Laserinstitut Hochschule Mittweida

HOCHSCHULE MITTWEIDA
University of Applied Sciences

Laser-based surface functionalization for advanced tribological performance

Jörg Schille

Agenda

1. Some facts about …

   - Laserinstitut Hochschule Mittweida (LHM)
   - High-rate laser texturing for advanced surface - functionalization

2. Research on laser technology in tribology

   - Motivation
   - Analysis method for CoF characterization
   - Dimple-shaped micro structures (static CoF)
   - Deep penetration welding dots (kinetic CoF)
   - (Sub) micrometer surface features

3. Tribomaps

1. Some facts about …

- Laserinstitut Hochschule Mittweida (LHM)
- High-rate Laser texturing for advanced surface functionalization

Laserinstitut Hochschule Mittweida (LHM)

- central scientific institution (In-Institute)
- research and academic education (B.Sc., M.Sc.)
- strategical main research topics:
  - → high-rate laser processing
  - → laser nano /micro processing

- 7 professors
- > 50 employees
- > 60 laser sources

- AG „Hochrate-Laserbearbeitung“ (Prof. U. Löschner)

Ultrashort pulse lasers / High-power lasers / Laser micro processing / High-rate laser processing / Laser surface functionalization / Laser safety

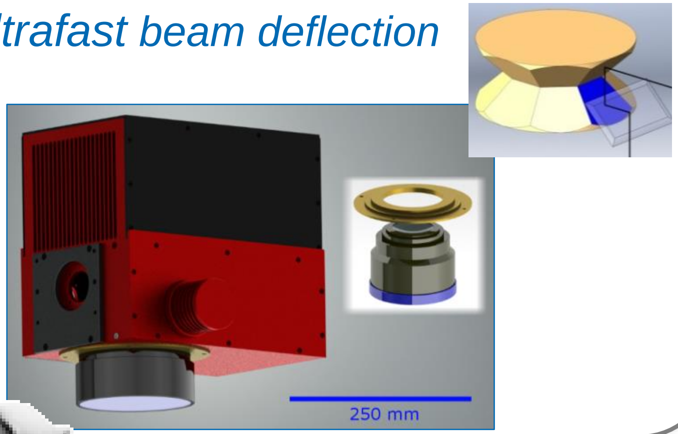
HOCHSCHULE MITTWEIDA

High-rate laser technology

- *Main goal* → Increasing processing speed for high-throughput and large-area processing

Powerful laser sources

Ultrafast beam deflection



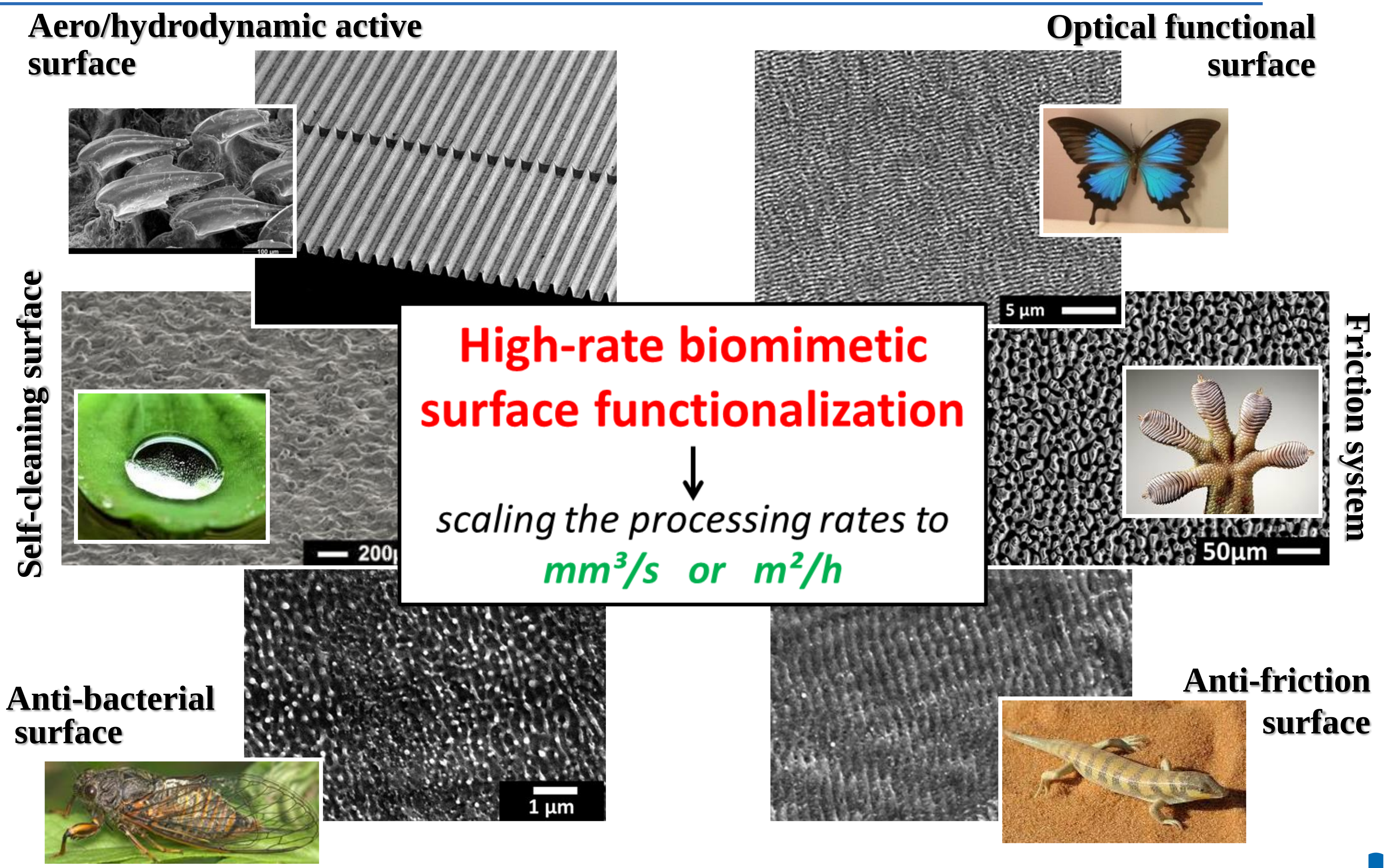
Upscaling laser processes

- Ultrashort pulse lasers with **kW** average laser powers
- Ultrafast laser beam movements with **km/s** scan speeds
- Large area (**m²**) 2D and 2,5D processing

optimization
irradiation conditions

optimization
machining strategy

(High-rate) laser texturing for advanced biomimetic functionalities



2. Research on laser technology in tribology

- Motivation
- Analysis method for CoF characterization
- Dimple-shaped micro structures (static CoF)
- Deep penetration welding dots (kinetic CoF)
- (Sub) micrometer surface features

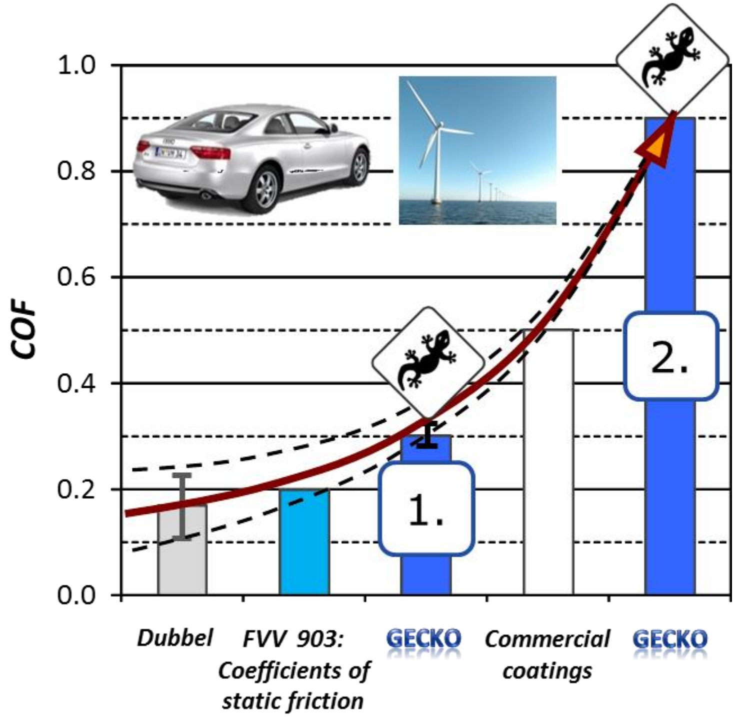
Motivation

- ***Coefficient of Friction (CoF) enhancement by laser surface texturing***

  - Delivery of **reliable and stable static CoF**
  - **Increase of static CoF** offers great potential to
    - ✓ decrease friction torque (seals, piston rings, thrust bearings, …)
    - ✓ increase load capacity and efficiency of tribological systems
    - ✓ save energy and material (less weight)
  - Applicable in automotive, heavy industry (wind turbine, ship building, …)

