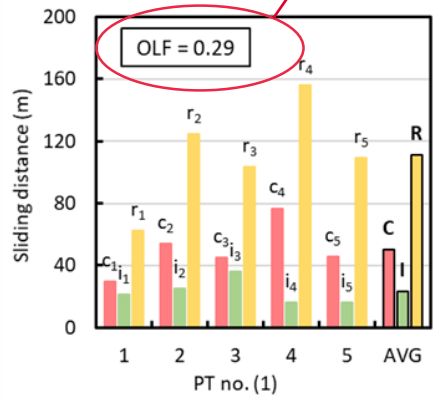




100% RH, 12°C







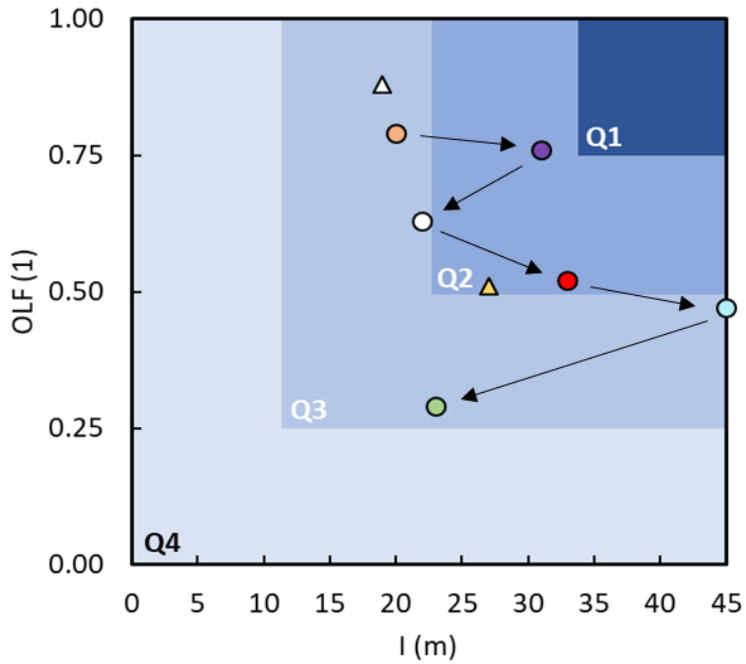
Long-lasting Period of Low Adhesion

THE EFFECT OF HUMIDITY AND DEW

RESULTS

Humidity and small amounts of water may have a slightly positive effect on the performance, as it increases retentivity.

The Performance Map



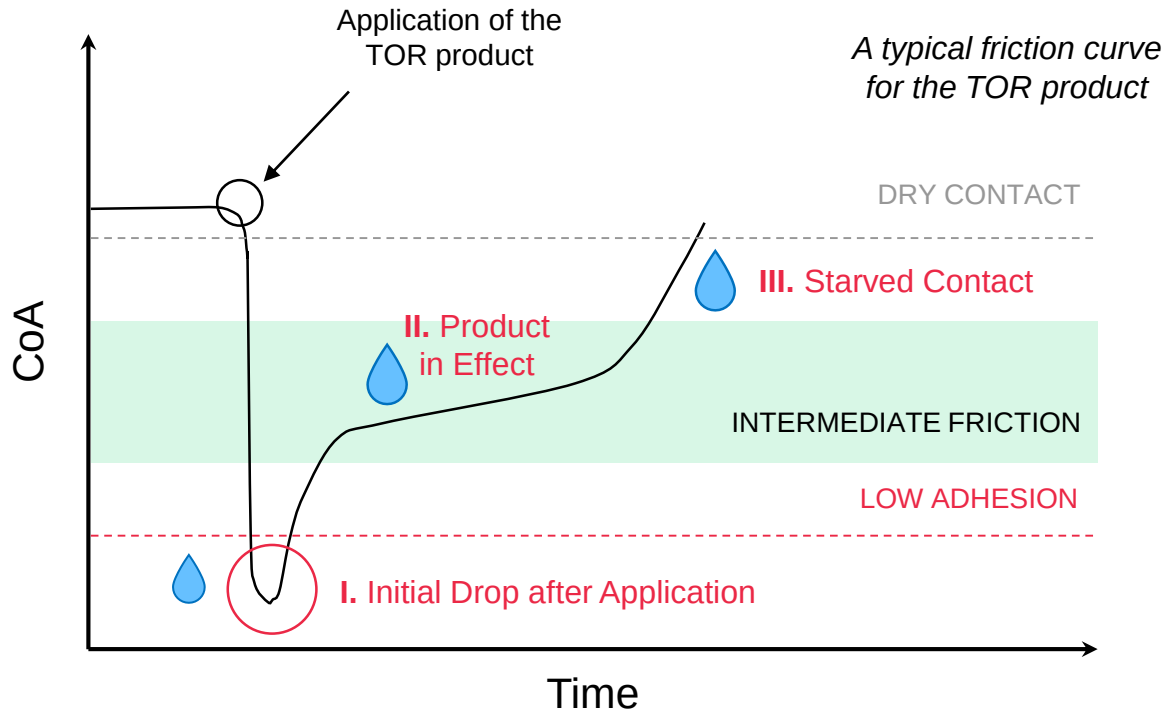
However, higher water amounts come at the cost of a prolonged low-adhesion period, which may result in a lower performance category.

