

Table of contents

Nr.	Name	Title	Page
1	Schlacher Josef	Design and processing of ceramic materials - 3D-printed multi-material components with improved mechanical properties	2
2	Bermejo Raul	Design and processing of ceramic materials - Bio-inspired layered ceramics with tailored microstructures	3
3	Gruber Manuel	Characterization of ceramic materials - Single crystalline materials for microelectronic applications	4
4	Harrer Walter	Characterization of ceramic materials - Fractography and Failure Analysis	5
5	Jabr Abdullah	Design and processing of ceramic materials - Sustainable fabrication of ceramics by the cold sintering process	6
6	Jana Arijit	Design and processing of ceramic materials - Innovative processing and characterizations of ceramic electrolytes for SOFC/SOEC	7
7	Kraleva Irina	Design and processing of ceramic materials - Ceramic manufacturing & Microstructural Analysis	8
8	Kreith Josef	Characterization of ceramic materials - Lock-in Infrared Microscopy (LIIM)	9
9	Lube Tanja	Characterization of ceramic materials - Fracture toughness tests for components	10
10	Munz Maximilian	Fracture toughness measured on curved surfaces	11
11	Prötsch Tobias	Design and processing of ceramic materials - Sintering of additively manufactured ceramic multi-materials	12
12	Staudacher Maximilian	Characterization of ceramic materials - Strength testing of additively manufactured structures	13
13	Supancic Peter	Mechanical characterization of glass - Bending strength of thin glass substrates	14

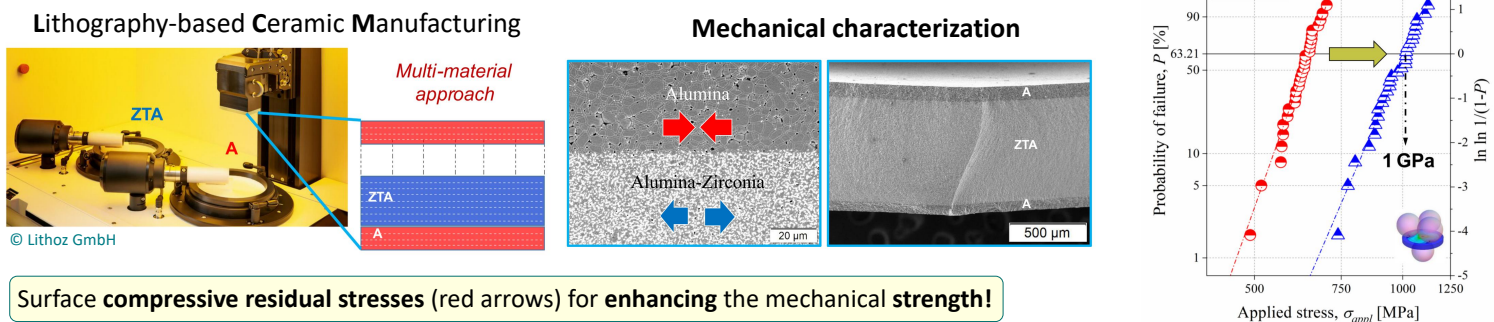
Design and processing of ceramic materials

