TECHNISCHE UNIVERSITÄT CHEMNITZ

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Institute for Machine Tools and Production Processes (IWP)
Faculty of Mechanical Engineering

Fraunhofer IWU

Surface Engineering by Microstructuring Processes

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SIG Structured & Freeform Surfaces

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Outline

1 Introduction
2 Generation of surfaces for reduction of friction
3 Increase of friction by turn-milled surfaces
4 Summary & Outlook

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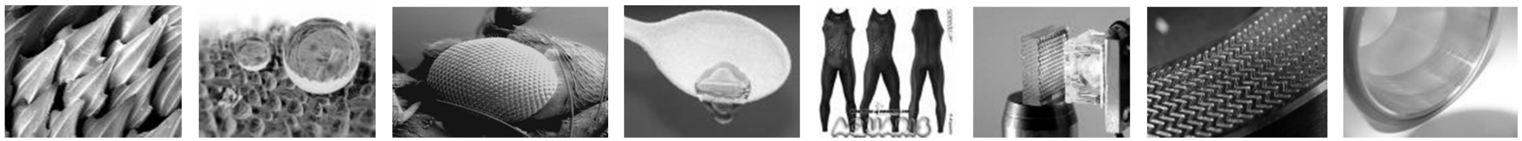
Introduction: Main functional properties of surfaces

Introduction
Friction Reduction
Friction Increase
Summary & Outlook

	Main Influence	Influenced Properties
Technological	Mechanical	Fatigue, hardness
	Tribological	Friction, wear, stiction
	Hydrodynamical	
Physical	Surface energy	Capillarity, wetting, adhesion
	Optical	Reflectivity, light absorption, diffraction
	Thermal	Heat transfer
Biological	Adsorption	



ref: Bruzzone/Costa/Lonardo/Lucca: Advances in engineered surfaces for functional performance. CIRP Annals – Manufacturing Technology 57 (2008) p. 750-769

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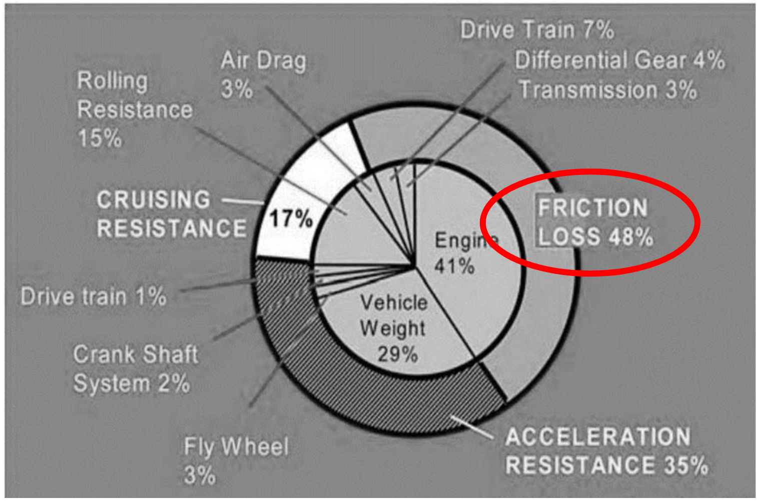
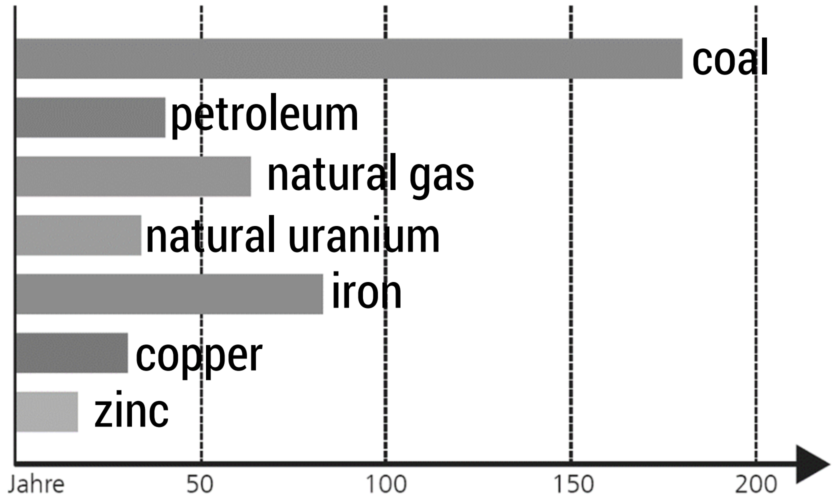
Reduction of friction

