Karlsruhe Institute of Technology

Institute for Applied Materials

Surface defect healing and strengthening of low-pressure injection moulded 3Y-TZP micro bending bars

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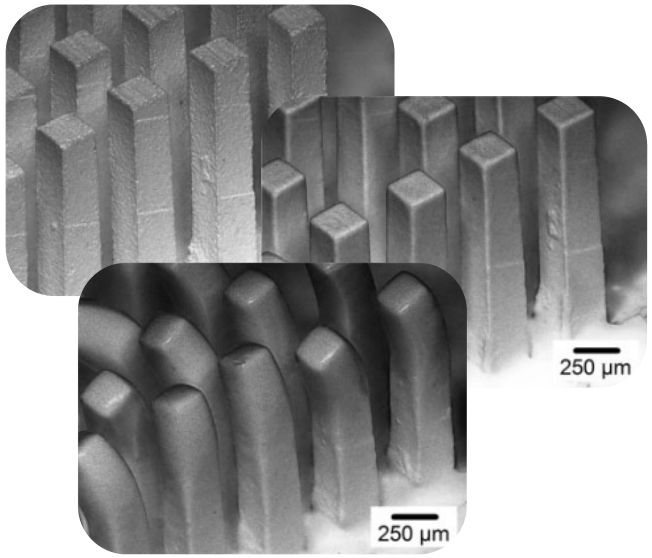
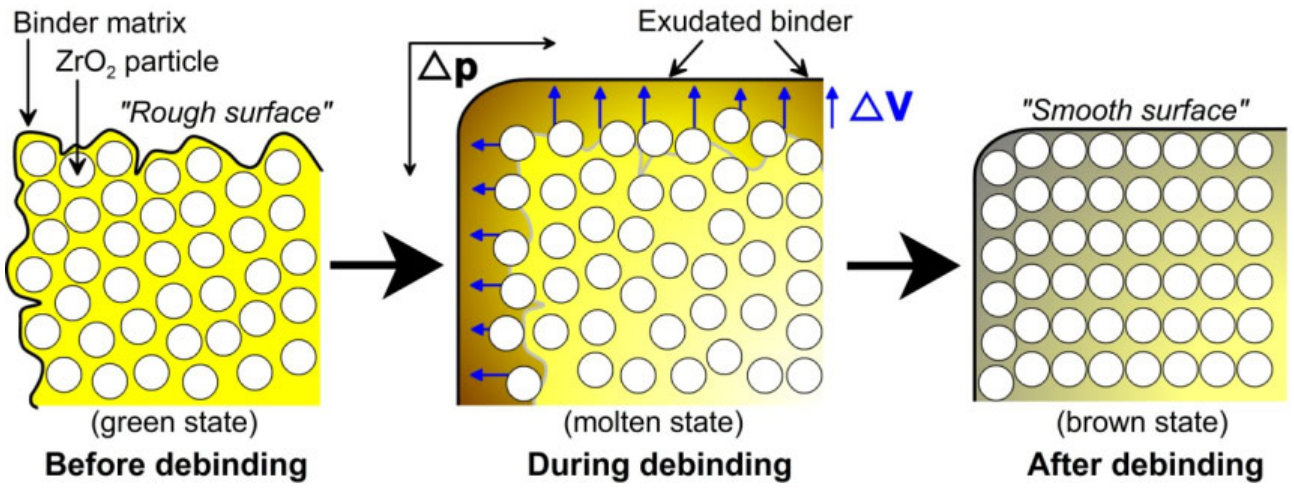
Institute for Applied Materials – Material Process Technology (IAM-WPT)





Motivation

Application of ceramics in microsystems technology

- Rising interest and demand by industry in miniaturization of ceramic components, e.g. in mechanical and electrical engineering as well as medical technology

Outstanding properties of ceramic materials

- High strength
- Temperature resistance
- Wear resistance
- Biocompatibility
- …