3D-printed multi-material components with improved mechanical properties

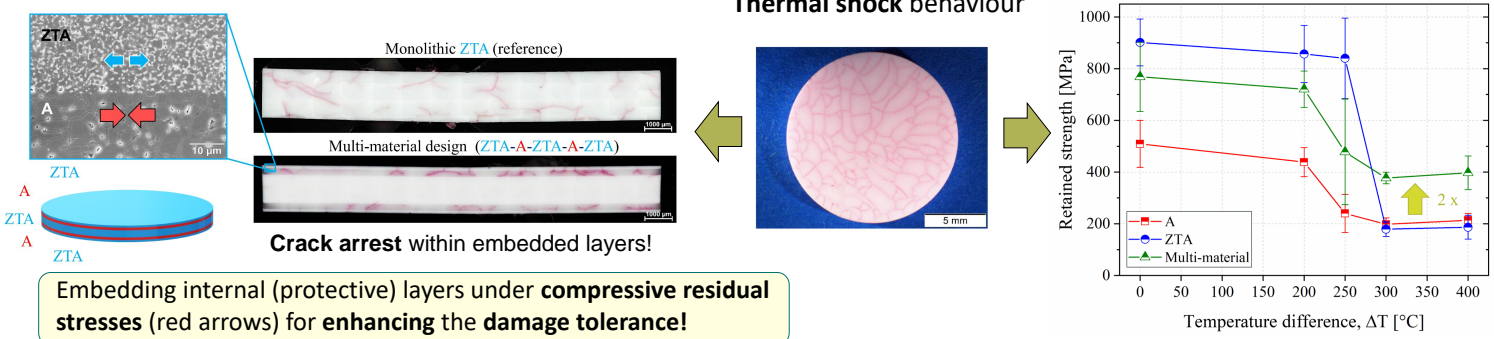
□ Motivation

- **Additive manufacturing** may open new pathways for designing complex-shaped ceramic parts and components
- **Goal:** 3D-printed alumina-based ceramic components with superior mechanical properties
- **Strategy:** Multi-material design concepts for further enhancing the strength and the damage tolerance

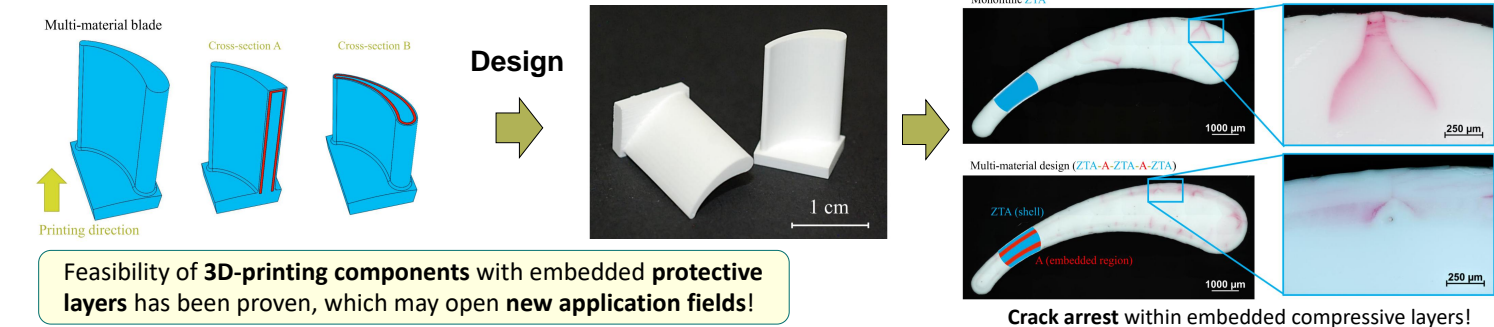
□ Design concept – Mechanical strength



□ Design concept – Damage tolerance



□ Demonstrator component



Dipl.-Ing. Dr.
Josef Schlacher
Department of Materials Science
Chair of Structural and
Functional Ceramics
josef.schlacher@unileoben.ac.at

More information:



In cooperation with:

LITHOZ



References:

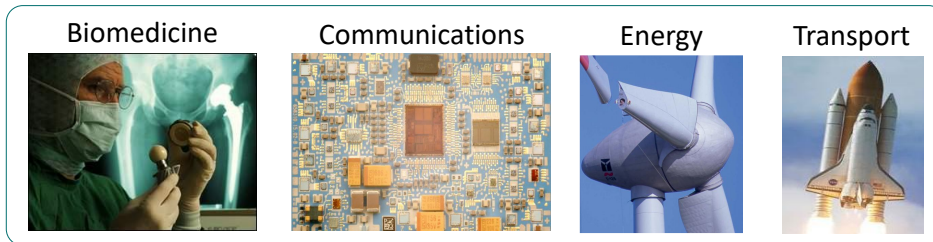
J. Eur. Ceram. Soc. 44 (2024)
Open Ceram. 5 (2021)