- **Motivation**
  - 30 % of world`s energy consumption used to overcome friction
  - Economic loss through friction and wear > 5 % of the GDP
  - Limited resources (e. g. natural gas, petroleum)



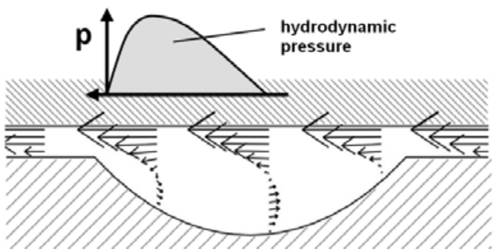
Energy balance in automobile powertrains
(Source: M. Nakasa (Toyota Motors), Proc. of Int. Tribo. Conf., Yokohama, 1995)



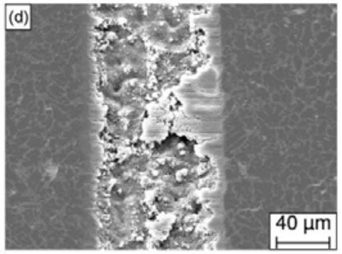
Estimated availability of natural resources (2009)

How do (closed) microstructures act?

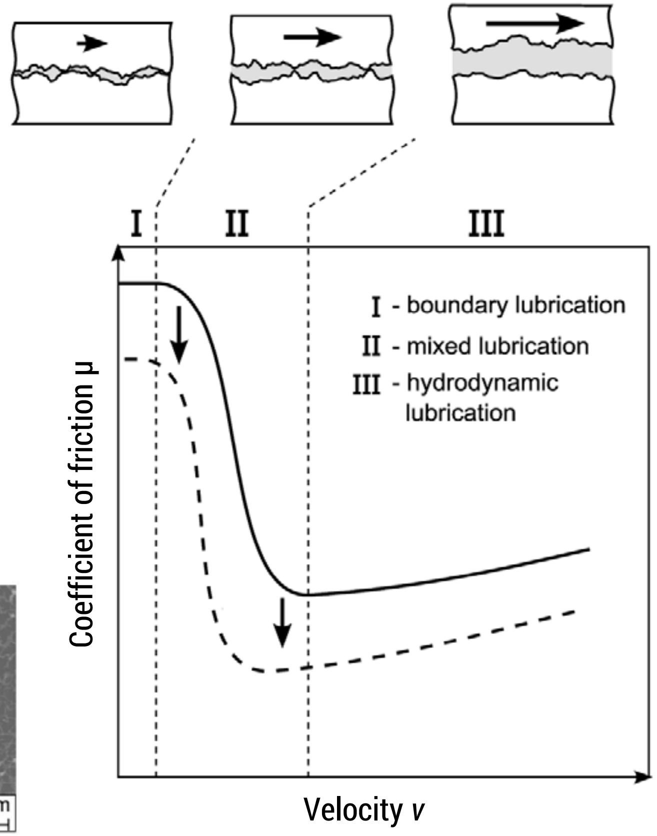
- **Micro pressure chamber**
  - Generation of hydrodynamic pressure
  - Lubricant film stabilisation
  - Low transition velocity to hydrodynamic lubrication
- **Reservoir effect**
  - Wear particle trapping
  - Improvements under starved lubrication