THE MECHANISMS OF OVER-LUBRICATION

THE FIRST AND THE SECOND SCIENTIFIC QUESTION

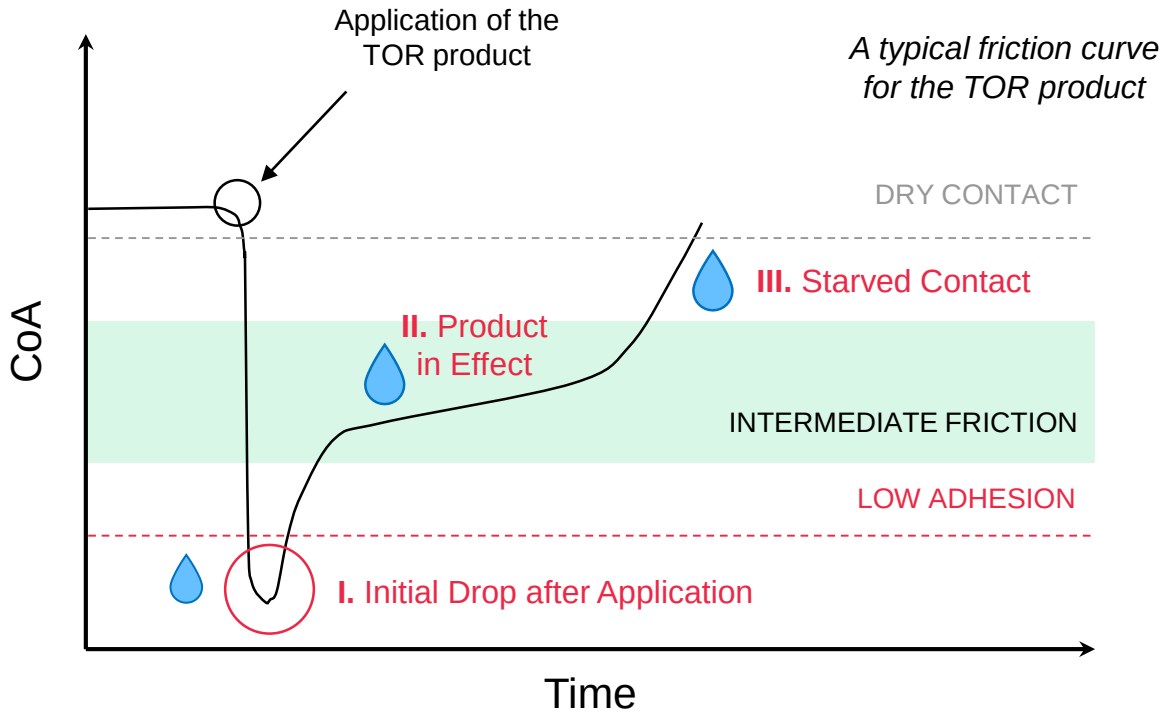
THE MECHANISMS OF OVER-LUBRICATION

TOR LUBRICANTS, WATER AND DEW

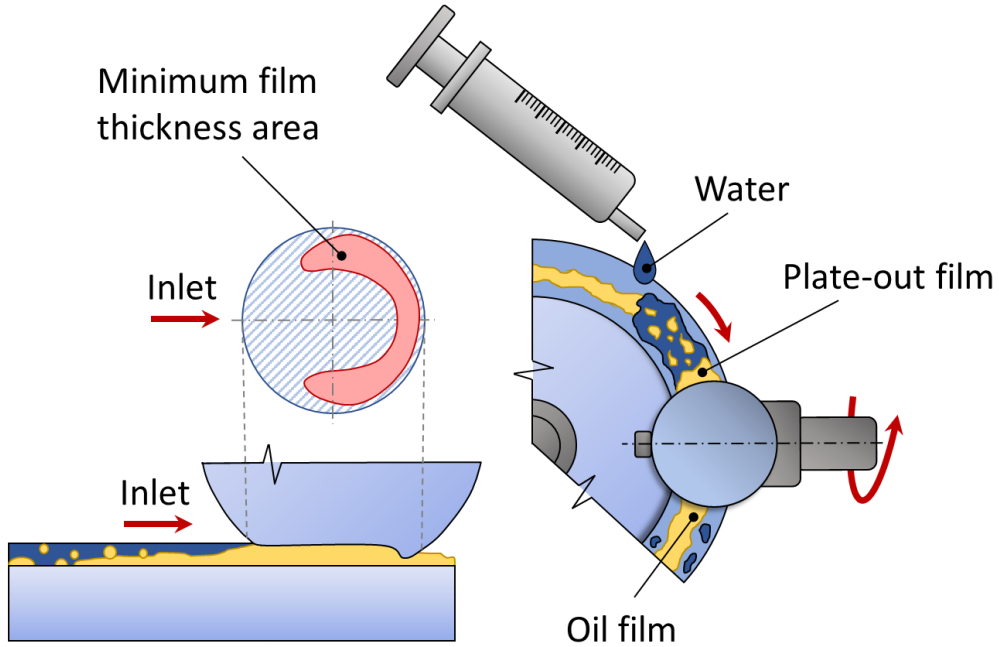


THE MECHANISMS OF OVER-LUBRICATION

TOR LUBRICANTS, WATER AND DEW



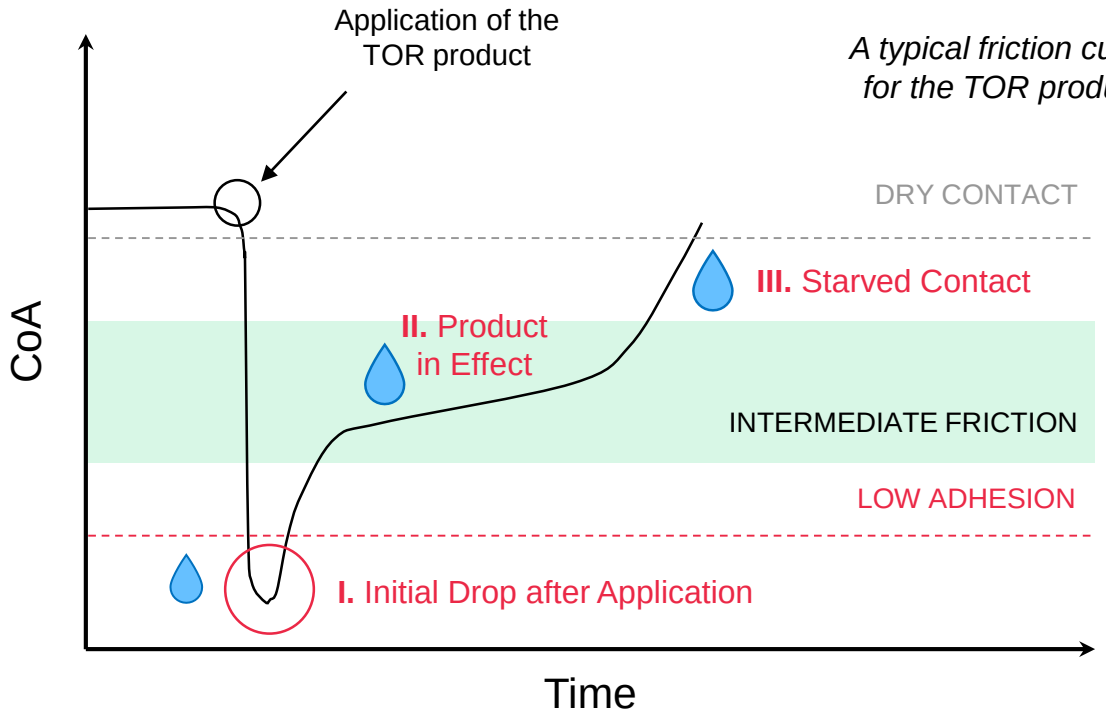
I. Initial Drop after Application:



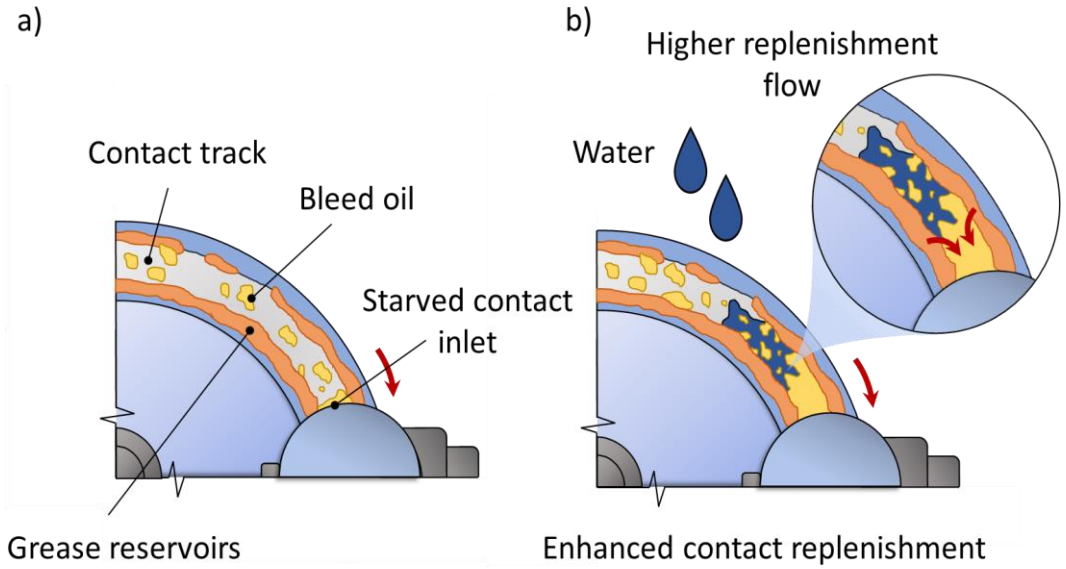
Better separation of surfaces and higher contact replenishment.

THE MECHANISMS OF OVER-LUBRICATION

TOR LUBRICANTS, WATER AND DEW



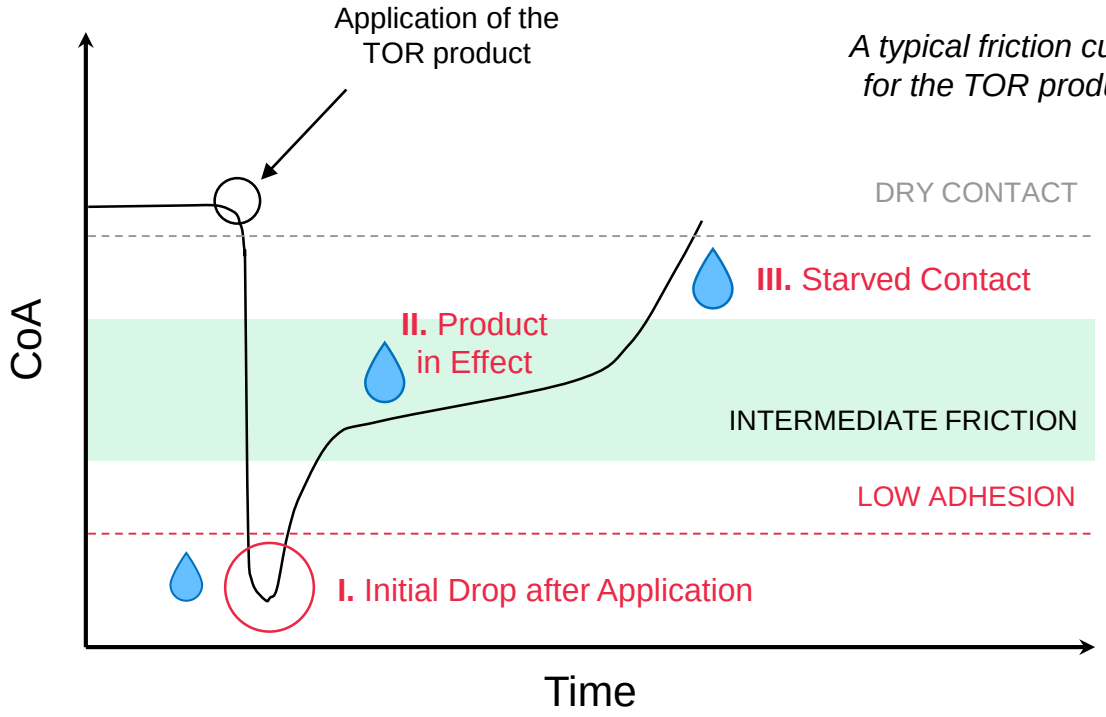
II. Product in Effect:



Grease absorbs water → Oil-bleeding, Lower viscosity → Higher contact replenishment → Thicker lubricating film

THE MECHANISMS OF OVER-LUBRICATION

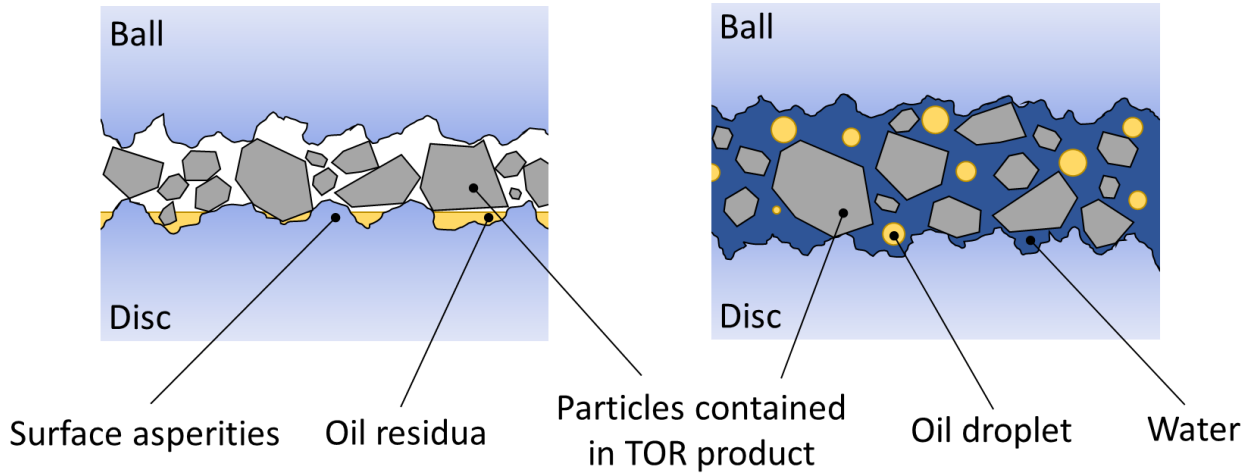
TOR LUBRICANTS, WATER AND DEW



III. Starved Contact:

Shear displacement compensation mechanism in starved contact leads to higher CoA

Mixture of water, oil and particles provides thicker lubricating film ensuring lower CoA