Design and processing of ceramic materials

Bio-inspired layered ceramics with tailored microstructures

□ Ceramics for use in structural and functional systems



Example of failure

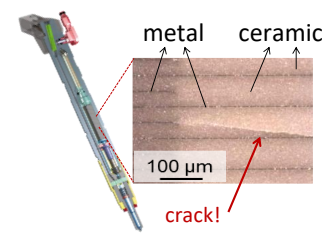


Fig. 1: Fuel injector for common rail systems

- **Problem:** Brittleness of ceramic parts – **unpredictable fracture**
- **Need** for tough and mechanically reliable ceramics

□ Vision → Build ceramics in a "bio-inspired" layered architecture

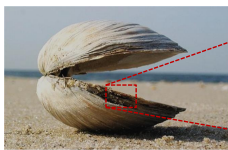


Fig. 2: Natural seashell



Fig. 3: Step-wise fracture of layered nacre

...from nature to the lab...

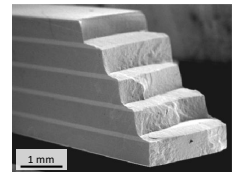
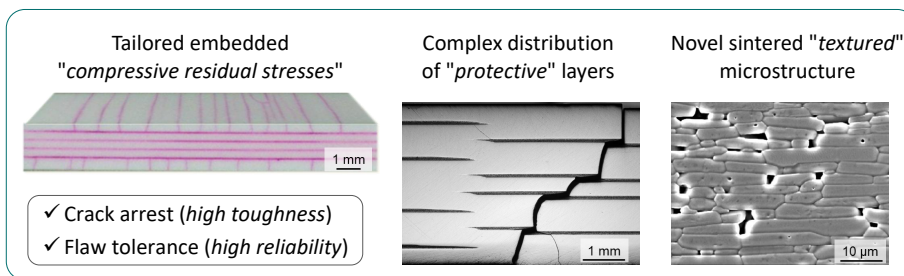


Fig. 4: Fracture of a layered ceramic

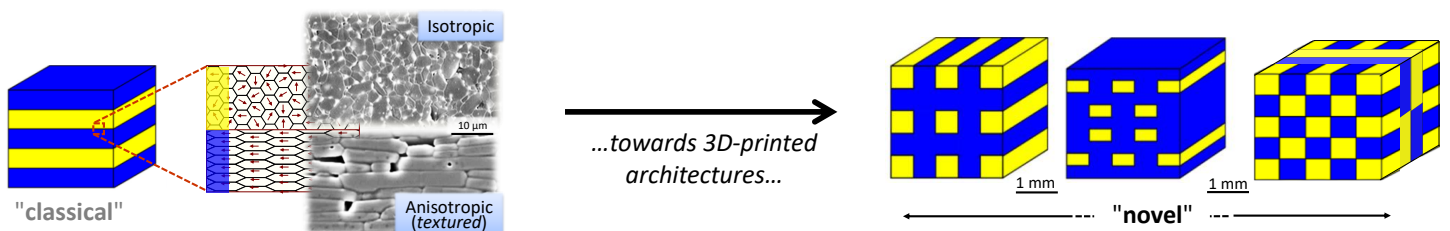
□ Design and characterization of layered ceramic composites



Aim: strong and tough ceramics

It is "hard" to be "tough"...
...it is "tough" to be "strong"

□ Novel processing of microstructures and architectures with enhanced properties



Univ.-Prof. Dr.
Raúl Bermejo
Department of Materials Science
Chair of Structural and
Functional Ceramics
raul.bermejo@unileoben.ac.at