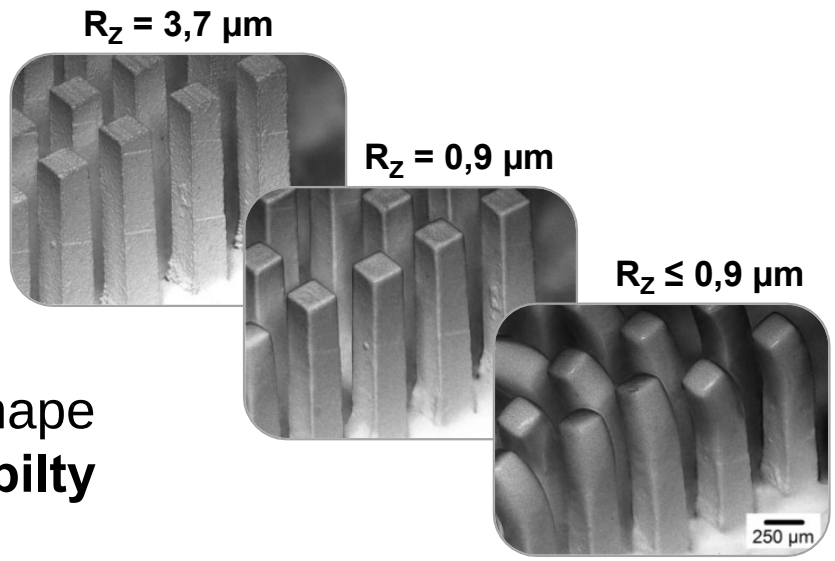
Threaded spindels (ZrO_2)

Smaract GmbH, Micro Precision Tools Inc.

Motivation

Starting point

- Thermal debinding causes deformation, but also improvement of surface finish
- Surface improvement ➔ **strengthening** (!)
- But: Factors influencing surface finish and shape retention not well-known ➔ **poor reproducibilty**