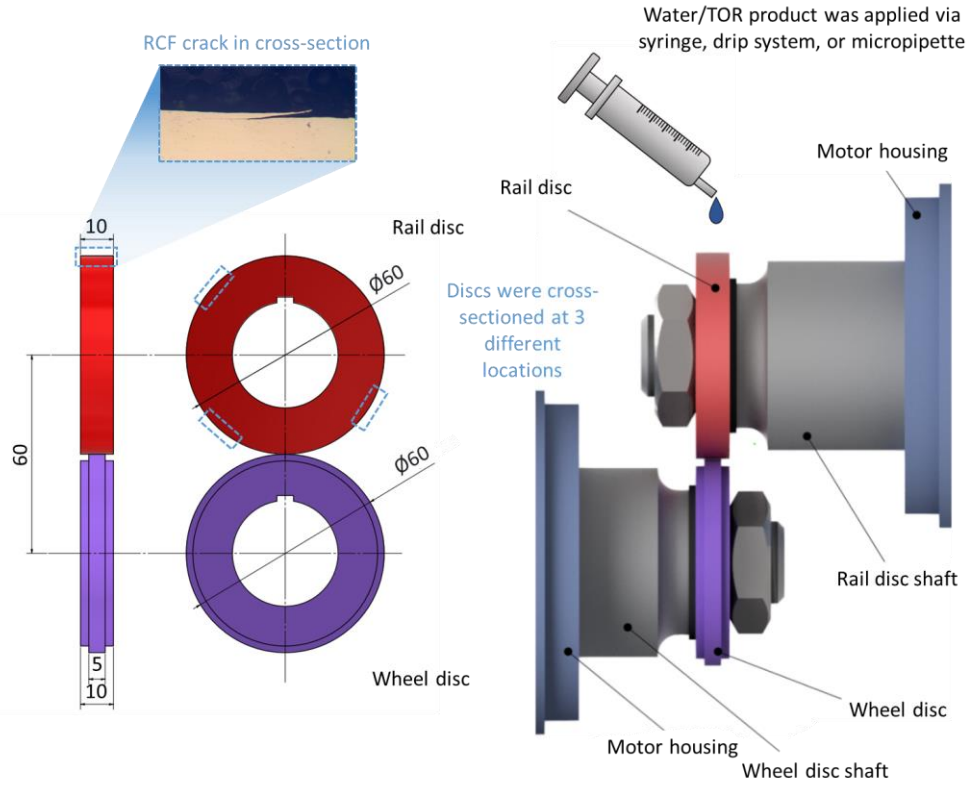


THE EFFECT ON WEAR AND RCF

THE THIRD SCIENTIFIC QUESTION

THE EFFECT ON WEAR AND RCF

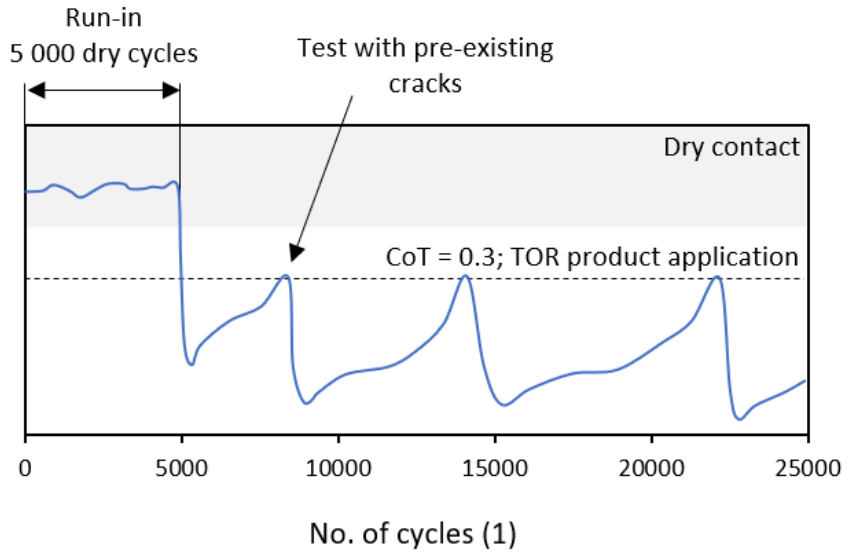
MATERIALS AND METHODS



U71Mn (rail) C-Class (wheel) 1.1 GPa 1.5 m/s slip 2%

1x TOR Lubricant 1x Friction Modifier

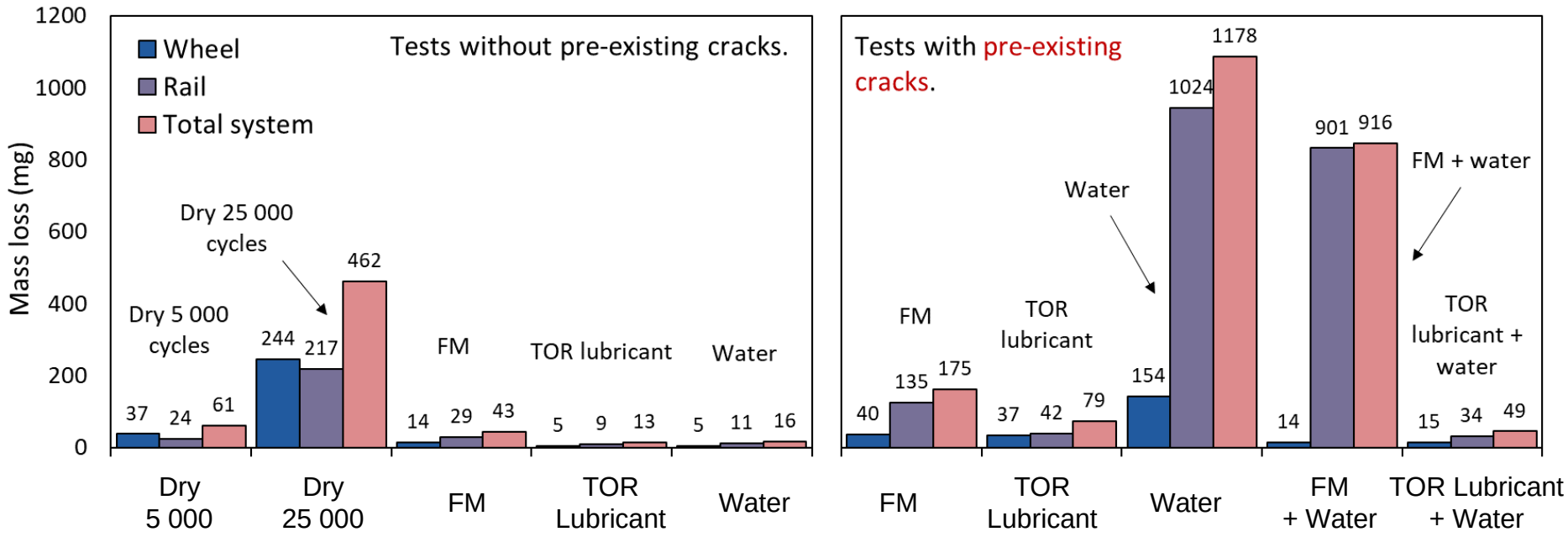
Tested Hypothesis: TOR lubricant will behave similarly to TOR hybrid under wet conditions, resulting in increased RCF due to high friction.



The TOR product was applied when CoA = 0.3 was reached. Water was applied at a rate of 1 drop/s.