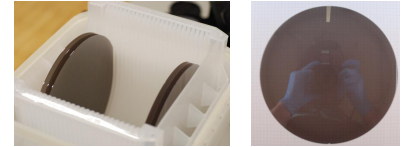
Scientific references



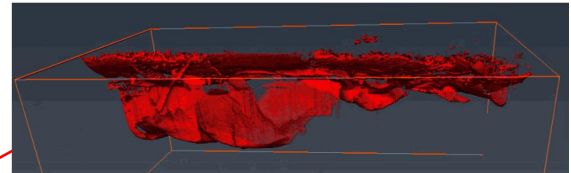
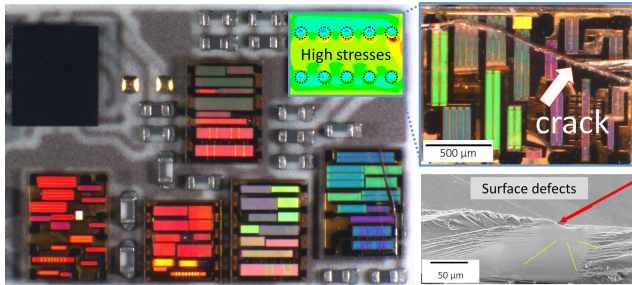
Characterization of ceramic materials

Single crystalline materials for microelectronic applications

- Single crystals are extensively used in **microelectronics**, with wafers serving as the essential substrates for the fabrication of **semiconductor, optoelectronic, and radio-frequency devices**.

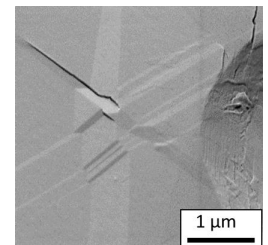
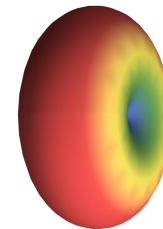
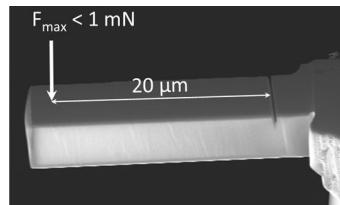
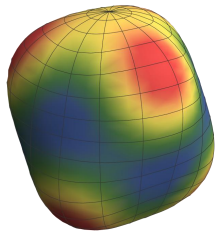
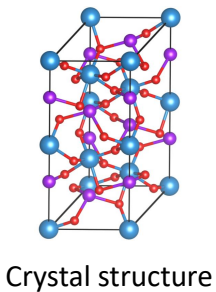


- Challenges:** The thereby used wide range of material classes with **distinct thermo-mechanical properties** may lead to **cracks** in those often **brittle** substrates.

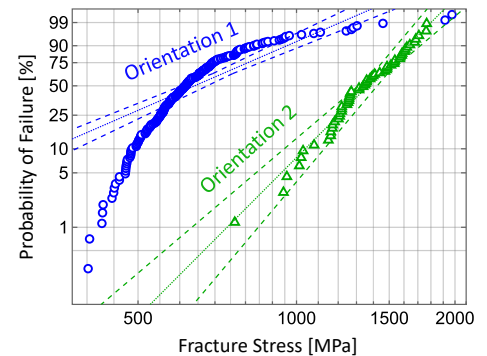
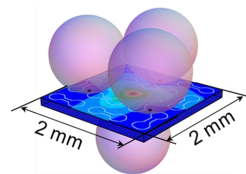
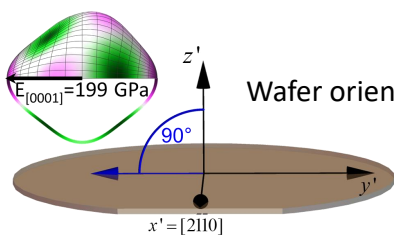


(Sub-) Surface defects, introduced during (mirror-) polishing of wafers, may act as critical defect responsible for failure of a component

- Requirements:** Deep understanding of **orientation-dependent mechanisms** leading to failure in single crystalline components:



- Goal:** Wafer orientations and surface conditioning for enhanced **mechanical reliability** while maintaining **functionality**



Dipl.-Ing. Dr.
Manuel Gruber

Chair of Structural and Functional Ceramics
Department of Materials Science
manuel.gruber@unileoben.ac.at

More information:



Materials & Design 213 (2022)
Acta Materialia 150 (2018), 373 – 80
Materials & Design 153 (2018), 221-31
J. Am. Ceram. Soc.101 (2018), 5705-16
J. Eur. Ceram. Soc. 37 (2017), 4397 – 406

Characterization of ceramic materials

Fractography and Failure Analysis

Fractography: Identification of fracture origins

Fracture features
(stress field at the moment of failure, crack branching patterns, hackle lines,.....) **Fracture origin**

Background
(processing, microstructure, service conditions,.....)