Source 1	Source 2	Source 3	Source 4	Source 5	Source 6	Source 7
dry	dry	dry	dry	uncoated	rusty	un-lubricated
0,45-0,80	0,15	0,2	0,15-0,30	0,10-0,15	0,12-0,20	0,15

KÖHLER (2005)



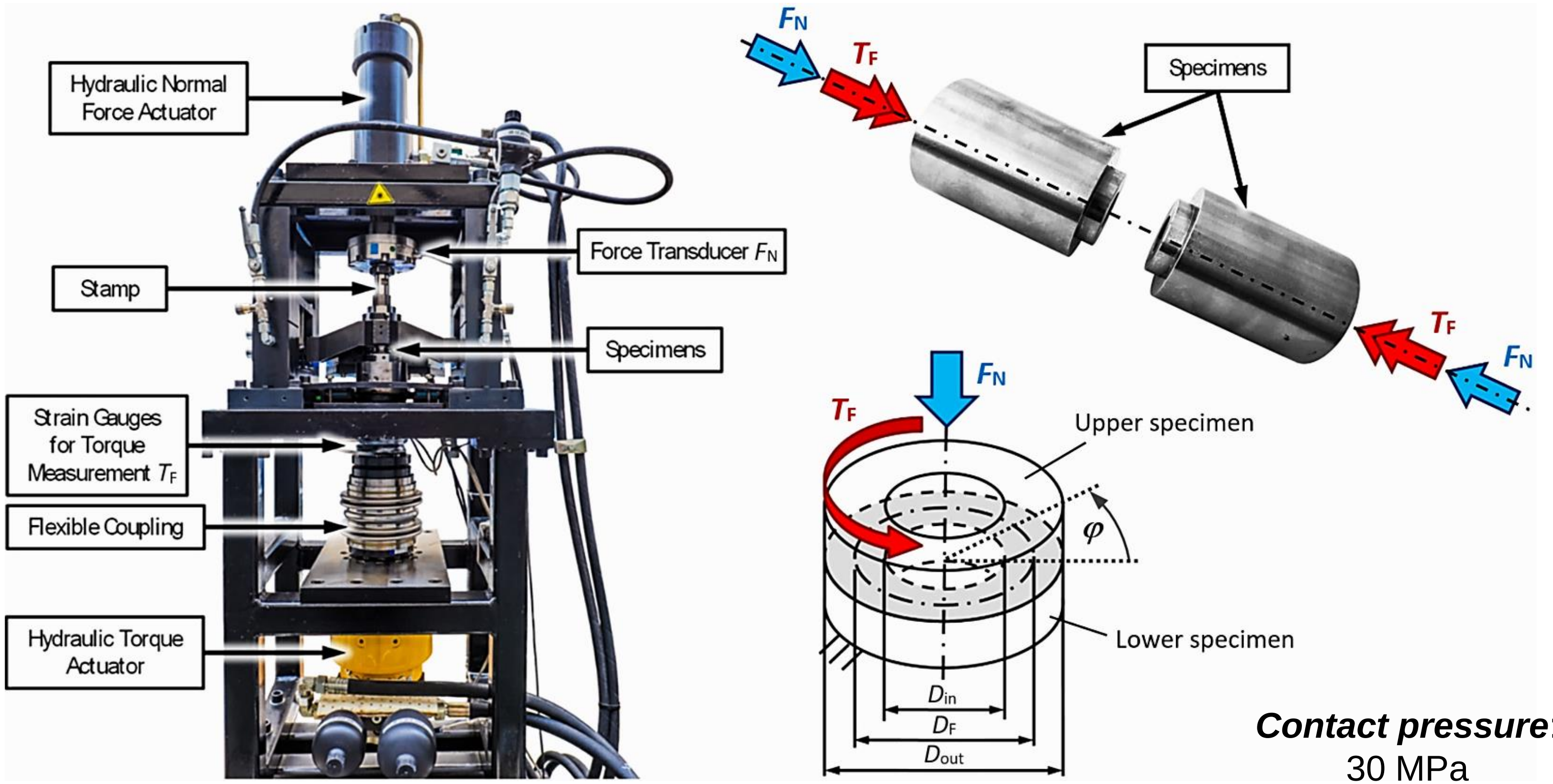
⇨ *AiF/DFG Cluster:* Gestaltung und Ermittlung charakterisierender Kennwerte von reibschlussoptimierten Oberflächen (GECKO), **TP-V: Reibwerterhöhende Laserstrukturierung** (2011-2014)

⇨ *AiF:* Entwicklung von **Tribomaps** für reibwerterhöhende Laserstrukturen (seit 2019)

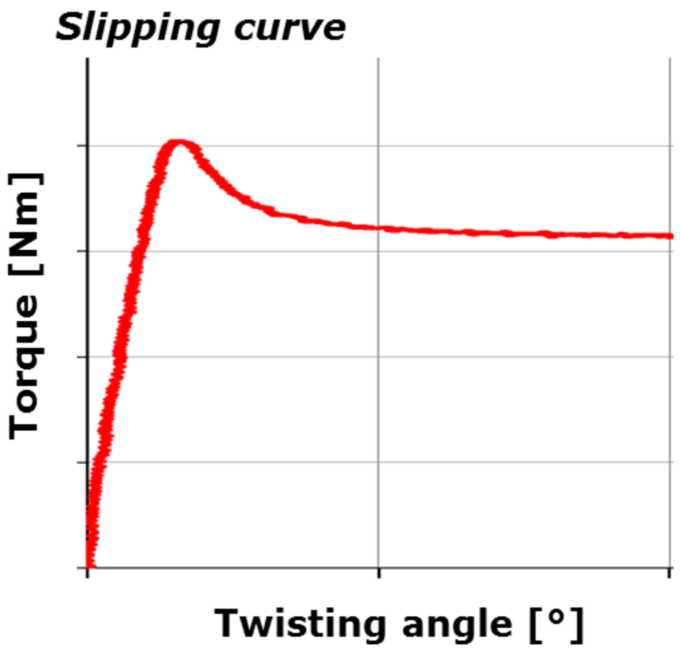
Analysis method for CoF characterization

