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# Nano-reinforced Bonded Coatings Part II: Testing of Bonded Coatings

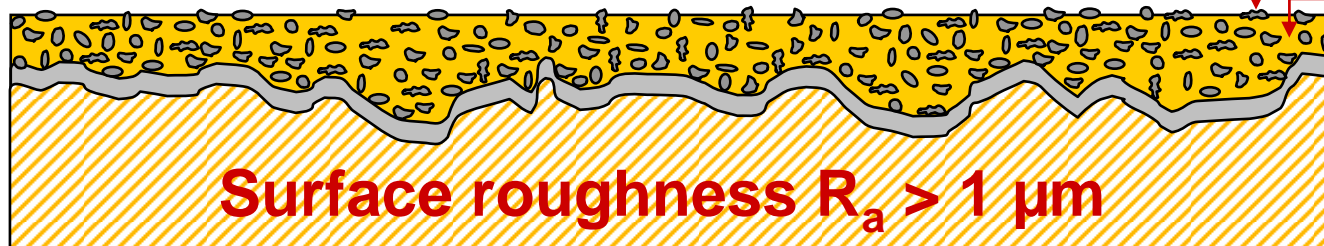
Rudolf Zechel, Klüber Lubrication München KG

Philipp Staub, Klüber Lubrication München KG

# Model of a bonded coating layer

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## A. Surface with bonded coating



Solid lubricant particles

Binder

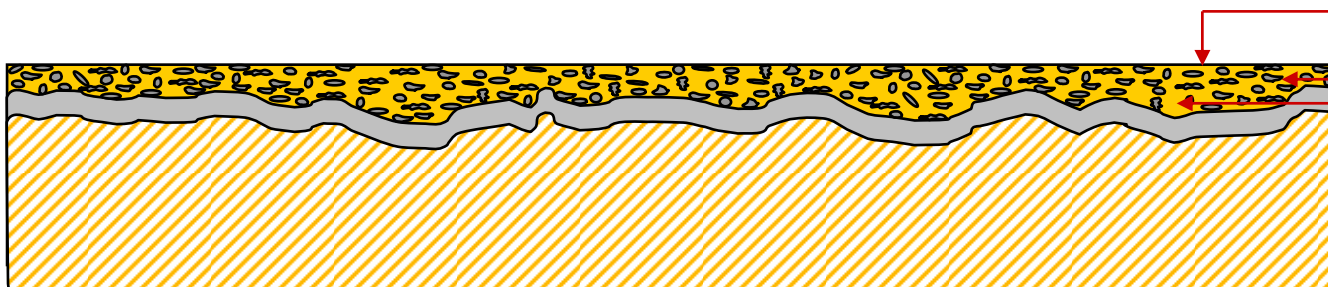
Bonded coating layer

approx. 7-15  $\mu\text{m}$

Phosphate layer

approx. 3-8  $\mu\text{m}$

## B. Bonded coating layer after running-in



With high-filled MoS<sub>2</sub> coatings:  
Bright surface  
(metallic)

Solid lubricant particles

Binder

# Damage Model – Limited Lifetime

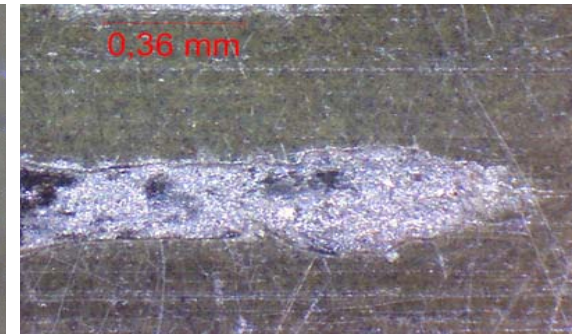
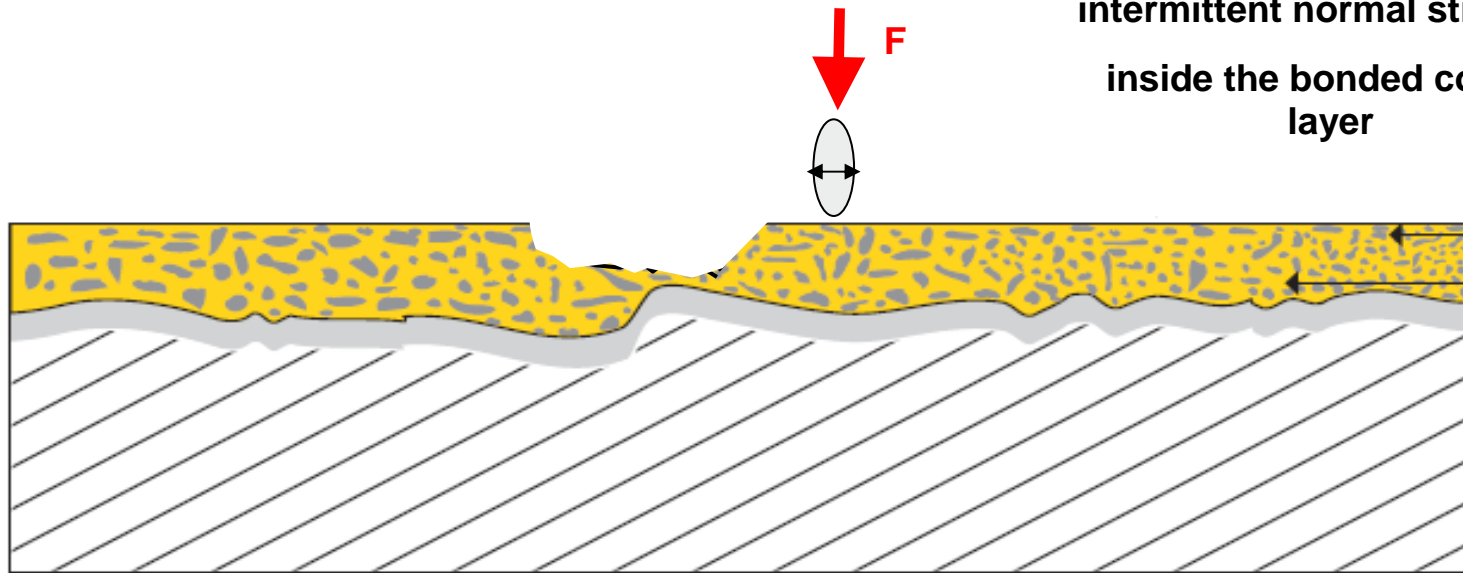
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reciprocating shear stress  $\tau$

