Defense of the PhD thesis

BRNO, CZECH REPUBLIC | 15th FEBRUARY 2018

Friction modification within wheel-rail contact

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INSTITUTE OF MACHINE AND INDUSTRIAL DESIGN

Content

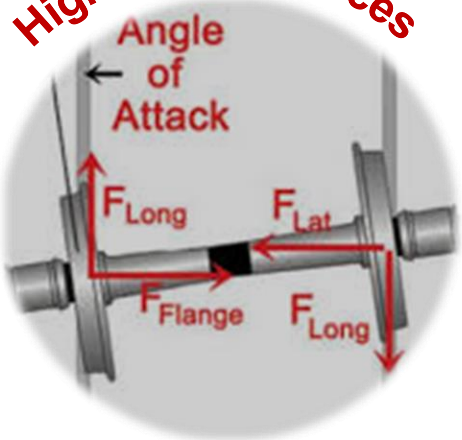
Introduction - Motivation

Adhesion loss

Wear

Corrugation

High contact forces

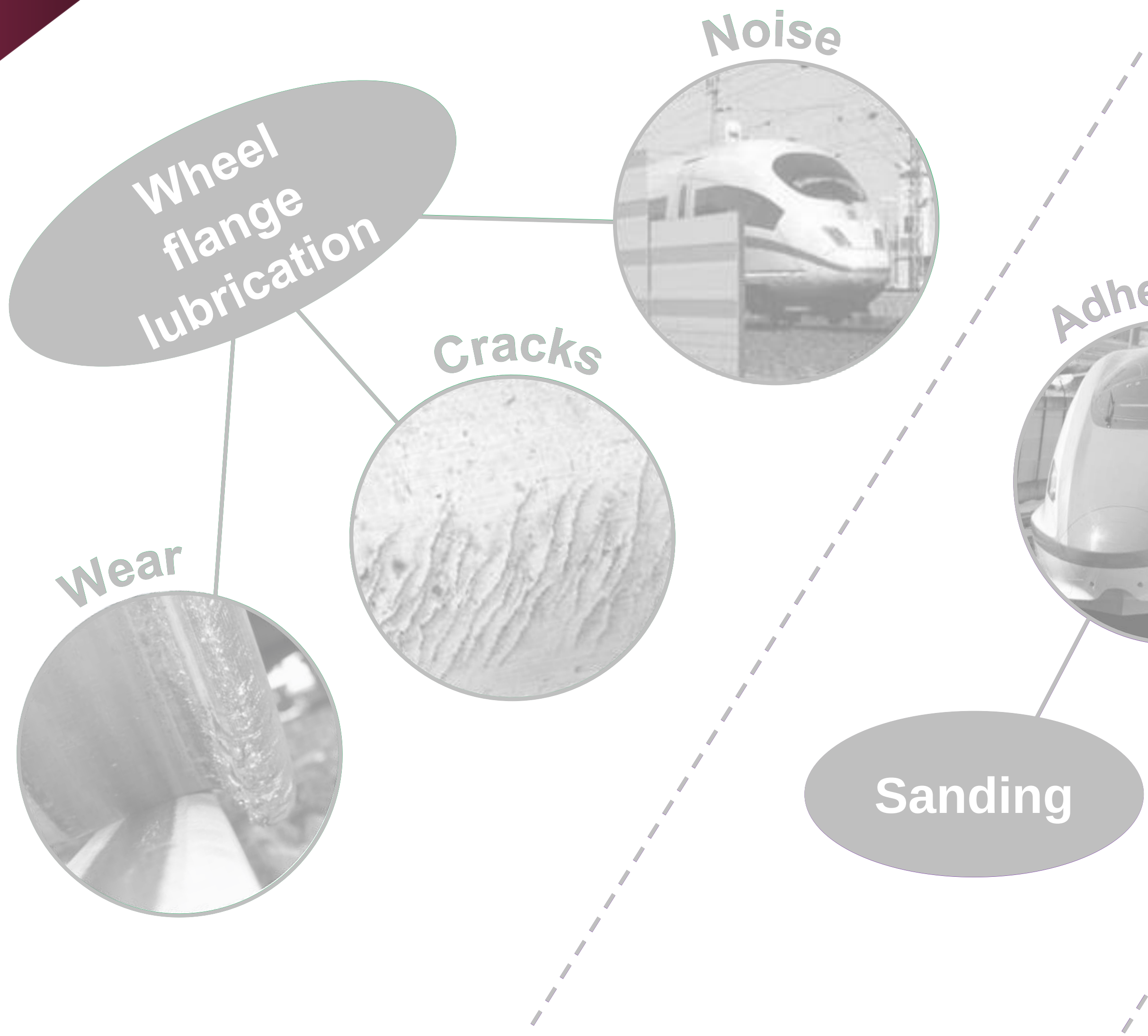


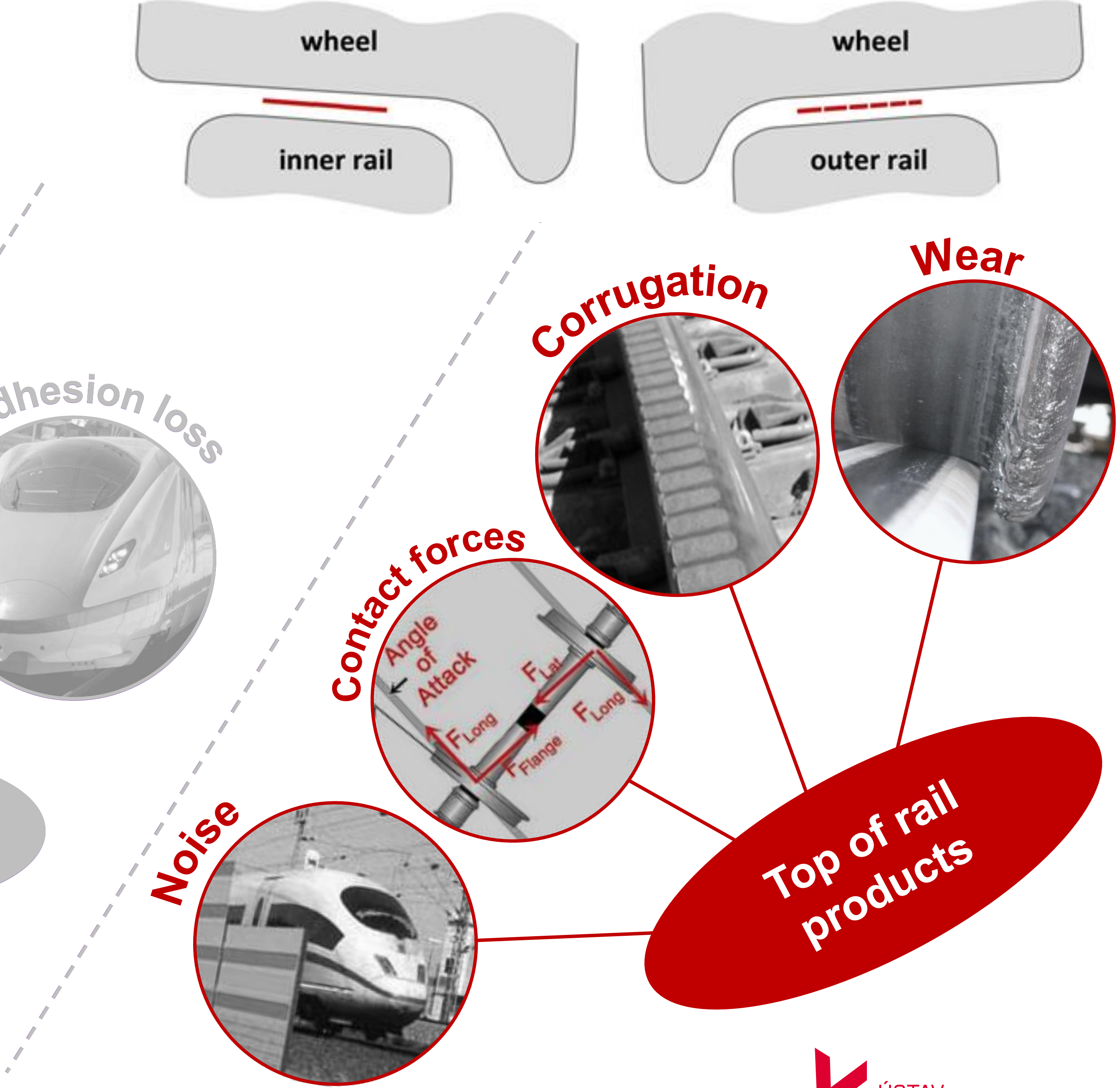
Noise and vibration

Wheel flange lubrication

Sanding

Friction management





Top-of-rail products

Application | **Products**

On-board system (train mounted)

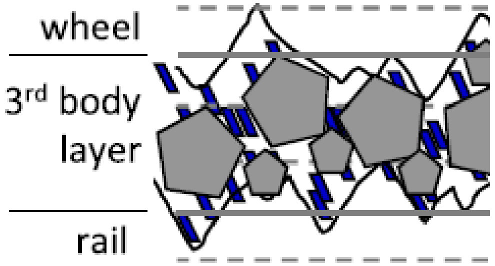
- Impact on a specific train(s)
- Adaptive control

Off-board system (wayside)

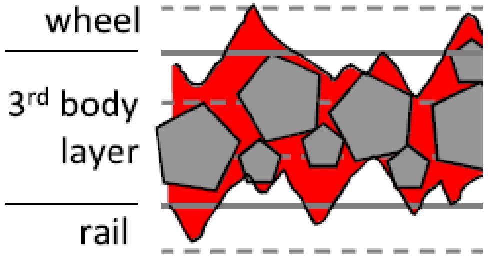
- Impact on a specific track
- Limiting carry distance
- Maintenance issues

Friction modifiers (water-based)

- Drying materials + 3rd body
- Delayed effect



Stock (2016, Wear)



Stock (2016, Wear)

TOR lubricants (oil or grease-based)

- Significant quantity-dependent effect
- Suitable carry-down characteristics

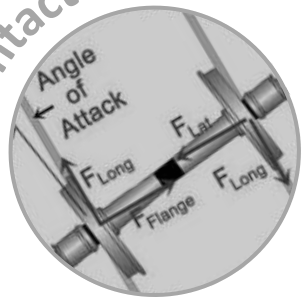
General requirements

Wear

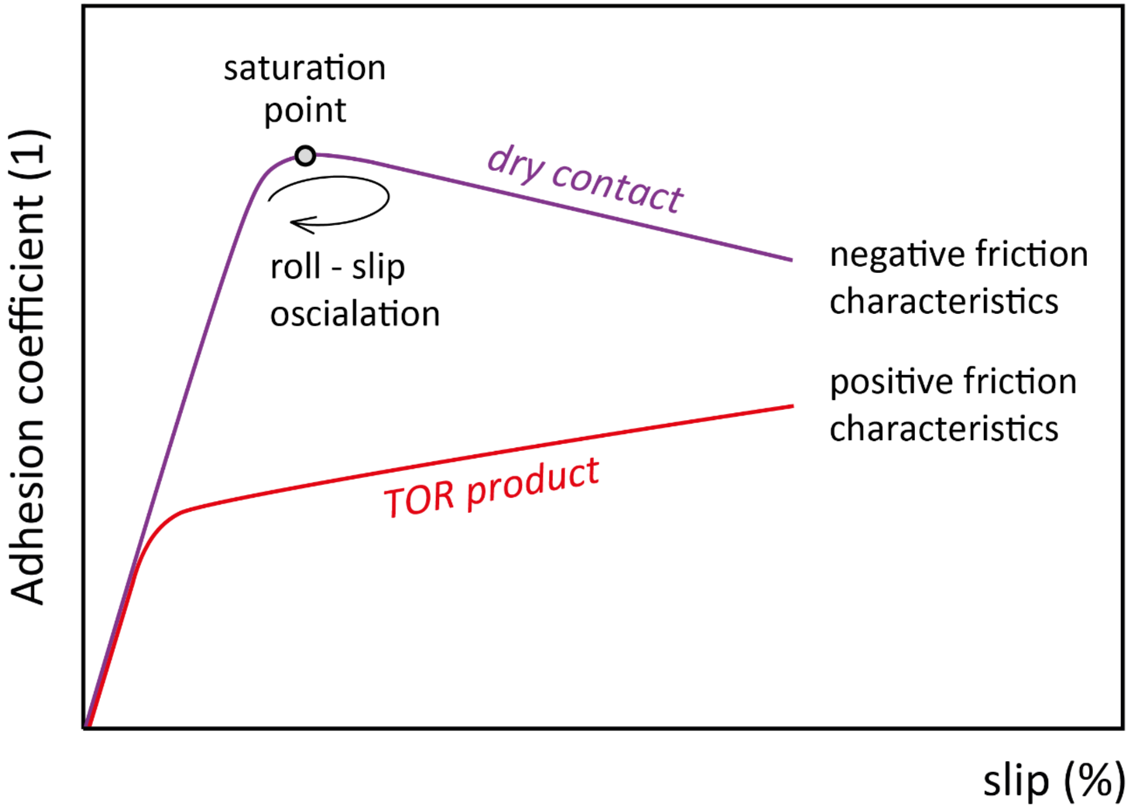
Corrugation

Noise

Contact forces



Required friction properties



TOR products should provide:

- Intermediate level of friction (0.35 ± 0.05)
- Positive traction curve

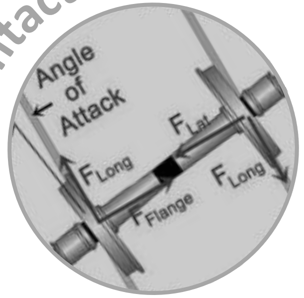
State of the art

Wear

Corrugation

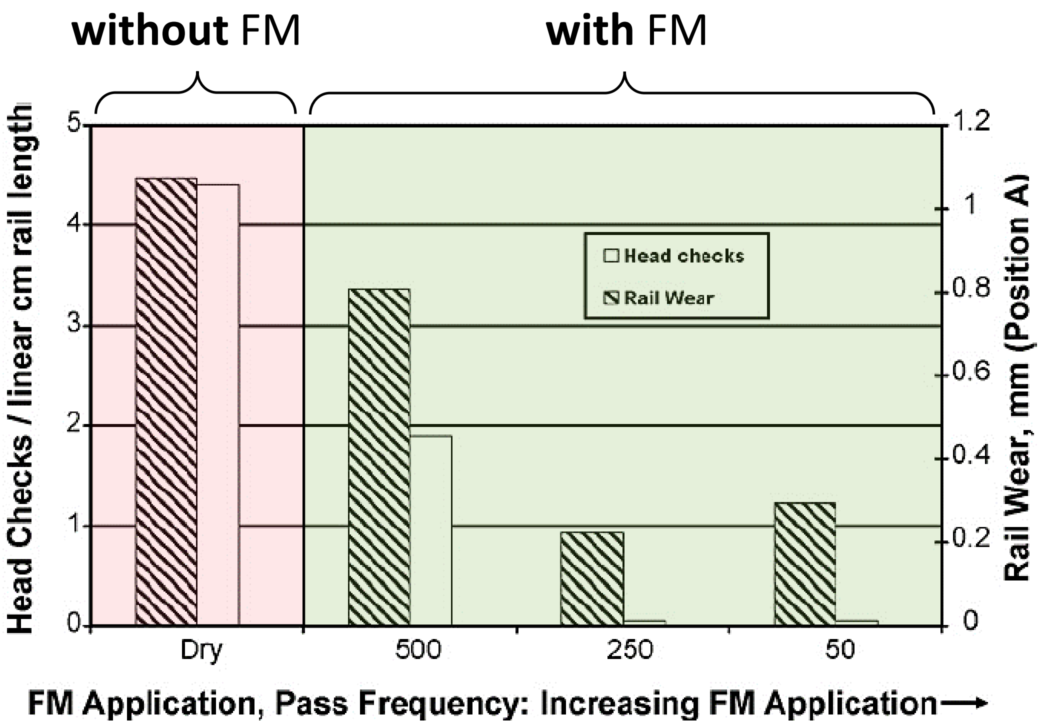
Noise

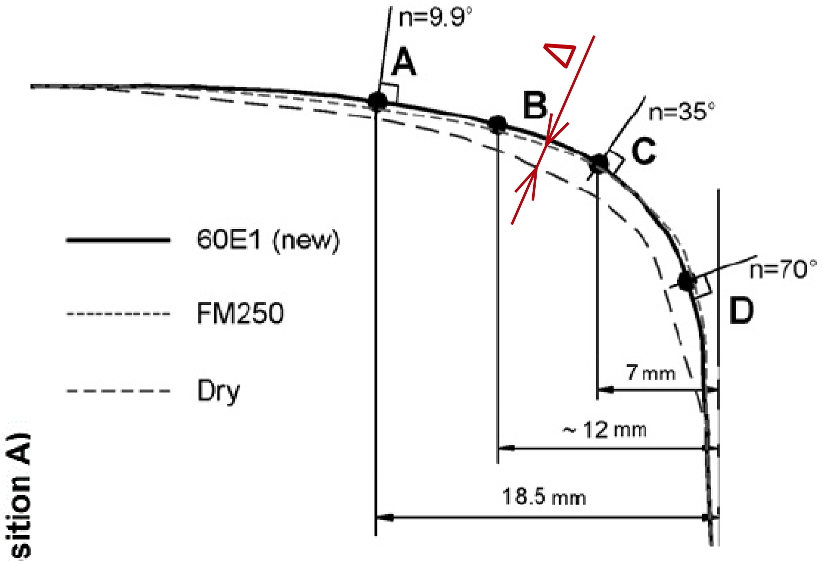
Contact forces

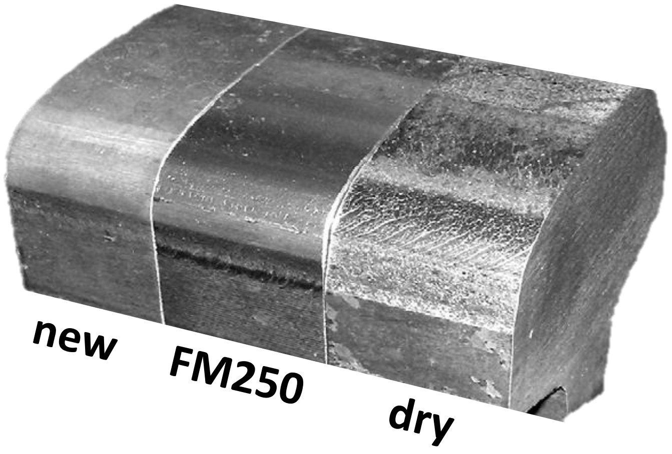


Benefits | Wear

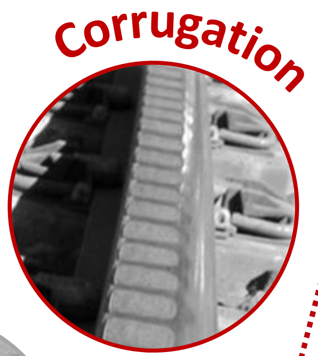
Figures: Eadie (2008, Wear)

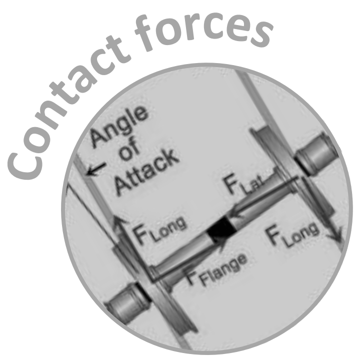






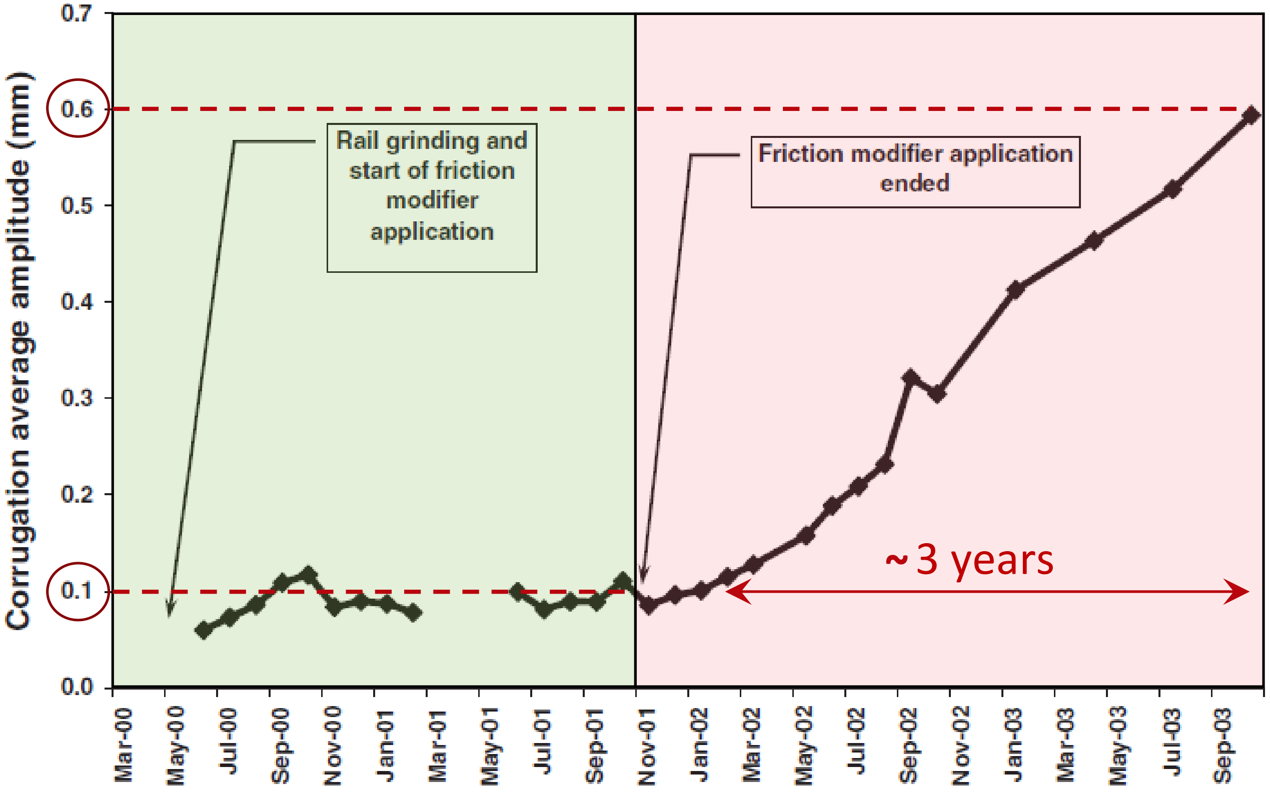
State of the art



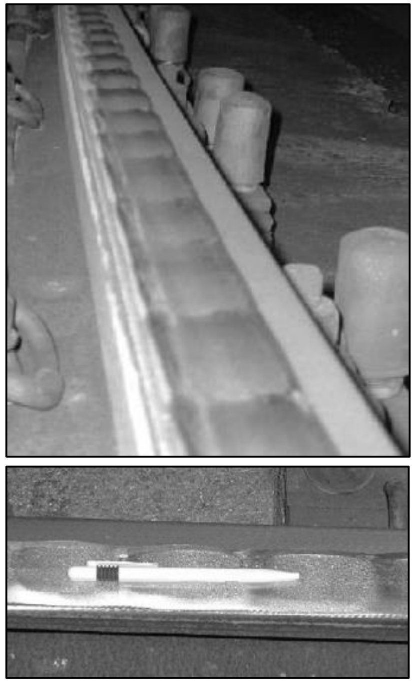


Benefits Corrugation

Eadie (2006, Journal of Sound and Vibration)



Eadie (2008, Wear)



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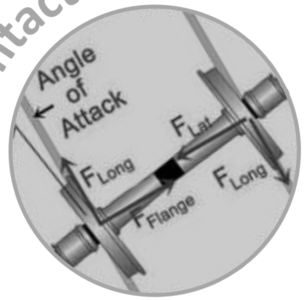
State of the art

Wear

Corrugation

Noise

Contact forces



Benefits | Noise

Eadie (2006, Journal of Sound and Vibration)

System number	1	2	3	4	5
Country	Spain	Italy	Spain	Netherlands	United Kingdom
System type	Metro	Tram	Light Rail	Tram	Tram
Curve radius (m)	220	25 (est.)	250	25	26
Speed (km/h)	50	5–10	65	10–15	15
Axle per car	4	8	4	8	6
Cars per train	6	1	6	1	1
Rail type/wt	UIC 54	AP4N Phoenix Type	UIC 54	RI 59	41G
Brake type	Disk	Disk	Disk	Disk	Disk
Gauge face lubrication	Onboard oil	Onboard oil	Onboard oil	Trackside oil	Onboard oil
Friction modifier Application method	Automatic trackside	Manual	Manual	Manual	Manual
Ave L_{Aeq} baseline (dB)	101.4	92.9	80.4	86.7	98.2
Ave L_{Aeq} friction modifier (dB)	95.1	83.1	72.5	73.3	75.4
Track condition	Corrugated	Worn	Corrugated	Worn	New
Track structure	Concrete sleepers/ballast	Imbedded	Concrete sleepers/ballast	Imbedded	Imbedded

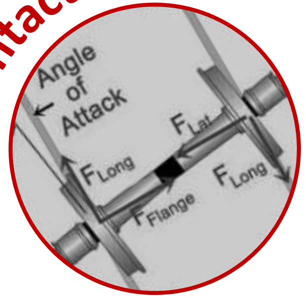
State of the art

Wear

Corrugation

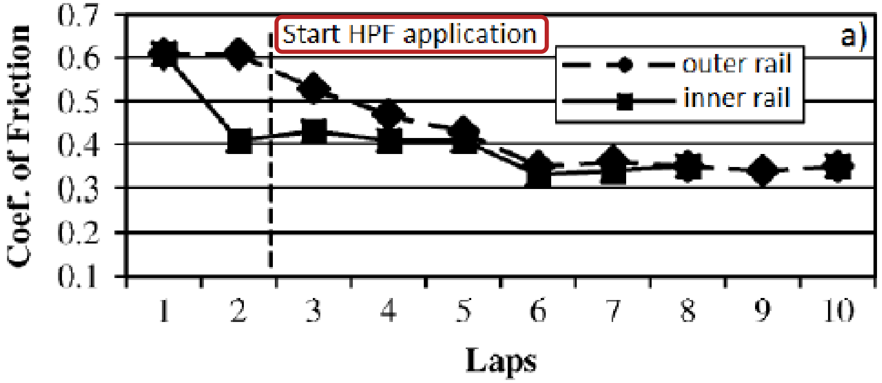
Noise

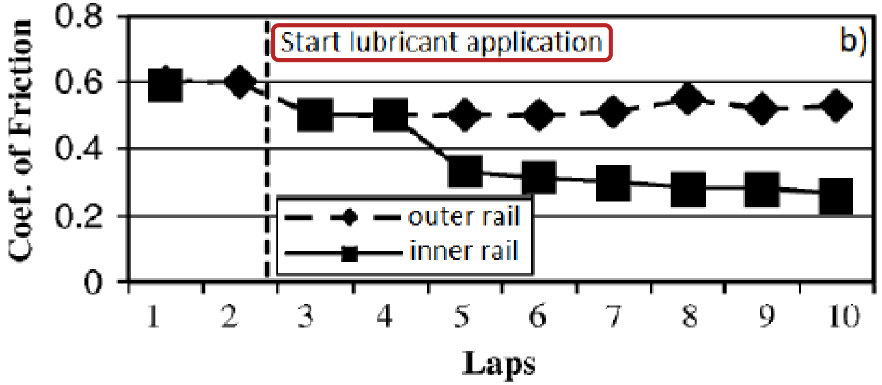
Contact forces



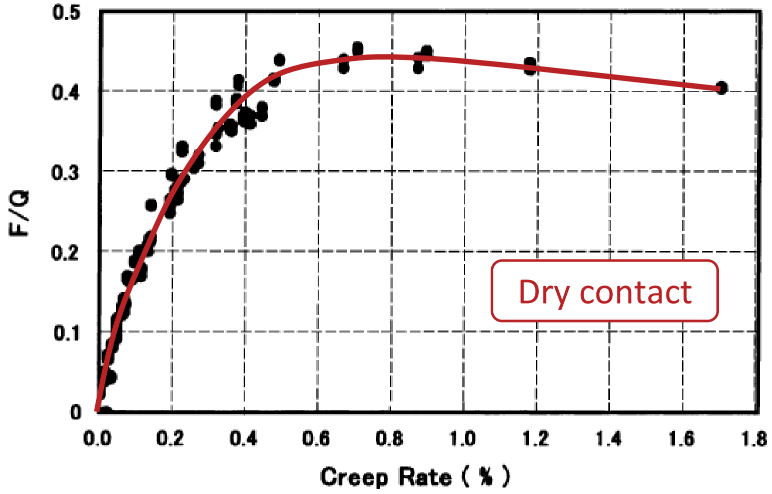
Benefits | Contact forces

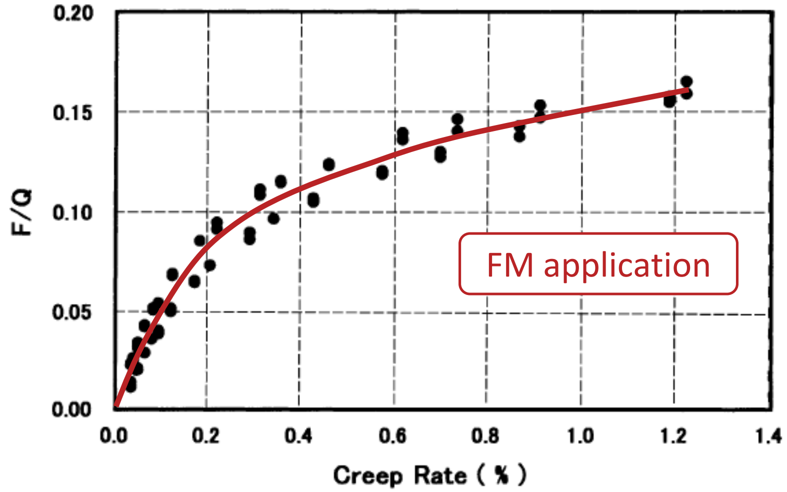
Eadie (2002, Wear)