Simulation (2D) of hydrodynamic pressure generation



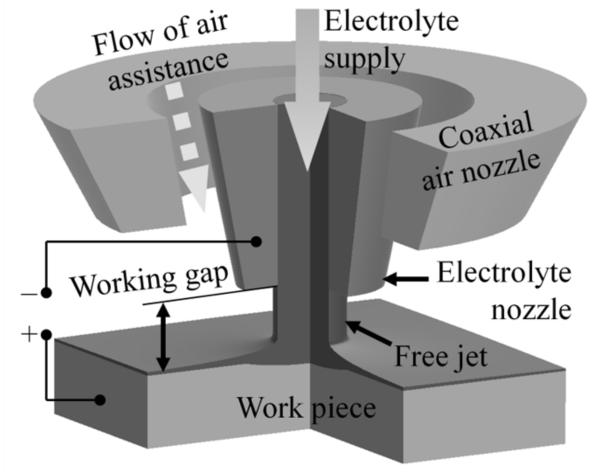
Wear particle trapping
(source: Zum Gahr et al: Friction control by surface engineering of ceramic sliding pairs in water)



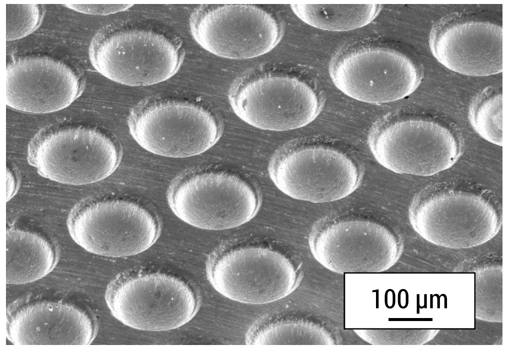
Aspired effects illustrated in the Stribeck diagram

Microstructuring by Jet-ECM

- **Principle**
  - Material removal by anodic dissolution
  - Achievable structure size mainly affected by nozzle diameter (≥ 25 µm)
- **Advantages**
  - No burr formation or thermal damage of material
  - No tool wear
- **Disadvantages**
  - Corrosion due to the electrolyte
  - Relatively low removal rate



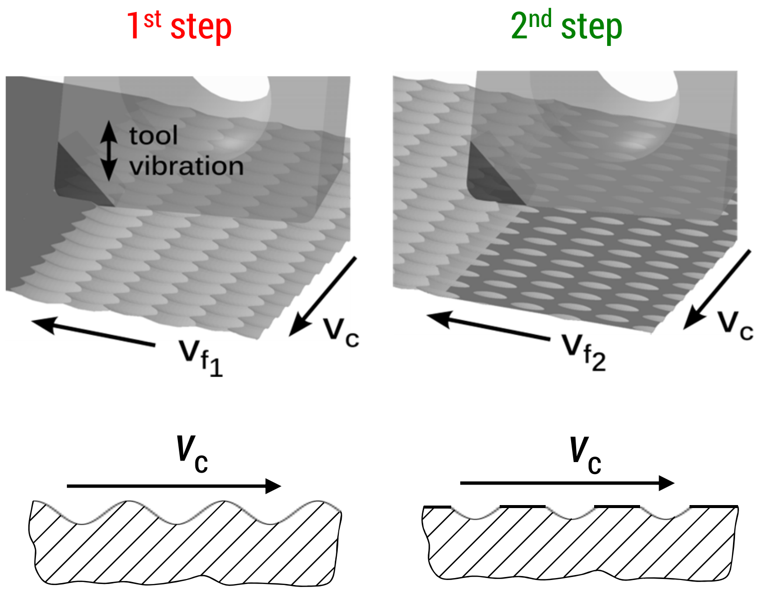
Principle of Jet-ECM



SEM-Image of micro dimples

Two-stage vibration-assisted turning

- **Principle**
  - 1st step: turning with ultrasonic vibration assistance in the direction of the passive force
  - 2nd step: turning without ultrasonic vibration assistance to remove peaks
- **Advantages**
  - High productivity
  - No additional processes needed
  - Application of standard tools
  - Less burr formation