- ***Torsion test bench***

$$\mu = \frac{F_R}{F_N} = \frac{2 \cdot TF}{D_R \cdot F_N}$$



Contact pressure:
30 MPa
100 MPa
300 MPa



Analysis method for CoF characterization

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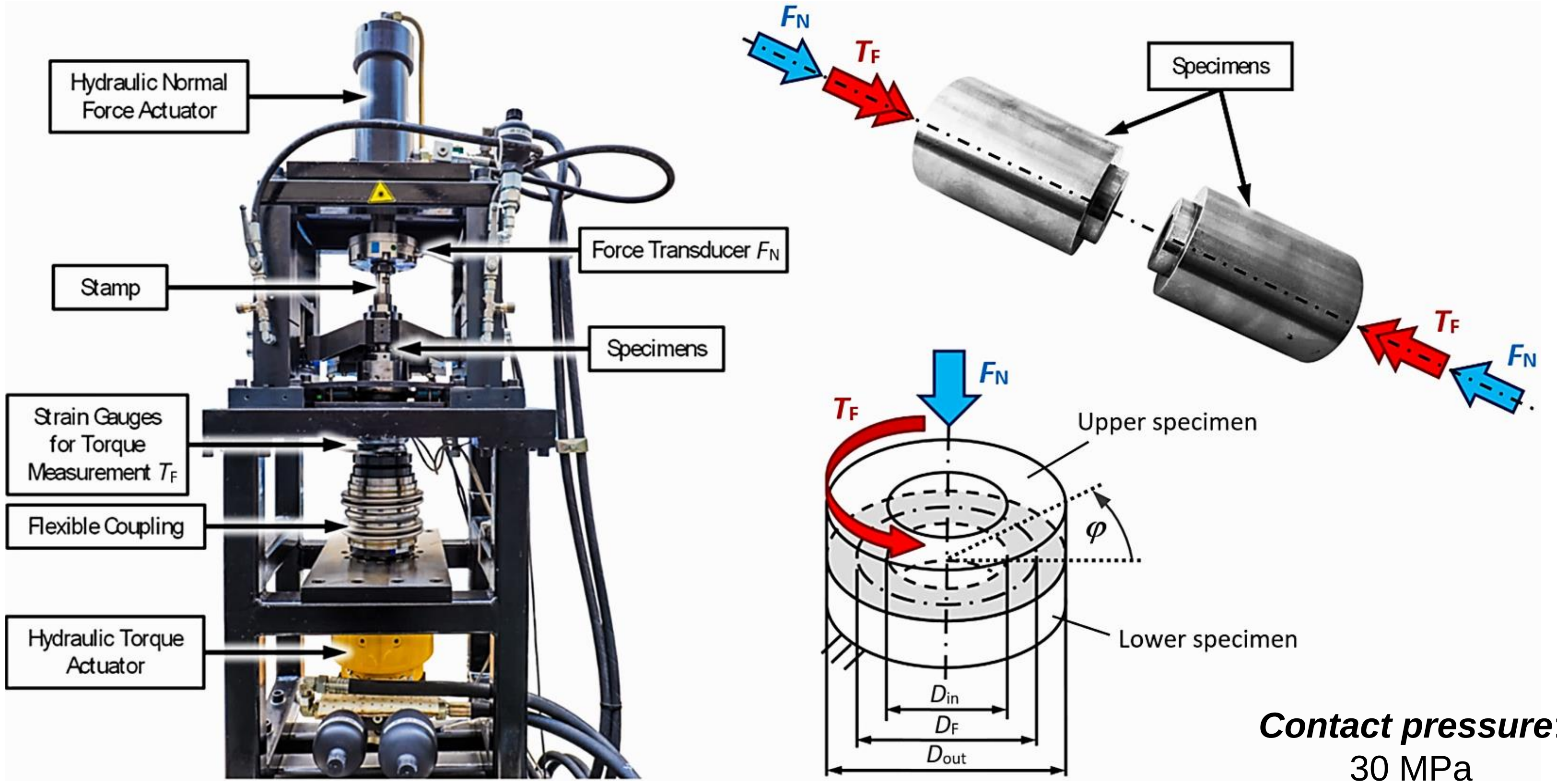
$$\mu = \frac{F_R}{F_N} = \frac{2 \cdot TF}{D_R \cdot F_N}$$



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Contact pressure:
30 MPa
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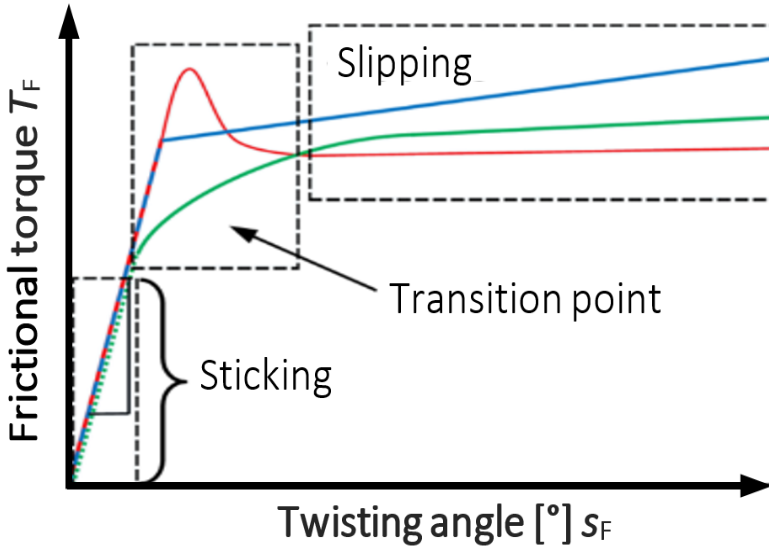
300 MPa

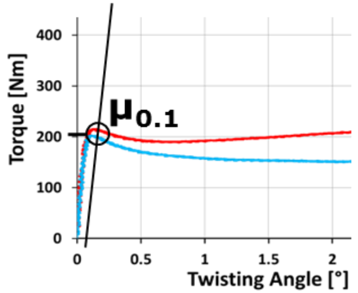


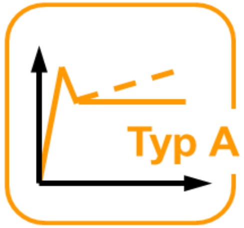
Analysis method for CoF characterization

Laserinstitut Hochschule Mittweida

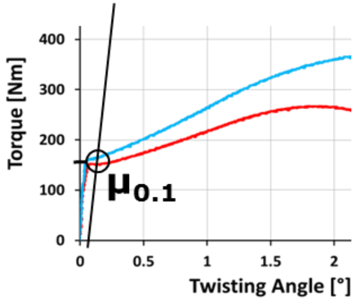
- ***Types of friction characteristic***

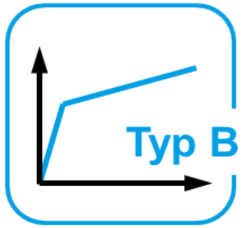
$$\mu = \frac{F_R}{F_N} = \frac{2 \cdot TF}{D_R \cdot F_N}$$



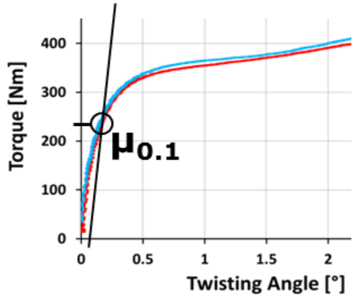


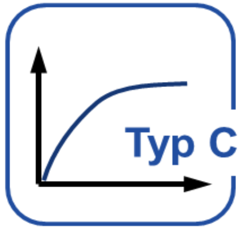
local maximum at transition point from sticking to sliding; decreasing slipping curve after reaching transition point; COF may increase again



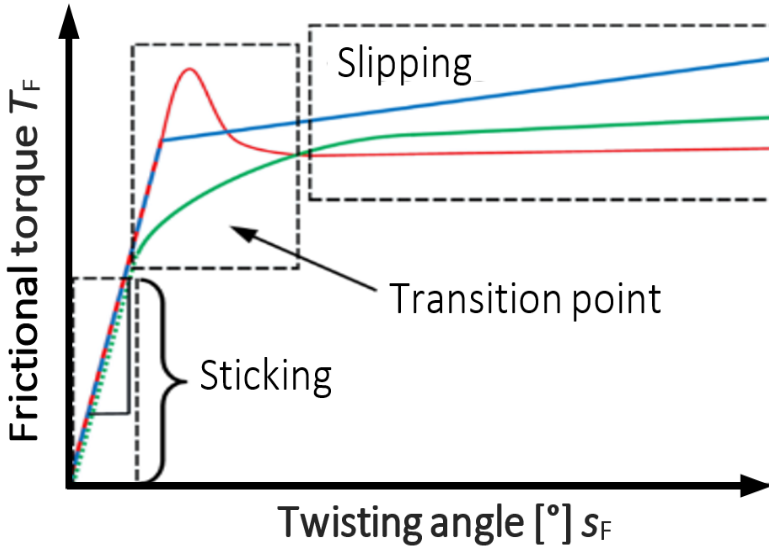


abrupt transition between sticking and sliding, stable or increasing COF after reaching the transition point