Matsumoto (2002, Wear)





Summary of literature review

Friction characteristic

Matsumoto (2002,2004)
Cuevas (2010)

Wear

Eadie (2008)
Li (2009)
Cuevas (2010)
Stock (2011)

Corrugation

Kalousek (1992)
Eadie (2002,2006,2008)
Egana (2005)

Friction modifiers

Rolling contact fatigue

Cuevas (2010)
Stock (2011)

Adhesion

Eadie (2002)
Tomeoka (2002)
Ishida (2008)
Li (2009)
Cuevas (2010)
Lewis (2013)
Lundberg (2015)
Areiza (2015)
Liu (2016)

TOR lubricants

Noise

Eadie (2005,2006,2006)
Curley (2015)
Liu (2016)

Summary of literature review

Friction modifiers

Friction characteristic
Matsumoto (2002,2004)
Cuevas (2010)

Wear
Eadie (2008)
Li (2009)
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Stock (2011)

Drying effect?

Quantity?

Adhesion
Eadie (2002)
Tomeoka (2002)
Ishida (2008)
Li (2009)
Cuevas (2010)
Lewis (2013)
Lundberg (2015)
Areiza (2015)
Liu (2016)

Composition?

Corrugation
Kalousek (1992)
Eadie (2002,2006,2008)
Egana (2005)

Noise, wear ?

Quantity?

Rolling contact fatigue
Cuevas (2010)
Stock (2011)

Noise
Eadie (2005,2006,2006)
Curley (2015)

Safety issues?

TOR lubricants

Aim of thesis

To clarify the friction behaviour and impact of the TOR products on friction in the wheel-rail contact, while the main attention is paid to low adhesion issues related to the application of these substances.

…friction, noise, and wear.

Scientific questions

Q1: *What is the influence of applied quantity and chemical composition of TOR products on their performance?*

Q2: *Can a safe braking distance be guaranteed when the contact is overdosed with TOR products?*

Hypotheses

H1:

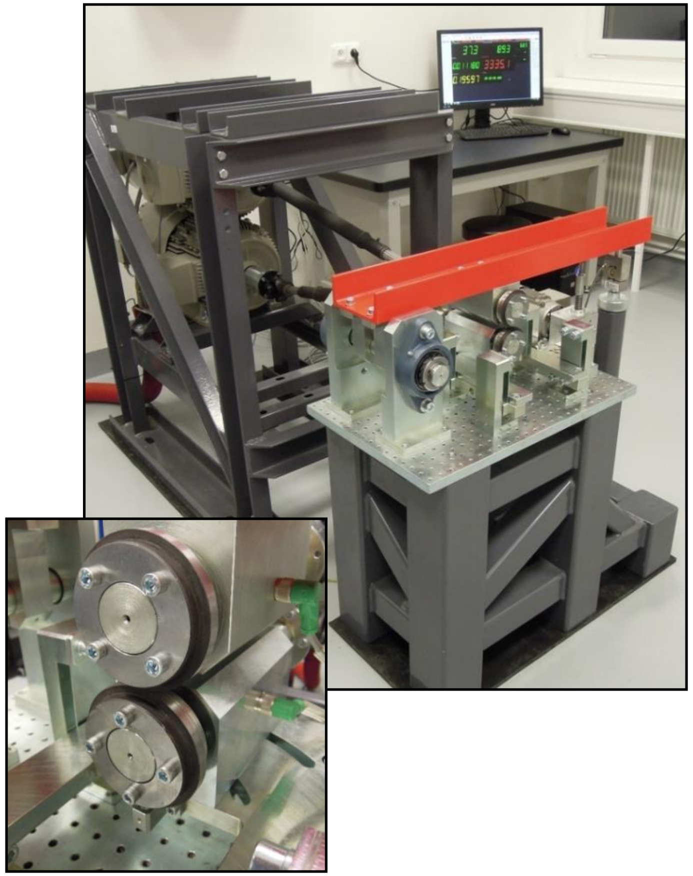
H2:

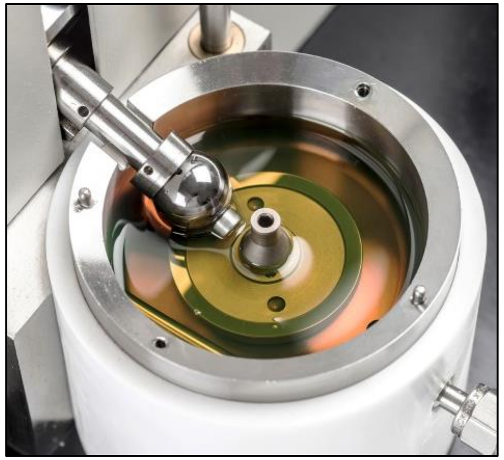
⋮

H9:

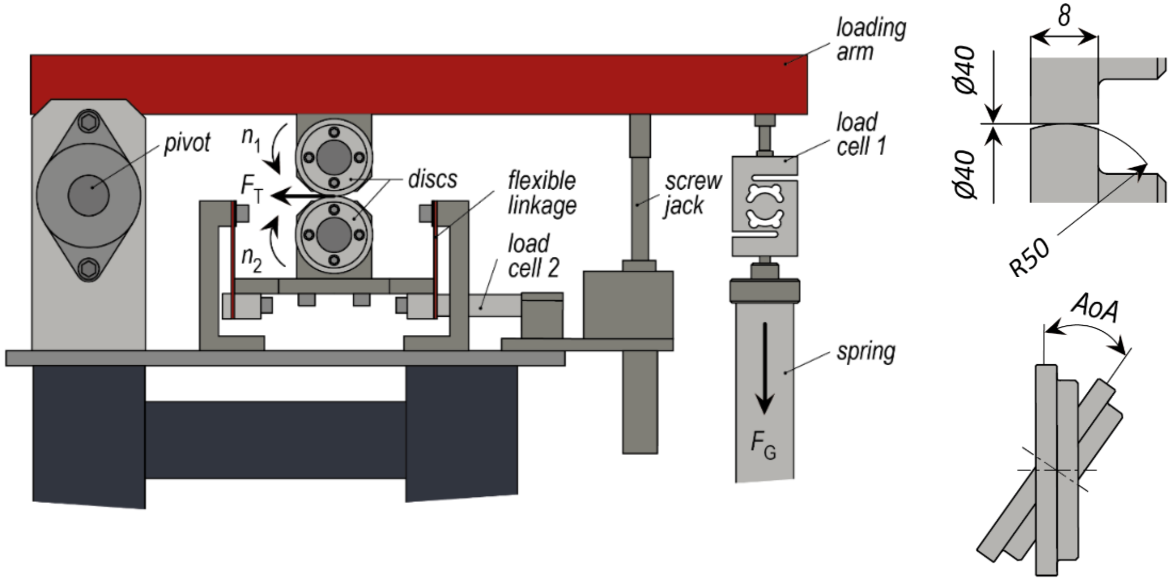
Materials and methods

Laboratory research | Field research

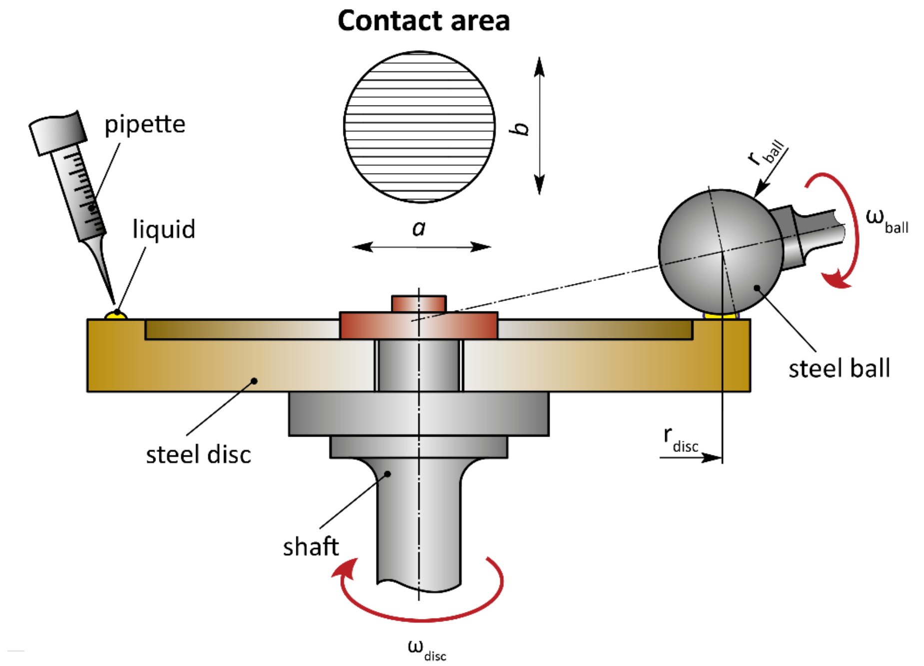




Twin-disc tribometer | Ball-on-disc tribometer



$$\mu = \frac{F_t}{F_n}$$



	Pressure (GPa)	Speed (mm/s)	SRR (%)	AoA (°)	Material of specimens
Ball-on-disc	0.8	300	1-10	0	C45, bearing steel
Twin-disc	0.8	1 000	8	4	bearing steel

- light rail system
- circular contact

- boundary or mixed lubrication regime

- traction curve (saturation)

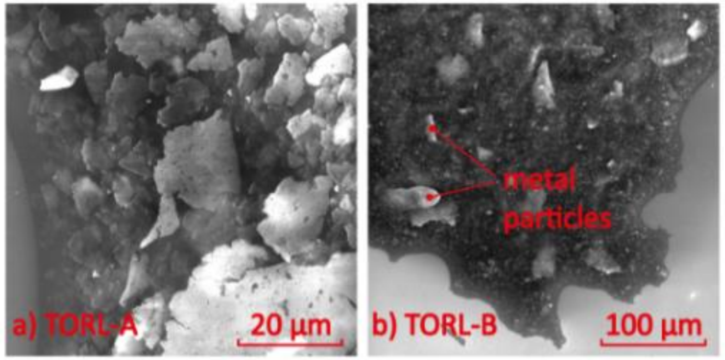
- critical case

- wheel steel R7T
- properties of FM itself

Tested TOR lubricants | Tested friction modifiers

Commercial TOR lubricants

- TORL-A (Cu and Zn)
- TORL-B (Cu and Al)
- Castor oil

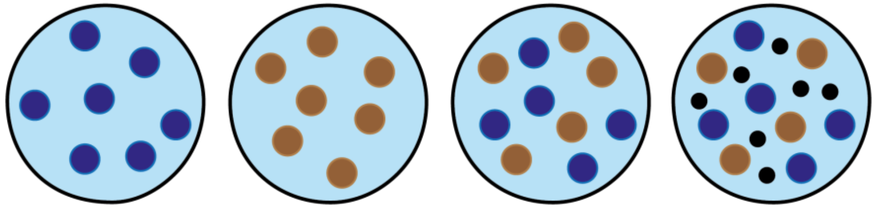


Predominant size: 4-10 µm

TORL-A 145 m/ml

TORL-B 3 m/ml

Substances with various complexity



- binding agent (bentonite)
- PFM (talc, zinc oxide)
- solid lubricant (molyka, graphite)

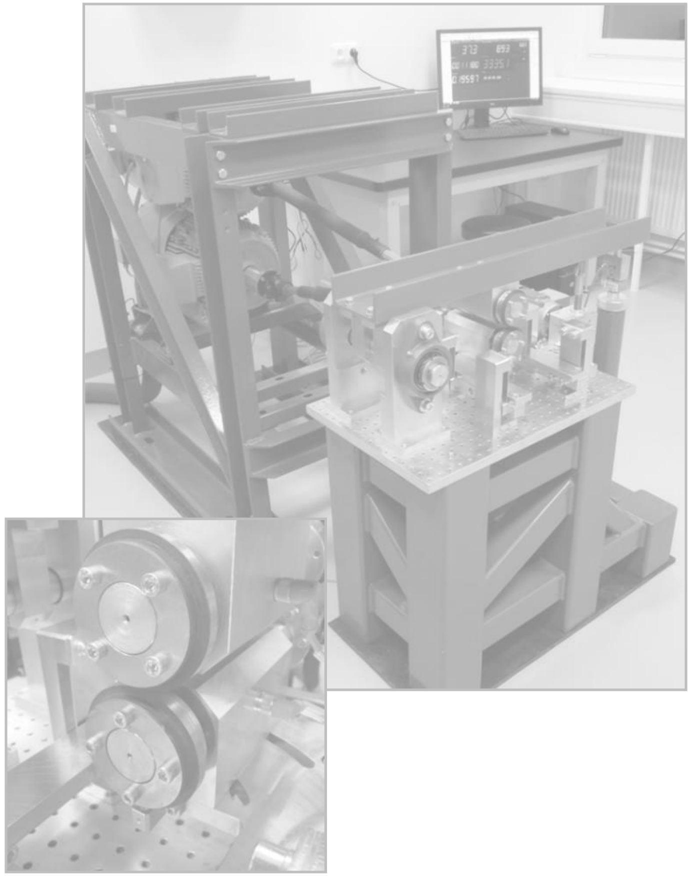
wet film ✕ **dry** film

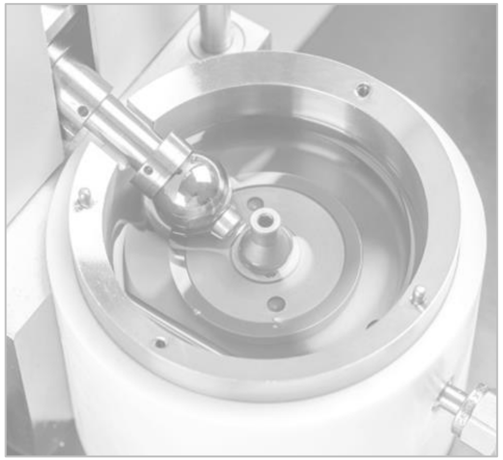
Safety issues? **Noise, wear ?** **Quantity?**