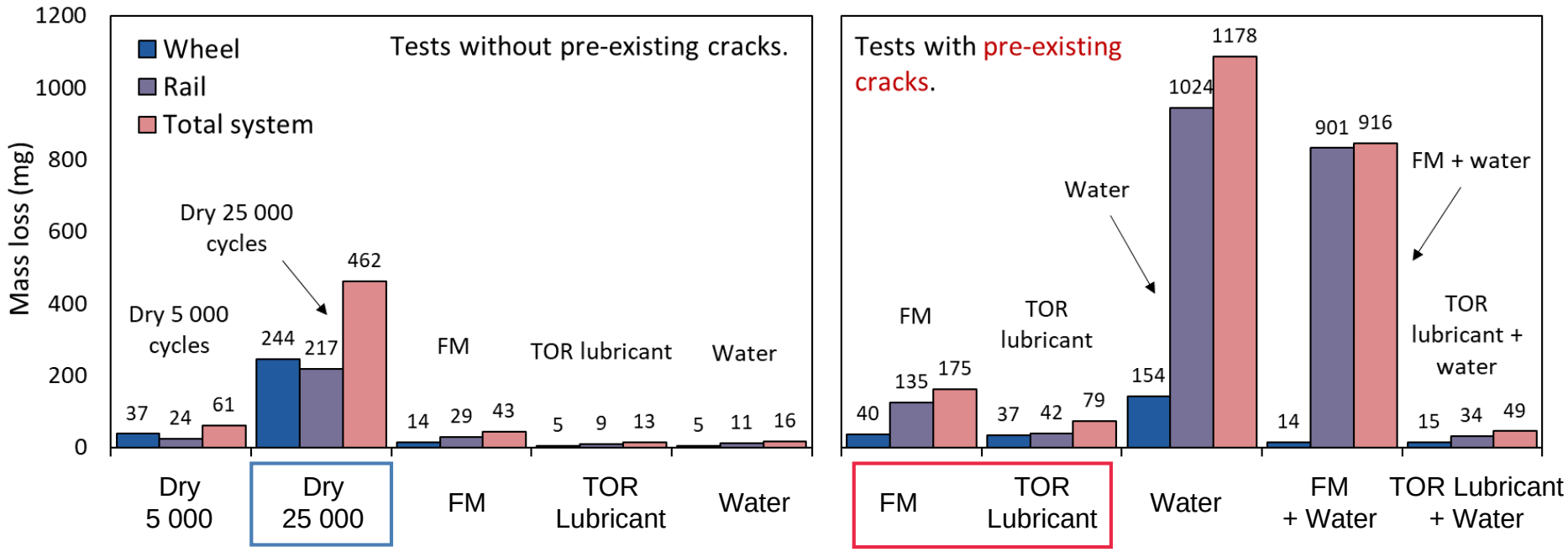
THE EFFECT ON WEAR AND RCF

RESULTS



THE EFFECT ON WEAR AND RCF

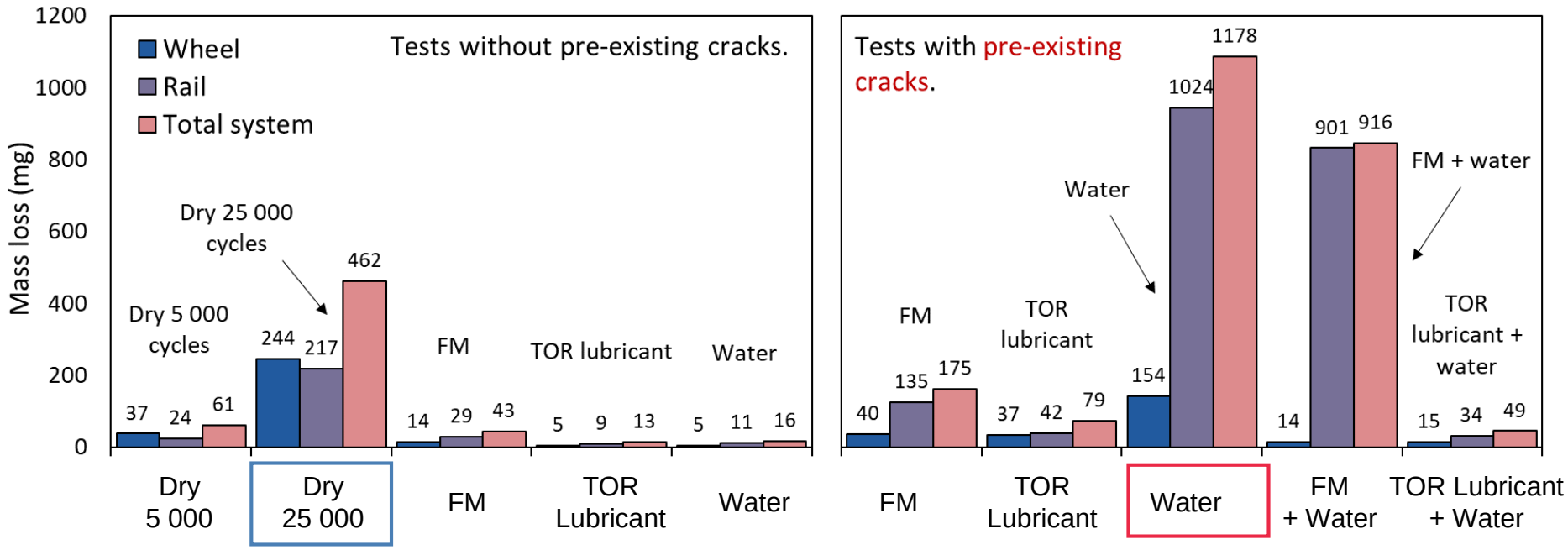
RESULTS



TOR products were effective in reducing wear in comparison with unlubricated conditions.

THE EFFECT ON WEAR AND RCF

RESULTS

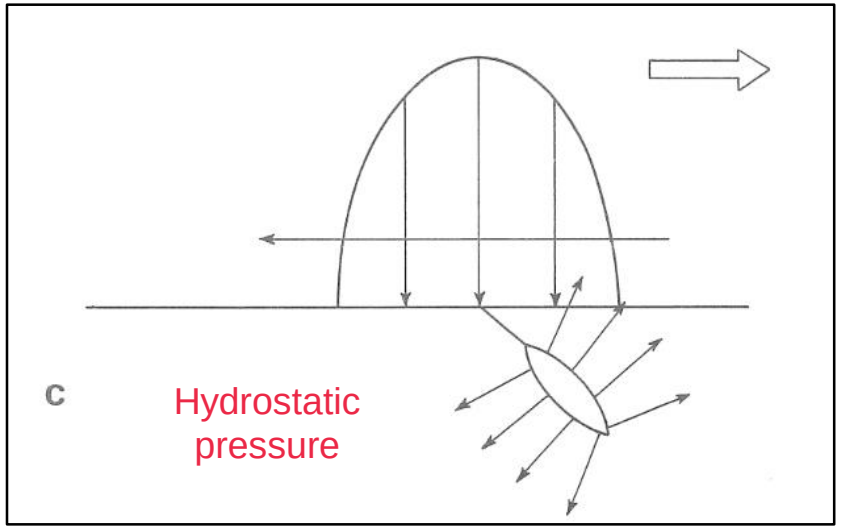


Water caused massive material removal and delamination.

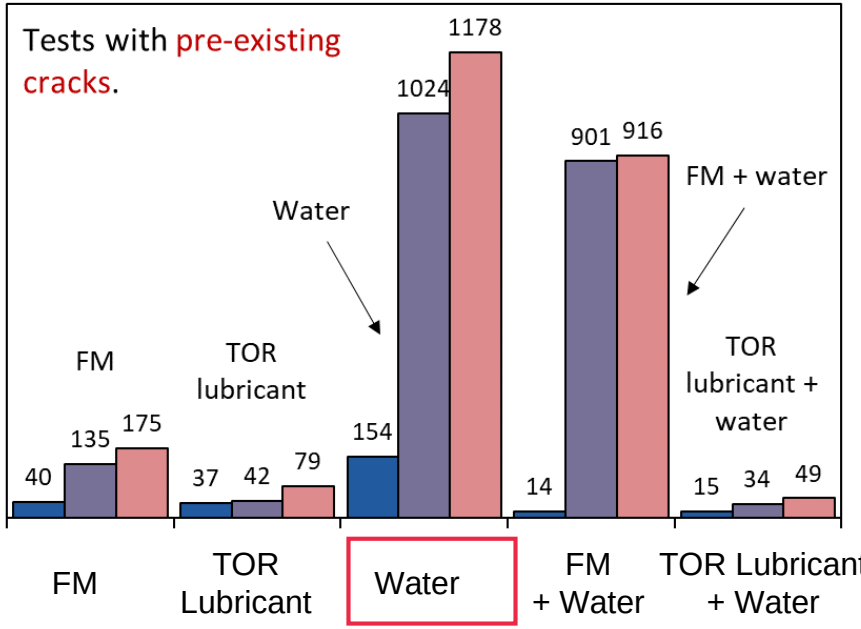
THE EFFECT ON WEAR AND RCF

RESULTS

Liquid-assisted Crack Propagation



Kaneta et al. (1987)



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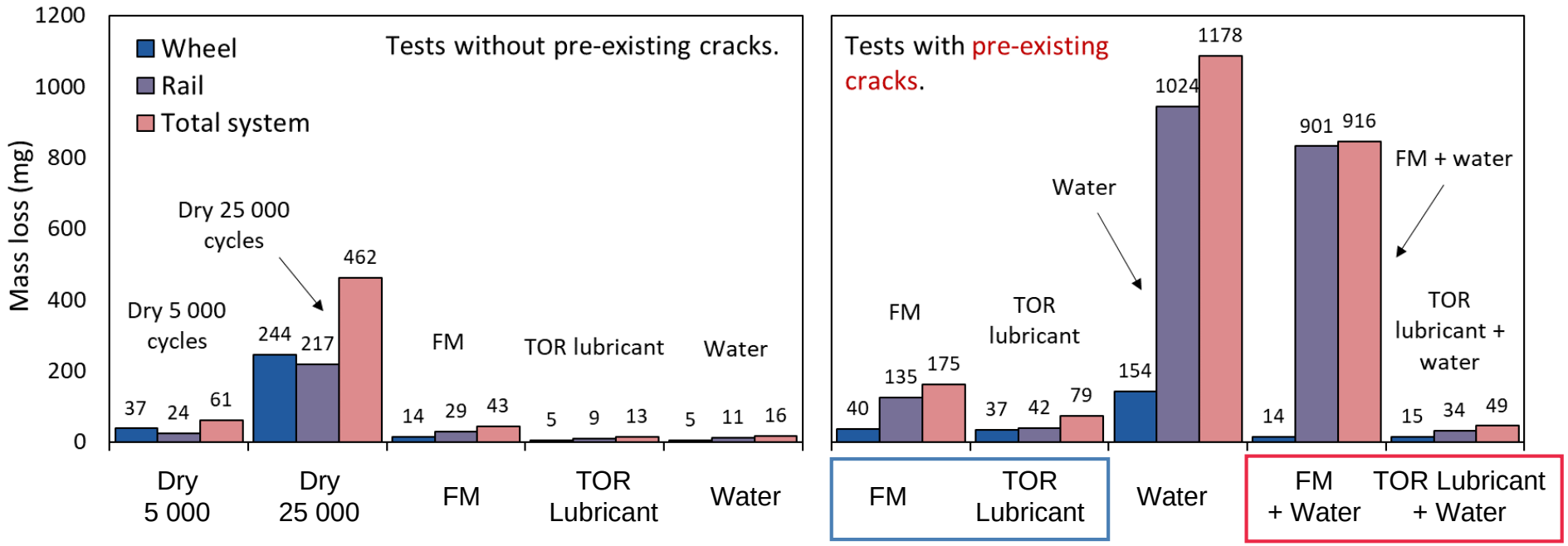
THE EFFECT ON WEAR AND RCF