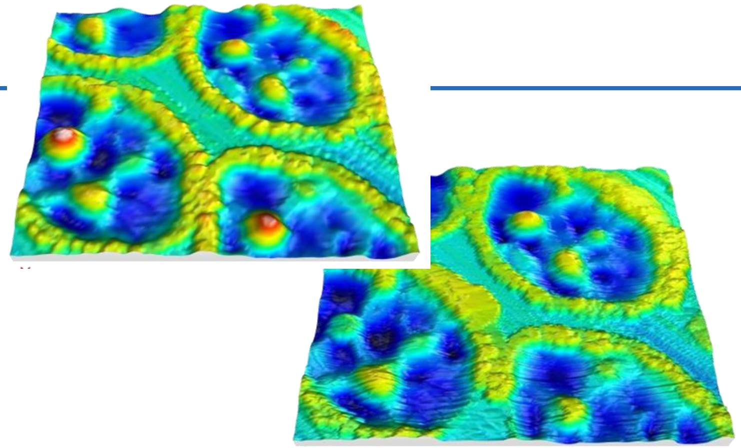


continuous transition of the slipping curve from sticking to sliding

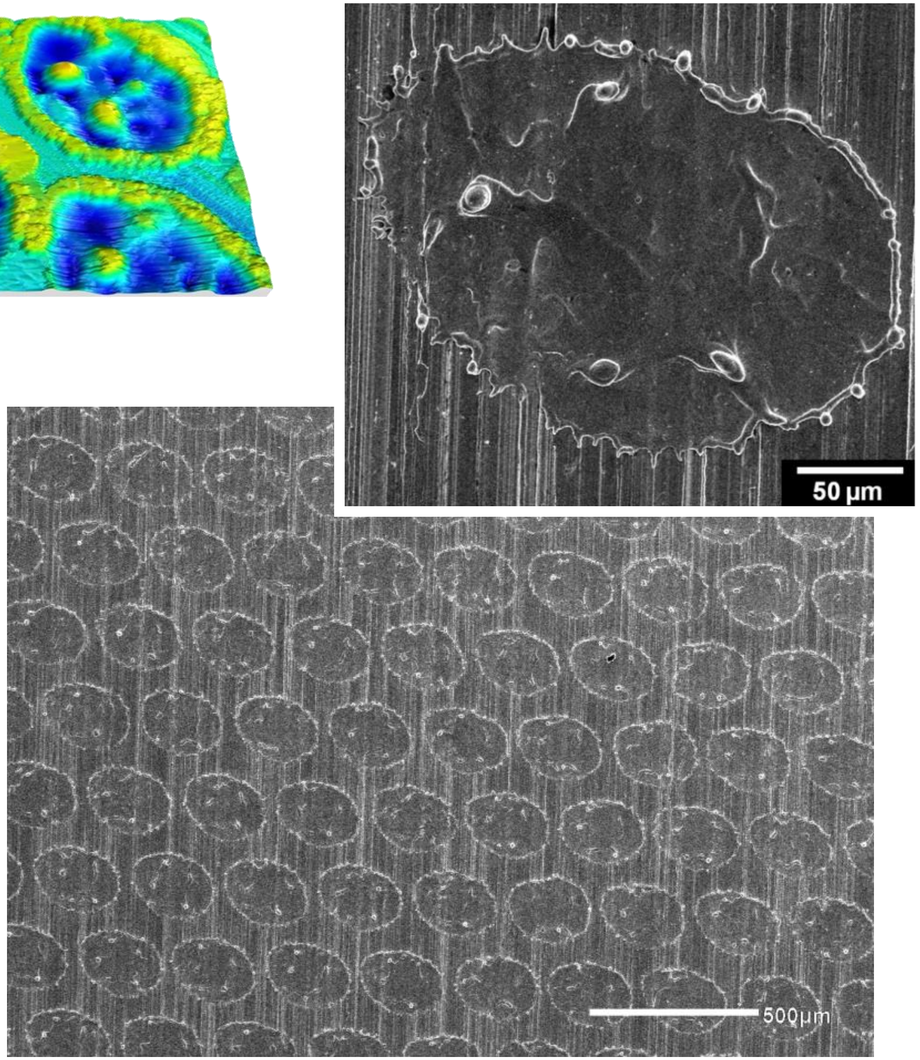


Schille et al.: High-Rate Laser Surface Texturing for Advanced Tribological Functionality. *Lubricants* **2020**, *8*, 33.

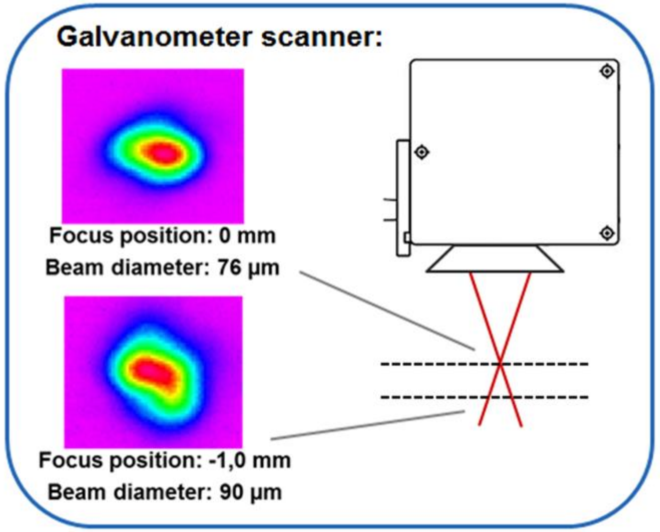
Dimple-shaped micro structures

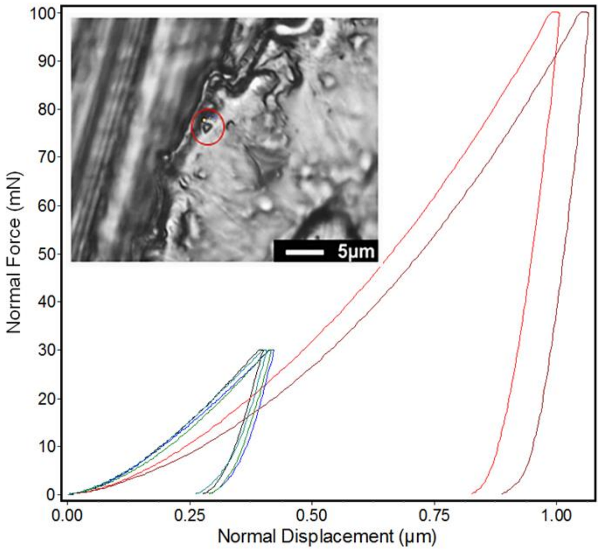


- ***Characteristic***
  - dimple-shaped micro structures (Ø100 µm)
  - molten and re-solidified wall structure
  - plasma melt dynamics
    - ✓ energy → melting
    - ✓ intensity → plasma



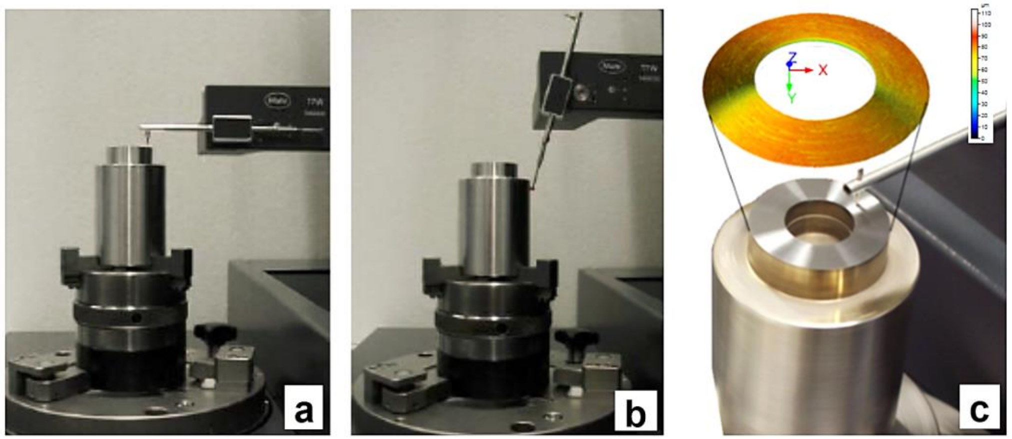
Hardness:
bulk material
398 ± 52 HV
re-solidified wall
784 ± 257 HV