Most used methods: microscopy (magnifying lens, stereo microscope, SEM, EDX,...), Thermography, RAMAN-spectroscopy, XRD, Fracture mechanics, FE-analysis,...

Theoretical approach:

$K \geq K_{Ic}$

$\sigma = \frac{M}{\sqrt{R}}$

$K_{Ic} = \sigma Y \sqrt{\pi a}$

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

according to R. W. Ripling and G. D. Quinn

Practical use:

1. Locating the fracture origin: stereo microscope

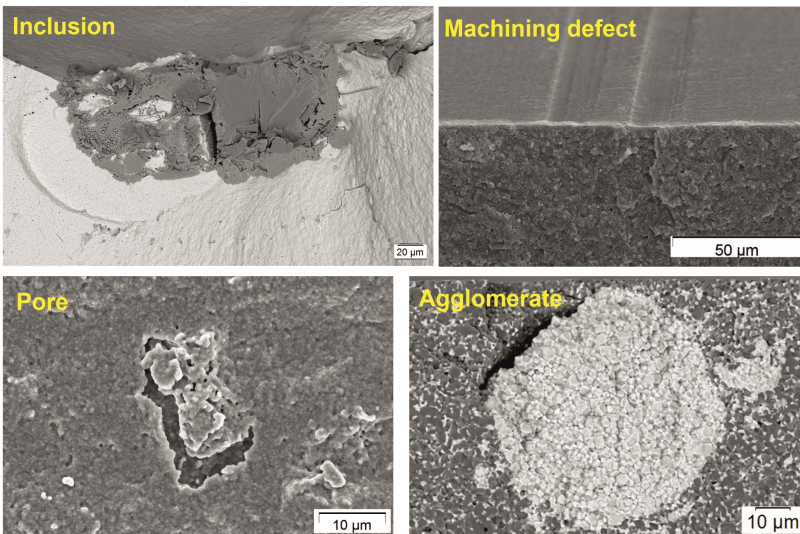
2. Precise identification: SEM-EDX

EDX: Si

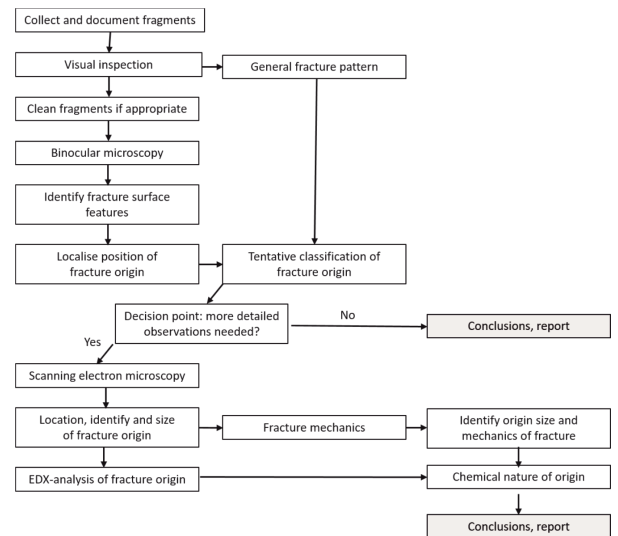
Pores

EDX: Fe, Cr, Ni

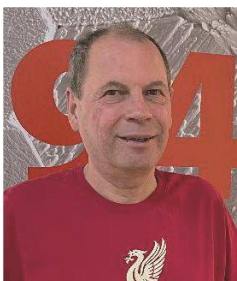
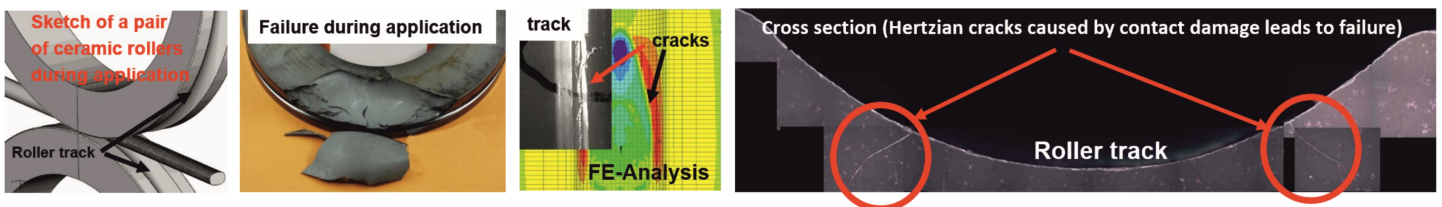
Examples for fracture origins in ceramics



Flowchart: failure analysis of ceramics



Example: Failure analysis on Si₃N₄-rollers for rolling of superalloy wires



Dipl.-Ing. Dr.
Walter Harrer
Chair of Structural and
Functional Ceramics
Department of Materials Science
walter.harrer@unileoben.ac.at

More information:

G. D. Quinn: *Fractography of Ceramics and Glasses*, U.S. Government Printing Office, Washington, USA, 2007, NIST Special publication 960-17