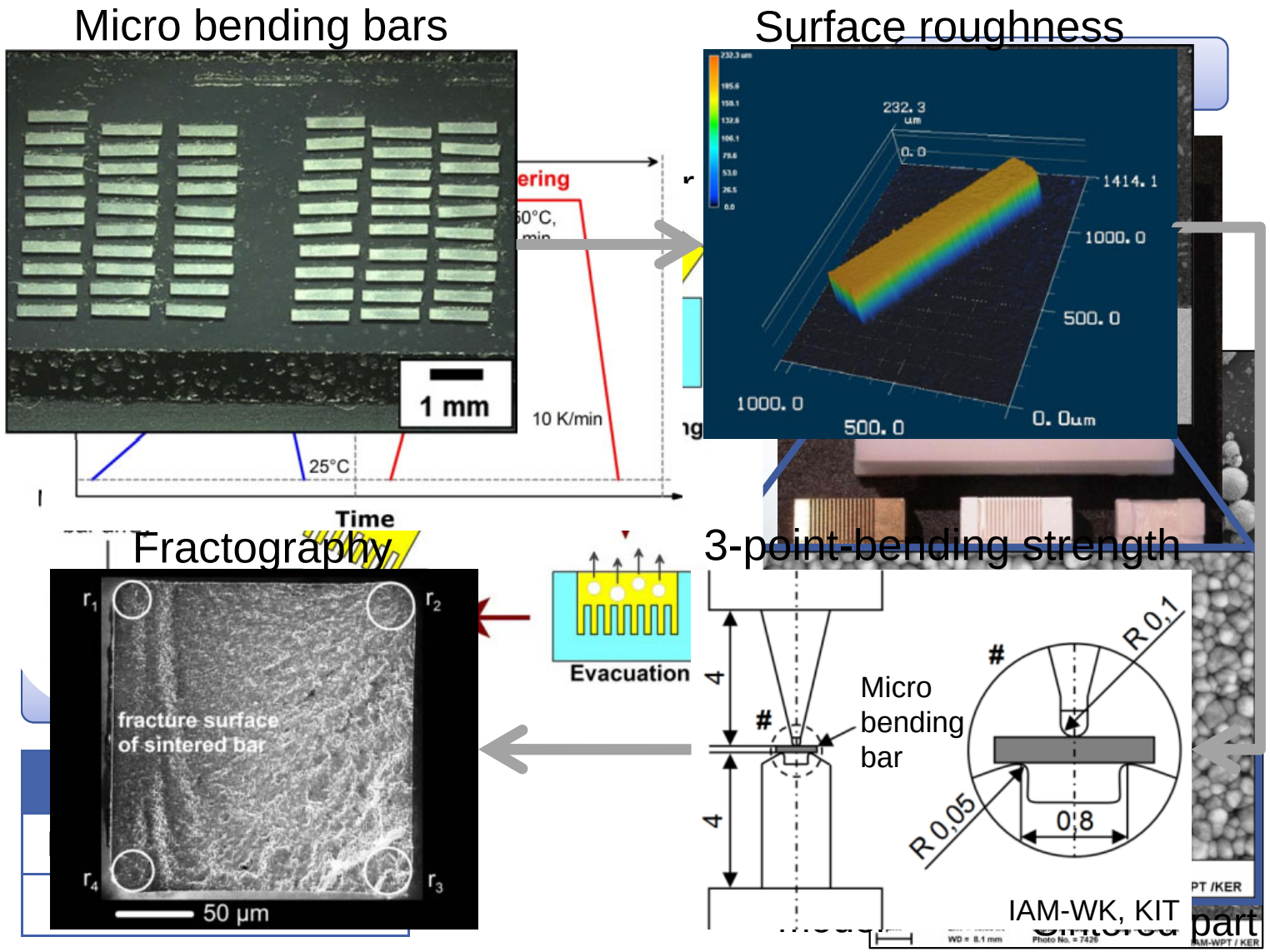


Objective

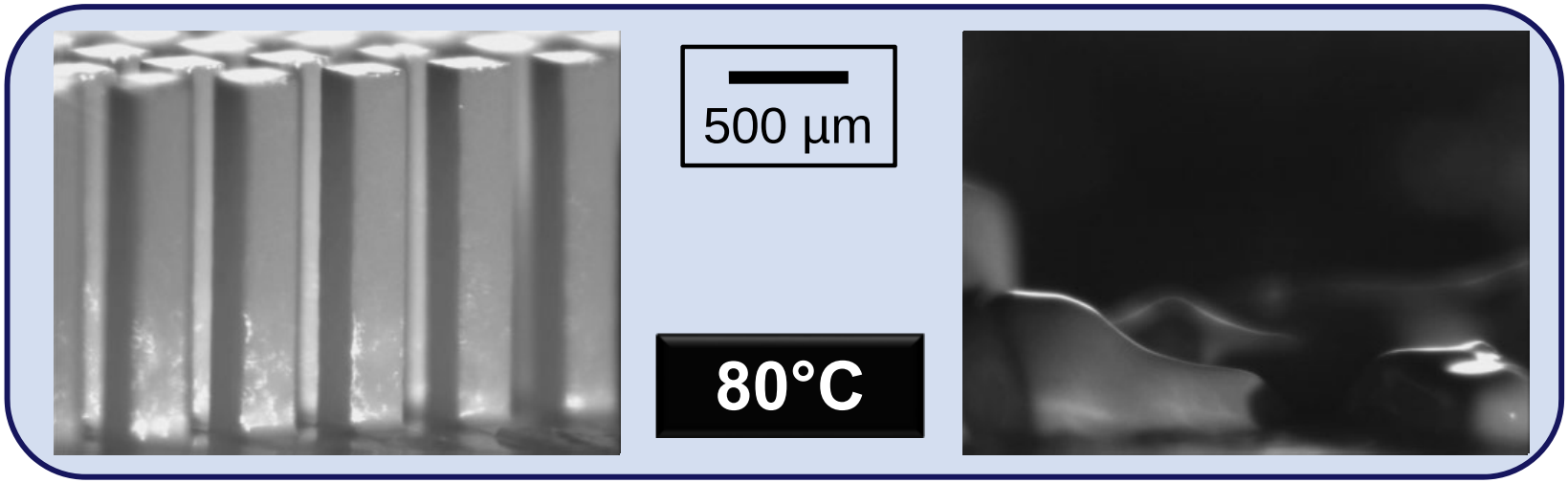
- Identify material- and process-related influencing factors
- Understand the relation among surface finish, deformation and debinding
- Systematically utilize debinding in order to improve mechanical properties

In-process step for improving mechanical properties without exhausting and cost-intensive surface post processing