and

intermittent normal stress  $\sigma$

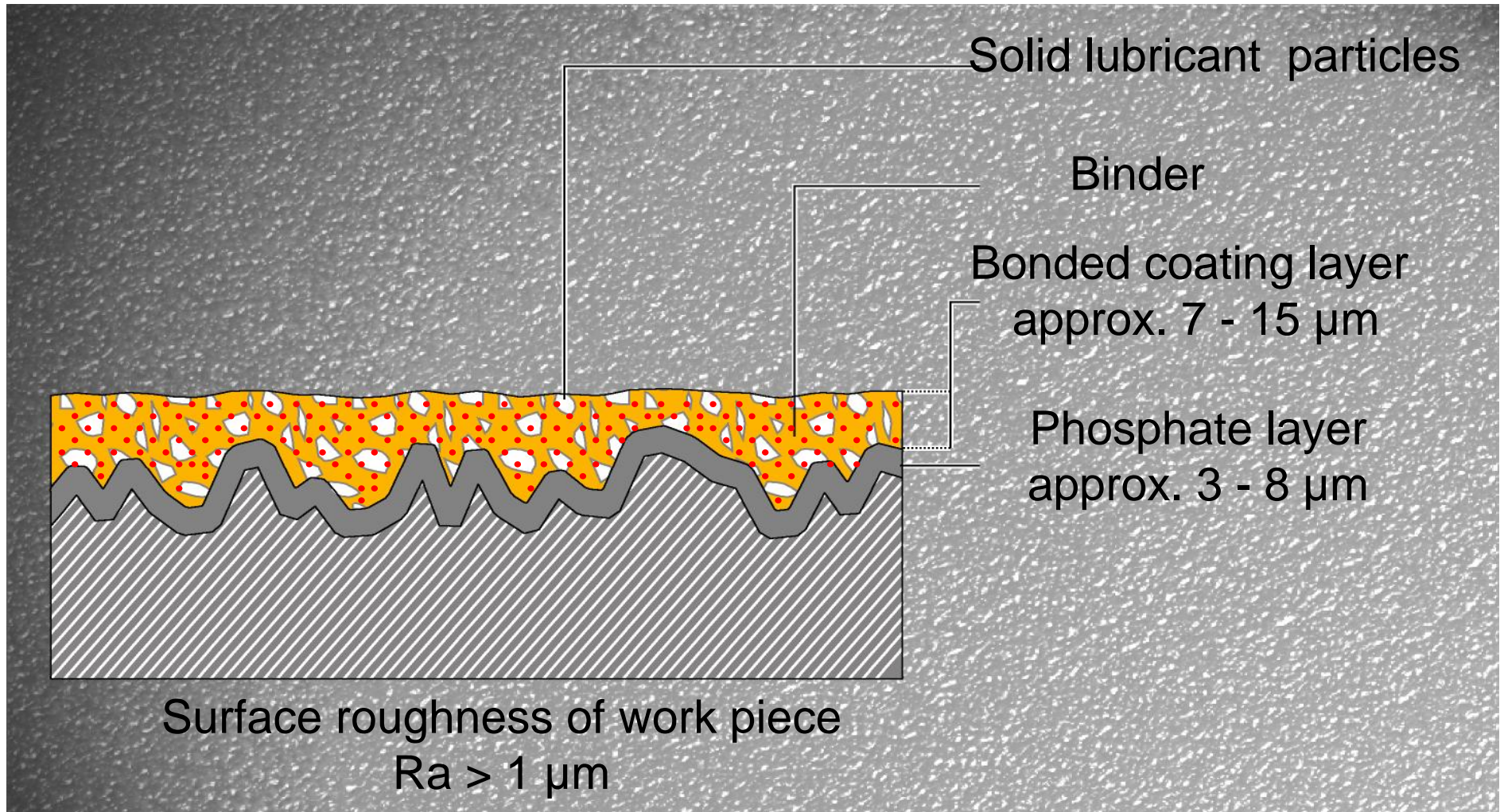
inside the bonded coating layer



# Testing of Bonded Coatings

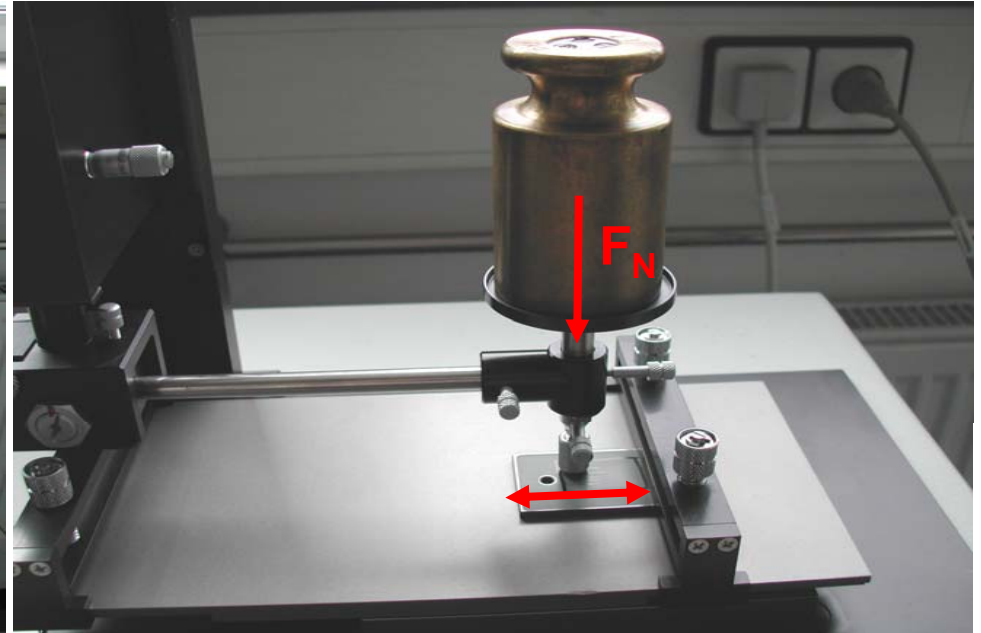
- Formulation of different coatings based on polyamidimid binder system
  - different nanoparticles
  - Solid lubricants: PTFE and MoS<sub>2</sub>
- Coating of cleaned and sandblasted test plates with curing after application
- Test on different test procedures
  - Heidon Ball Plate test
  - Oscillating friction and wear tester
  - Oscillating slide plate test rig
  - Sliding friction test rig (principle: ball-disk)
  - Tannert sliding indicator
- Rating of lifetime
  - Rating: no. of strokes until layer break-through

# Model of a bonded coating layer with nano-particles



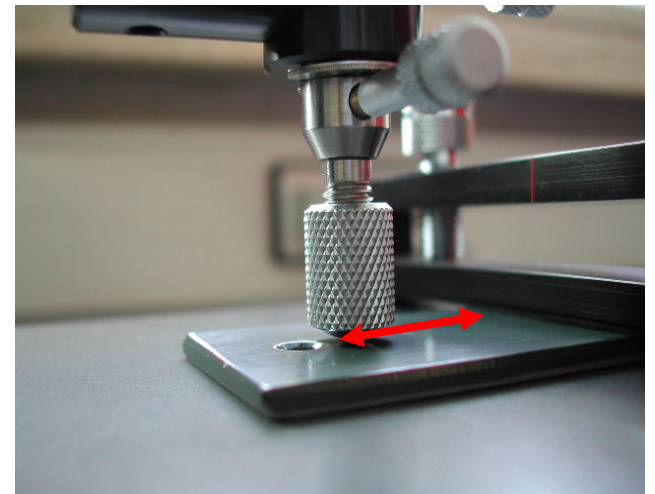
# Heidon Ball on Plate Test Rig

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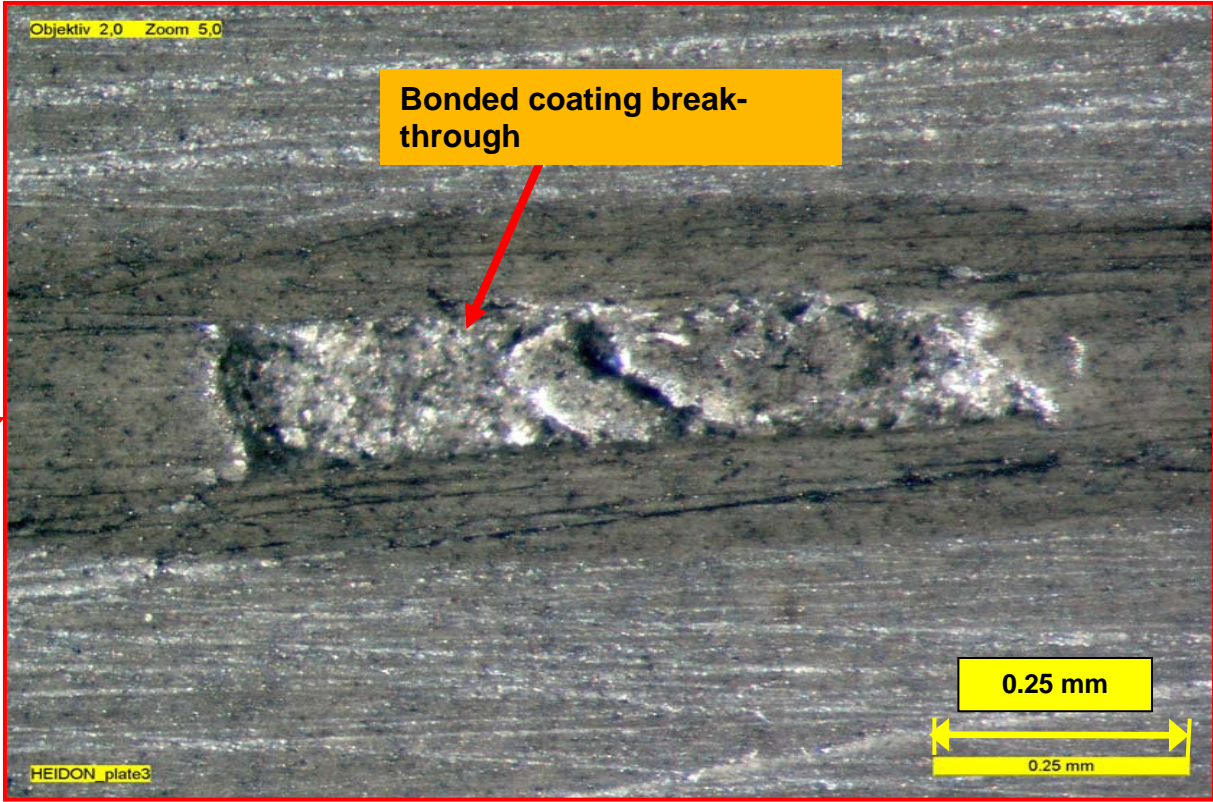
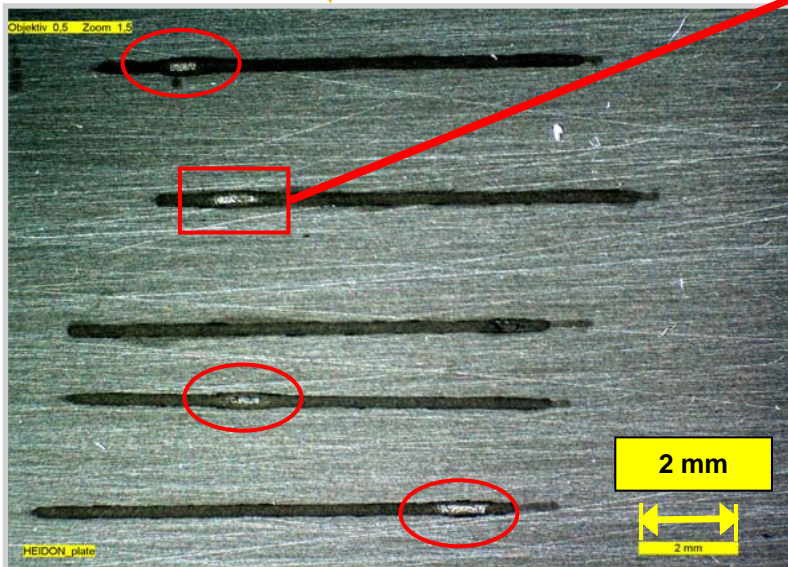
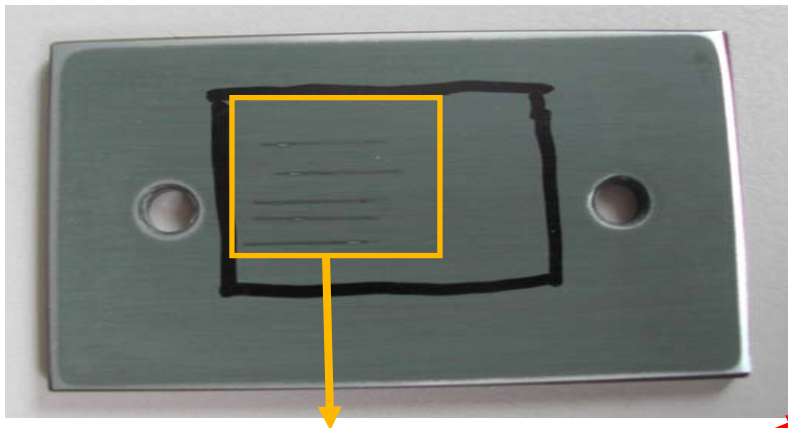
## Test conditions:

Geometry top specimen:	Ball $\varnothing$ 5mm
Geometry bottom specimen:	Plate Alu
Load:	7 N / 10 N
Hertzian Pressure pH:	1424 / 1603 N/mm <sup>2</sup>
Sliding speed [mm/s]:	40 mm/s
Stroke [mm]:	10 mm
Temperature:	25° C