W. Harrer, R. Morrell, R. Danzer: *A brief guide to conducting failure analysis on ceramic components*, *Practical Metallography* 60 (2023), 580-593



Design and processing of ceramic materials

Sustainable fabrication of ceramics by the cold sintering process

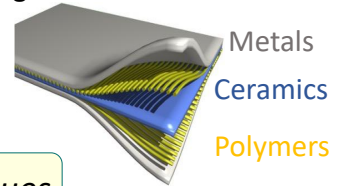
❑ **Challenge:** Sintering of ceramics requires high temperatures > 1000°C

➖ **High energy consumption & Carbon emissions**



➖ **Limited materials design and integration**

- Thermal stresses
- Decomposition/reaction between different phases

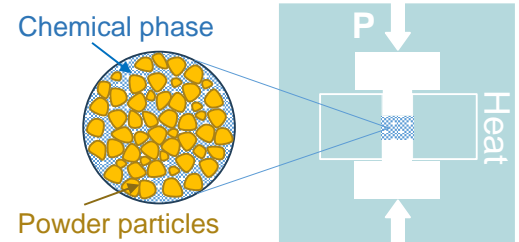


Need for alternative low-temperature sintering techniques

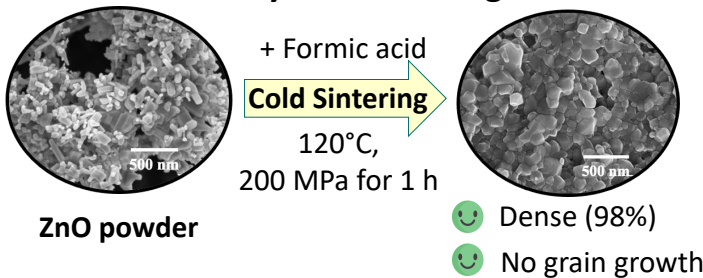
❑ **The Cold Sintering Process:** innovative technique that enables densification of ceramics at unprecedented low temperatures < 300°C

The principle: Geologically inspired pressure-solution creep mechanism

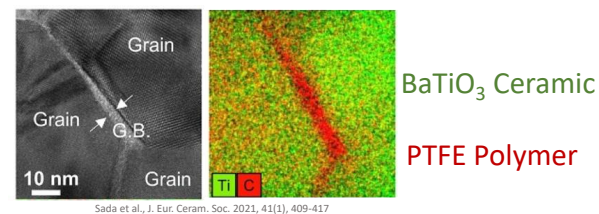
- 1) **Dissolution:** activated by the transient phase (**Chemistry**)
- 2) **Diffusion:** by chemical potential gradients induced by **Pressure**
- 3) **Precipitation:** due to liquid phase evaporation at low **Temperature**