Experimental procedure



Factors influencing surface finish and shape retention during thermal debinding



Amount of dispersant in feedstock

Humidity of debinding atmosphere

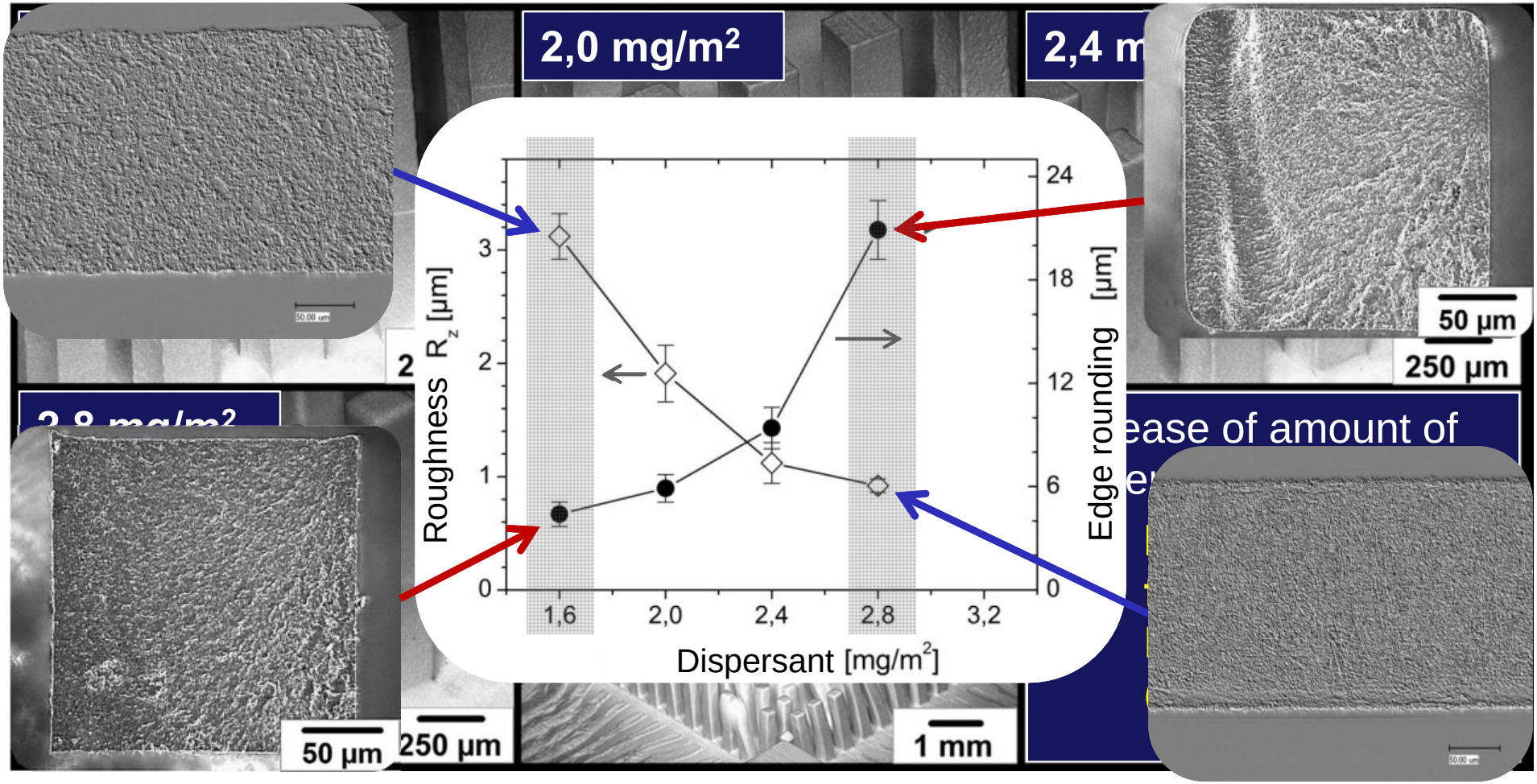
Wax absorption by silicone moulds

Storage conditions of green parts

Absorptivity of debinding support

Pre-treatment of silicone moulds

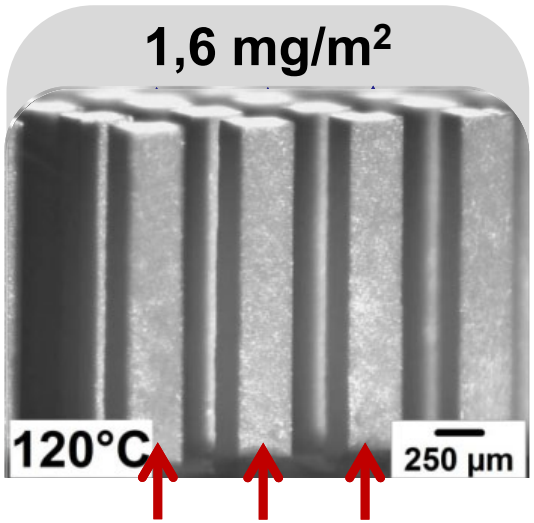
Influencing factor: Amount of dispersant