RESULTS

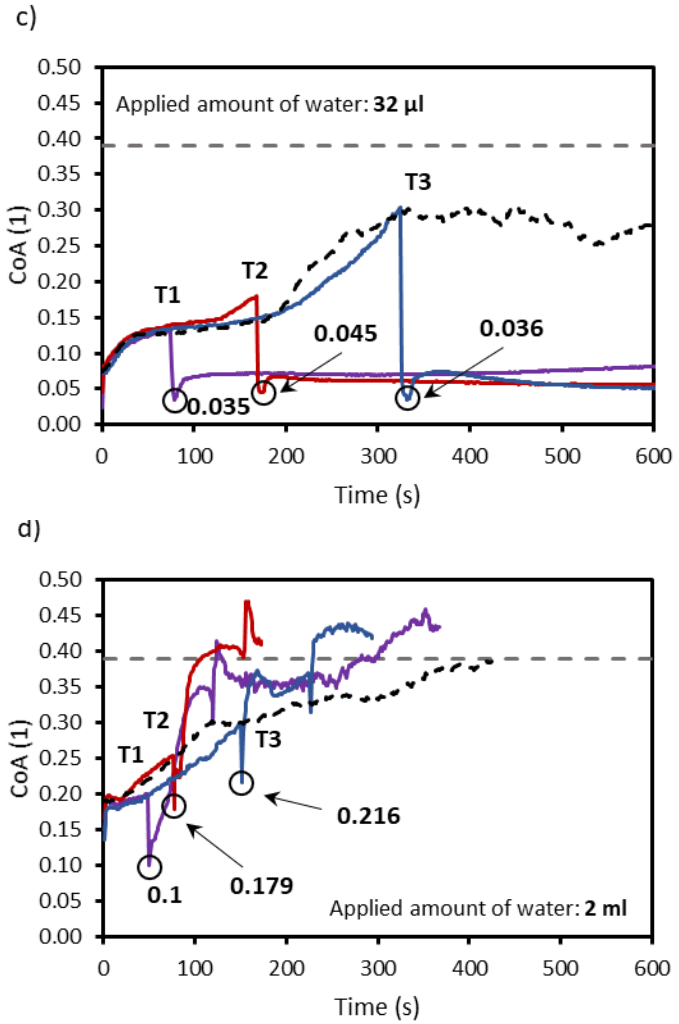


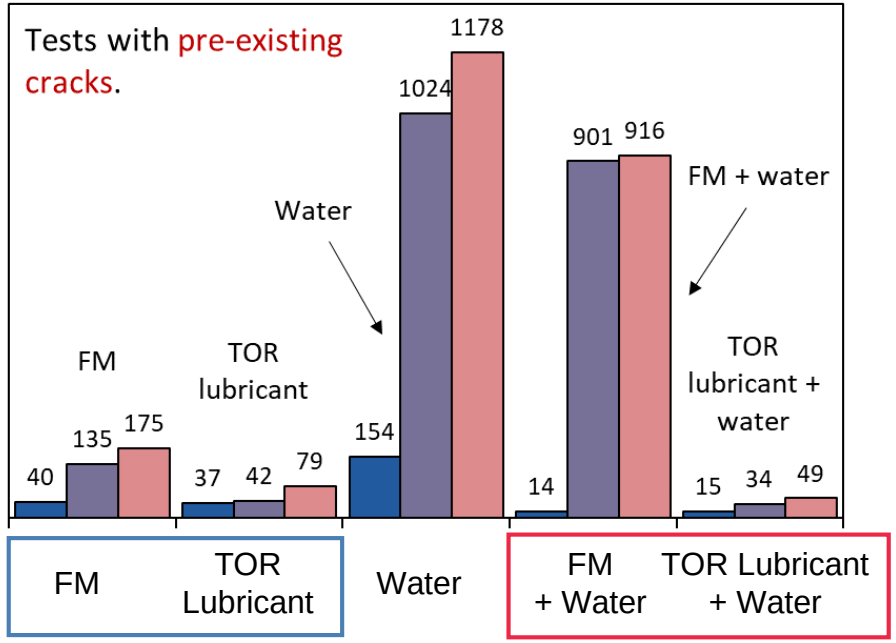
Unlike TOR lubricant, FM could not maintain its function in wet conditions.

THE EFFECT ON WEAR AND RCF

RESULTS

FM film is easily removed by water, and thus, in case of contamination, the surface remains unprotected.



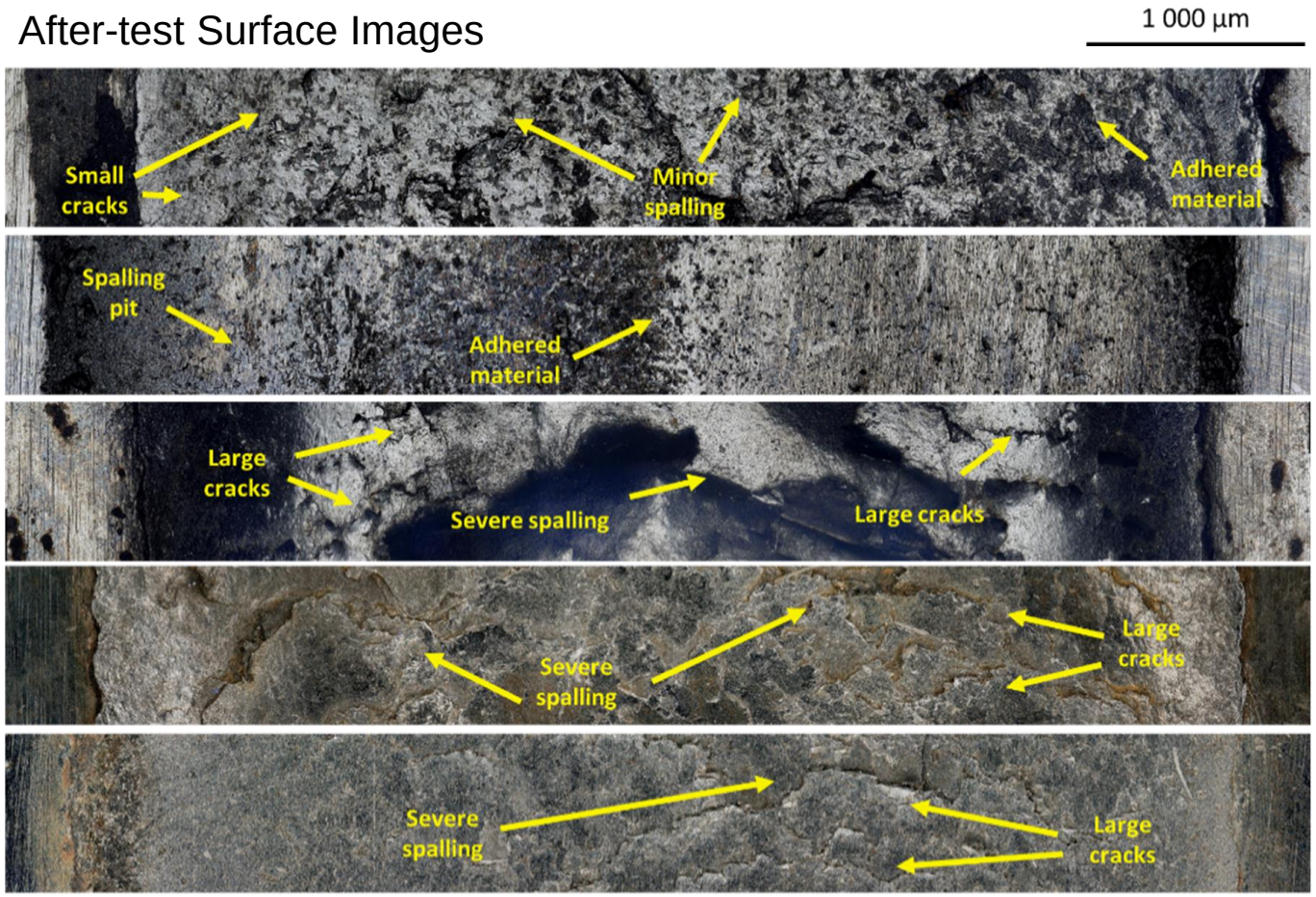


Unlike TOR lubricant, FM could not maintain its function in wet conditions.