❑ **Densification by cold sintering**

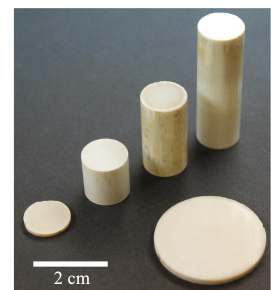
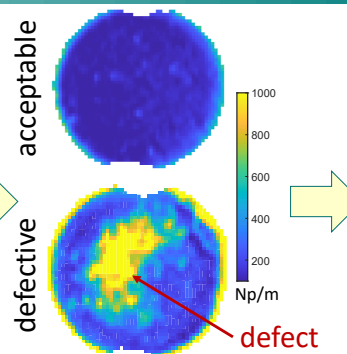
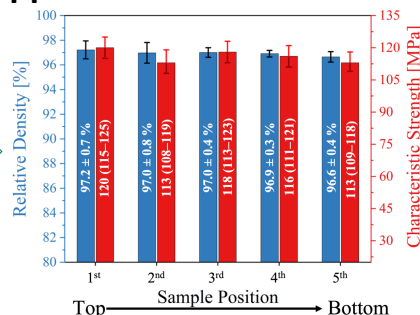
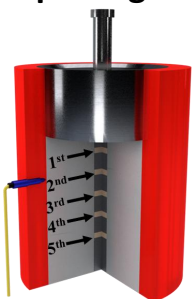


❑ **Integration of ceramics/polymers/metals**



😊 Unique composites and grain boundaries design

❑ **Exploring scaling up opportunities**



✅ Cold sintering multiple parts

✅ No properties gradients

✅ Quality control: Non-destructive ultrasonic testing

✅ Up scaling part's size



Dipl.-Ing. Dr.
Abdullah Jabr

Chair of Structural and Functional ceramics
Department of Materials Science
abdullah.jabr@unileoben.ac.at

More information:



ISFK
www.isfk.at

In cooperation with:



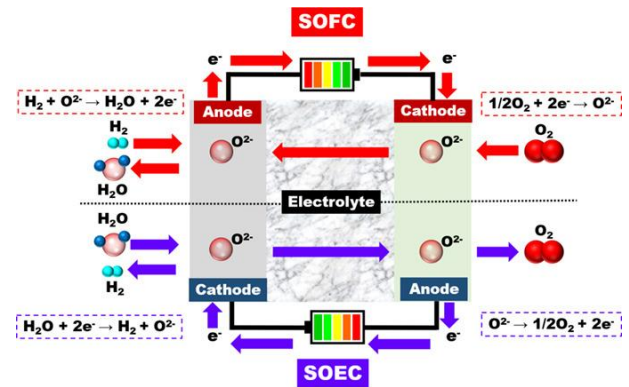
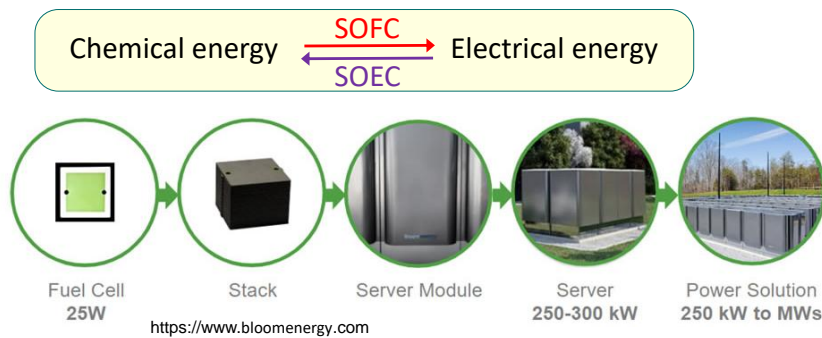
PennState