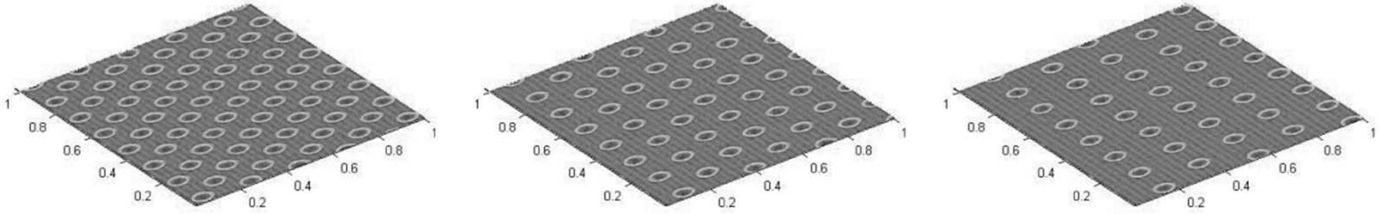


Principle of the two-stage vibration assisted turning process and correspondent surfaces (cross section)

MATLAB® Process Simulation

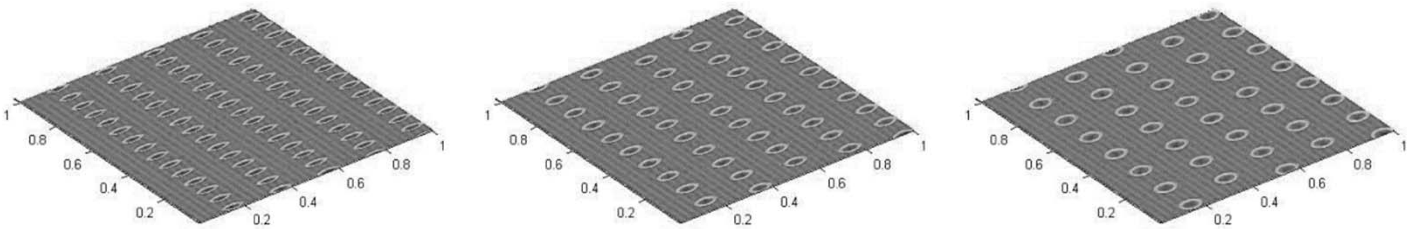
Turning process	Ultrasonic vibration	Tool
Feeds $f_{step\ 1}$, $f_{step\ 2}$	Amplitude $A_{p\text{-}p}$	Geometry
Depths of cut $a_{p\text{-}1}$, $a_{p\text{-}2}$	Frequency f_{US}	Material
Cutting speed v_c		

Influence of the feed f_{step1} on the surface structure: distance between dimples