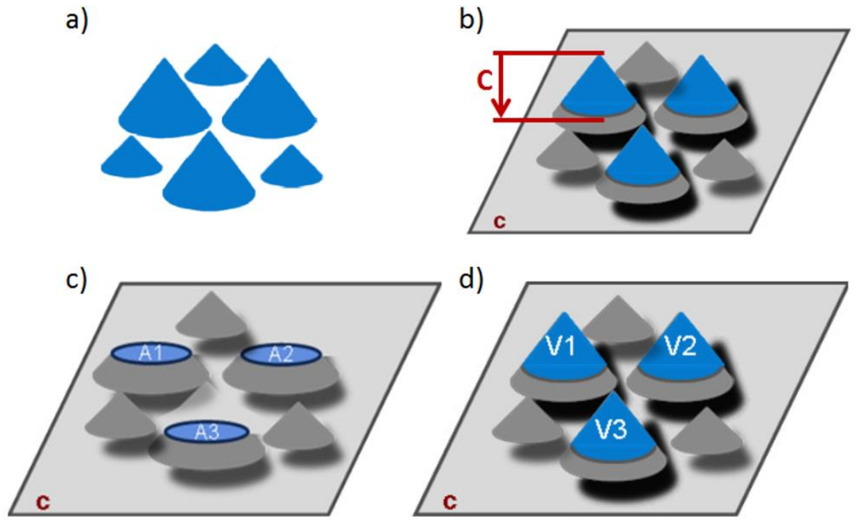




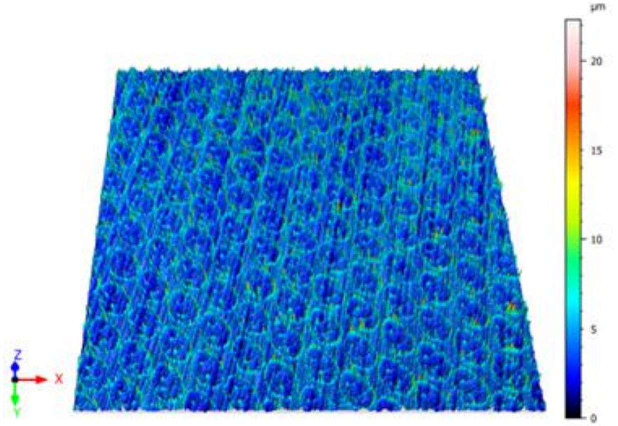
Dimple-shaped micro structures

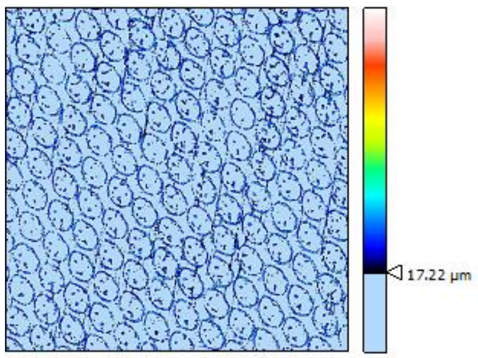
- ***Topography analysis***





- number of islands
- mean surface of the islands
- mean material volume at specific height c





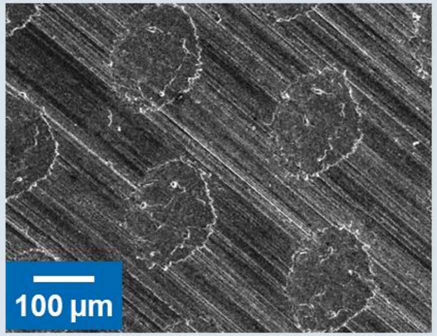
Surface Parameters:

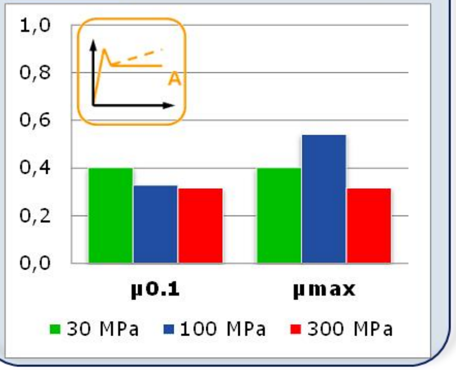
NI= 4579
MSI=225 µm²
MVM= 0,32 µm³/µm²

Dimple-shaped micro structures

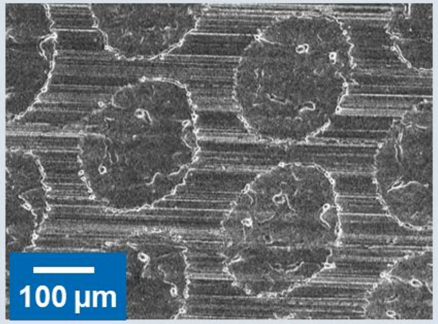
- ***Friction analysis (fine-grinded counter parts)***

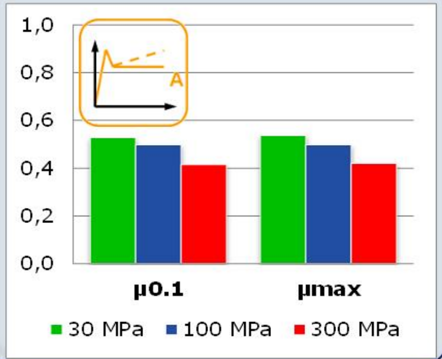
dimension: 200 x 130 µm²
height: 4 µm
number of islands: 2570



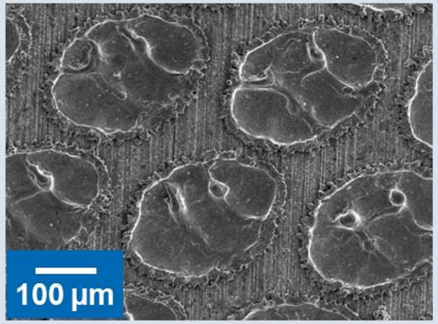


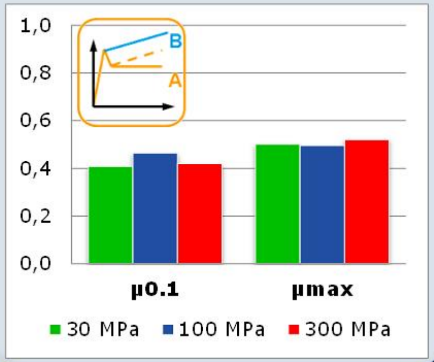
dimension: 250 x 160 µm²
height: 7 µm
number of islands: 4600