THE EFFECT ON WEAR AND RCF

RESULTS

After-test Surface Images



Friction Modifier
(Dry Conditions)

TOR Lubricant
(Dry Conditions)

Water

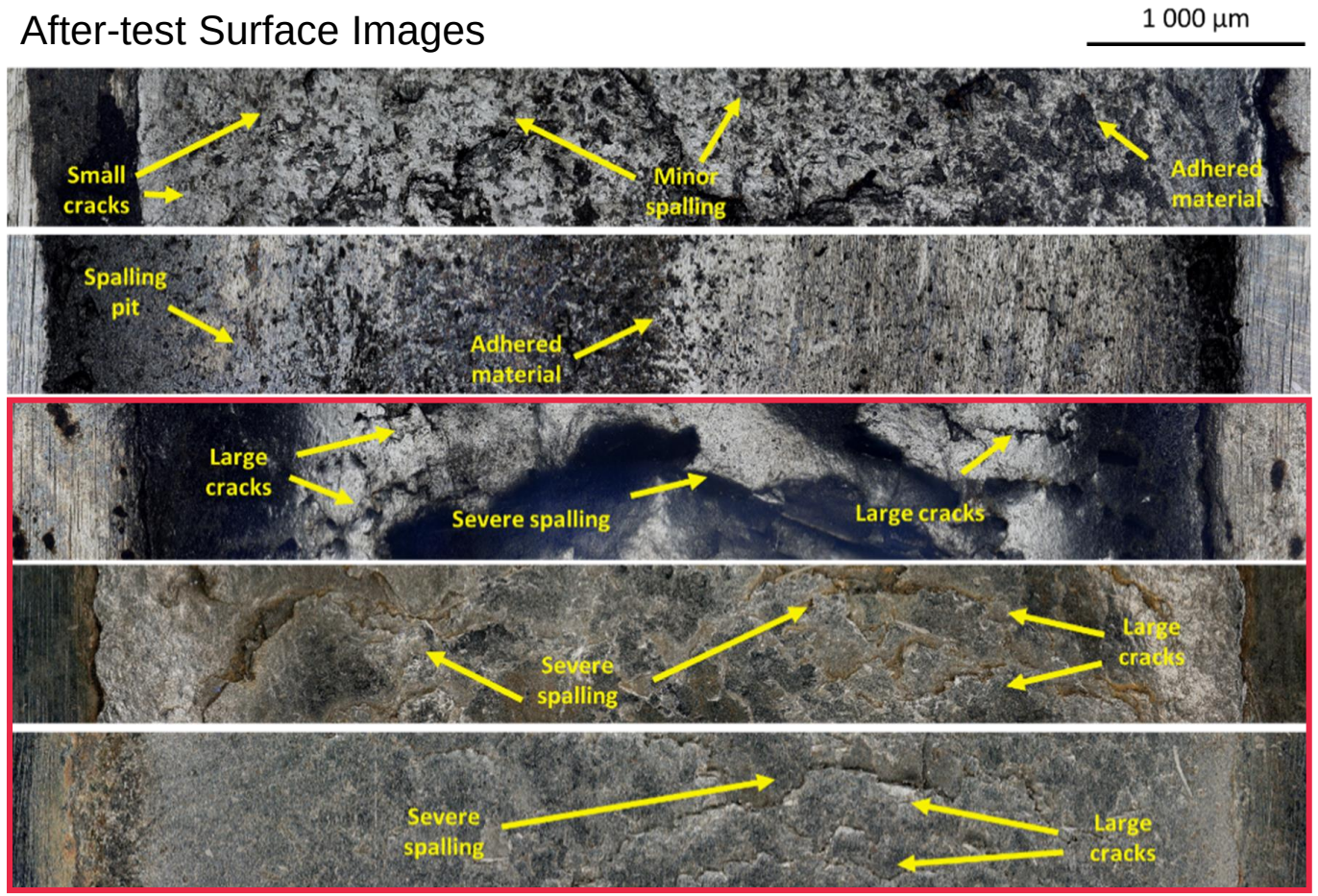
Friction Modifier
(Wet Conditions)

TOR Lubricant
(Wet Conditions)

THE EFFECT ON WEAR AND RCF

RESULTS

After-test Surface Images



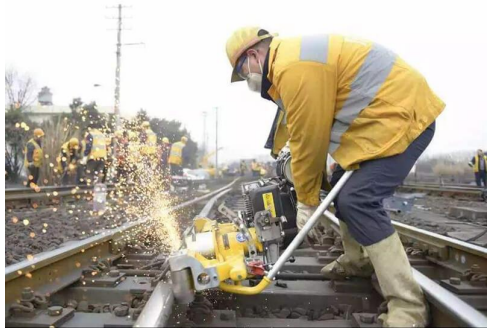
Friction Modifier
(Dry Conditions)

TOR Lubricant
(Dry Conditions)

Water

Friction Modifier
(Wet Conditions)

TOR Lubricant
(Wet Conditions)

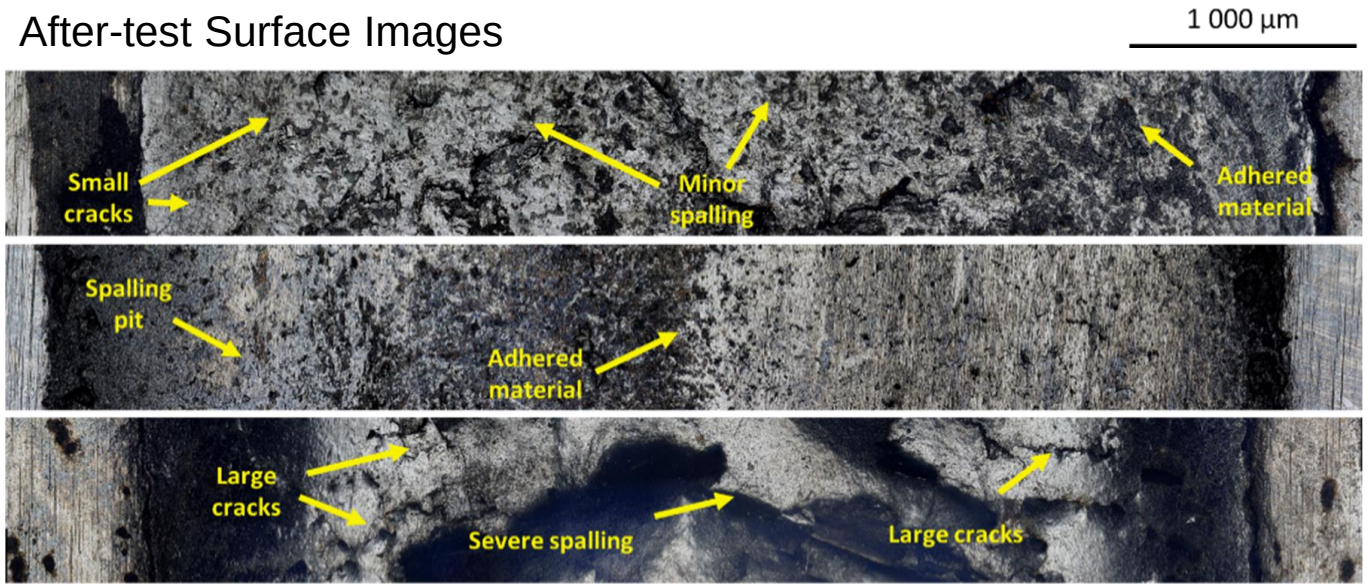


Rail Grinding

THE EFFECT ON WEAR AND RCF

RESULTS

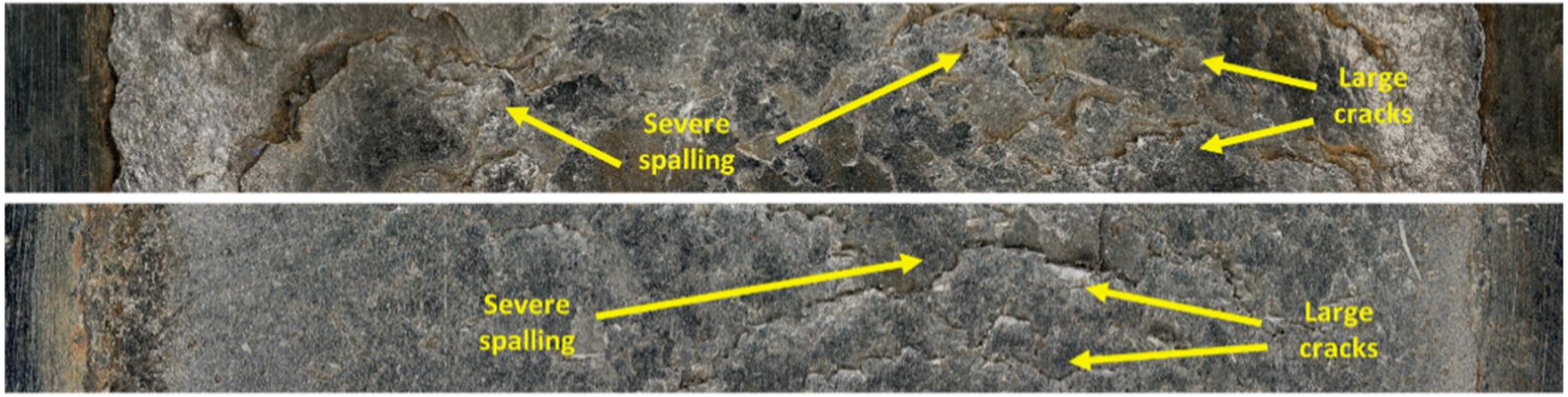
After-test Surface Images



Friction Modifier
(Dry Conditions)

TOR Lubricant
(Dry Conditions)

Water



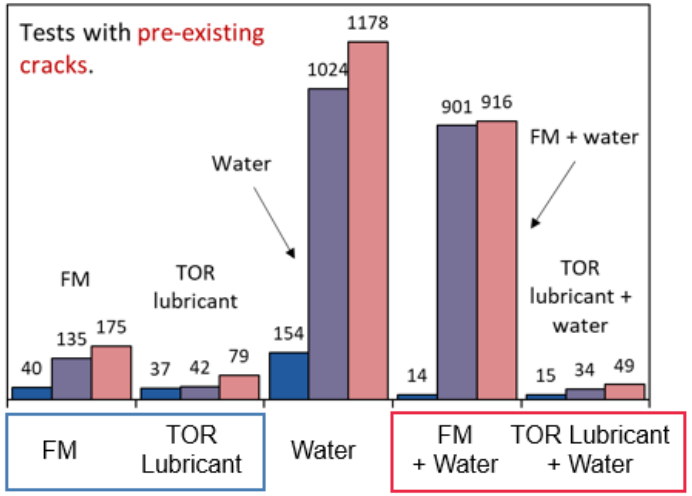
Friction Modifier
(Wet Conditions)