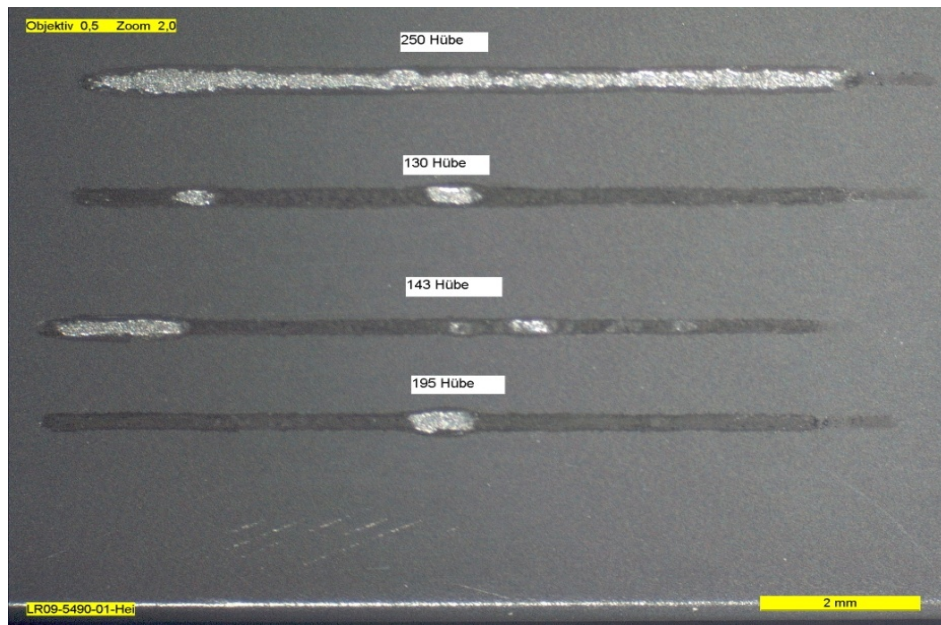


# Heidon Ball on Plate Test

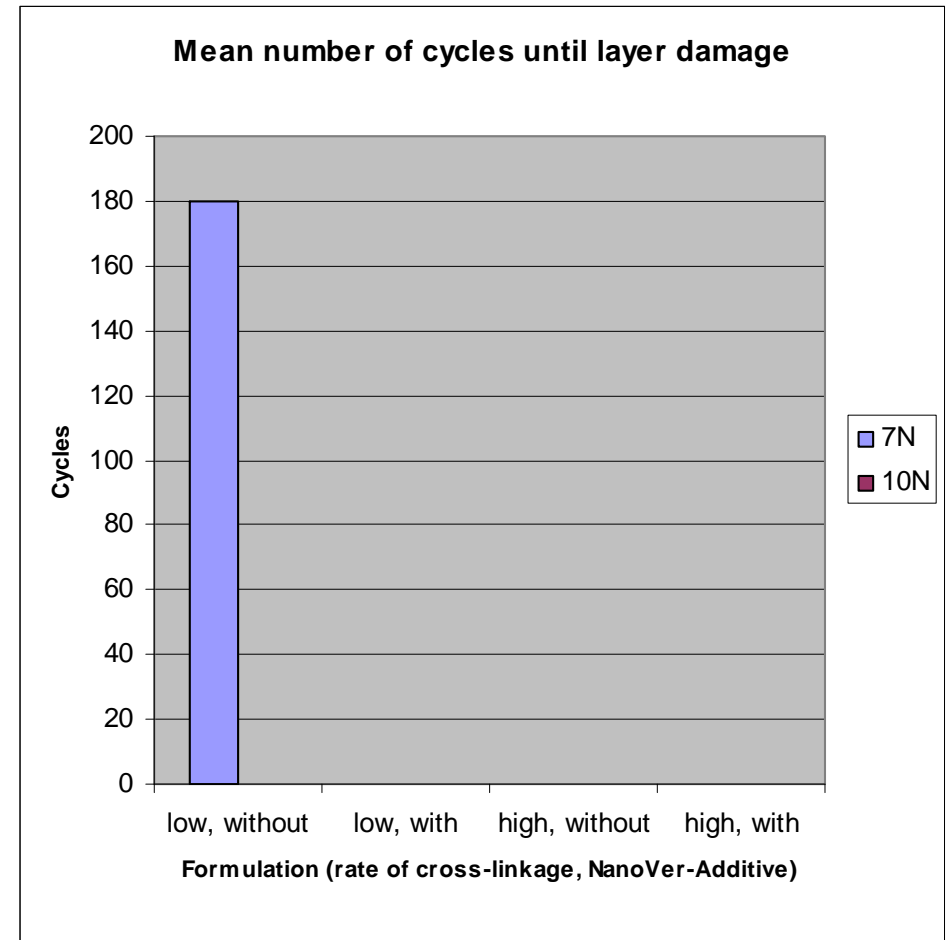


**Test result:**  
No. of cycles to damage (adhesion) of bonded coating layer

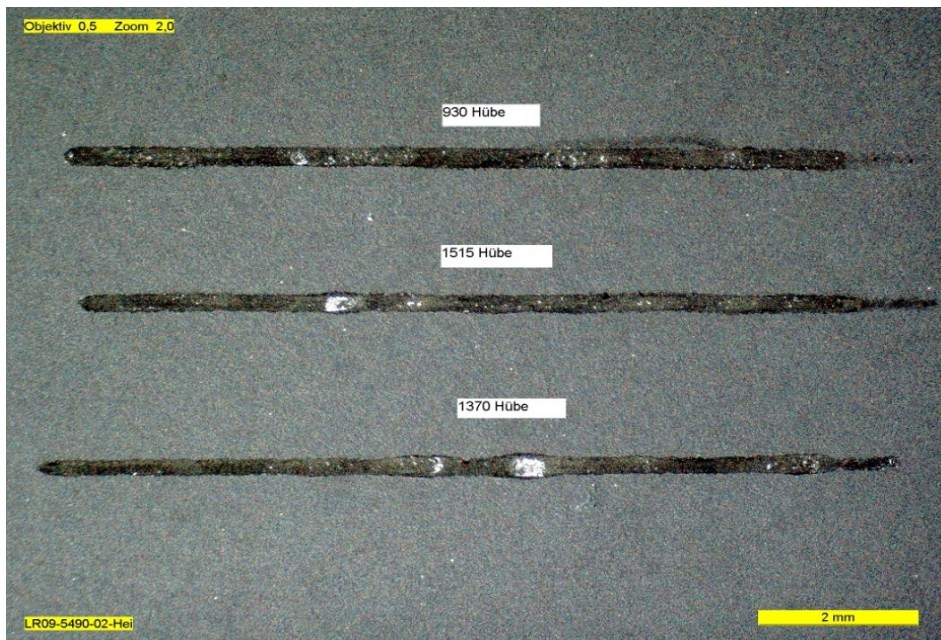
# Without co-curing agent, without NanoVer-Additive

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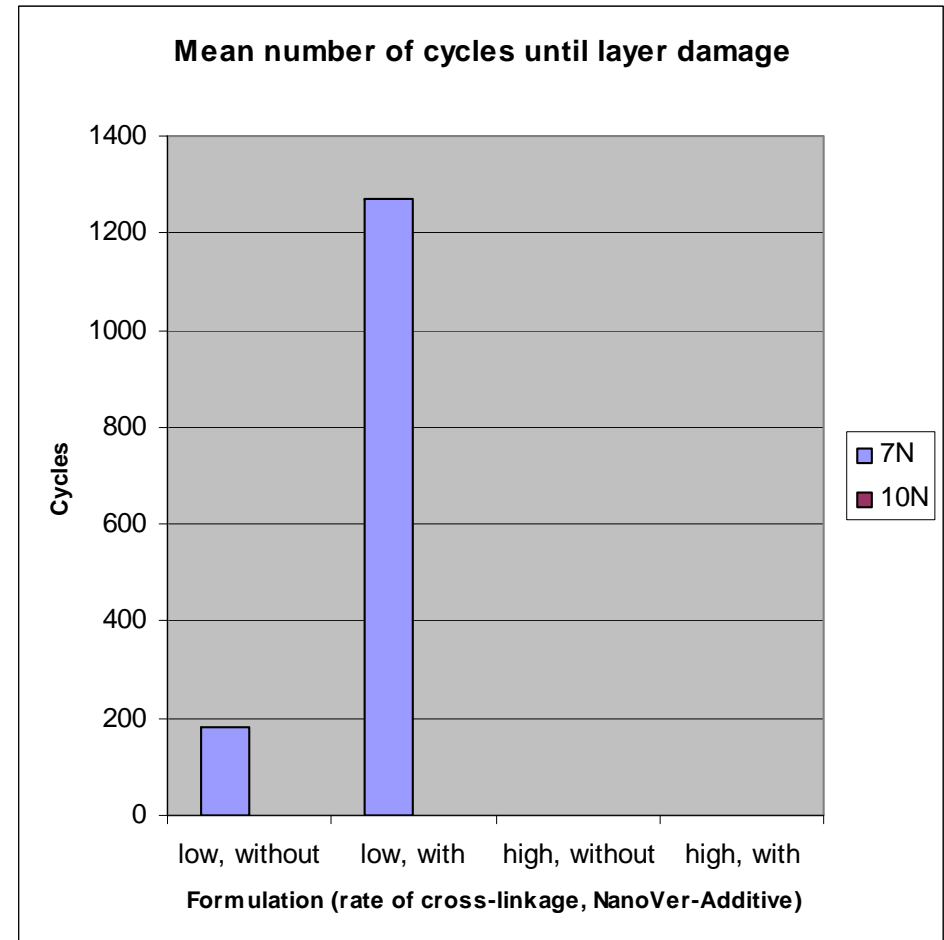
Wear pictures of single tests