Quantity? **Composition?** **Drying effect?**

Materials and methods

Laboratory research





Field research

Materials and methods – field research

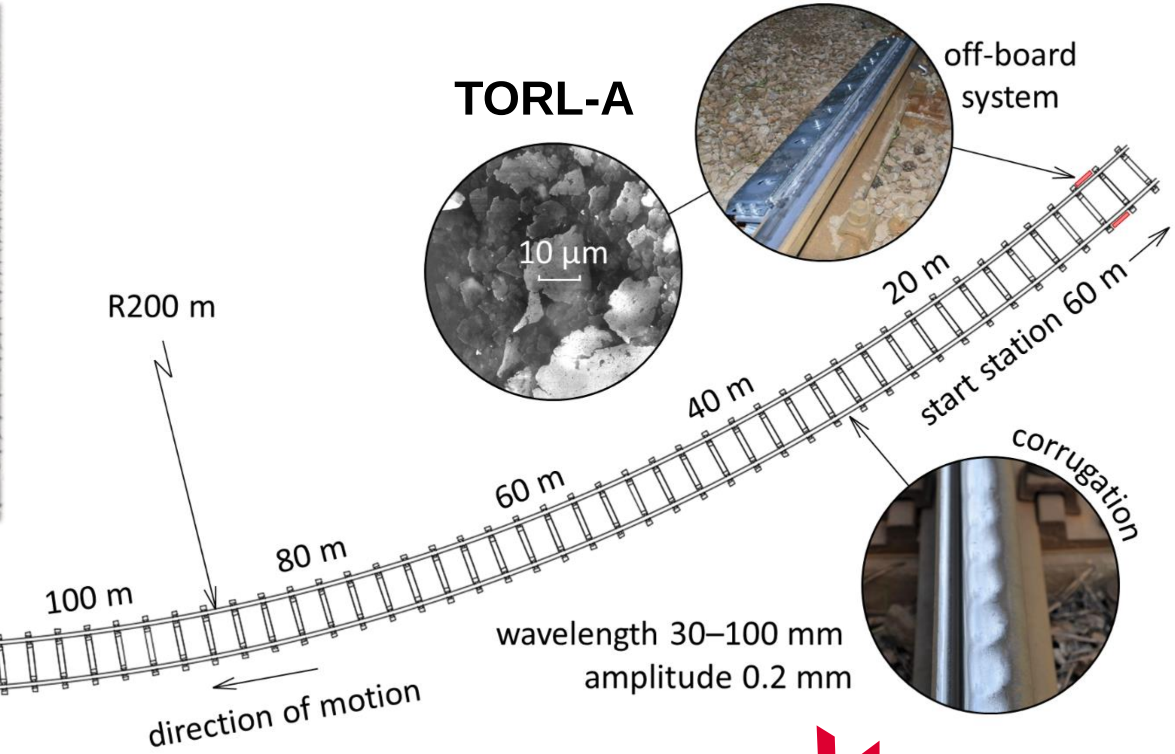
Characteristics of track

- low speed (< 40 km/h); low load
- tracks with extreme curves
- on-street as well as right-of-way running

Type of **experiments**

- braking tests
- noise measurements

(long-term experiments)



Results – Friction modifiers

Friction modifiers

Friction characteristic
Matsumoto (2002,2004)
Cuevas (2010)

Drying effect?

Wear
Eadie (2008)
Li (2009)
Cuevas (2010)
Stock (2011)

Quantity?

Composition?

Adhesion
Eadie (2002)
Tomeoka (2002)
Ishida (2008)
Li (2009)
Cuevas (2010)
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Liu (2016)

Corrugation
Kalousek (1992)
Eadie (2002,2006,2008)
Egana (2005)

Noise, wear ?

Quantity?

Rolling contact fatigue
Cuevas (2010)
Stock (2011)

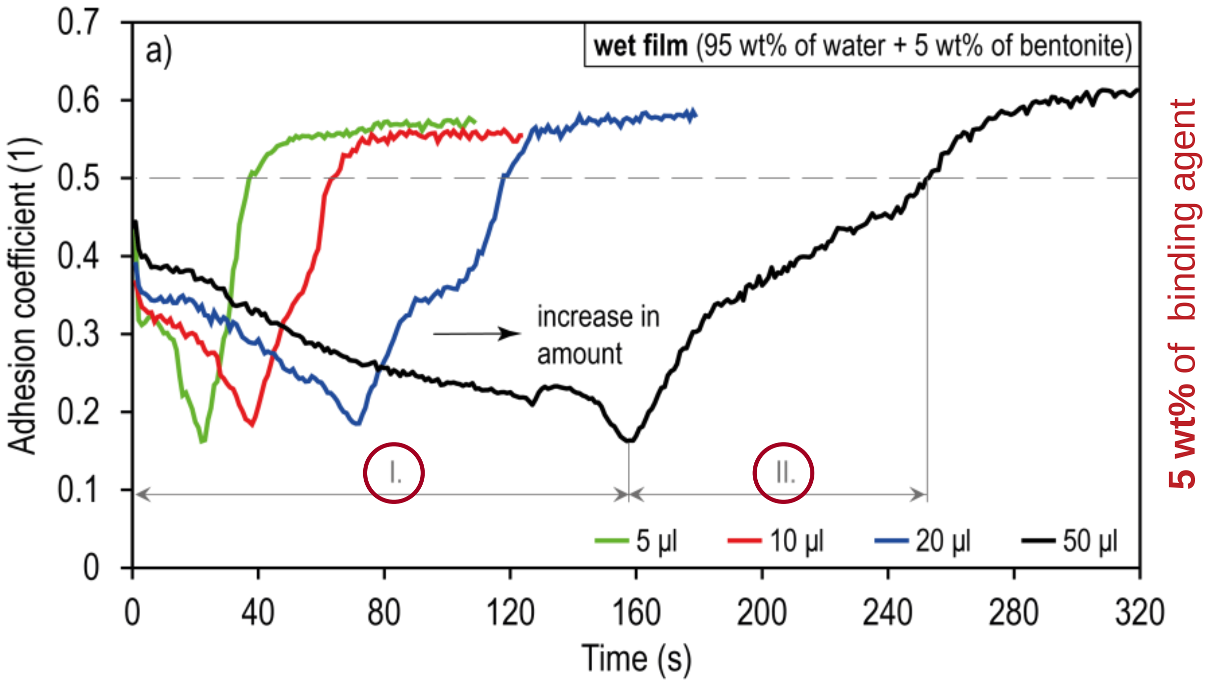
Safety issues?

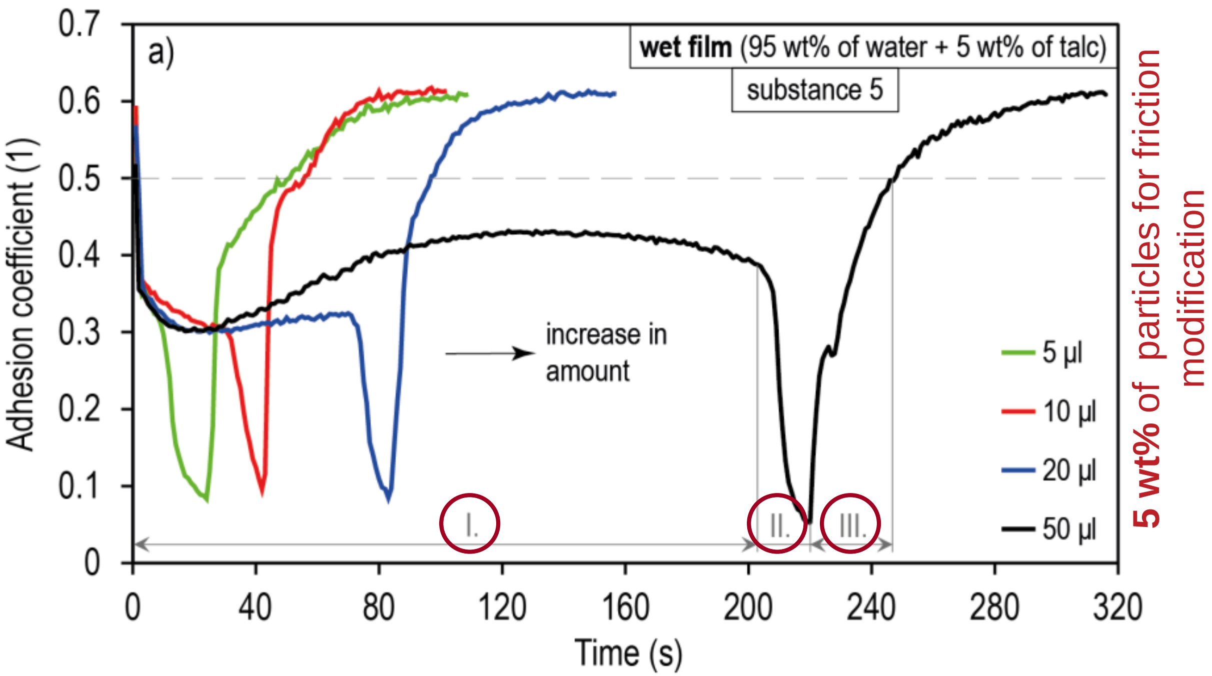
Noise
Eadie (2005,2006,2006)
Curley (2015)

TOR lubricants

5 wt% 10 wt% 15 wt%

5 wt% 10 wt% 15 wt%



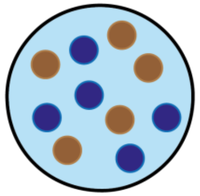


- No adhesion risks.
- Apparent viscosity is the key parameter.

- Poor adhesion during *part II*.
- High content of talc particles can cause low adhesion.

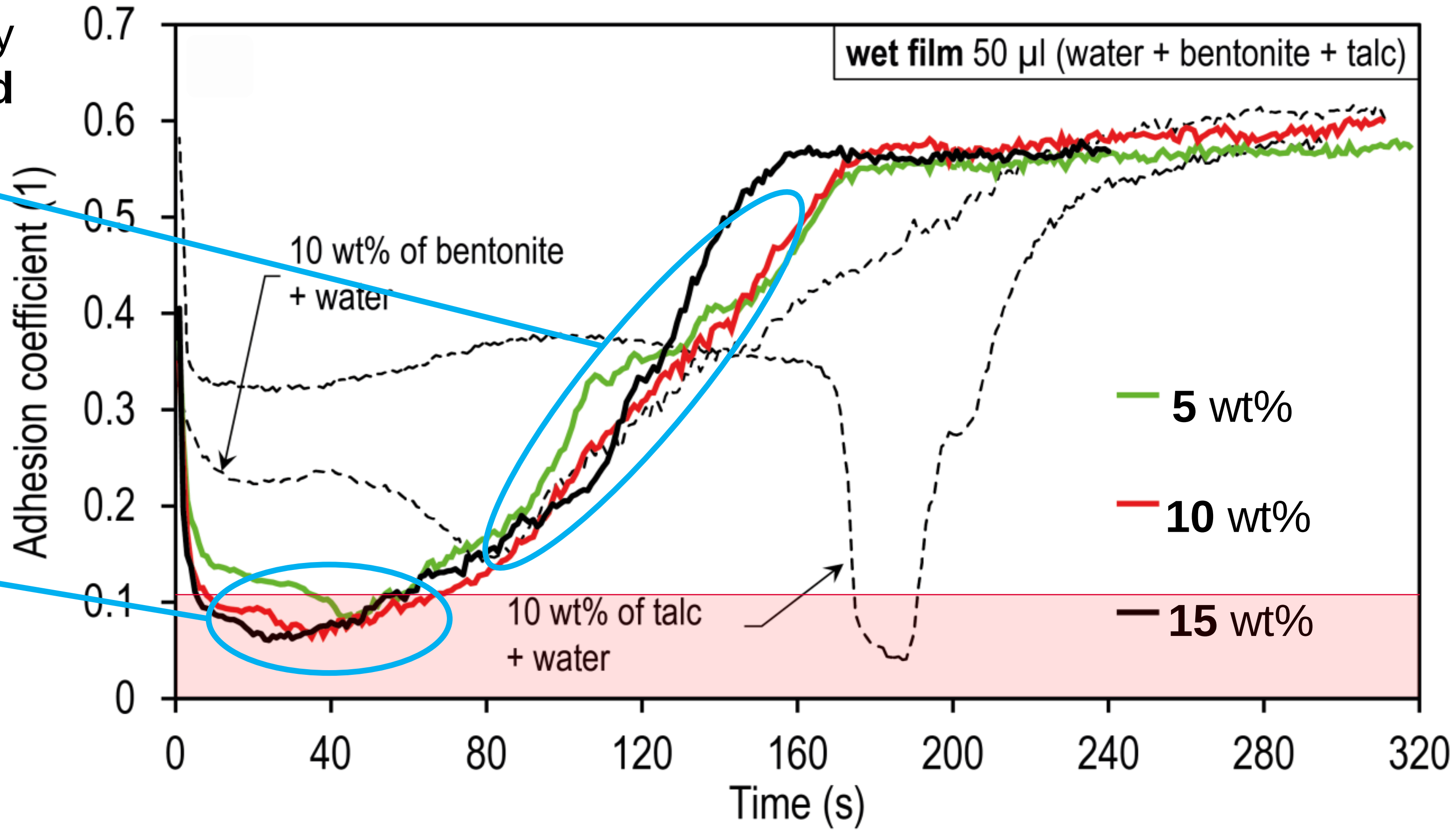
- **quantity** → lasting effect
- **composition** → average adhesion

Results – three constituent substances



Water + binding agent + PFM

- The shape of friction curve is mainly controlled by the effect of **water and binding agent**.
- The **minimum adhesion** coefficient is especially given by **PFM** (talc).