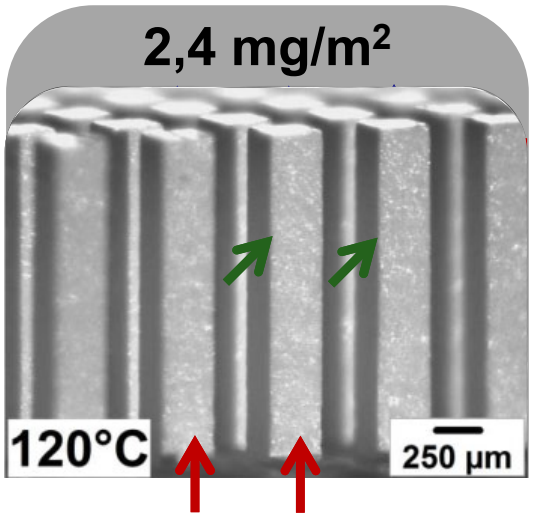


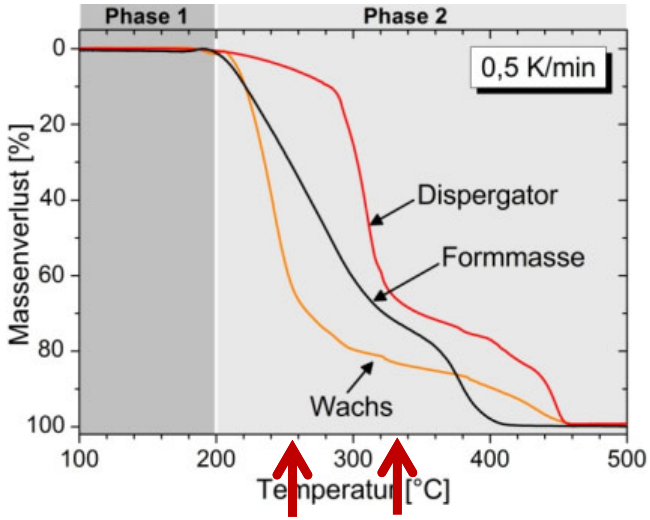
Sample condition: After thermal debinding (brown state)

Thermal debinding of ceramic micro parts

- What is happening during thermal debinding?
- Which processes cause the observed effects?