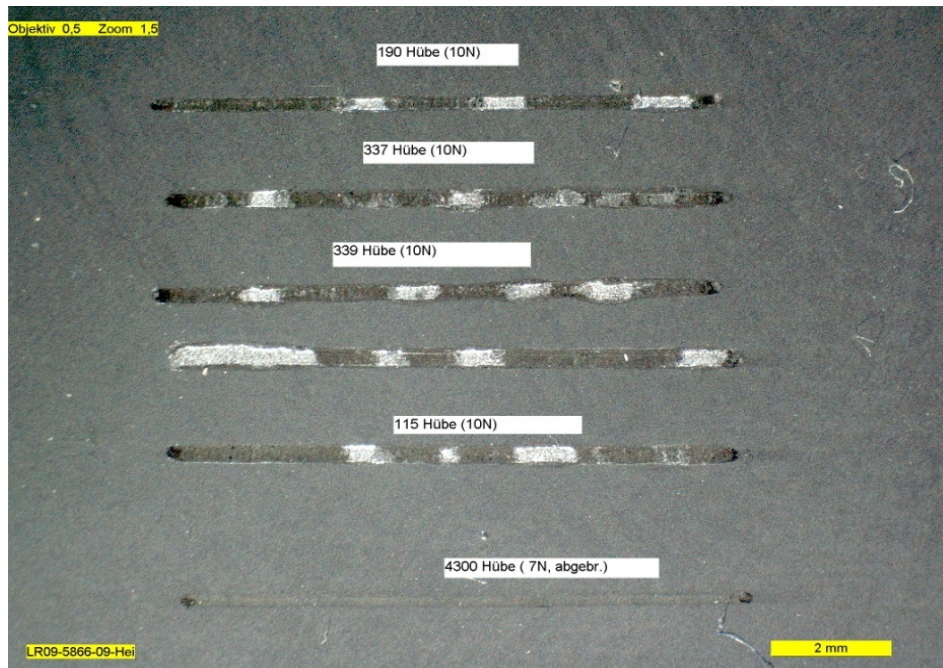
# Without co-curing agent, with NanoVer-Additive



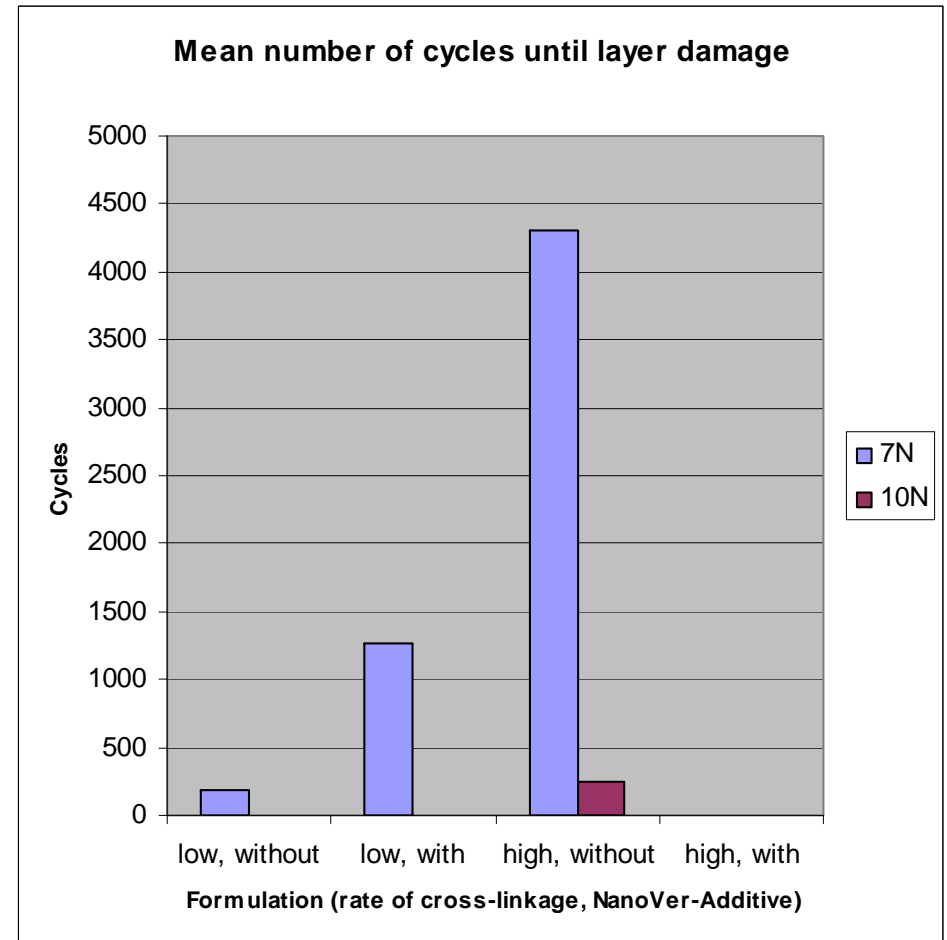
Wear pictures of single tests



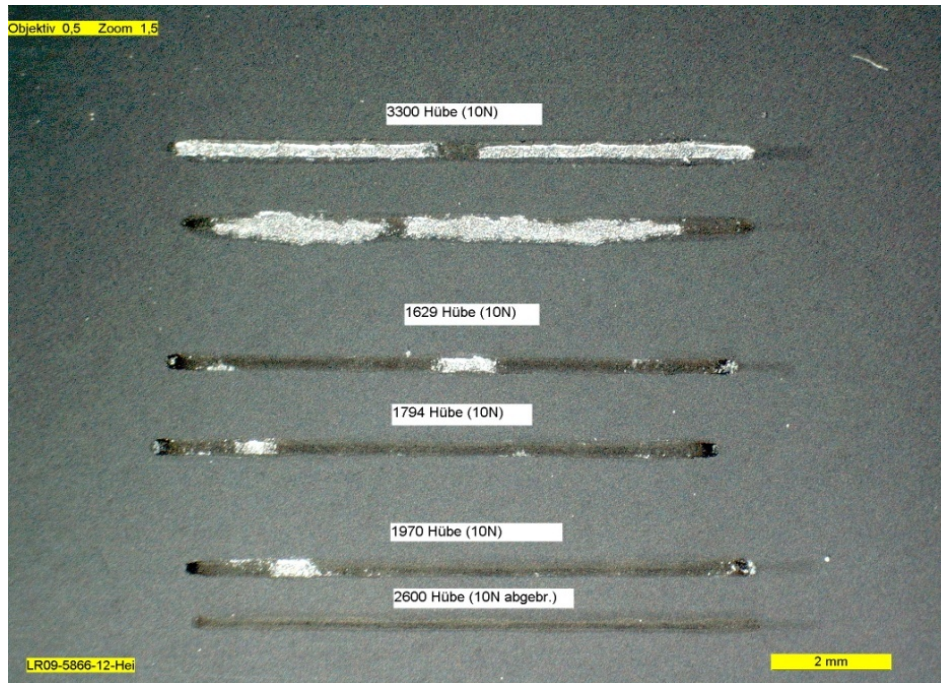
# With co-curing agent, without NanoVer-Additive



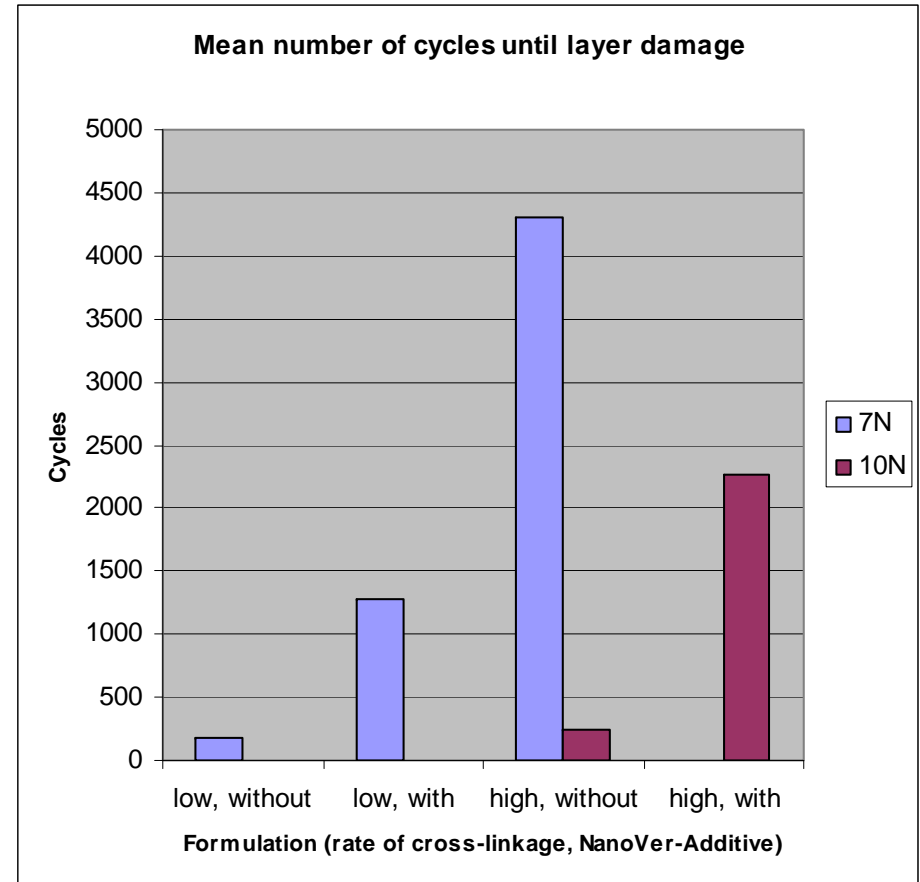
Wear pictures of single tests,  
Load increase to 10N



# With co-curing agent, with NanoVer-Additive

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Wear pictures of single tests,  
Load increase to 10N



