

TECHNISCHE UNIVERSITÄT

CHEMNITZ

**Professorship Micromanufacturing Technology** Institute for Machine Tools and Production Processes (IWP) Faculty of Mechanical Engineering





### Surface Engineering by Microstructuring Processes

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SIG Structured & Freeform Surfaces

Padua - 19/20 Nov 2014







#### 1 Introduction

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





#### Introduction: Main functional properties of surfaces

Introduction		Main Influence	Influenced Properties
Friction	Technological	Mechanical	Fatigue, hardness
		Tribological	Friction, wear, stiction
Friction Increase		Hydrodynamical	
Summary 8	Physical	Surface energy	Capillarity, wetting, adhesion
Outlook		Optical	Reflectivity, light absorption, diffraction
		Thermal	Heat transfer
a o a	Biological	Adsorption	
ef: Bruzzone/Costa/Lonardo/Lucc Advances in engineered surfaces I unctional performance. CIRP Ann. Marufacturing Technology 57 2008) p. 750-769			





Friction Reduction

#### **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)



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#### 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

## ntroduction

Friction Reduction

Friction Increase

Summary & Outlook





Friction

Reduction

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#### **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
- Introduction Friction Reduction Friction Increase Summary & Outlook
- 1<sup>st</sup> step: turning with ultrasonic vibration assistance in the direction of the passive force
- 2<sup>nd</sup> 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)





Friction

Reduction

Summary ( Outlook

#### **MATLAB®** Process Simulation

0.2

 $v_{\rm c}$  = 100 m/min

Turning process	Ultrasonic vibration	Tool
Feeds $f_{\text{step 1}}, f_{\text{step 2}}$	Amplitude A <sub>p-p</sub>	Geometry
Depths of cut $a_{p-1}$ , $a_{p-2}$	Frequency f <sub>US</sub>	Material
Cutting speed $v_{c}$		

Influence of the feed <u>f<sub>step1</sub> on the surface structure</u>: distance between dimples



0.2

 $v_{c} = 150 \text{ m/min}$ 

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www.tu-chemnitz.de/mb/mft

 $v_{c} = 200 \text{ m/min}$ 









- 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





Friction

**Friction** 

Increase

Umment

#### **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<sub>N</sub>
  → 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







Friction

**Friction** 

Increase

Sunnavz

Outlook

### **Turn-milling: Kinematics and process parameters**

- Principle
  - Turn-milling of the face side with an inclined end mill
  - Cutting speed v<sub>c</sub> depends on rotational speed n<sub>WZ</sub> and diameter d<sub>WZ</sub> 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

- Benefit
- Introduction

Friction Reduction

Friction Increase

Summary & Outlook

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



Comparison of simulated (left) and machined surface (right)  $(f_{rad} = 0.3 \text{ mm}, f_{ztan} = 0.2 \text{ mm}, d_{WZ} = 6 \text{ mm}, \beta = 15^{\circ})$ 

Parameter	Symbol	Unit				
Feed per tooth	<b>f</b> <sub>ztan</sub>	mm				
Radial feed	$f_{\rm rad}$	mm/rev				
Tool inclination angle	β	o				
Tool diameter	d <sub>wz</sub>	mm				
Adjustable process para	meters in the	simulation				







### Determination of the coefficient of static friction

- Principle
- Introduction

Friction Reduction

Friction Increase

Summary & Outlook

- 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*



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Torque



Fraunhofer

#### Introduction

Friction Reduction

- Friction Increase
- Summary & Outlook



- 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







Fraunhofer



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Summary & 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)



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# Thank you for your attention!