f_{step1} = 0.1 mm f_{step1} = 0.15 mm f_{step1} = 0.2 mm

Influence of the cutting speed v_c on the surface structure: distance and shape



v_c = 100 m/min v_c = 150 m/min v_c = 200 m/min

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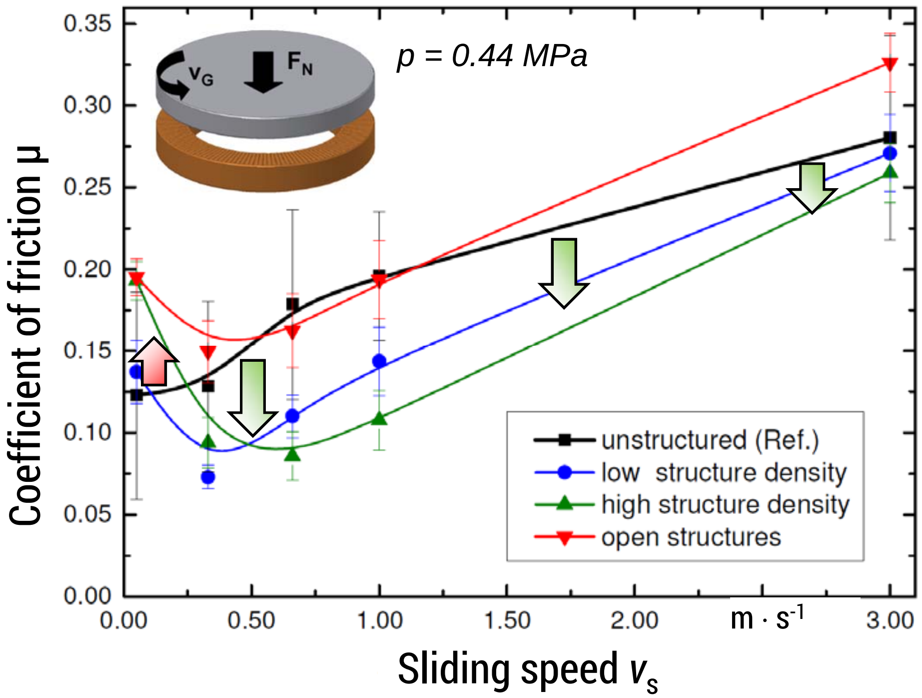
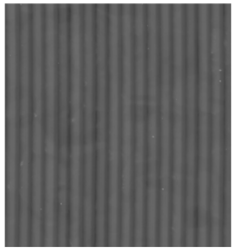
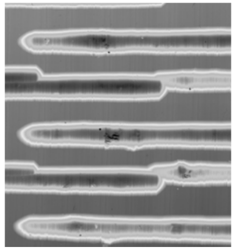
Tribological evaluation

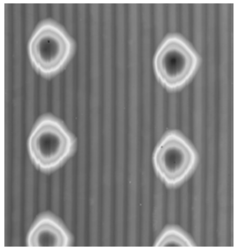




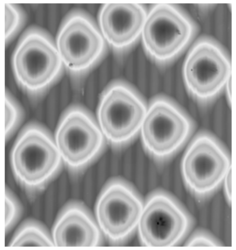
Unstructured (reference)



Open structures



Low structure density



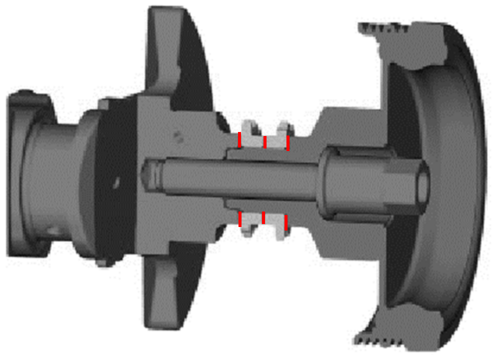
High structure density

- Effect on friction observed in the boundary, mixed and hydrodynamic friction regime
- Reduced friction coefficient in the case of closed microstructures (dimples)
- Open structures are not able to support tribological load

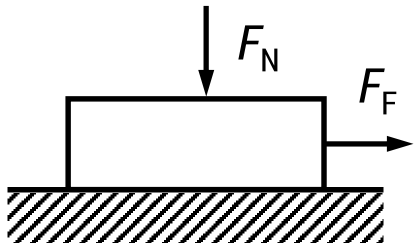
Increase of static friction

- **Motivation**
  - Increasing power density in technical systems
  - Smaller assembly groups due to lightweight construction

  → Demand for higher transmittable forces/torque
- **Possible solutions**
  - Increase the normal force F_N
    → often limited by material properties
  - Increase the coefficient of static friction μ by coatings, friction-enhancing shims or laser ablation → additional processes
- **Approach**
  - Microstructuring of the surface by an <u>adjusted final machining process</u>