## Summary of Heidon results

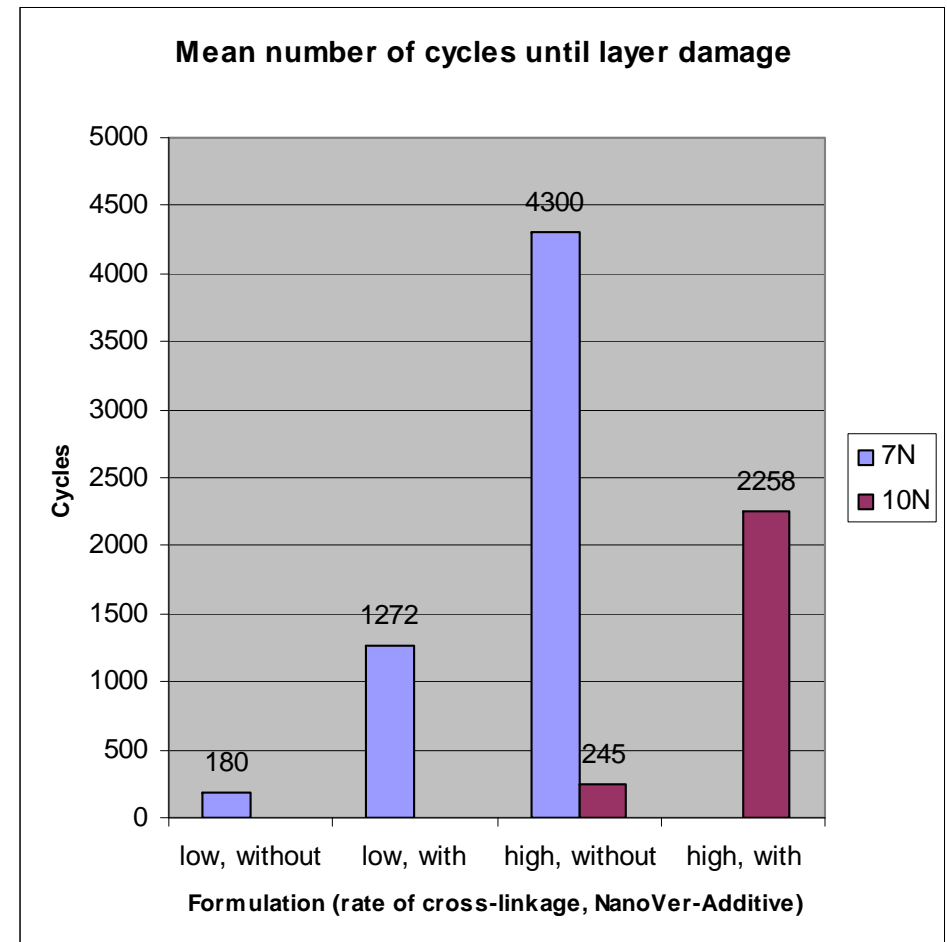


By using NanoVer-Additive the lifetime will increase to 7-10 times higher lifetime.

High rate of cross-linkage will increase the lifetime, too.

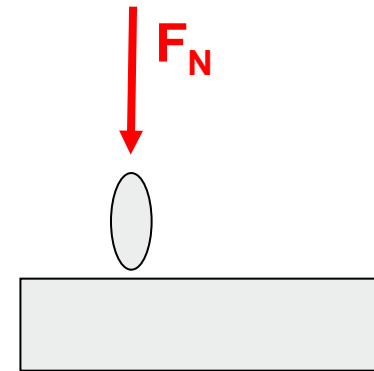
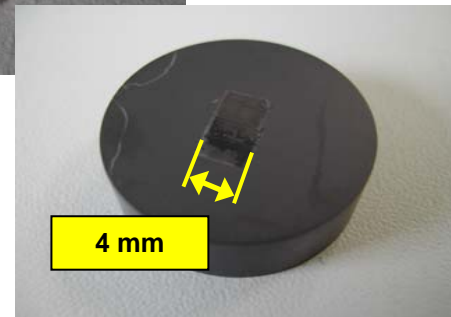
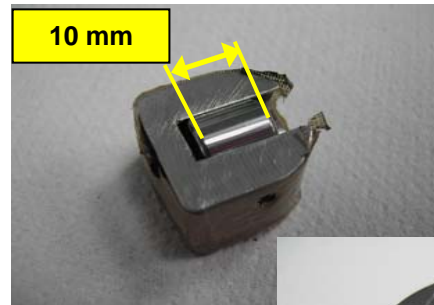
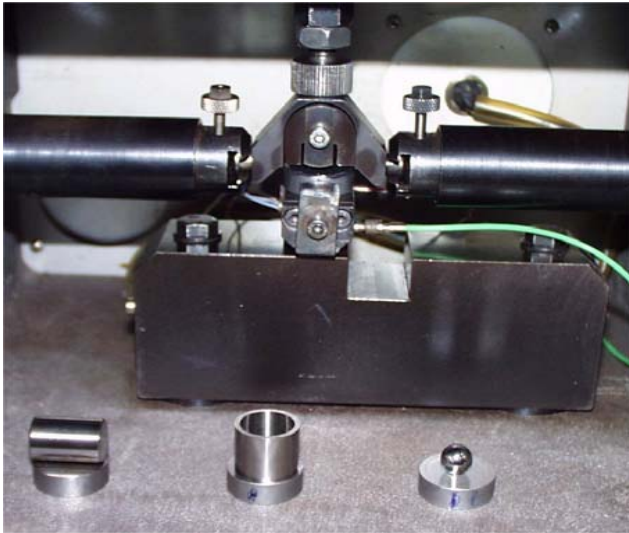
Coating damage will occur earlier with increased load.

By using NanoVer Additive at increased load the lifetime will be increased dramatically.



# Oscillating Friction Wear Test (SRV)

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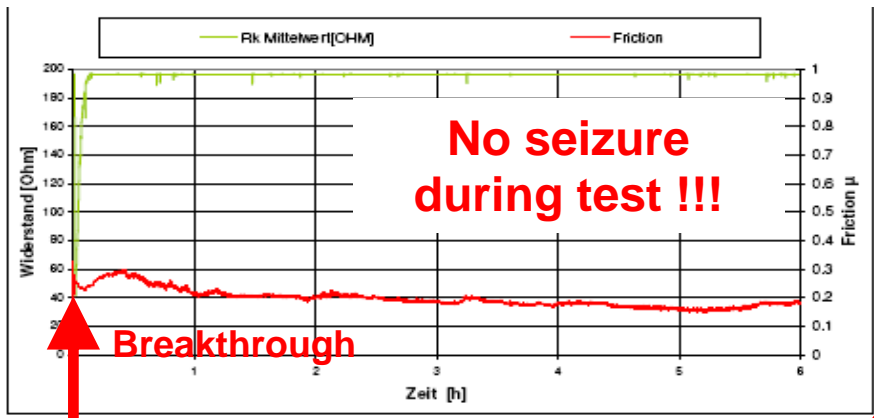
## Prüfdaten

Frequency:	30 Hz
Load:	200 N (400N/mm <sup>2</sup> )
Stroke:	4 mm
Temperature:	RT
Geometry:	Cylinder (D 10mm)
Test duration:	6h

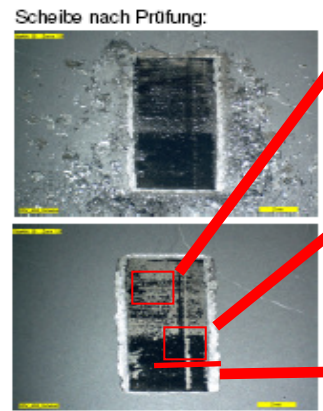
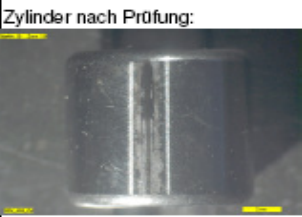


# Test results SRV: LR09-5866

(Pretreatment/curing: sand blasted/ 60 min. 200° C)

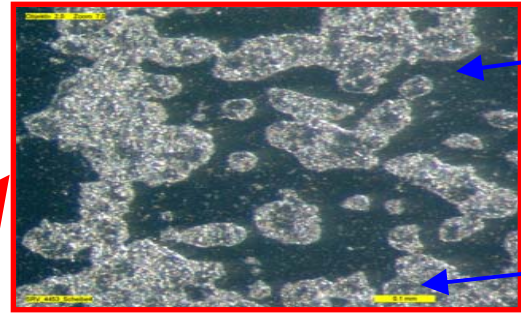


Bemerkung:  
 Prüfparameter: 200N/30Hz/4mm/RT/6h/Linie quer  
 Kontaktwiderstand bricht kurz nach Start der Prüfung sofort ein. Durch das Einglätten des MoS<sub>2</sub> entsteht während der Prüfung eine neue (Reaktions-) Schicht die bis 6h nicht voll zerstört ist. Es kommt zu keinem Fresser



Charge:	-
Produkt:	SHA-57/09-01 +B 25,2μm
SRV Prüfungs ID:	4453
LabView ID:	1698
Prüfer:	TC/PS
Prüfdatum:	22.12.2009

**SHA-57/09 + NP + B**  
**SRV ID 4453**



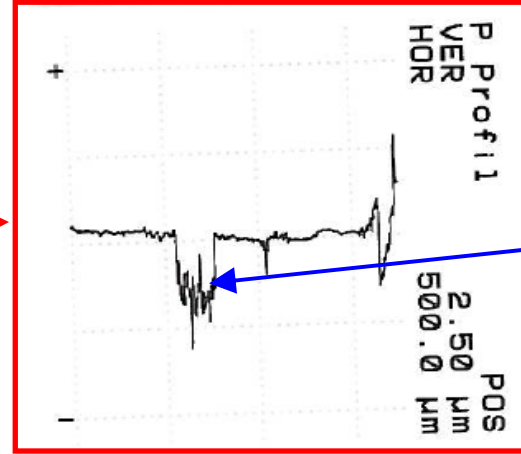
**Layer.**  
**Ingredients**  
**MoS<sub>2</sub> / Binder**  
**Nanoparticles**