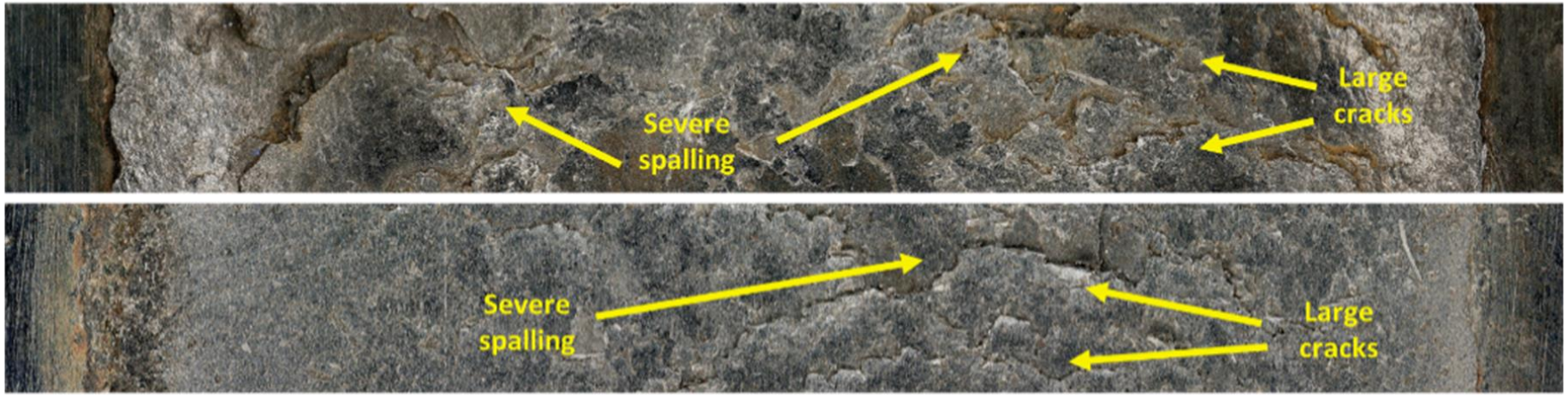
TOR Lubricant
(Wet Conditions)

THE EFFECT ON WEAR AND RCF

RESULTS

Although there was almost no material loss under the TOR lubricant in wet conditions, large cracks were spotted on the surface.





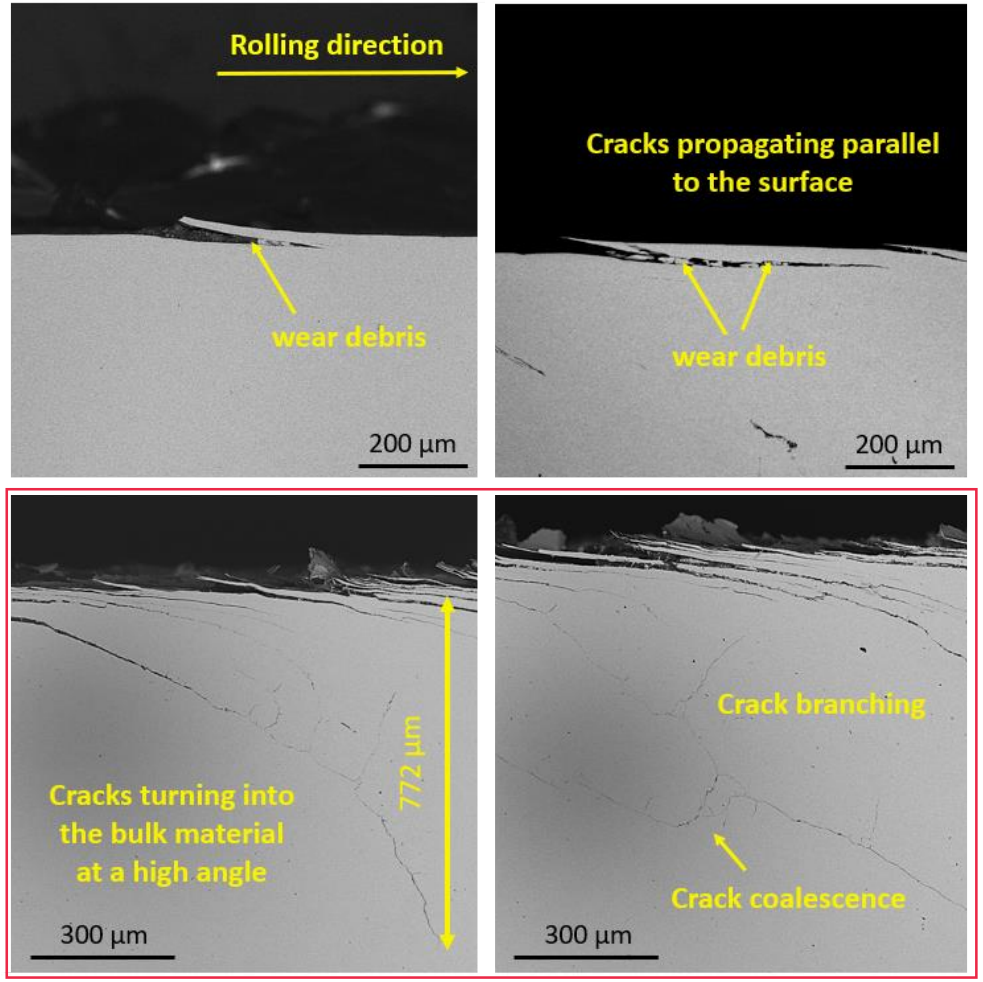
Friction Modifier
(Wet Conditions)

TOR Lubricant
(Wet Conditions)

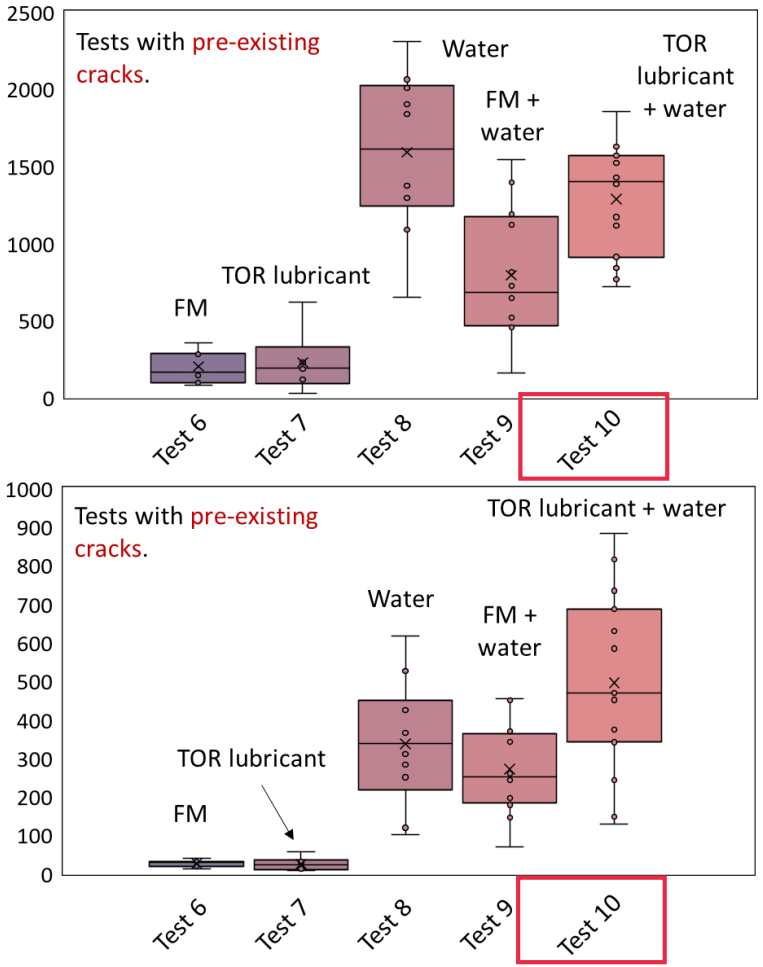
THE EFFECT ON WEAR AND RCF

Dry conditions

TOR Lubricant



TOR Lubricant in Wet Conditions

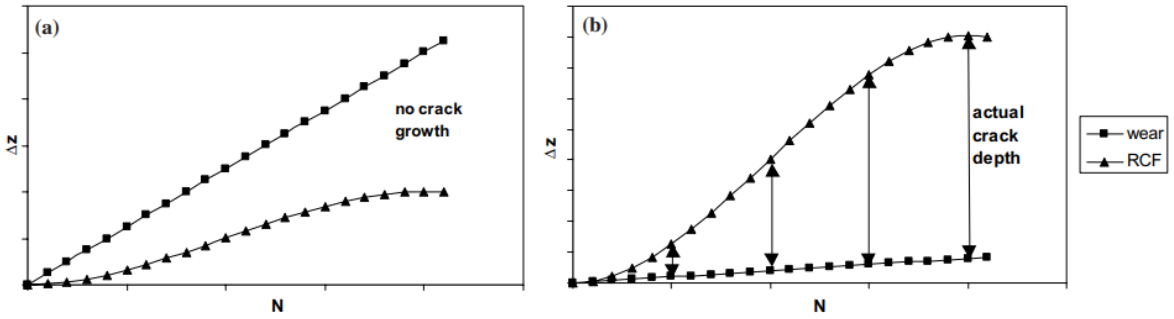


Out of all tests, the TOR lubricant under wet conditions led to the development of the deepest cracks.