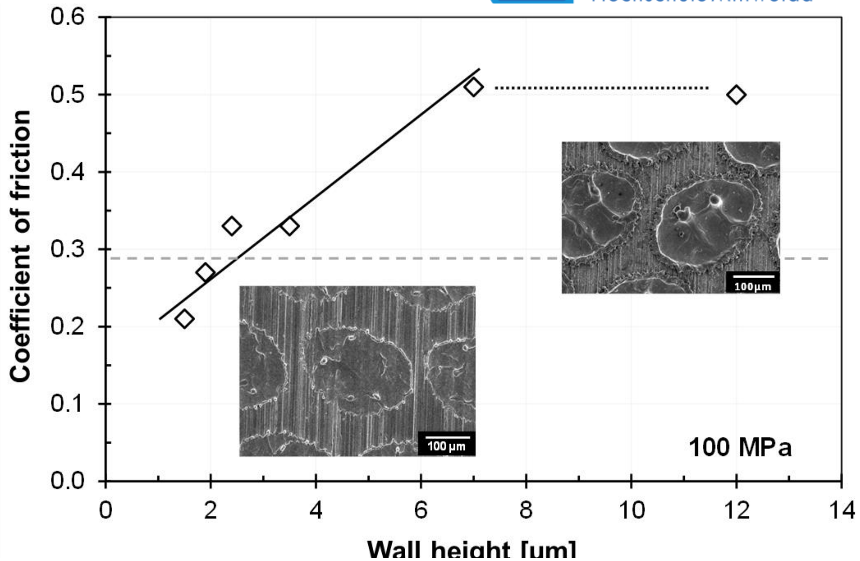


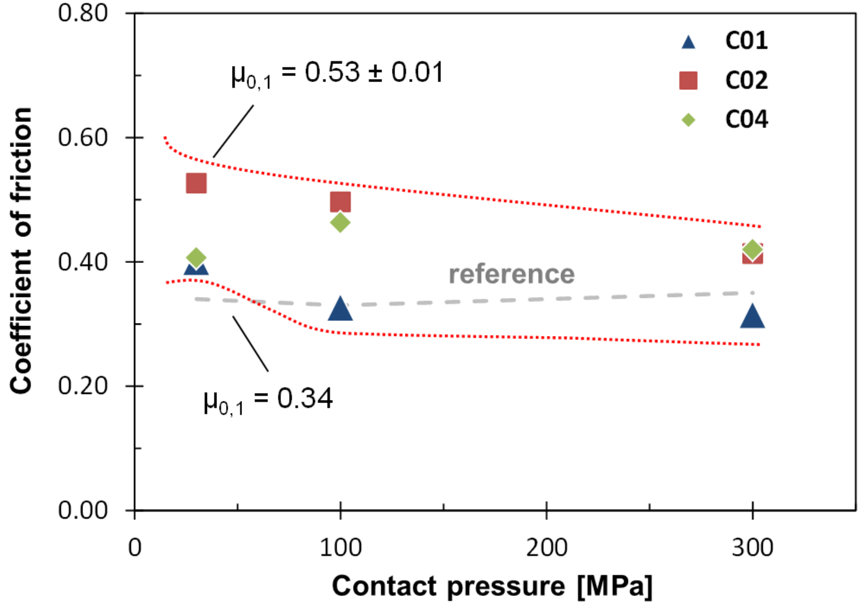


dimension: 250 x 160 µm²
height: 12 µm
number of islands:1790





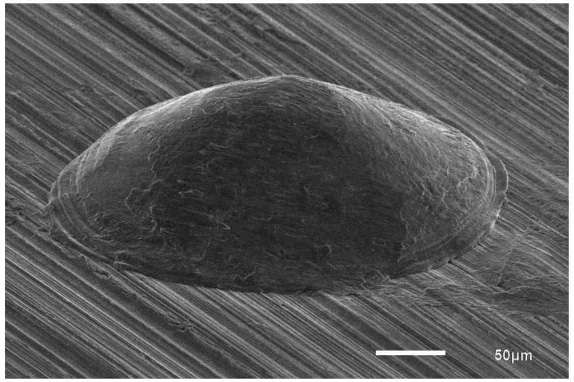


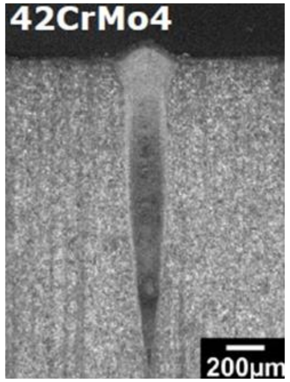


Schille et al.: Experimental Study on Laser Surface Texturing for Friction Coefficient Enhancement. Journal of Laser Micro/Nanoengineering 10 (2015), Nr. 3, 245-253

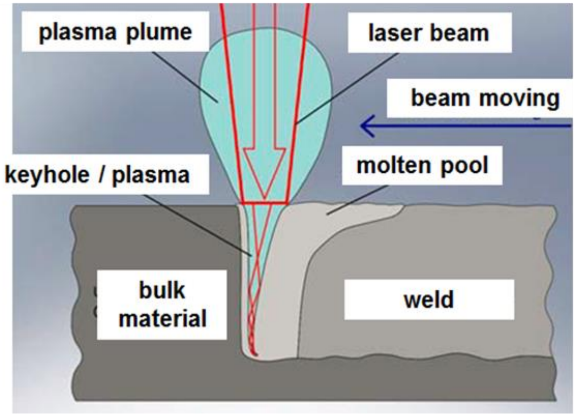
Deep penetration welding dots (kinetic CoF)

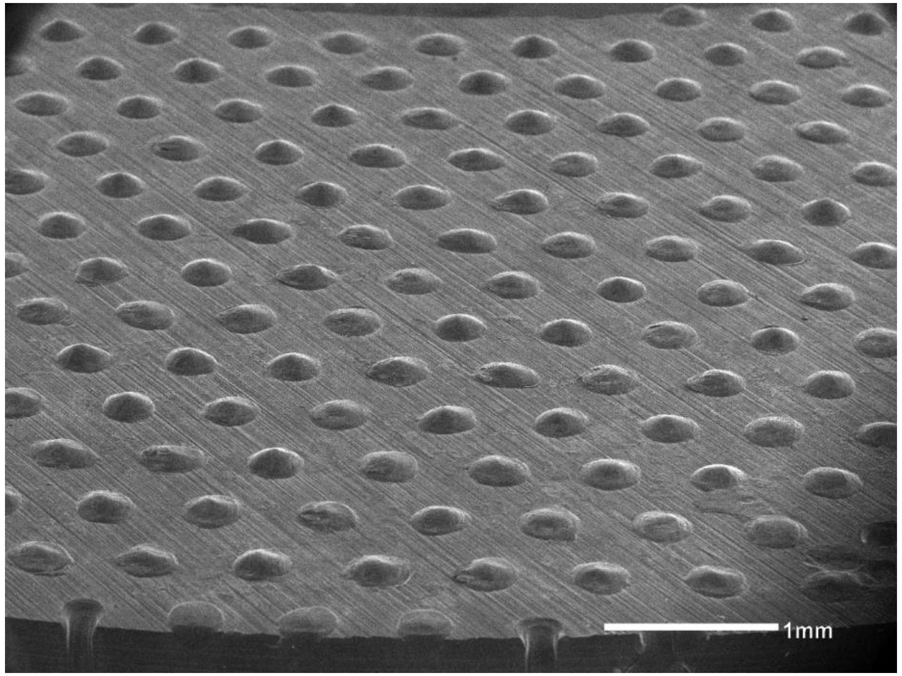
- ***Characteristic***
  - lenticular-shaped bulges (Ø=200 .. 300 µm; h=100 µm)
  - deep penetration welding effects
  - keyhole → weld root
  - hardness increase (500 .. 800 HV)
  - geometry / hardness depend on
    laser power, irradiation time





Deep penetration welding:

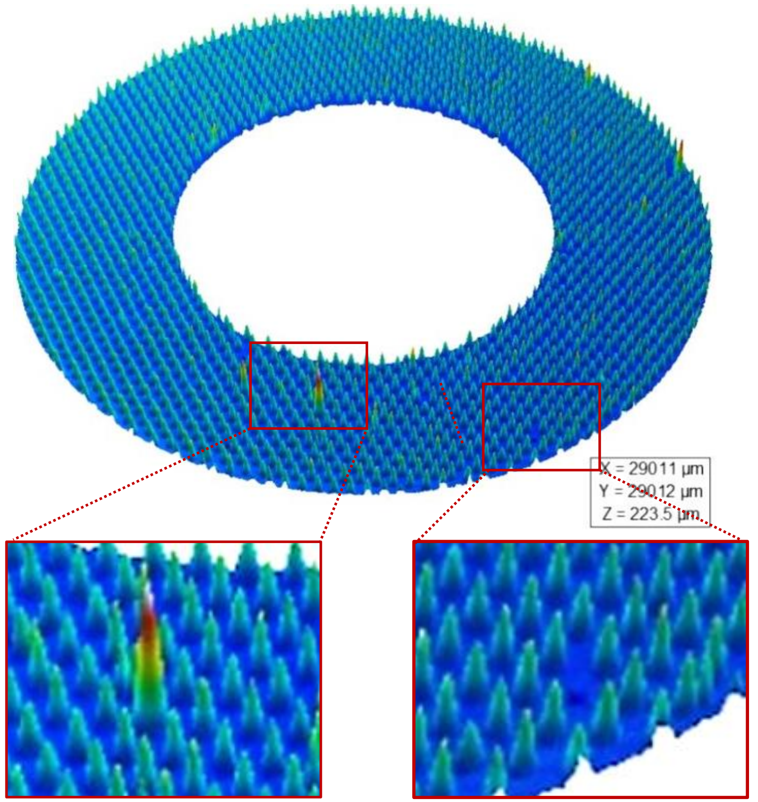


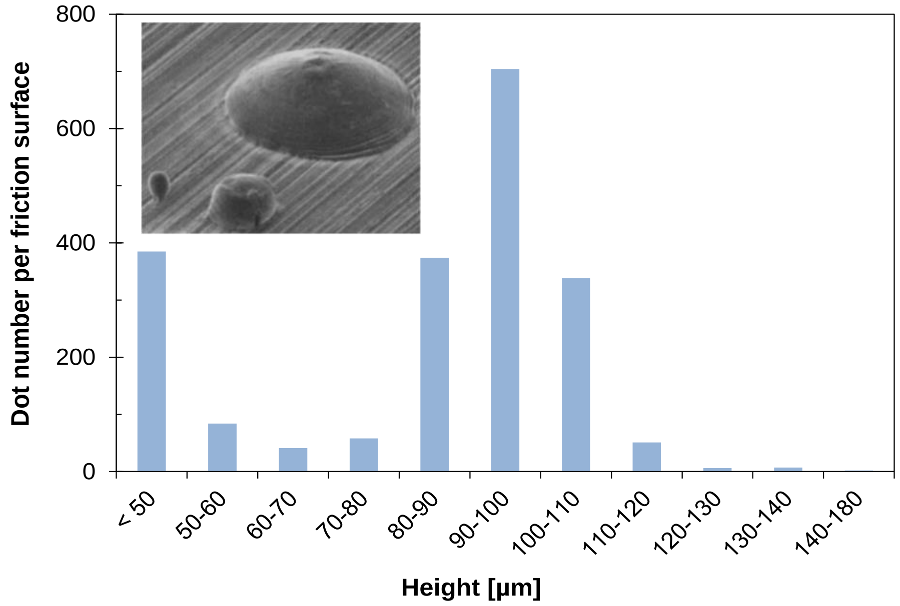


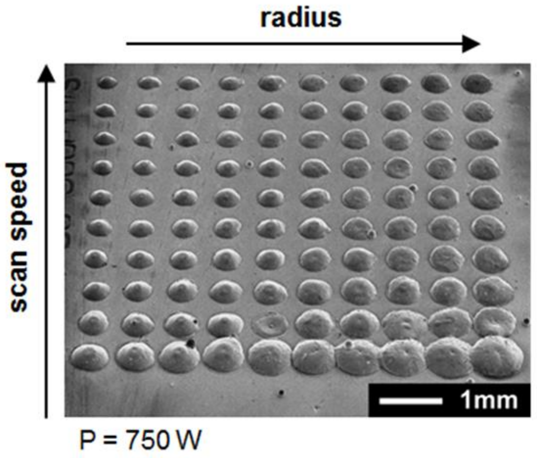
- **high-brillant cw fibre laser**
  - laser power: 1000 W
  - irradiation time: 10…2000 µs
  - PRF: max. 10 kHz