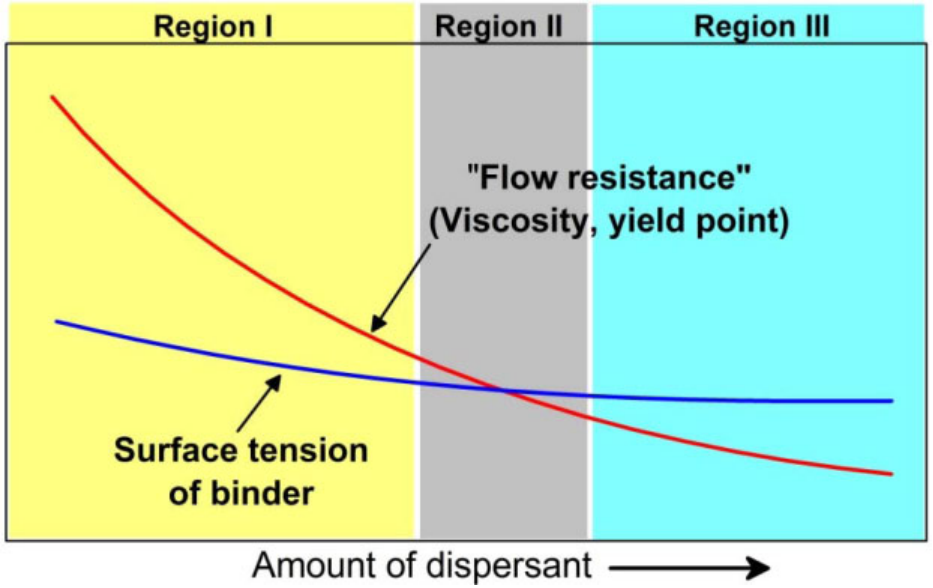


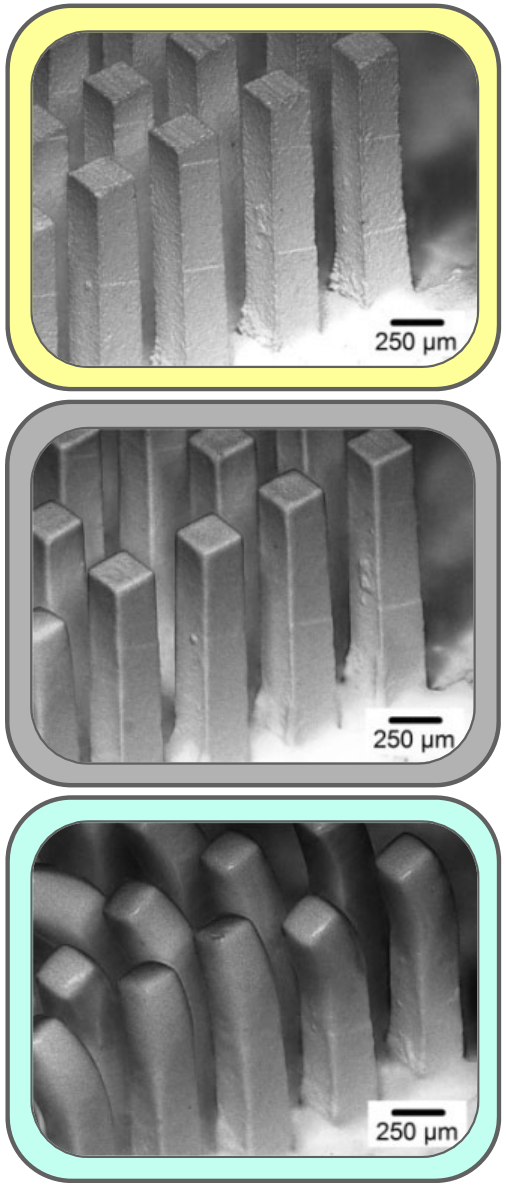


- **Below 200°C**: Liquid phase binder migration by capillary action of the debinding support
- **Above 200°C**: Gas phase diffusion of binder and its decomposition products

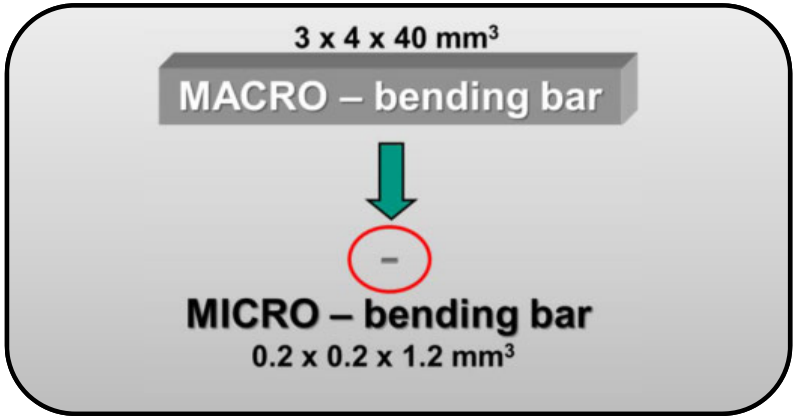
Surface improvement and deformation

- Criterion: Near-surface particles must be mobile (!)
- **Particle mobility** determined by flow properties of the feedstock (“flow resistance“)
- **Surface tension** of exudated surface binder film acts as driving force for rearrangement of mobile particles
- **Rearrangement** only takes place, if near-surface particles exhibit sufficient mobility





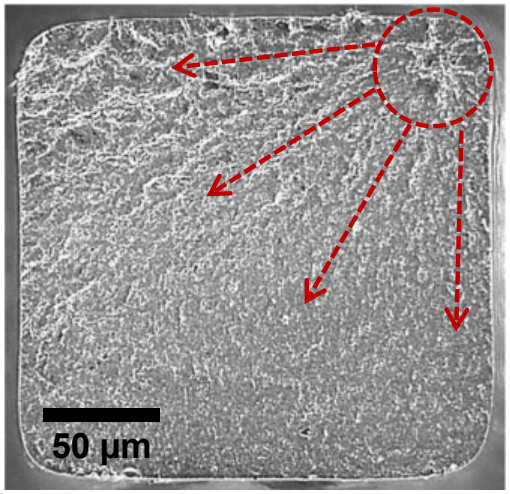
Specific properties of micro bending bars



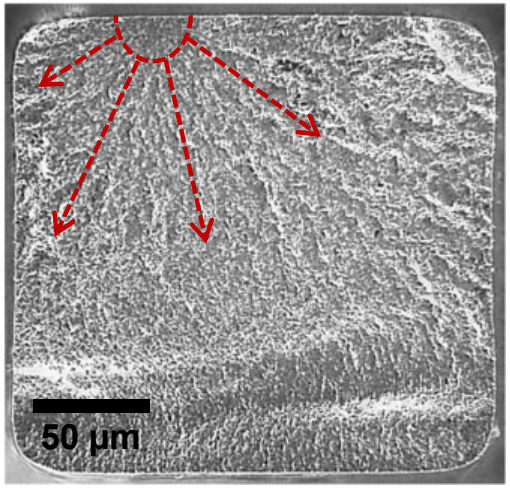
- **Surface-to-volume ratio** of micro bending bars approx. **17 times higher** than macroscopic ones
- Micro bars theo. more sensitive to surface defects
- Fractographically evidenced by 450 micro bars: **Fracture mainly due to surface defects (~ 97%)**

Strengthening possible by reduction of number and size of surface defects (!)