**Flaking**



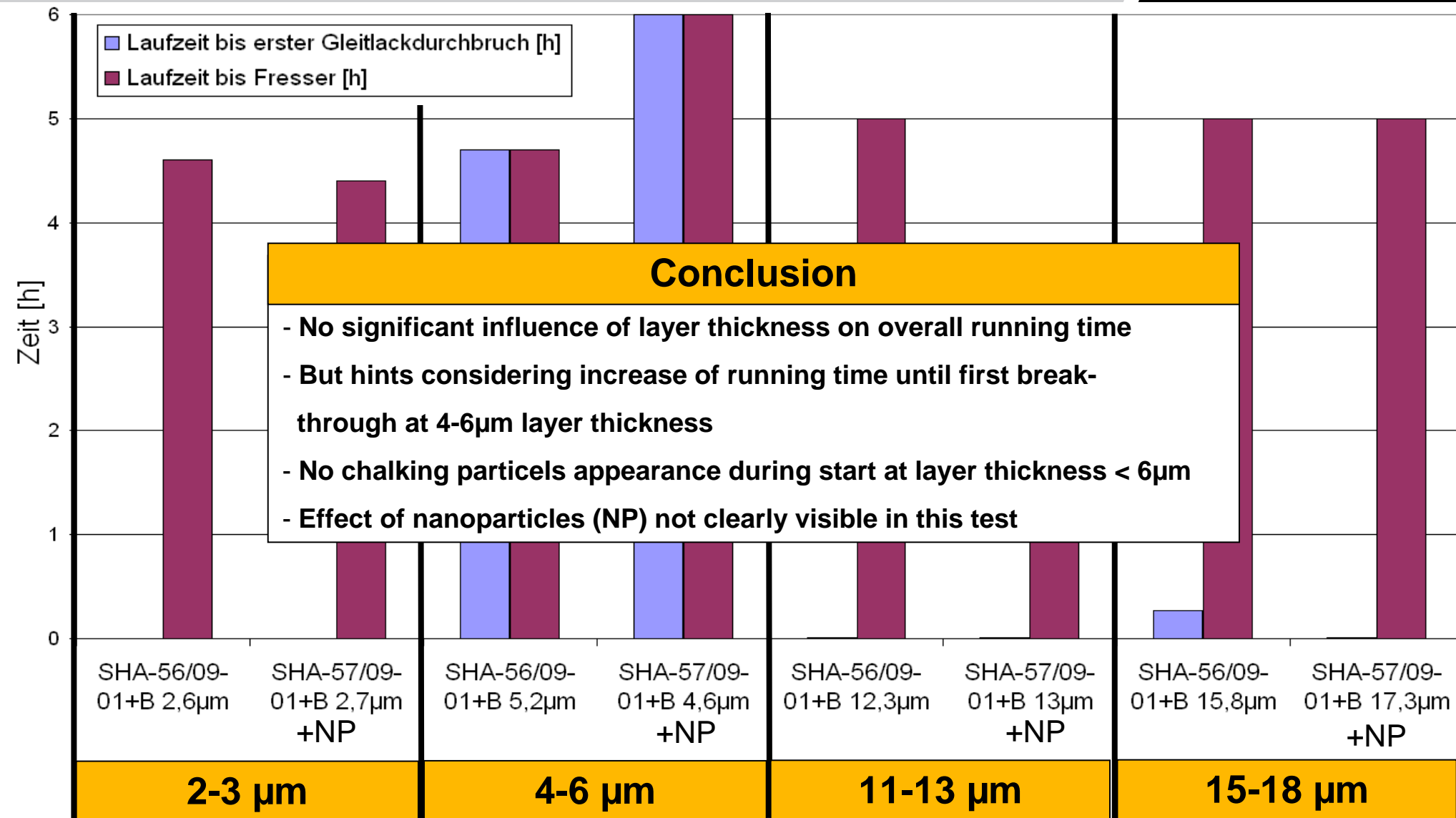
**Flaking**

**Layer.**  
**ingredients**  
**MoS<sub>2</sub>**  
**Binder**  
**Nanoparticles**



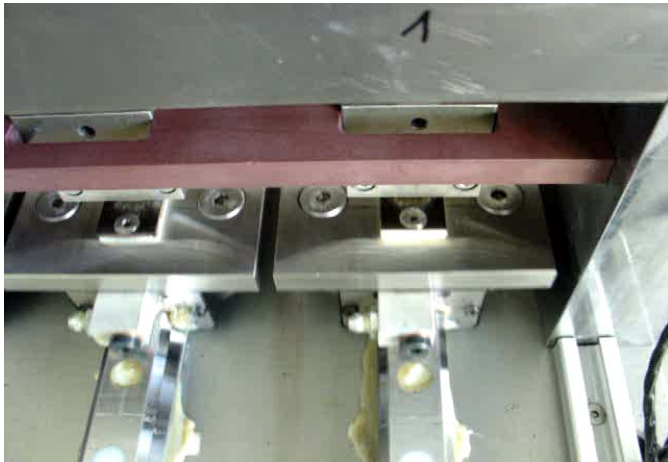
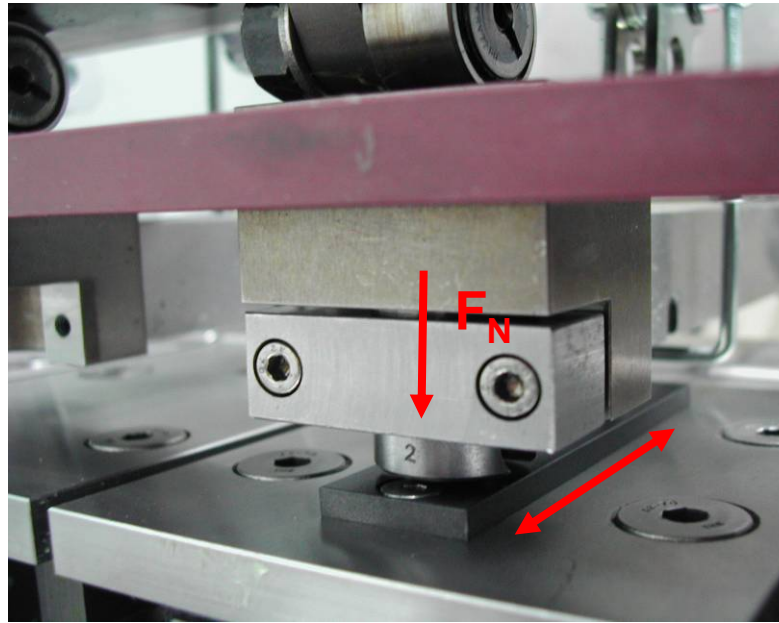
**Break depth**  
**~ 2,5μm**

# Summary SRV running time / layer thickness variation



# Oscillating slide plate test rig (OGP)

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## Test conditions:

Contact geometry:	Line contact
Material top specimen:	100 Cr6 steel
Material bottom specimen:	Steel or plastic
Load:	200 N
Sliding speed:	50 mm/s
Stroke:	50 mm
Temperature:	RT

# Testing method

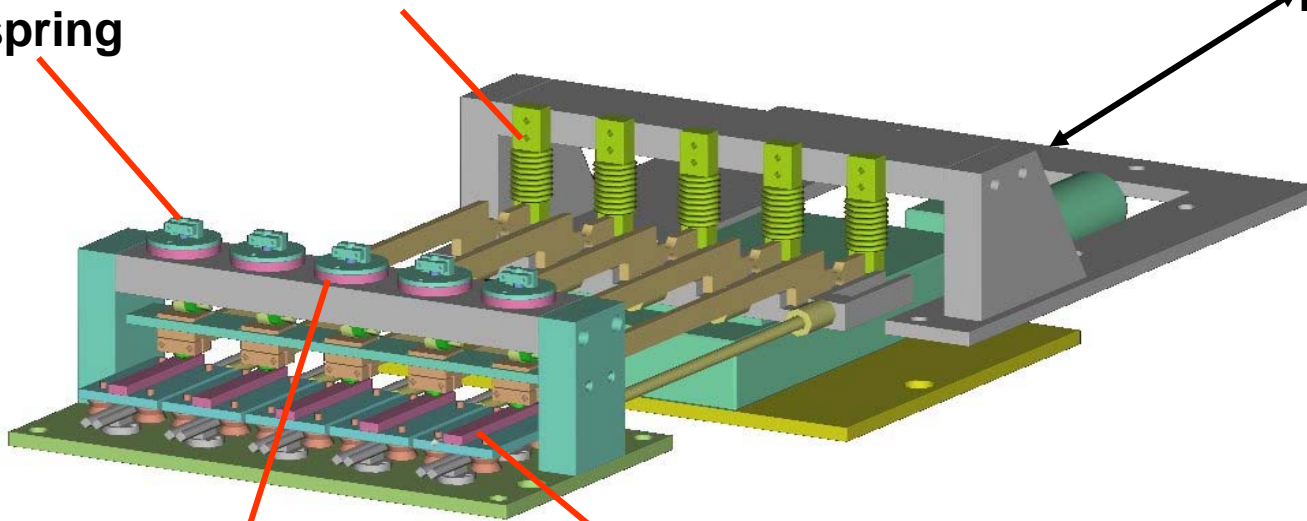
## Oscillating slide plate test rig

### Test unit

test load by  
disc spring

load sensor

linear drive unit



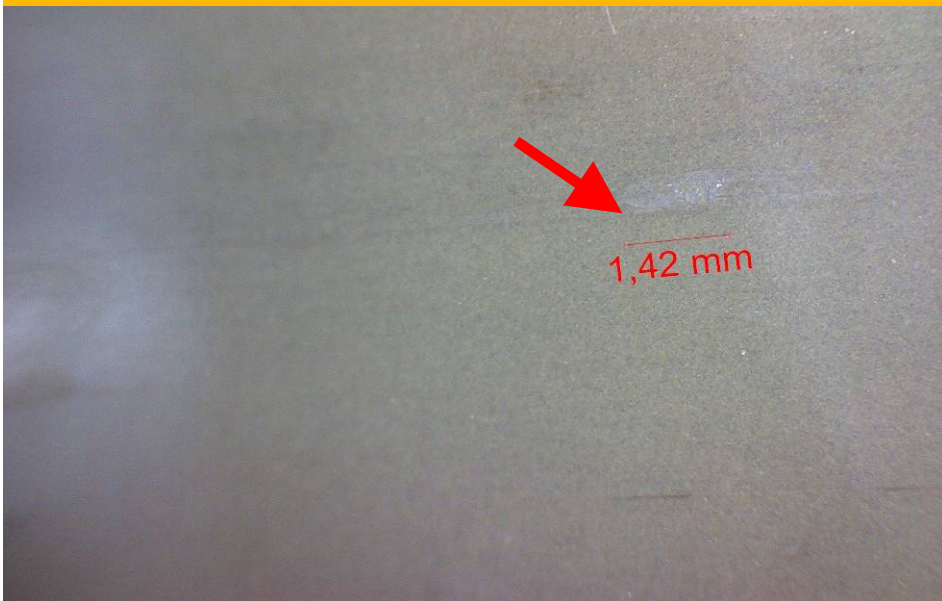
inductive position sensor

slide plates

# Fatigue damage on bonded coating



OGP-PL369-1 (after 121 m)



OGP-PL369-1 (after 185 m)



OGP-PL369 (after 570m)