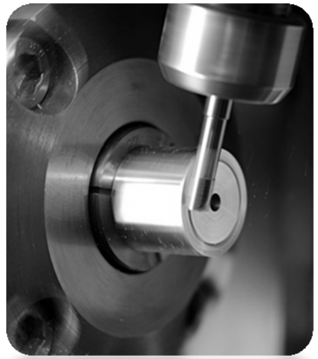
Friction-locked connection: pulley at a crankshaft

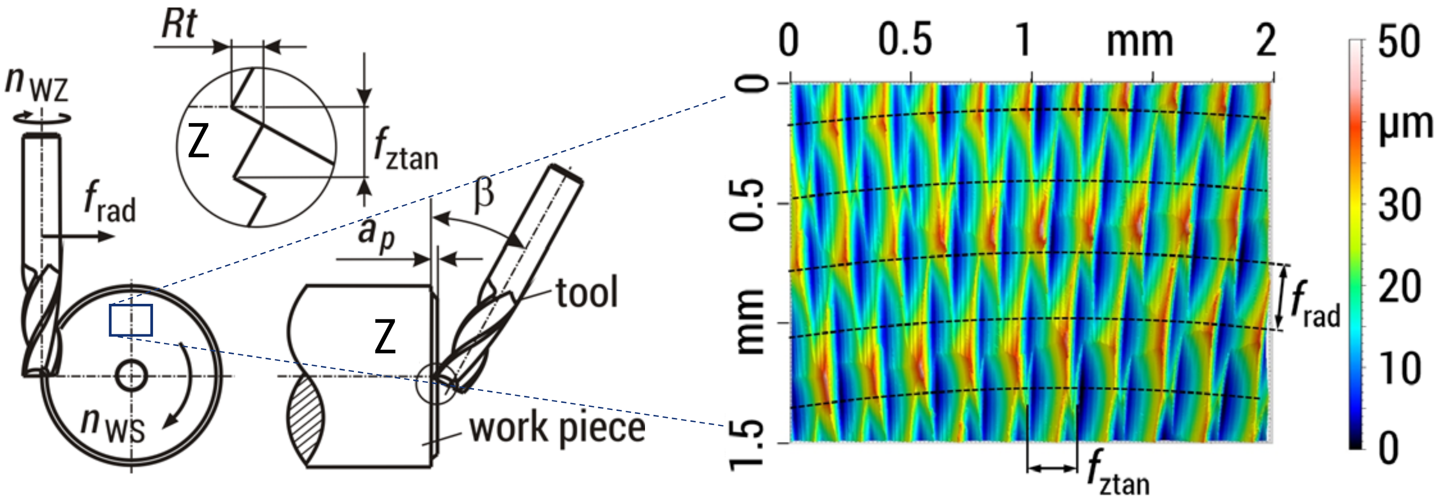


$$F_F = F_N \cdot \mu$$

Turn-milling: Kinematics and process parameters

- **Principle**
  - Turn-milling of the face side with an inclined end mill
  - Cutting speed v_c depends on rotational speed n_{WZ} and diameter d_{WZ} of the tool
  - Purpose: sharp-edged profile, which induces a strong grooving into the counter surface



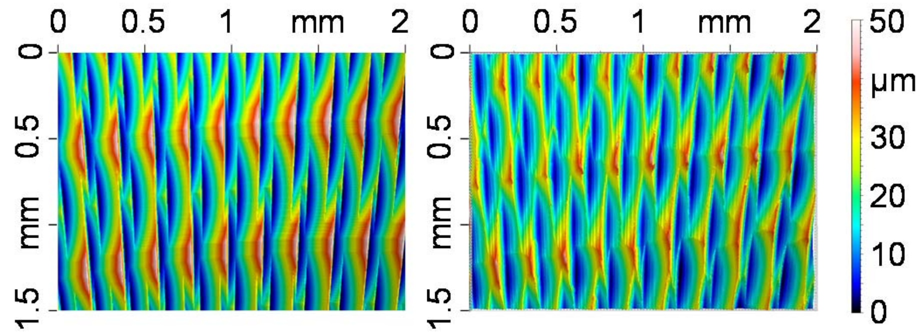


Process principle and section of the surface detected with laserscanning microscopy