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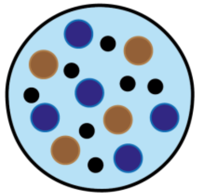
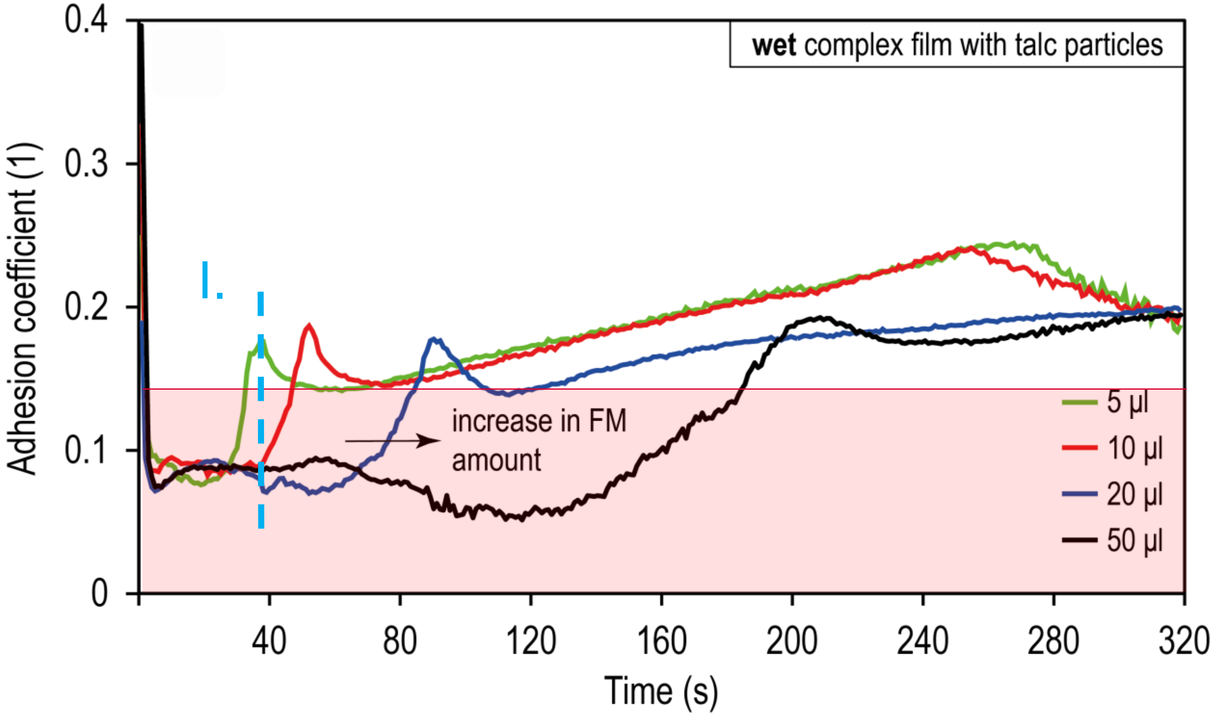
…friction, noise, and wear.

Results – complex substances

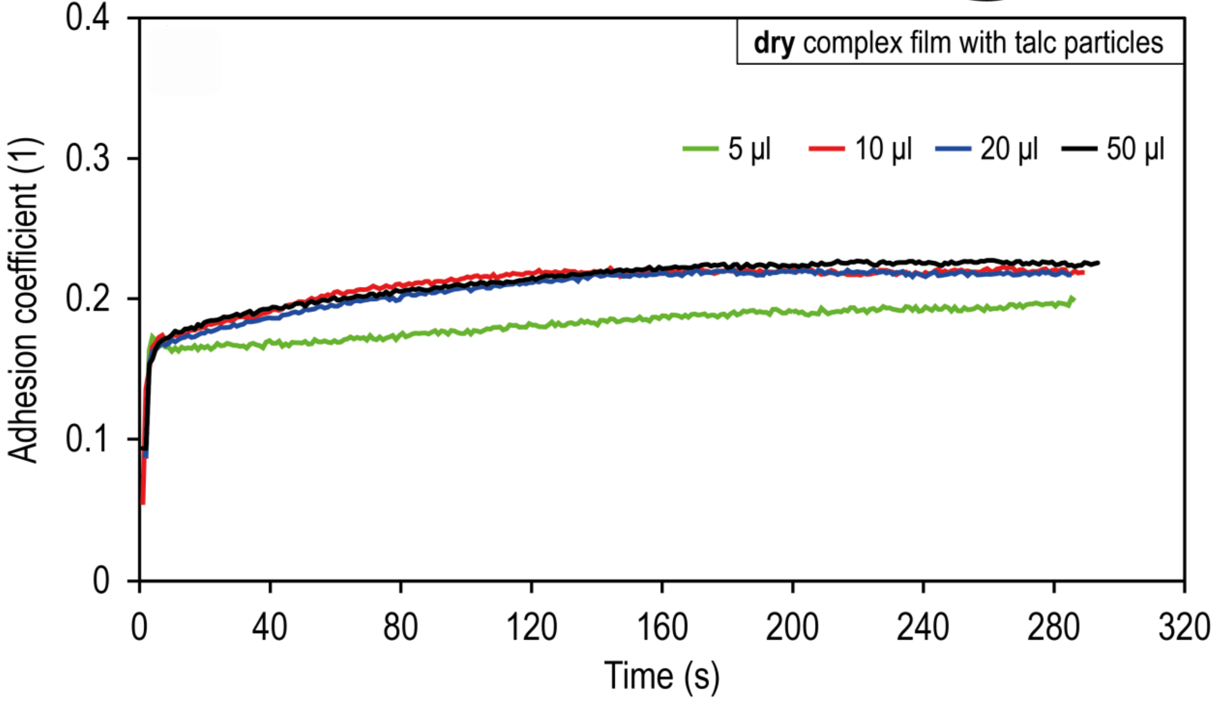


Wet complex substance



- Molyka causes **critical low adhesion** immediately after the application (lubricant + water).
- After *phase I*, substances provide **the intermediate level of adhesion**.

Dry complex substance

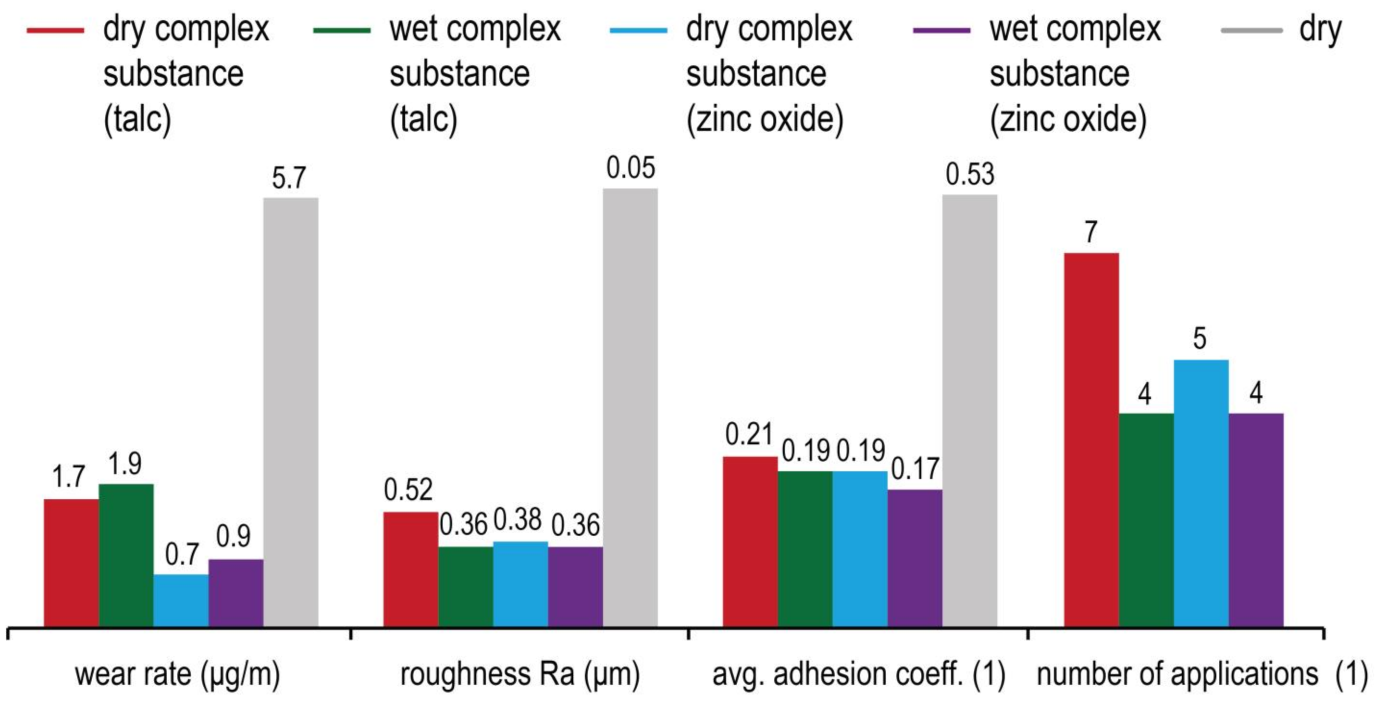


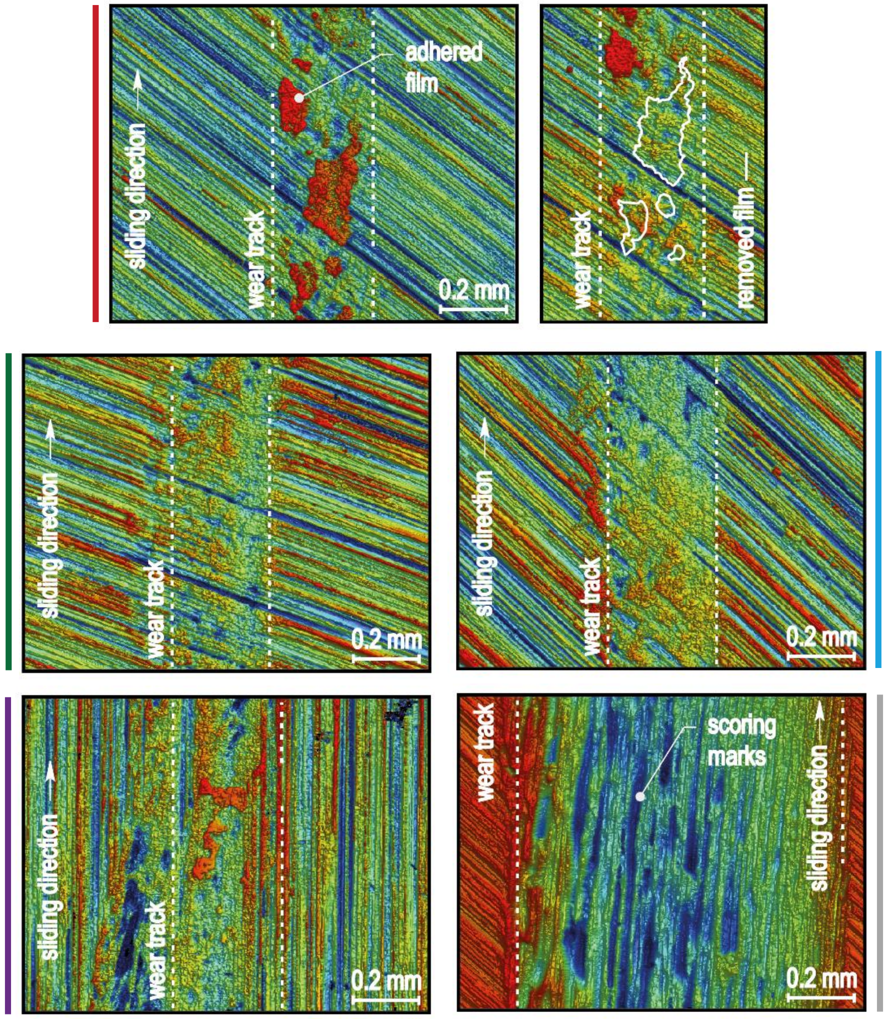
- Dry substances provide required and stable adhesion **without adhesion risks.**
- The effect of quantity seems to be negligible.

Results – disc surface analysis

Disc surface analyses revealed that:

- All tested FMs significantly reduce wear (by 66-87%) and surface damage.
- The predominant wear mechanism was scoring.





Results – TOR lubricants

Friction modifiers

Friction characteristic

Matsumoto (2002,2004)
Cuevas (2010)

Wear

Eadie (2008)
Li (2009)
Cuevas (2010)
Stock (2011)

Drying effect?

Quantity?

Adhesion

Eadie (2002)
Tomeoka (2002)
Ishida (2008)
Li (2009)
Cuevas (2010)

Lewis (2013)
Lundberg (2015)
Areiza (2015)
Liu (2016)

Composition?

Corrugation

Kalousek (1992)
Eadie (2002,2006,2008)
Egana (2005)

Noise, wear ?

Quantity?