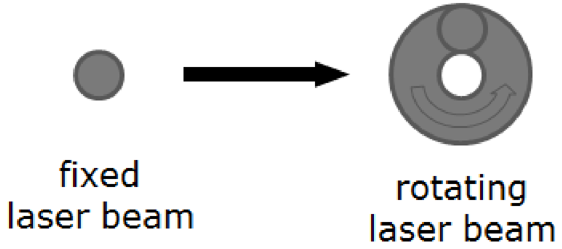
Deep penetration welding dots (kinetic CoF)

- ***Topography analysis***







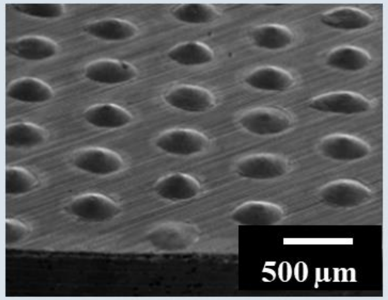


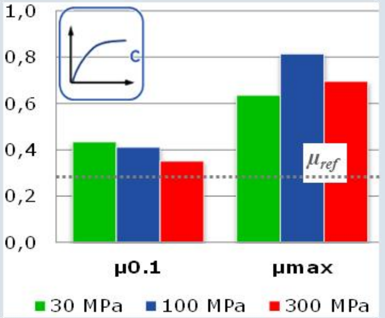
h/Ø: 0.23 **0.18 … 0.32**

Deep penetration welding dots (kinetic CoF)

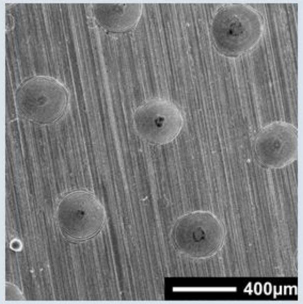
- ***Friction analysis (fine-grinded counter parts)***

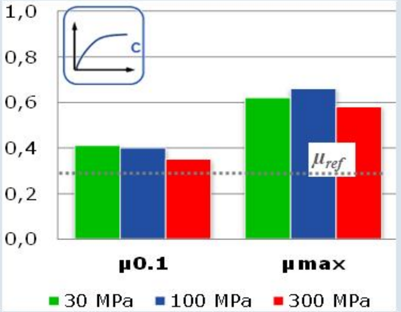
diameter: 330 µm
height: 70 µm
number of dots: 3.2 /mm²



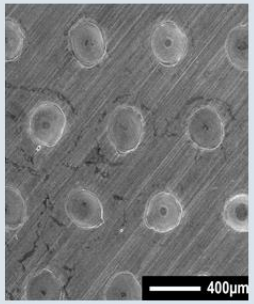


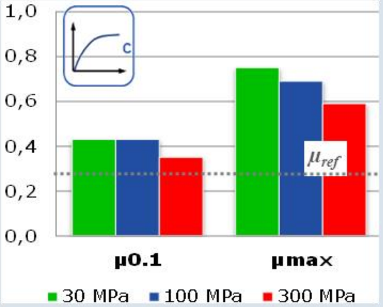
diameter: 330 µm
height: 70 µm
number of dots: 2.0 /mm²

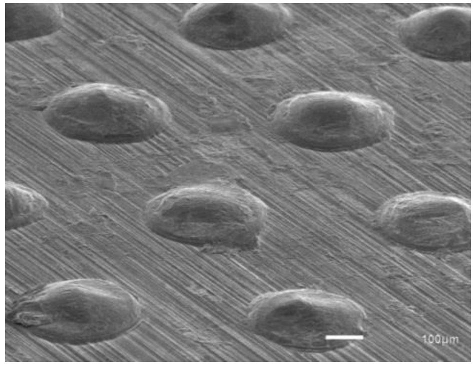


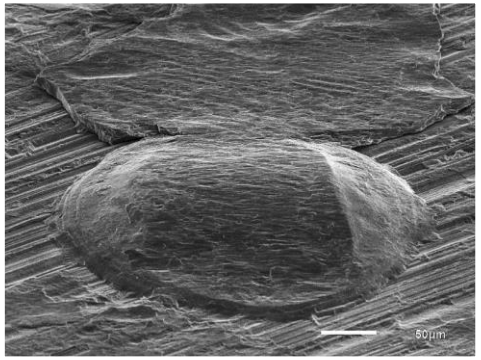


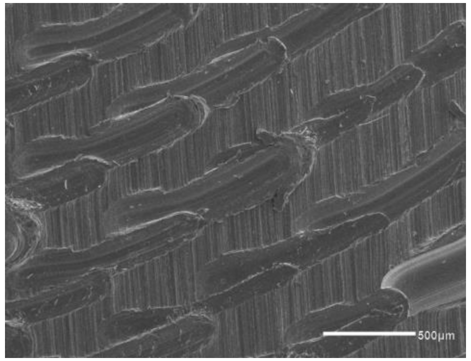
diameter: 274 µm
height: 70 µm
number of dots: 3.2 /mm²







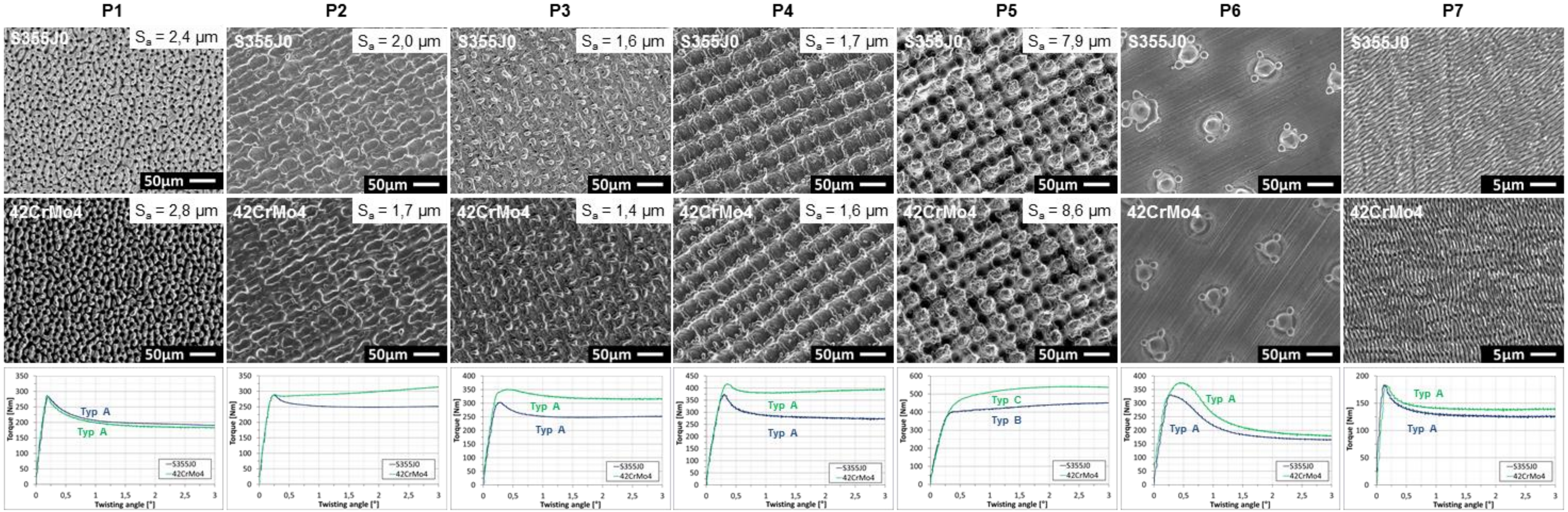




Schille et al.: Experimental Study on Laser Surface Texturing for Friction Coefficient Enhancement. Journal of Laser Micro/Nanoengineering 10 (2015), Nr. 3, 245-253