MATLAB® Process Simulation

Introduction
Friction Reduction
Friction Increase
Summary & Outlook

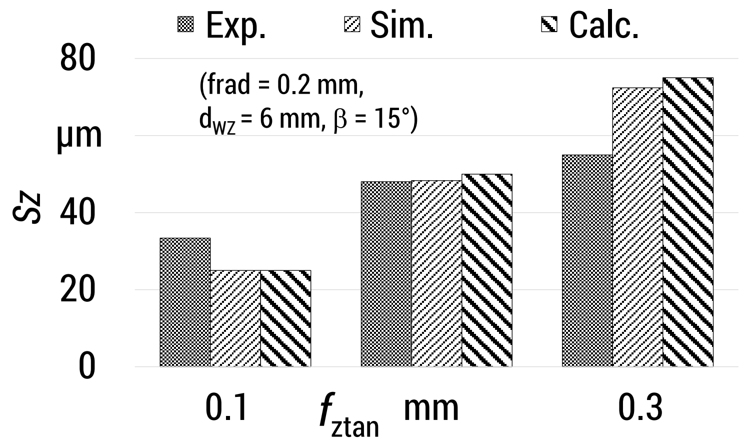
- **Benefit**
  - Qualitative impression of the surface
  - Fast determination of 2D/3D surface parameters
  - Efficient process design



Comparison of simulated (left) and machined surface (right)
(f_{rad} = 0.3 mm, f_{ztan}=0.2 mm, d_{WZ} = 6 mm, β = 15°)

Parameter	Symbol	Unit
Feed per tooth	f_{ztan}	mm
Radial feed	f_{rad}	mm/rev
Tool inclination angle	β	°
Tool diameter	d_{WZ}	mm

Adjustable process parameters in the simulation



Comparison of Roughness Values *Sz*
(f_{rad} = 0.2 mm, d_{WZ} = 6 mm, β = 15°)

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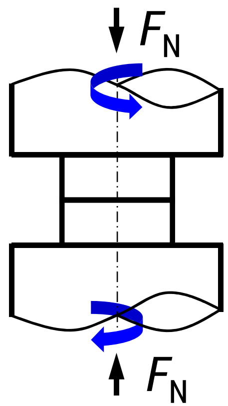
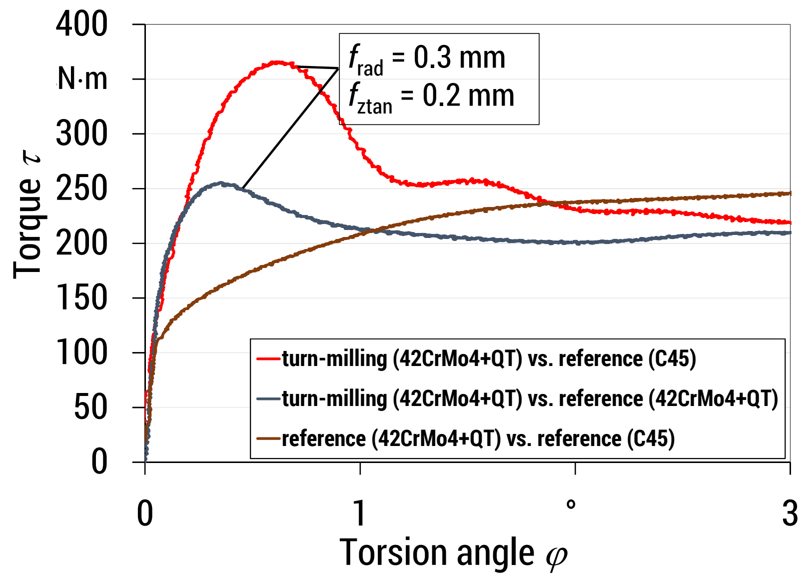
Determination of the coefficient of static friction