Rolling contact fatigue

Cuevas (2010)
Stock (2011)

Noise

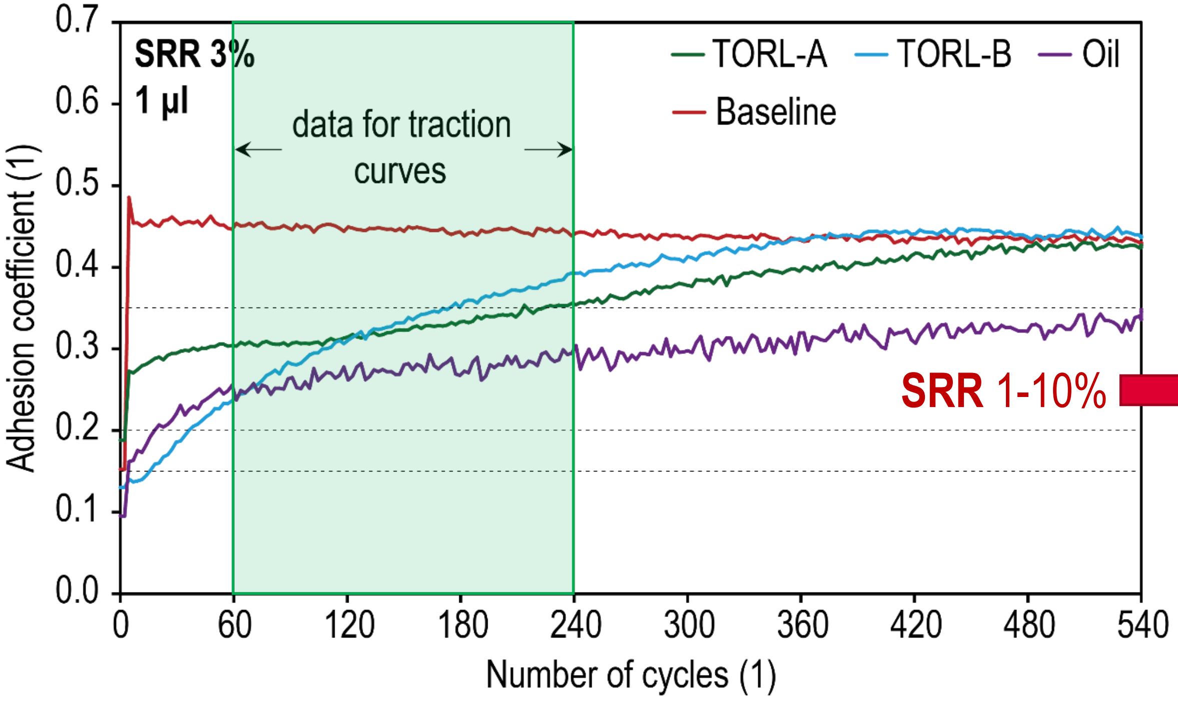
Eadie (2005,2006,2006)
Curley (2015)

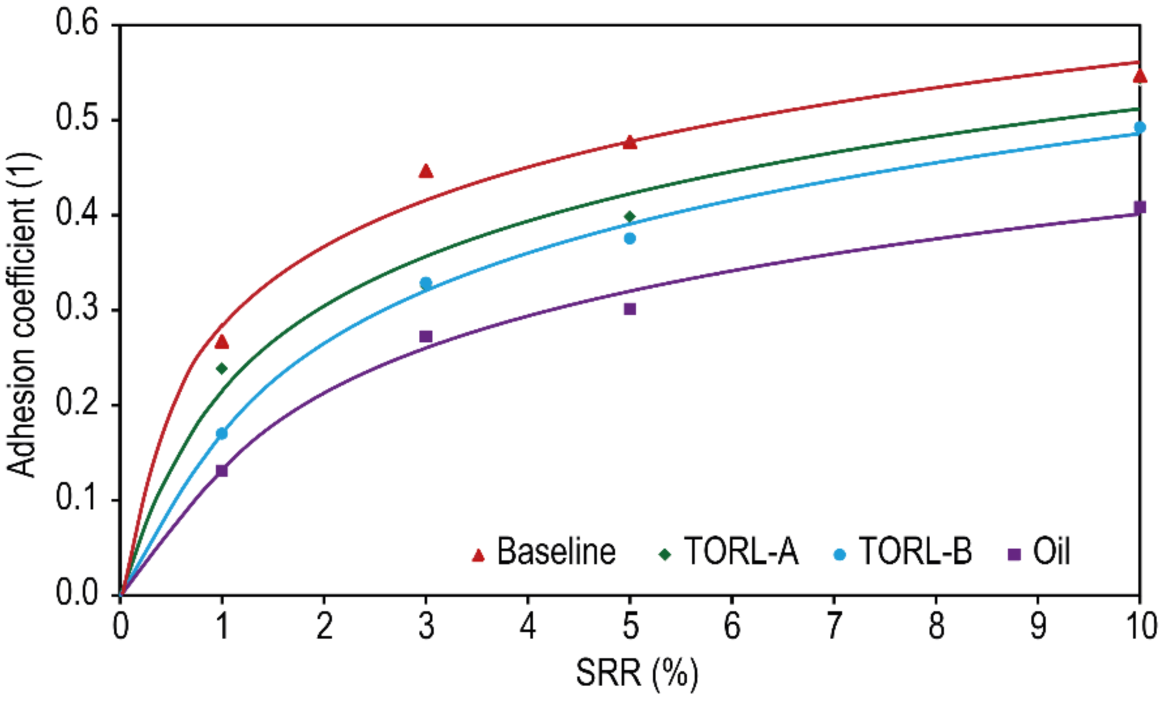
Safety issues?

TOR lubricants

Results – laboratory research – effect of SRR

SRR 1-10% | **Friction curves** | **Traction curves**





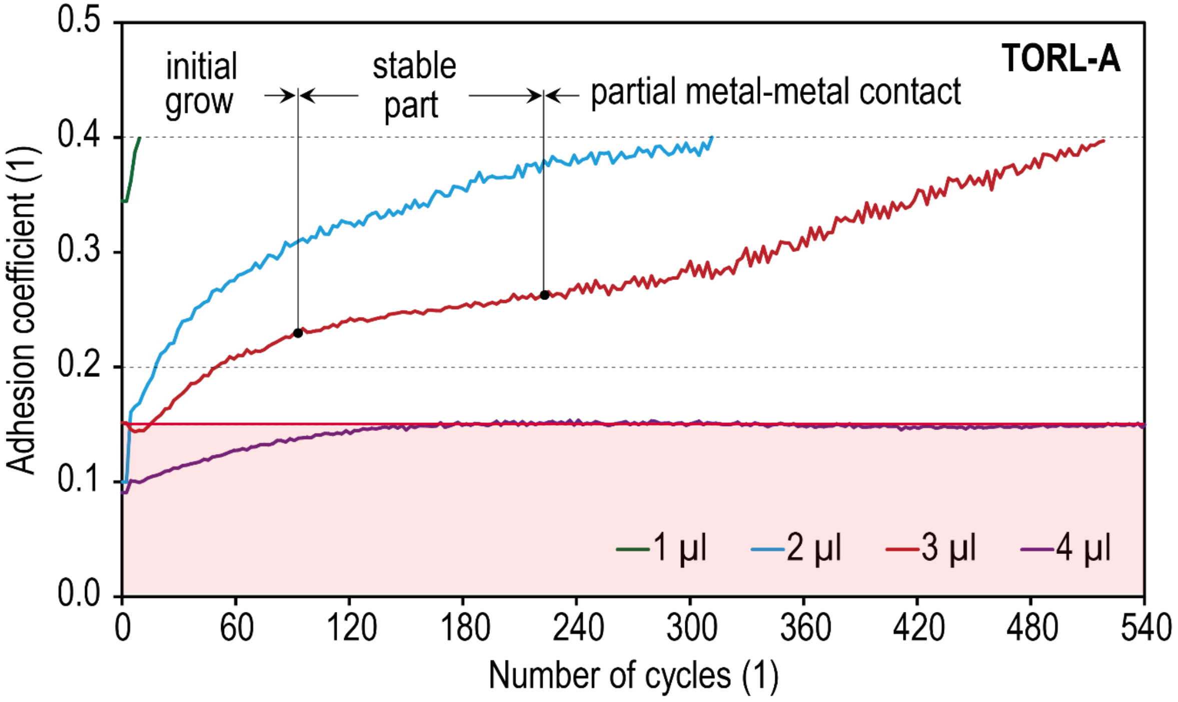
- TOR products provide the intermediate adhesion.
- TORL-A is able to provide stable adhesion.
- Similar lasting effect.

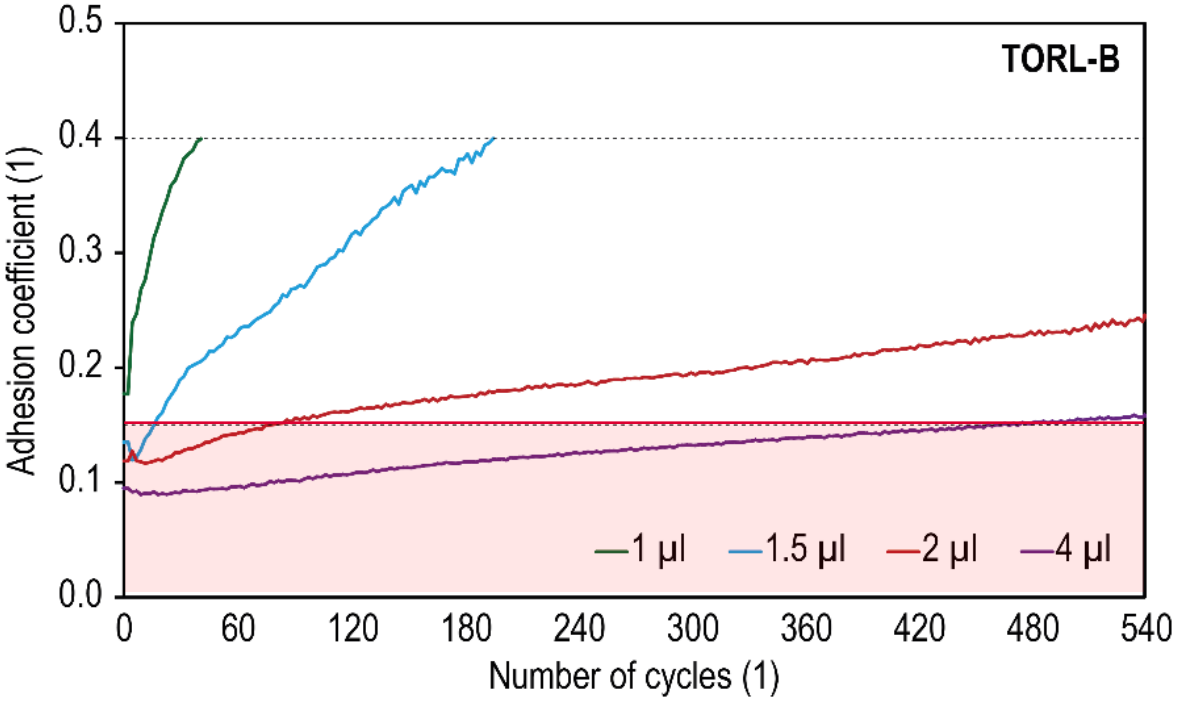
Both **TOR lubricants** provide:

- intermediate level of friction, and
- positive traction curve.

Results – laboratory research – **effect of quantity**

TORL-A	TORL-B





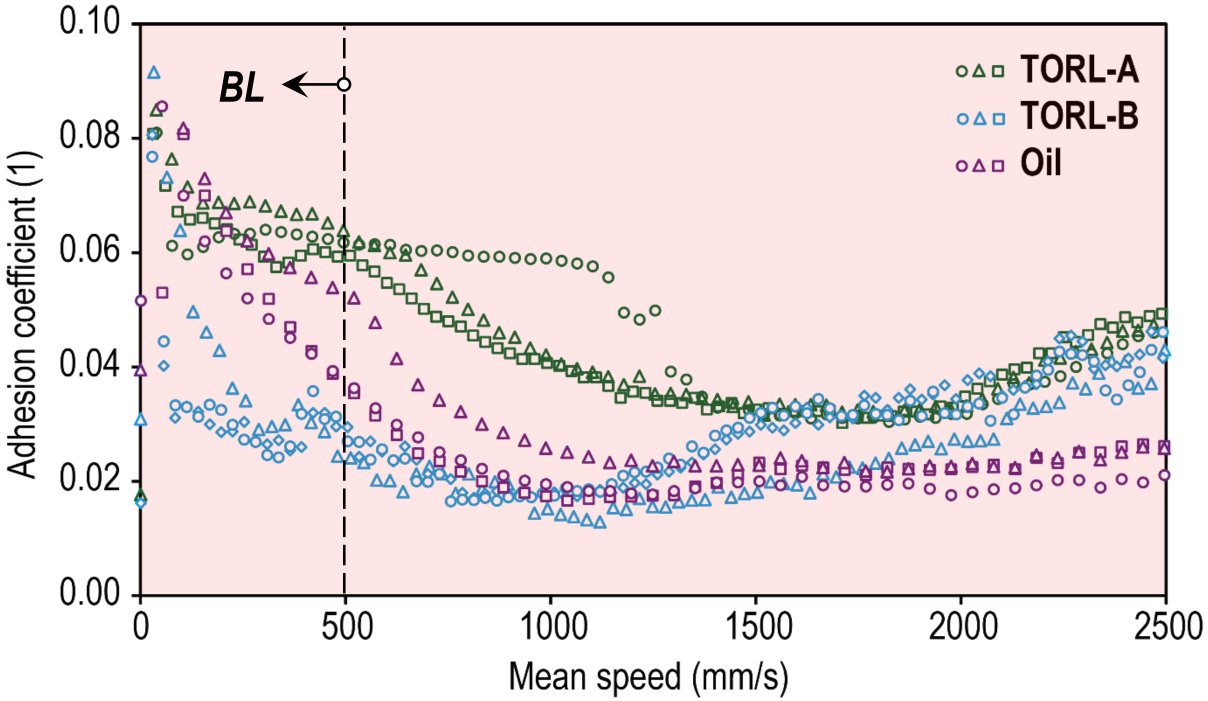
- Applied quantity significantly affects friction behaviour of TOR lubricants.
- TORL-A provides so-called **N-shape behaviour**.
- **Poor adhesion** occurs if contact is overdosed.

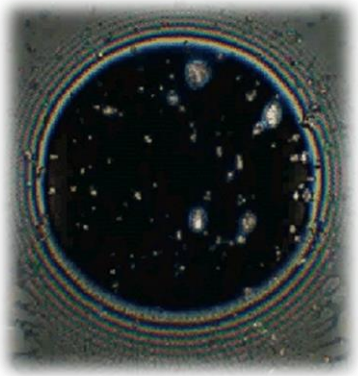
The worst possible case?