Volume defect

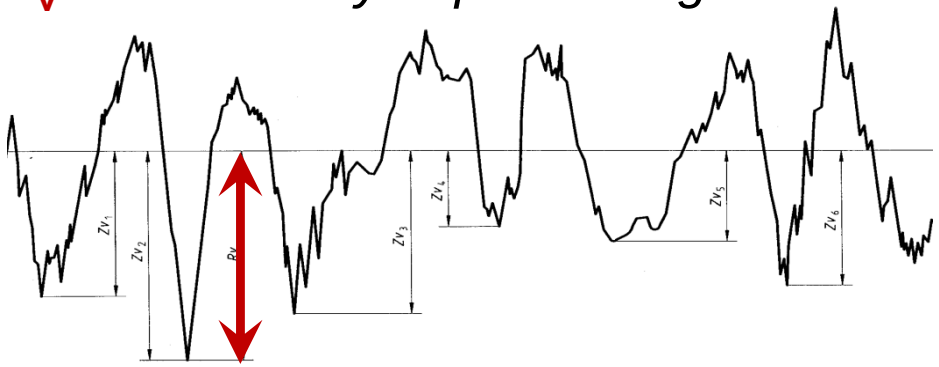


Surface defect



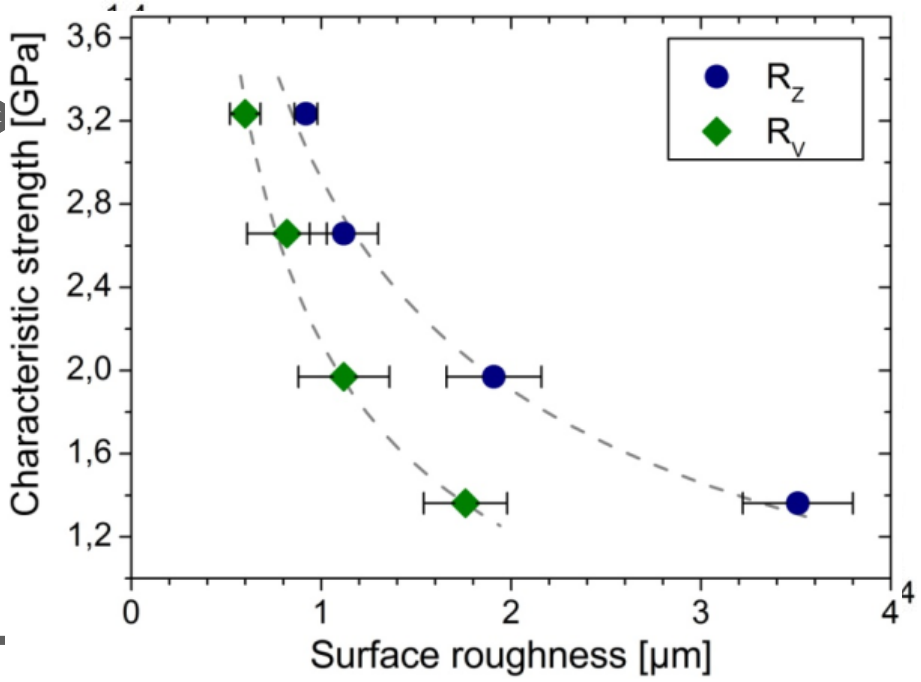
Surface roughness and critical defect size

R_v = *Max. valley depth of roughness*



DIN EN ISO 4287

$$a_c \approx \frac{1}{\pi}\left(\frac{K_{Ic}}{\sigma_b Y}\right)^2$$



- Roughness R_v can be seen as **size for critical flaws** within the range of the maximum bending moment