→ Extensive spalling

# Performance increase

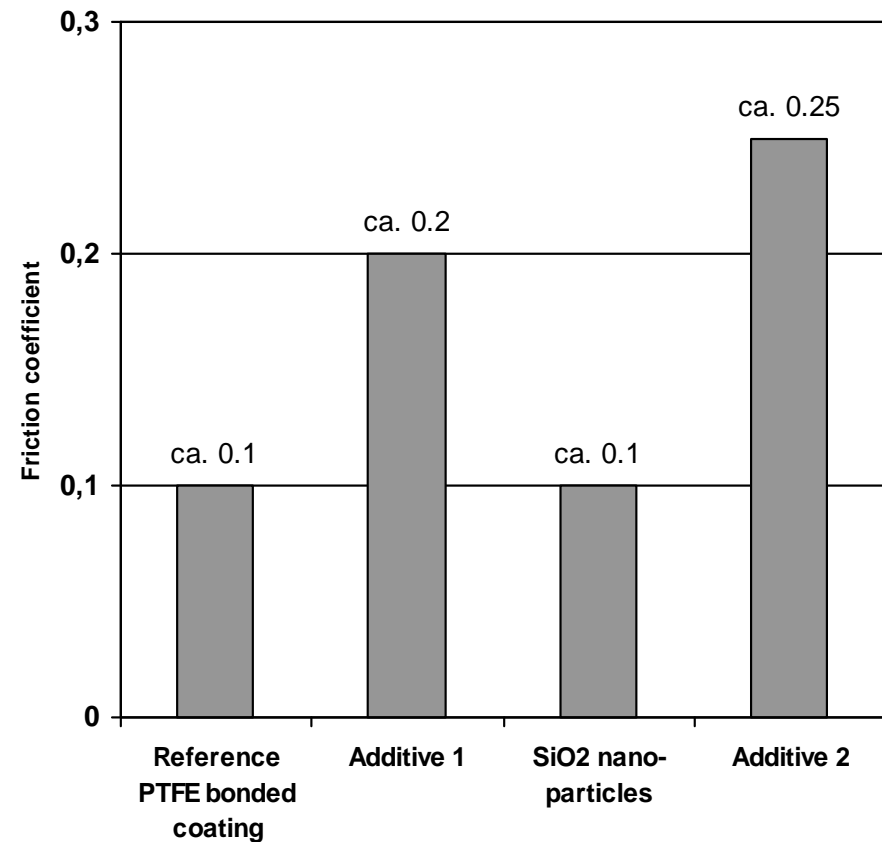
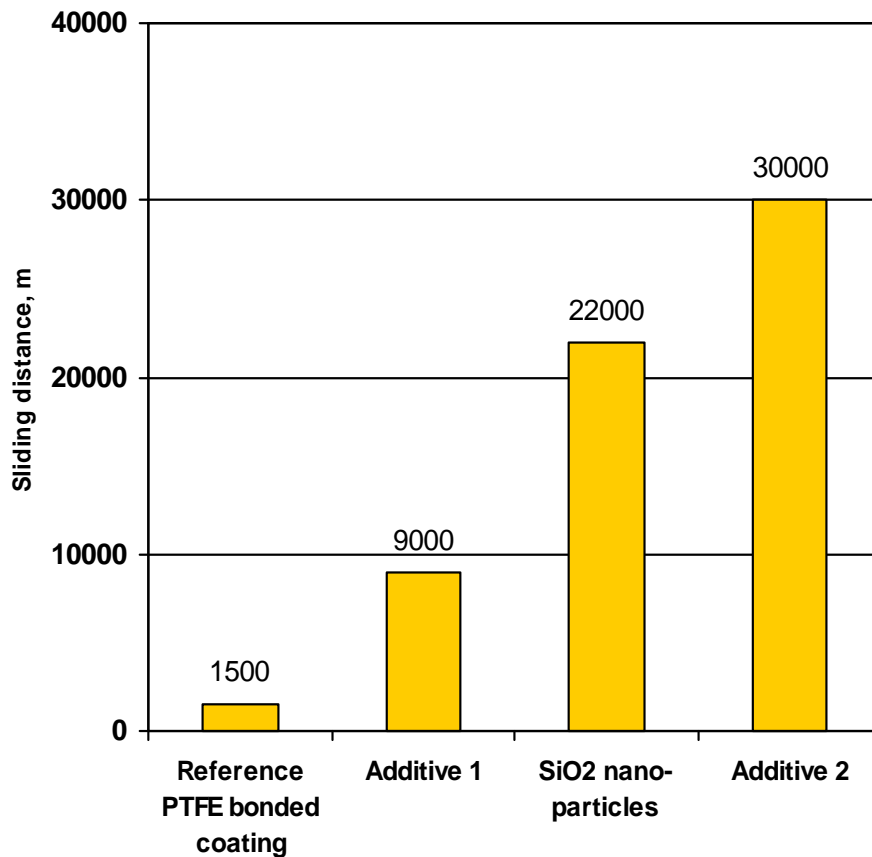
determined on oscillating slide plate test rig (OGP)



Results: Oscillating slide plate test rig (OGP), steel/steel pairing

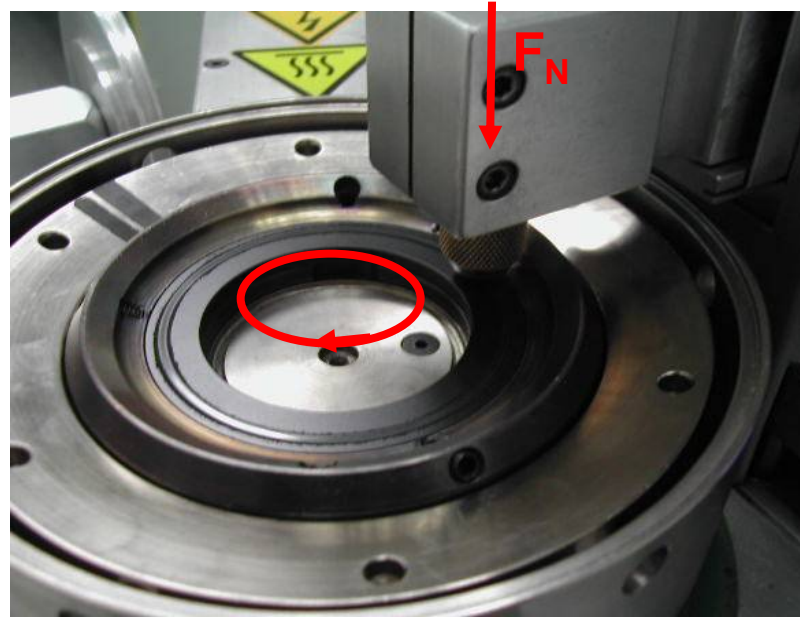
Linear load 200 N ( $p_H = 400 \text{ N/mm}^2$ ), 50 mm/s, stroke = 50 mm, room temperature

Initial layer thickness: 25  $\mu\text{m}$ ; shut-down criterion: rise in severe wear



# Sliding friction test rig

Principle: ball-disk



Ball

Cylinder

Pin

## Test conditions

Speed:	0.16 m/s
Test load:	30/50/70 N
Temperature:	25 ° C
Geometry:	point contact on ball Ø12.7 mm
Duration of test:	variable (2h)

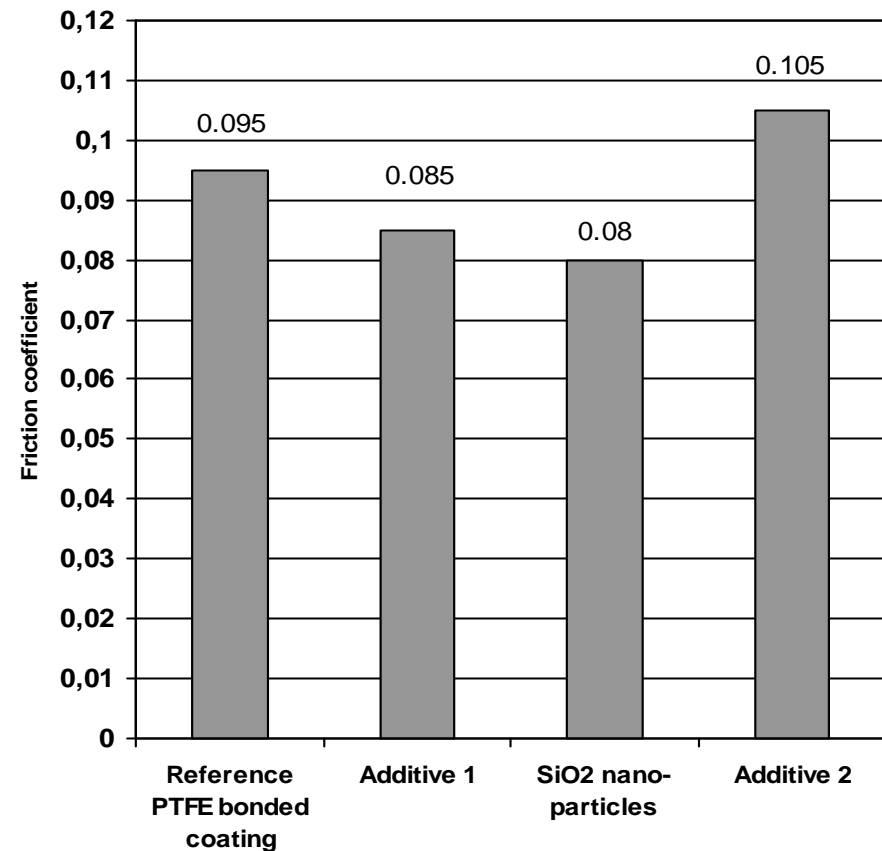
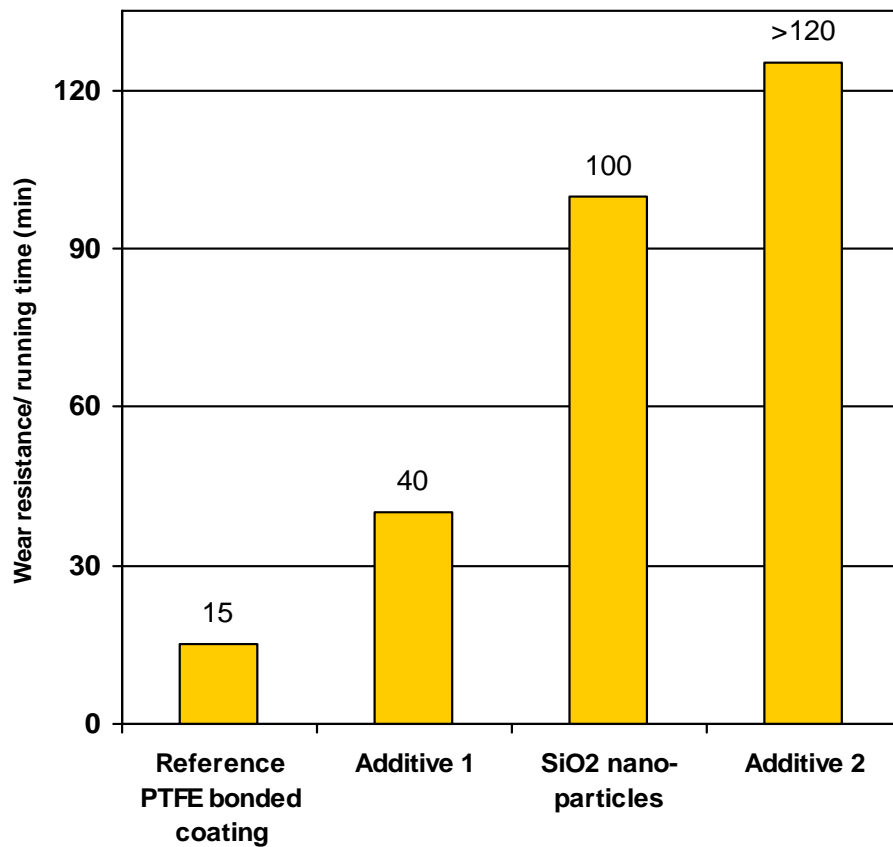
# Performance increase determined on ball-disk test rig