Fully flooded conditions

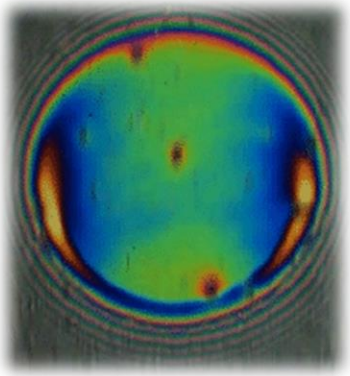
Results – laboratory research – **effect of quantity**

Stribeck test | **Optical tribometer**

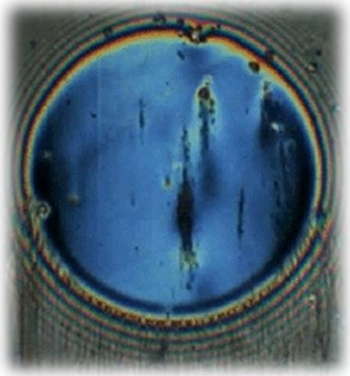




0.05 m/s, SRR 0%
h_c = 20 nm



0.7 m/s, SRR 0%
h_c = 300 nm



0.2 m/s, SRR 50%
h_c = 200 nm

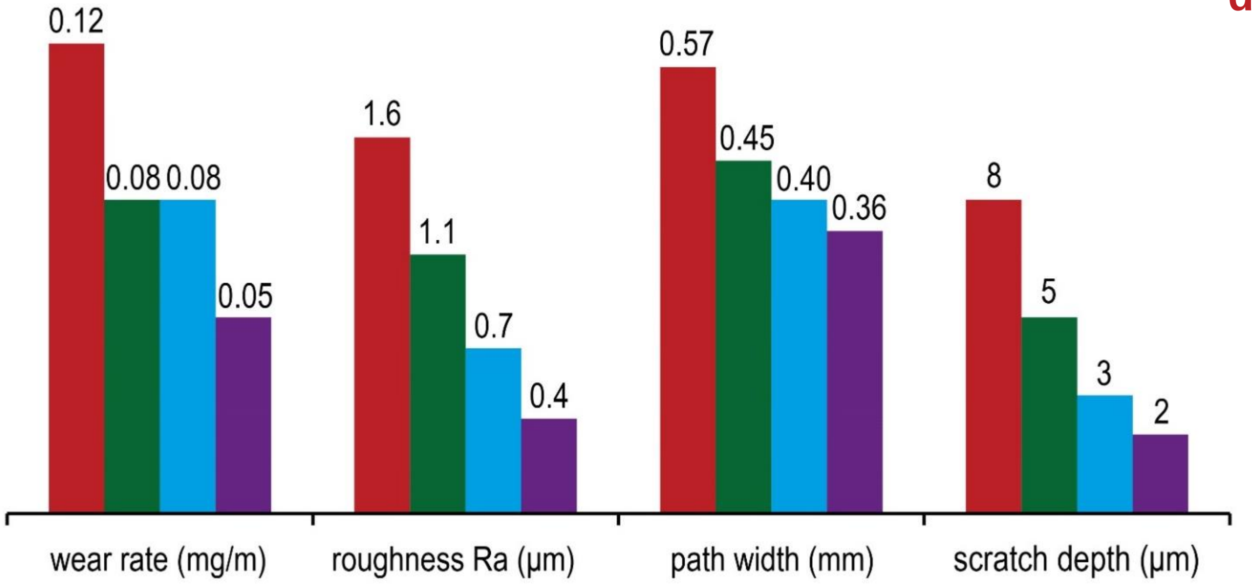
particles are able to enter the contact.

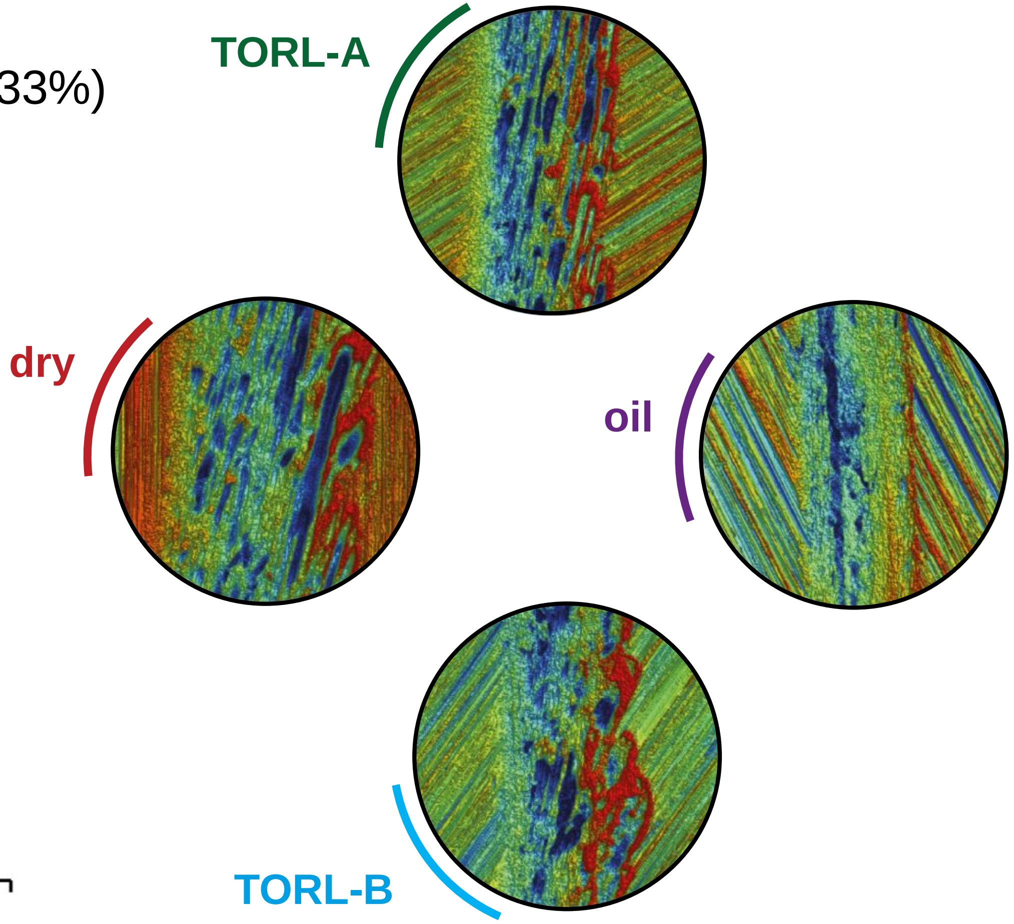
- There is a limit for TOR lubricants quantity below which adhesion is mainly controlled by metal particles, while above this quantity adhesion is mainly given by the base medium.

Results – laboratory research **– surface analysis**

Disc surface analyses revealed that:

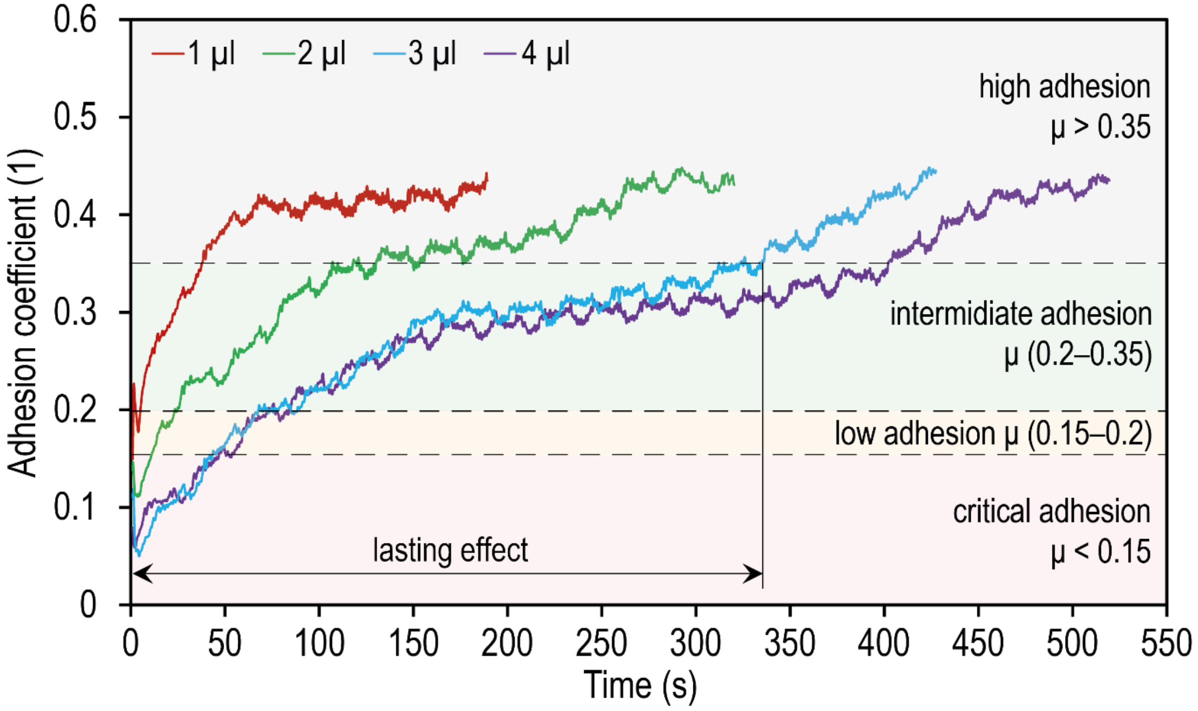
- Both testes TOR lubricant significantly reduce wear (by 33%) and surface damage.
- The predominant wear mechanism was scoring.

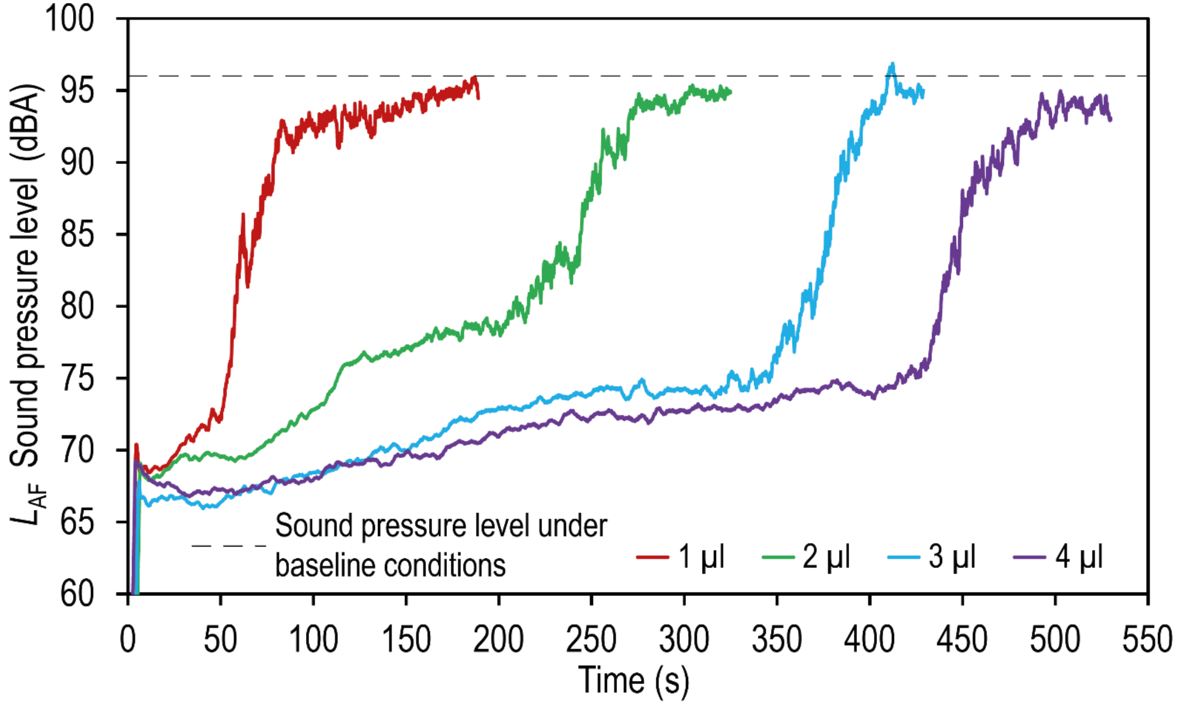




Results – laboratory research – adhesion and noise

Friction curves | **Noise measurements** | **AoA 4°**

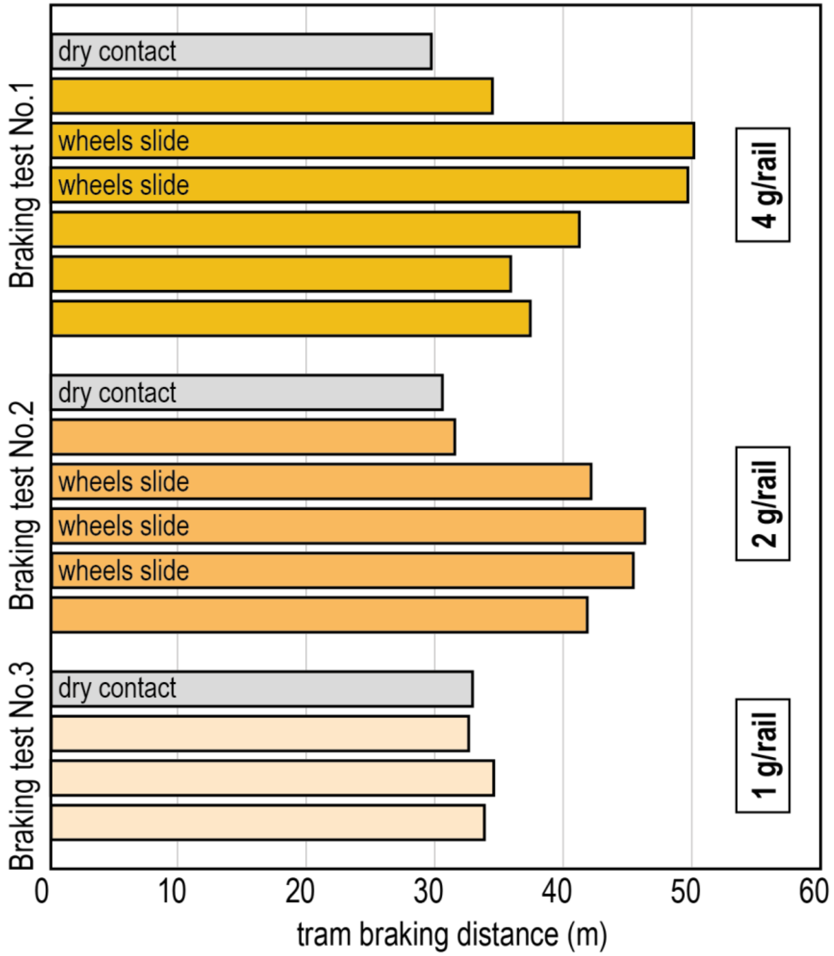




- Good agreement with results from ball-on-disc tribometer - poor adhesion, N-shape behaviour.
- TOR lubricant is able to significantly reduce noise (approx. by 28 dBA).

Results – field research of **TOR lubricants**

Braking test



overdosing

↓

unacceptable long braking distance

+

formation of flat spots

+

limited carry distance (100 m)

long-term experiments

1 g/rail each 110 axles

Noise measurements

Off-board application **ON**

Average L_{aeq}: **76.7 ± 2.5 dBA**

×

Off-board application **OFF**

Average L_{aeq} : **77.6 ± 2.6 dBA**

- Only negligible effect of TOR lubricant on noise.
- Noise reduction depends on the type of tram (up to 5 dB).

Discussion – Friction modifiers

Friction modifiers

Friction characteristic

Matsumoto (2002,2004)
Cuevas (2010)

Drying effect?

Wear

Li (2009)
Cuevas (2010)
Stock (2011)

Quantity?

Adhesion

Composition?