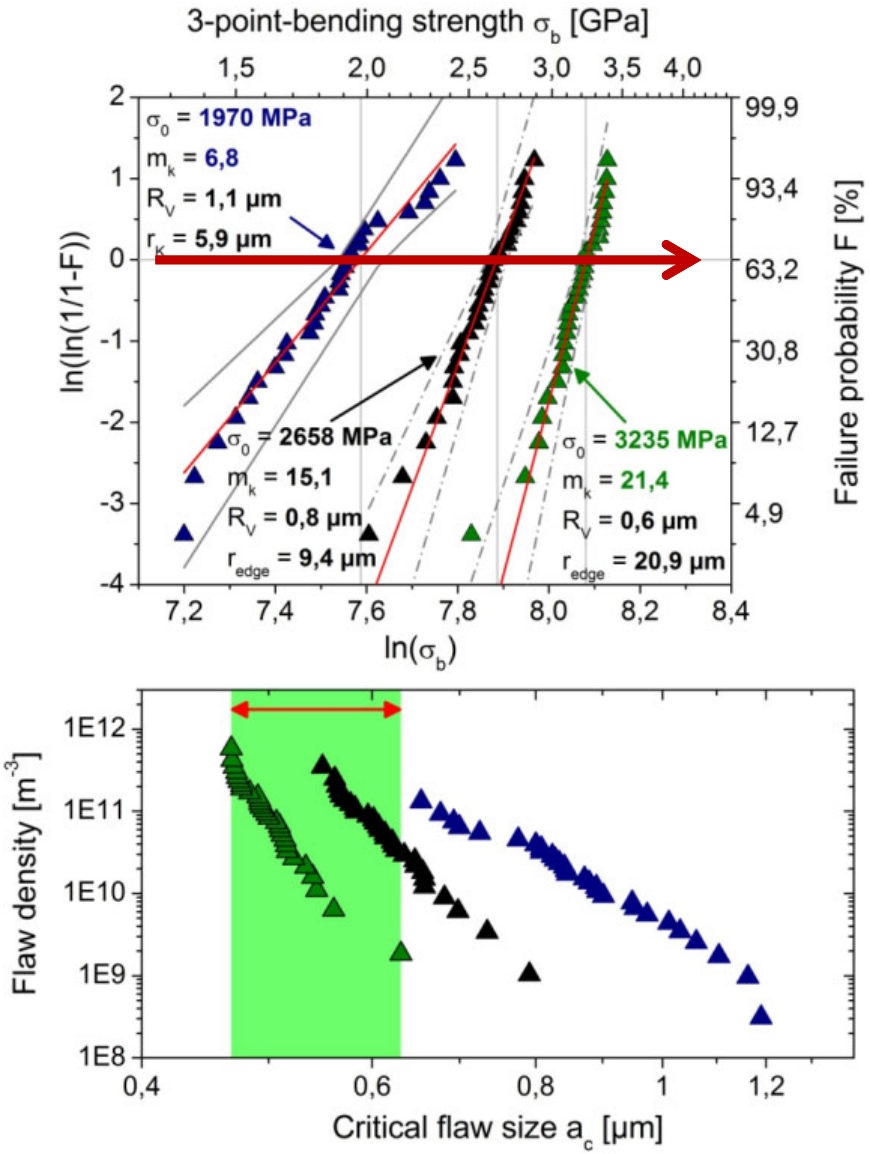
Strengthening by reduction of number and size of critical surface flaws (!)

Mechanical properties of 3Y-TZP micro bars

- Effect of surface defect healing results in strengthening, but also in improved mechanical reliability

Increase of Weibull's modulus from 6,8 up to 21,4

- **Surface defect healing results in …**
  - Reduction of number and size of surface defects
    ➔ ***Increased strength***
  - Narrower size distribution of critical surface defects
    ➔ ***Enhanced reliability***



Mechanical properties of 3Y-TZP micro bars

σ_1 [MPa]	m	σ_2 [MPa]
1970	6,8	**450 – 680**
2660	15,1	**1220 – 1470**
3240	21,4	**1530 – 1750**

Calculation by using ***Weibull size effect***

$$\sigma_2 = \sigma_1 \left(\frac{S_{e,1}}{S_{e,2}}\right)^{1/m}$$

$$\sigma_2 = \sigma_1 \left(\frac{V_{e,1}}{V_{e,2}}\right)^{1/m}$$

Typical strength values for…

- “as-fired” 3Y-TZP [**1**]
- surface finished 3Y-TZP [**2-4**]

Surface defect healing

Thermal debinding of micro parts results in highly improved mechanical properties, which is possible for macro parts only by exhausting and cost-intensive surface post processing !

[**1**] Tseng WJ, Ceram Int (1999); [**2**] Tosoh Corp, TZ-3YS-E; [**3**] Swain MV, J Am Ceram Soc (1986); [**4**] Nettleship I, Int J High Tech Ceram (1987)

Summary

- **Surface defect healing** occurs during thermal debinding of low-pressure injection moulded ceramic micro parts
- Material- and process-related factors detected, which affect **reproducibility of surface and edge rounding**
- Edge rounding can be limited, but not decoupled from surface defect healing
- Utilisation of the effect of surface defect healing allows **significant improvement of mechanical properties** of ceramic micro components

Outlook

- **Transfer** of the effect to **real micro components** and other ceramic / metallic materials
- **Transfer** of the effect from small-scale **to mass production** (HPIM, high-pressure injection moulding)
  - In-process step for improving the mechanical reliability of micro components without surface post processing

    ➔ Economic potential (!)

Acknowledgements

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Thank you for your attention