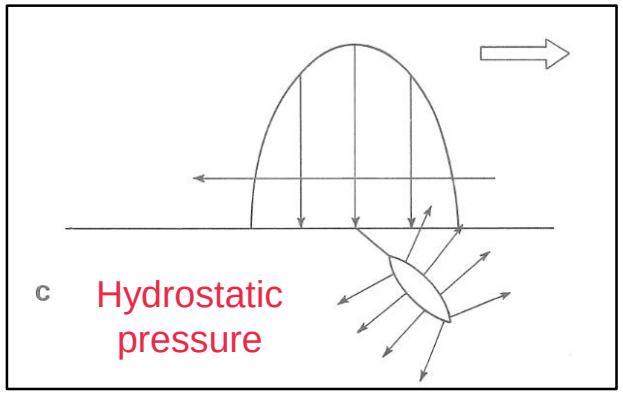
THE EFFECT ON WEAR AND RCF

RESULTS

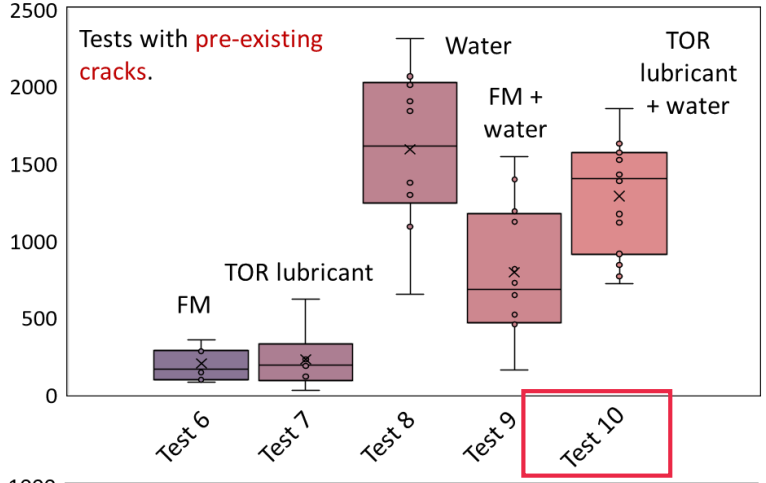
„Competition“ between Wear and Crack Growth

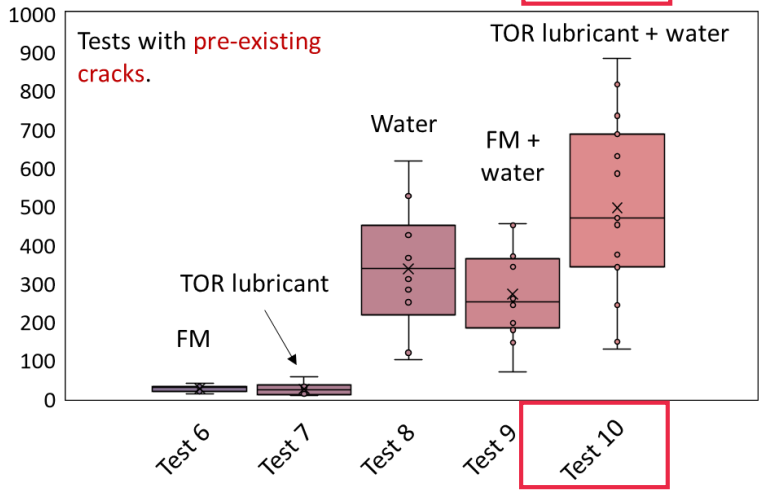


Liquid-assisted Crack Propagation



upper: Donzella et al. (2005); lower: Kaneta et al. (1987)





Out of all tests, the TOR lubricant under wet conditions led to the development of the deepest cracks.

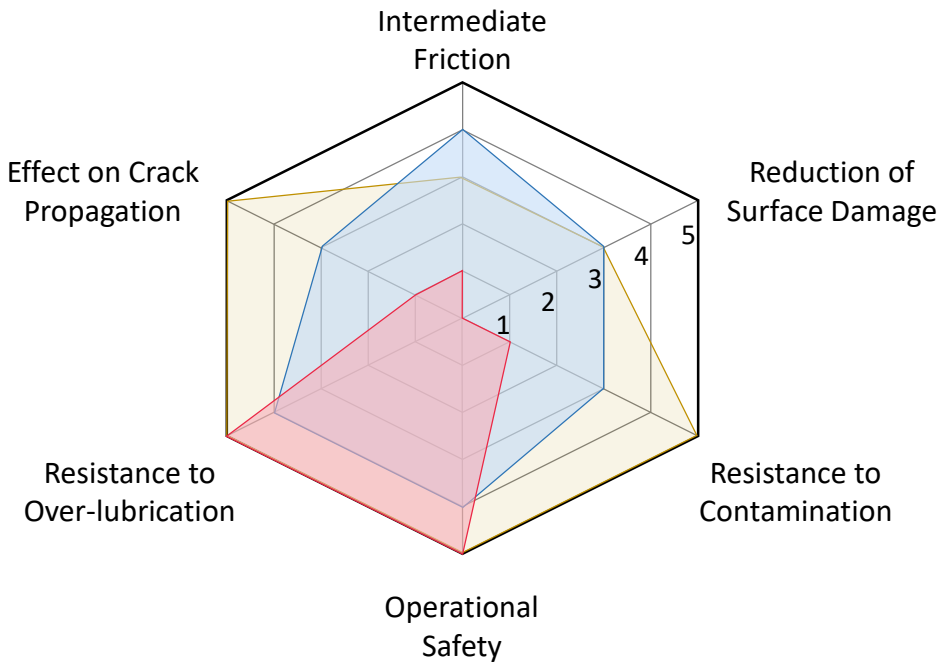
THE ROLE OF OXIDES

EXCLUDED FROM THE ONLINE VERSION AS IT IS CURRENTLY UNDER REVIEW

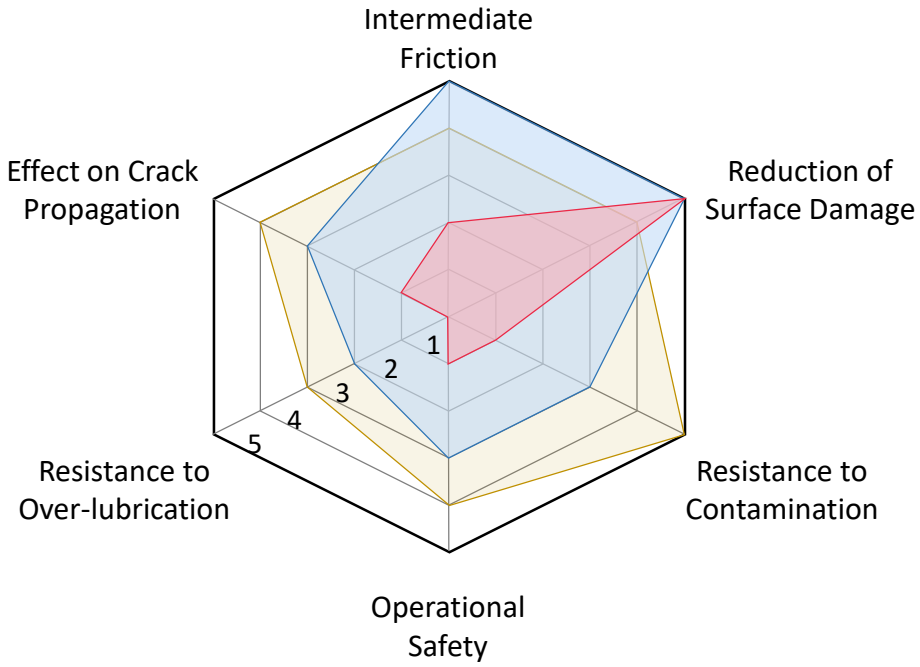
THE EFFECT OF CONTAMINATION ON FRICTION MODIFICATION

THE EFFECT OF CONTAMINATION ON FRICTION MODIFICATION

Friction Modifiers



TOR Lubricants



Contamination scenarios:

Dry and Clean Rail

Light Moisture (humidity, dew)

Water (precipitation)

1 = the worst (e.g. severe wear); 5 = the best (e.g. virtually no wear)
The scale is illustrative only and serves to indicate qualitative trends. No weighting between individual criteria is implied.

THE EFFECT OF CONTAMINATION ON FRICTION MODIFICATION

THE MAIN TAKEAWAY

„For friction modifiers, contamination is a matter of cost.
For TOR lubricants, it's a matter of safety.“

THE EFFECT OF CONTAMINATION ON FRICTION MODIFICATION

Back to my Personal Motivation:

Trams will most likely continue to squeal…

THE EFFECT OF CONTAMINATION ON FRICTION MODIFICATION

PRACTICAL IMPLICATIONS

Weather-dependent Application

- Equip applicators with RH, temperature, dew point, and precipitation sensors
- Suspend or reduce application when thresholds are exceeded

Application Bar

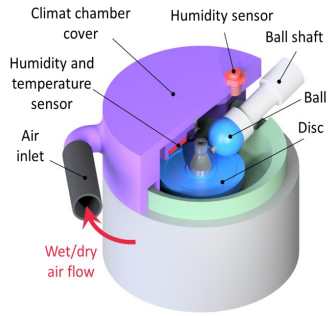
TOR Product Tank

THE EFFECT OF CONTAMINATION ON FRICTION MODIFICATION

PRACTICAL IMPLICATIONS

Weather-dependent Application

- Equip applicators with RH, temperature, dew point, and precipitation sensors
- Suspend or reduce application when thresholds are exceeded



New-generation TOR Products

- The methodology can be used to develop TOR products that perform effectively under contaminated conditions.

1st **Lab-to-Lab**	2nd **Lab-to-Field**	Future step **Field**
Comparative test, Q1-Q4 Result transferability Effect of amount Suitable TOR product	Test close to track conditions Track performance parameters Suitable amount Suitable application strategy	Interaction of naturally formed third body layer and TOR product
Mini-traction machine	Contact simulator + BUT tribometer	Railway track + BUT tribometer

Research pathway: from laboratory to field application.

THANK YOU!

Šimon Skurka

Simon.Skurka@vut.cz

BRNO UNIVERSITY OF TECHNOLOGY

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