Results: ball-disk test rig, steel/steel pairing

Point load 50 N ( $p_H = 1474 \text{ N/mm}^2$ ), 0.16 m/s, room temperature

Initial layer thickness: 25  $\mu\text{m}$ ; shut-down criterion: impedance value 50 %



# Test method: Tannert sliding indicator

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**Scope:** Sliding and stick-slip behaviour of lubricants and materials subject to low sliding speeds.

**Standard:** Klüber test conditions

**Specimens:** two sliding elements and a sliding tongue (79.5 x 20 x 3 to 5 mm), various material pairings possible

Sliding elements:

Block 29.8 x 24.9 x 15 mm (surface contact)

Cylinder  $\varnothing 13$  x 13 mm (surface contact)

Cylinder  $\varnothing 10$  x 10 mm (linear contact)

**Test conditions:**

Sliding speed: max. 0.243 or 0.486 mm s<sup>-1</sup>

Sliding distance: 20 mm

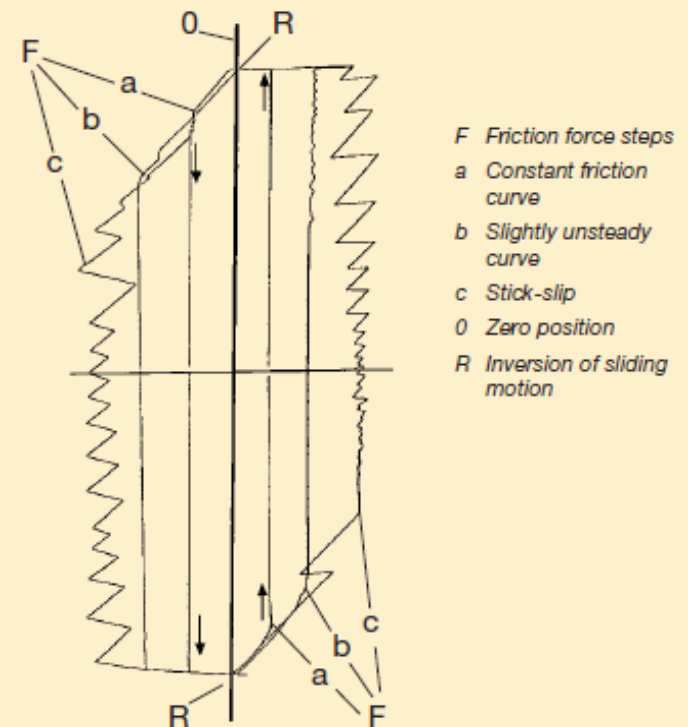
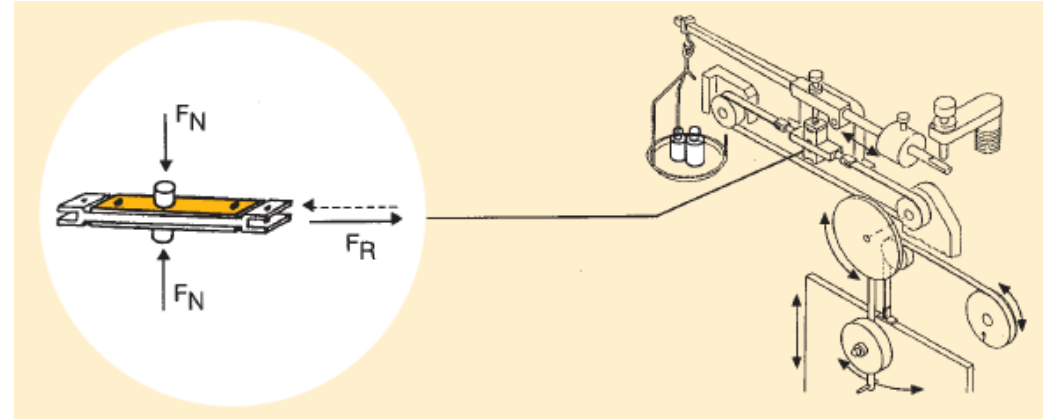
Temperature: RT to 150 ° C

Load: variable from 50 to 1200 N

Geometry: line and/or surface

Given parameters: number of runs, time [h]

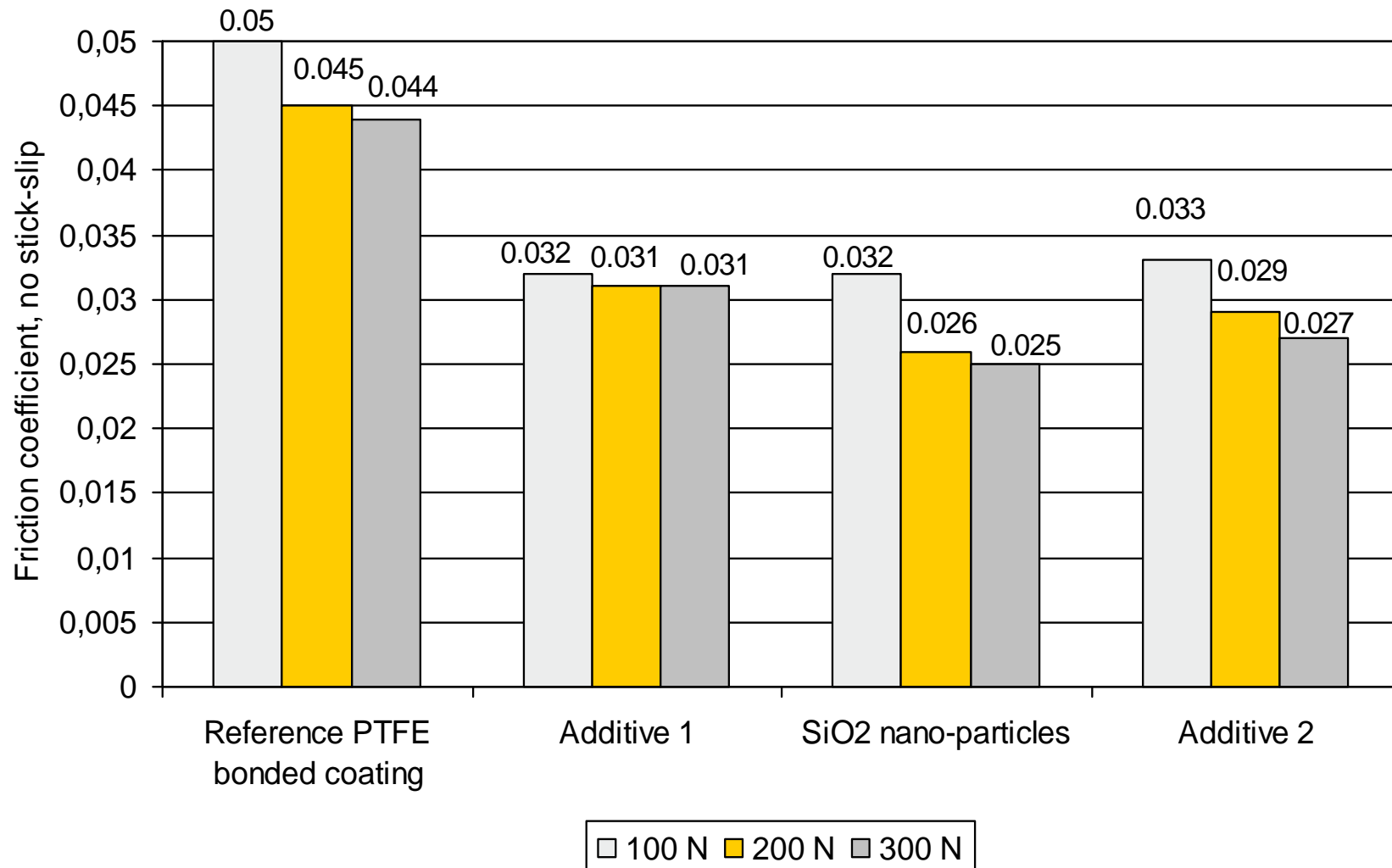
**Test result:** determination of the friction coefficient and identification of stick-slip



# Performance increase determined on Tannert sliding indicator



Results: Tannert sliding indicator, steel/steel pairing, linear load 100; 200; 300 N ( $p_H = 285; 400; 500 \text{ N/mm}^2$ ),  
Room temperature, initial layer thickness: 25  $\mu\text{m}$



# Applications and Support



## Opportunities:

- New applications where hard material coatings are needed (cost saving benefit)
- Replacement of existing applications with safety and lifetime increase or cost reduction (thin layers)
- Existing applications with requirements to higher performance (lifetime, load carrying capacity)

BMBF NanoVer – with support by



under the auspices of