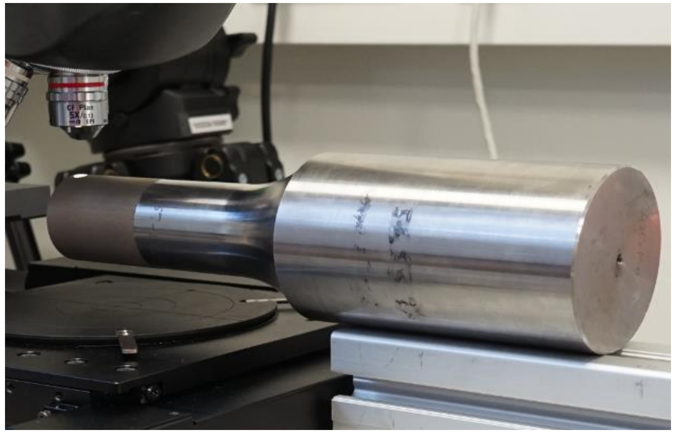
(Sub) micrometer surface features

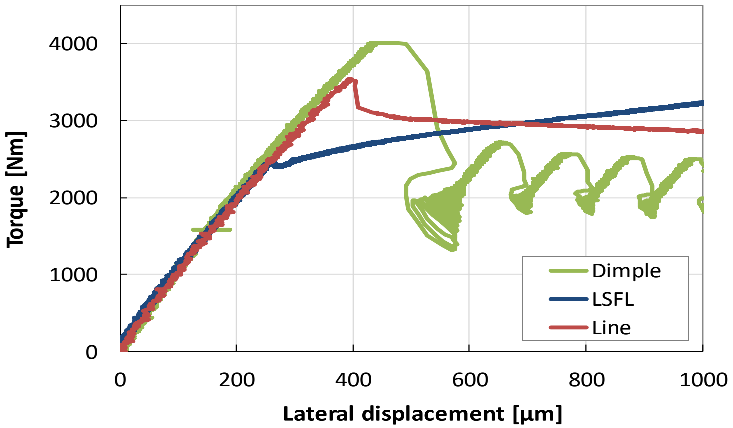
Reference values: $\mu_{0,1}$(S355 J0) = 0,29 | $\mu_{0,1}$(42CrMo4) = 0,31

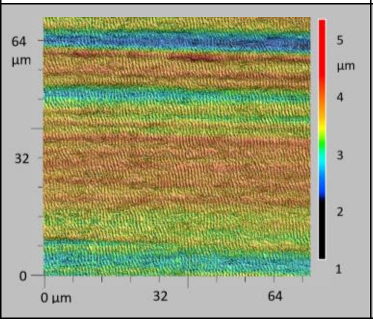
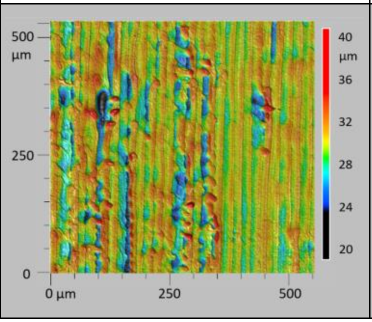
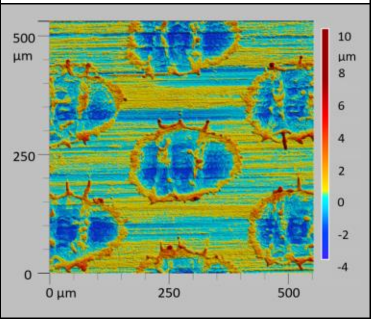


P1	P2	P3	P4	P5	P6	P7
$\mu_{0,1}$ (S355J0) = 0,44	$\mu_{0,1}$ (S355J0) = 0,46	$\mu_{0,1}$ (S355J0) = 0,49	$\mu_{0,1}$ (S355J0) = 0,6	$\mu_{0,1}$ (S355J0) = 0,63	$\mu_{0,1}$ (S355J0) = 0,5	$\mu_{0,1}$ (S355J0) = 0,3
Δ $\mu_{0,1}$ = + 51,7 %	Δ $\mu_{0,1}$ = + 58,6 %	Δ $\mu_{0,1}$ = + 68,9 %	Δ $\mu_{0,1}$ = + 106,9 %	Δ $\mu_{0,1}$ = + 117,2 %	Δ $\mu_{0,1}$ = + 72,4 %	Δ $\mu_{0,1}$ = + 3,4 %
$\mu_{0,1}$ (42CrMo4) = 0,44	$\mu_{0,1}$ (42CrMo4) = 0,46	$\mu_{0,1}$ (42CrMo4) = 0,55	$\mu_{0,1}$ (42CrMo4) = 0,66	$\mu_{0,1}$ (42CrMo4) = 0,68	$\mu_{0,1}$ (42CrMo4) = 0,55	$\mu_{0,1}$ (42CrMo4) = 0,29
Δ $\mu_{0,1}$ = + 41,9 %	Δ $\mu_{0,1}$ = + 48,4 %	Δ $\mu_{0,1}$ = + 77,4 %	Δ $\mu_{0,1}$ = + 112,9 %	Δ $\mu_{0,1}$ = + 119,4 %	Δ $\mu_{0,1}$ = + 77,4 %	Δ $\mu_{0,1}$ = - 6,5 %

Shaft-hub connection





Tribological characteristic			
Laser texture	LSFL	Line pattern	Dimple-shaped texture
Surface pressure	85 ± 2 MPa	92 ± 9 MPa	84 ± 2 MPa
COF type	B	A	A
μ_{20}	0.24 ± 0.01	0.34 ± 0.02	0.32 ± 0.01
Δ μ_{20}	+ 20 %	+ 70 %	+ 60 %
μ_{max}	0.24 ± 0.01	0.35 ± 0.01	0.40 ± 0.02
Δ μ_{max}	+ 20 %	+ 75 %	+ 100 %
Processing rate	14.4 cm²/min	21.0 cm²/min	14.0 cm²/min
Topography measurements (before testing)			

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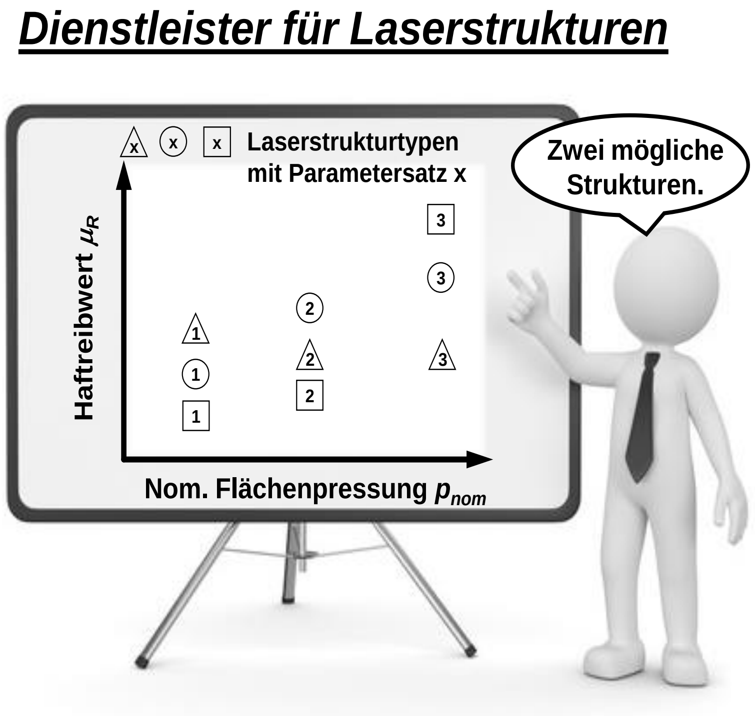
3. Tribomaps

Laserinstitut Hochschule Mittweida

HOCHSCHULE MITTWEIDA

AiF-Project: „Entwicklung von Tribomaps für reibwerterhöhende Laserstrukturen“



Vielen Dank

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