Eadie (2002)
Tomeoka (2002)
Ishida (2008)
Li (2009)
Cuevas (2010)

Lewis (2013)
Lundberg (2015)
Areiza (2015)
Liu (2016)

Corrugation

Kalousek (1992)
Eadie (2002,2006,2008)
Egana (2005)

Noise, wear ?

Quantity?

Rolling contact fatigue

Stock (2011)

Safety issues?

Noise

Eadie (2005,2006,2006)
Curley (2015)

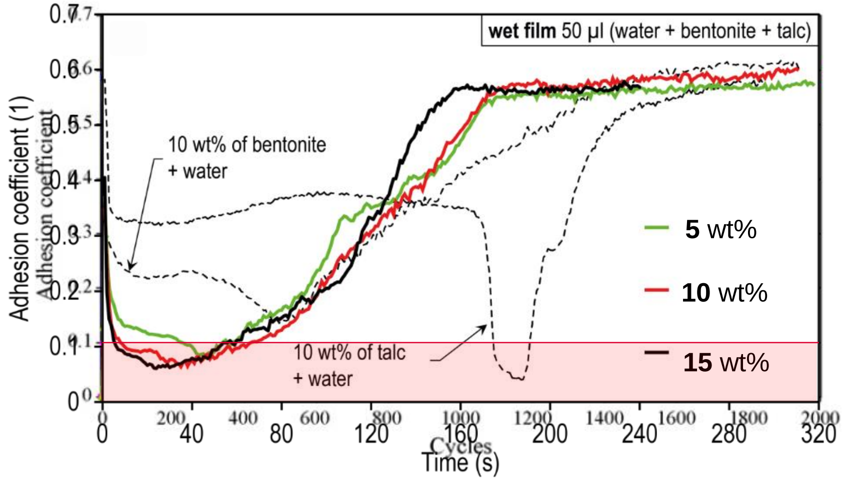
TOR lubricants

Composition? Drying effect?

Quantity?

Discussion – Friction modifiers

- Only commercial products were tested by other authors.
- The gradual increase in adhesion was observed.
- These results correspond to the three-constituent substance.
- Friction properties are mainly given by mixture of water and binding agent.

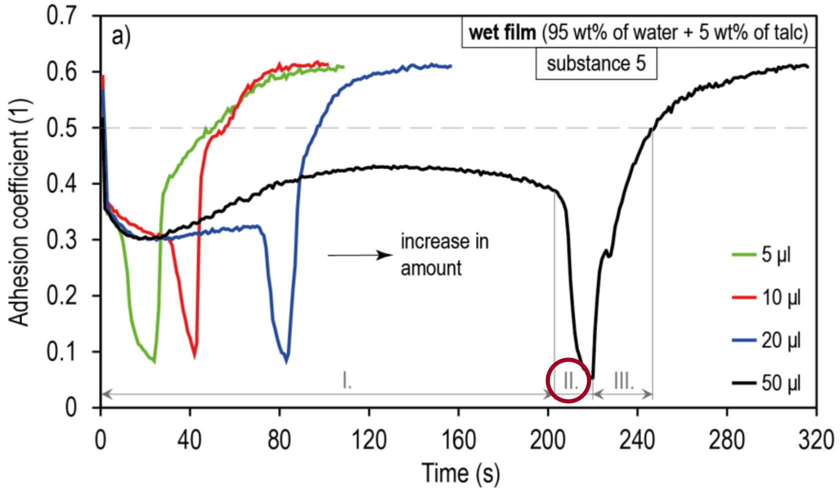


- Less complex substances can provide beneficial friction behaviour.
- Large quantities do not lead to critically low adhesion.
- High content of PFM can cause low adhesion and electric insulation.

Cuevas (2010)

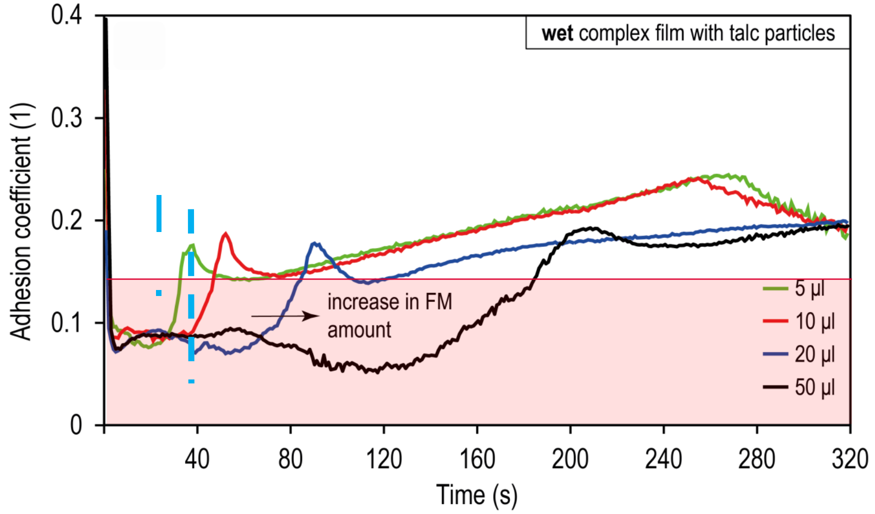
↓

Metal particles should be added to avoid electric insulation.

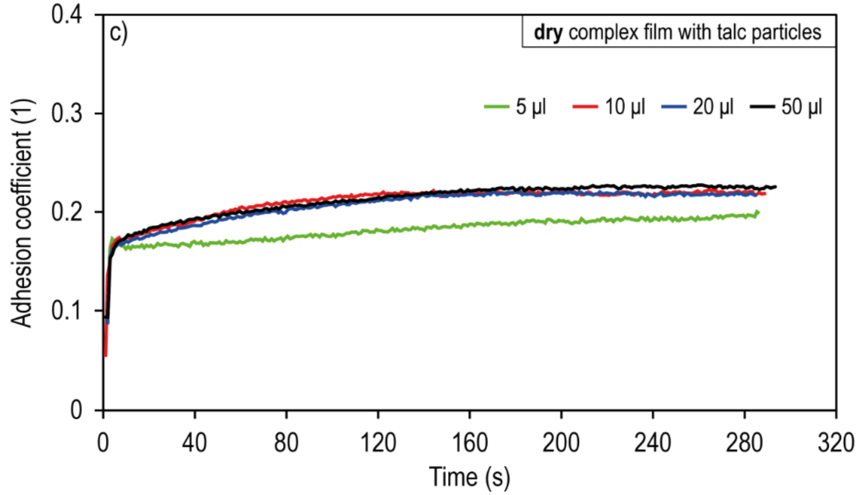


Composition? Drying effect?
Quantity?

Discussion – Friction modifiers



Wet × **Dry**



- Water + solid lubricant → low adhesion
- Minimum adhesion is not dependent on quantity.

- Very beneficial friction behaviour
- Effect of quantity is not significant.

- Applied quantity is not so significant as for TOR lubricants
- Time gap needed for evaporation is necessary → application.

Discussion – TOR lubricants

Friction modifiers

Friction characteristic

Matsumoto (2002,2004)
Cuevas (2010)

Drying effect?

Wear

Eadie (2008)
Li (2009)
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Stock (2011)

Quantity?

Adhesion

Composition?

Eadie (2002)
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Lewis (2013)
Lundberg (2015)
Areiza (2015)
Liu (2016)

Corrugation

Kalousek (1992)
Eadie (2002,2006,2008)
Egana (2005)

Noise, wear ?

Quantity?

Rolling contact fatigue

Cuevas (2010)
Stock (2011)

Safety issues?

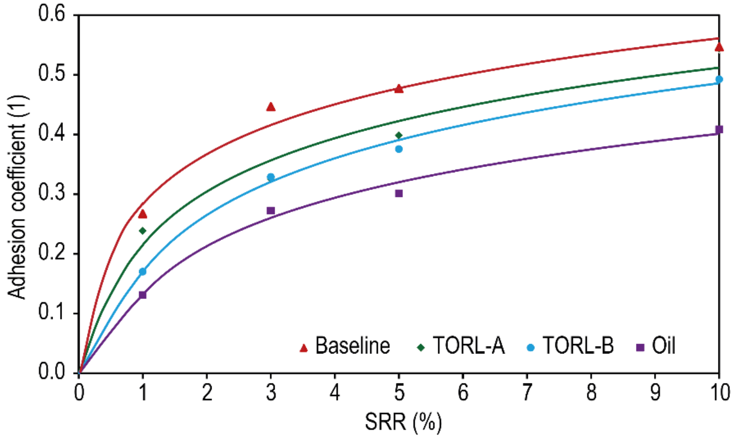
Noise

Eadie (2005,2006,2006)
Curley (2015)

TOR lubricants

Safety issues? Noise? Quantity?

Discussion – TOR lubricants



TOR products provide:

- Intermediate level of friction ✔
- Positive traction curve ?
- TORL-B: gradual increase in adhesion. Cuevas (2010) ✔
- Overdosing leads to the critically low adhesion. Liu (2016), Areiza (2015) ✔

↓

unacceptable long braking distance + limited carry distance

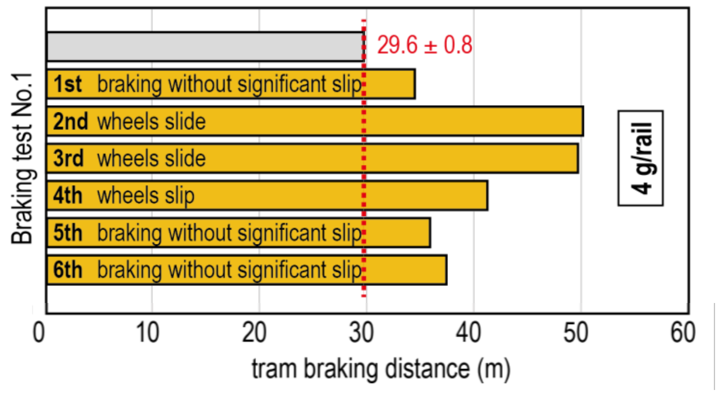
Lundberg (2016) ✔ Yu (2015) ✘

Safety issues

1 g/rail each 110 axles

↓

Only negligible effect of TOR lubricant on noise (older trams).



It seems to be difficult to achieve a significant reduction of noise without the impact on traction and braking.

Another way of **application** – requirements on device

Conclusions of the PhD thesis

TOR lubricants

- The ability of TOR lubricants to provide the required adhesion level, wear and noise reduction was investigated using laboratory and field measurements.
- Overdosing can lead to risky situations.
- Applied quantity is a key parameter for friction performance (requirements on application unit).

FMs

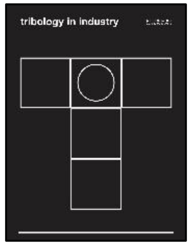
- For the first time, the effect of composition of FMs on adhesion and wear was studied for both liquid and dried form of FM.
- High content of PFM can cause critically low adhesion and electric insulation.
- In the case of complex substance, evaporation is a key parameter for friction performance (requirements on application unit).

Conclusions of the PhD thesis

TOR lubricants

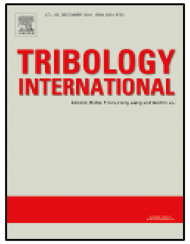
A. GALAS, R., M. OMASTA, I. KRUPKA and M. HARTL. Laboratory investigation of ability of oil-based friction modifiers to control adhesion at wheel-rail interface. *Wear,* 2016, 368–369, 230-238.
Journal impact factor = 2.531, Quartile Q1, CiteScore = 3.00
Author's contribution 50%

B. GALAS, R., M. OMASTA, M. KLAPKA, S. KAEWUNRUEN, I. KRUPKA and M. HARTL. Case Study: the Influence of Oil-based Friction Modifier Quantity on Tram Braking Distance and Noise. *Tribology in Industry*, 2017, 39(2), 198-206.
CiteScore = 1.32
Author's contribution 50%



FMs

C. GALAS, R., D. KVARDA, M. OMASTA, I. KRUPKA and M. HARTL. The role of constituents contained in water-based friction modifiers for top-of-rail application. *Tribology International*, 2018, 117C, 87-97.
Journal impact factor = 2.903, Quartile Q1, CiteScore = 3.16
Author's contribution 50%



List of publications

journals with impact factor

GALAS, R., M. OMASTA, I. KRUPKA and M. HARTL. Laboratory investigation of ability of oil-based friction modifiers to control adhesion at wheel-rail interface. *Wear,* 2016, 368–369, 230-238.

GALAS, R., D. KVARDA, M. OMASTA, I. KRUPKA and M. HARTL. The role of constituents contained in water-based friction modifiers for top-of-rail application. *Tribology International*, 2018, 117C, 87-97.

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SPERKA, P., R. GALAS, M. OMASTA, I. KRUPKA and M. HARTL. Particle tracking in the central zone of an elastohydrodynamic contact. Tribology International, 2017. (Under review)

peer-reviewed journals

GALAS, R., M. OMASTA, M. KLAPKA, S. KAEWUNRUEN, I. KRUPKA and M. HARTL. Case Study: the Influence of Oil-based Friction Modifier Quantity on Tram Braking Distance and Noise. Tribology in Industry, 2017, 39(2), 198-206.

GALAS, R., D. SMEJKAL, M. OMASTA and M. HARTL. Twin-Disc Experimental Device for Study of Adhesion in Wheel- Rail Contact. Engineering Mechanics, 2014, 21(5), 329-334.

conference proceedings

GALAS, R. and M. OMASTA. The Effect of Friction Modifier on the Wheel- Rail Contact. In The Latest Methods of Construction Design. Cham: Springer International Publishing, 2016, 133-138.

OMASTA M., R. GALAS, J. KNAPEK, M. HARTL and I. KRUPKA. Development of an adaptive top-of-rail friction modification system, 2017. In Proceedings of the Stephenson Conference: Research for Railways, IMechE, London, UK, 2017, 325-332.

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conference abstracts

GALAS, R., M. OMASTA, I. KRUPKA and M. HARTL. Effect of Friction Modifiers on Adhesion in Wheel- Rail Contact. International Tribology Conference, 2015, Tokyo, Japan.

GALAS, R., M. OMASTA, I. KRUPKA and M. HARTL. Wheel Rail Adhesion and Film Formation – The Influence of Friction Modifier Composition. The 17th Nordic Symposium on Tribology - NORDTRIB 2016, 2016, Hämeenlinna, Finland.

GALAS, R., M. OMASTA, I. KRUPKA and M. HARTL. The "low adhesion" problem – the influence of friction modifier composition on adhesion and film formation in wheel-rail contact. First International Conference on Rail Transportation, 2017, Chengdu, China.

Thank you for attention

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