- **Principle**
  - Twisting two specimens (structured vs. reference) each other by 5° under defined normal force (53 kN)
  - Recording the torsion angle and torque

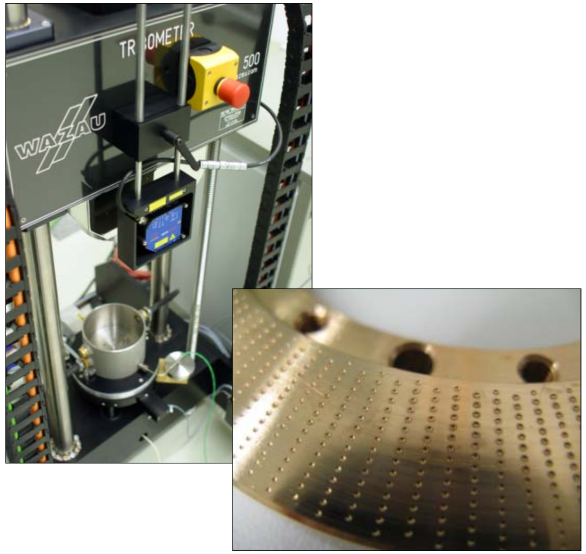


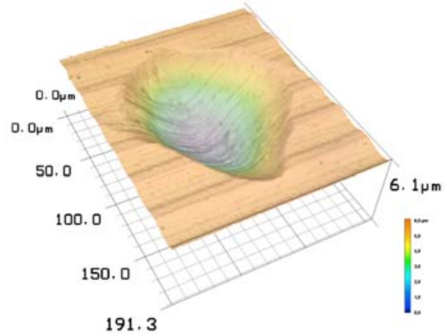
- **Results**
  - Significant increase of the coefficient of static friction compared to reference test
  - Combination of *hard* (42CrMo4+QT, structured) vs. *soft* (C45, reference) leads to higher static friction compared to combination *hard vs. hard*



Summary

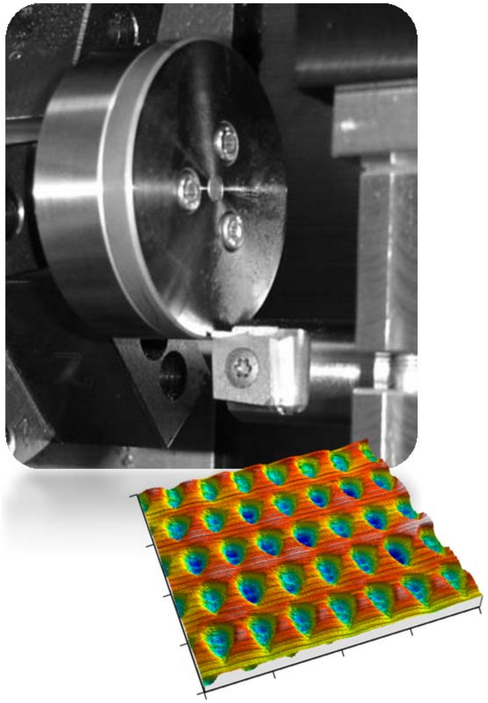
- Microstructuring of surfaces provides a high potential for increasing the efficiency of technical products
- Jet-ECM and ultrasonic vibration-assisted turning are suitable manufacturing processes to generate surfaces for the reduction of friction
- Turn-milling is a suitable manufacturing process to generate surfaces for the increase of static friction
- Computerised simulation of processes enables the fast determination of 2D and 3D-surface parameters for an efficient process design





Outlook

- Further investigation of manufacturing processes for surface microstructuring
- Find/Create suitable surface parameters (e. g. to describe directional properties)
- Determination of the relationship between surface parameters and tribological properties
- Improvement of the simulation models (e. g. tool wear, tool geometry)
- ...



Thank you for your attention!