FWF Österreichischer
Wissenschaftsfonds

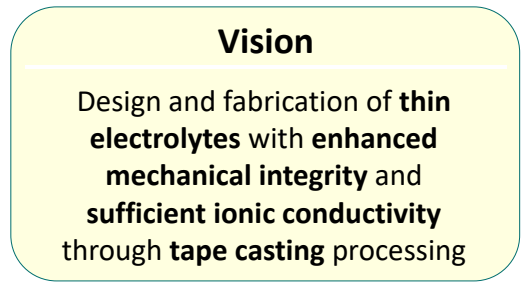
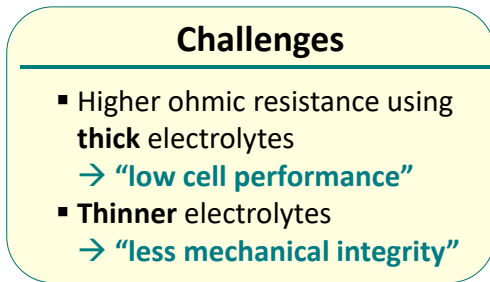
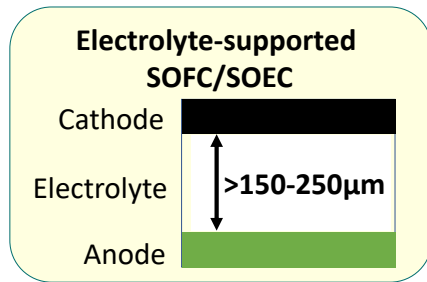
Design and processing of ceramic materials

Innovative processing and characterizations of ceramic electrolytes for SOFC/SOEC

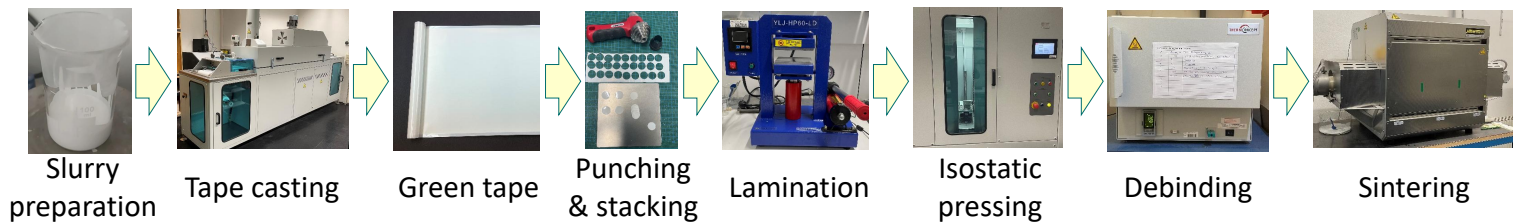
Principle of Solid Oxide Fuel (Electrolyzer) Cells:



Problem definition

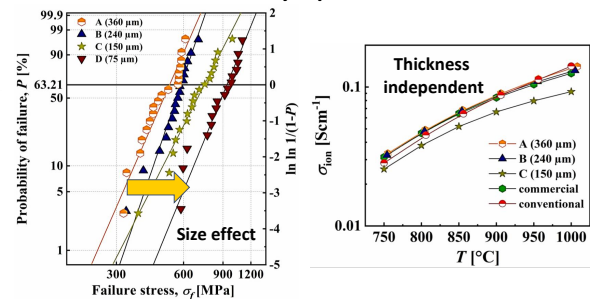
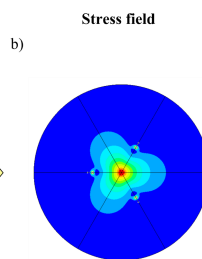
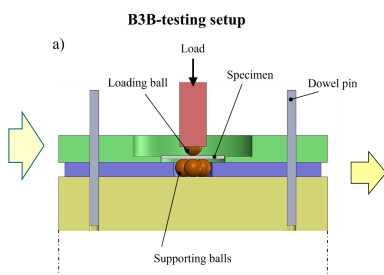


Processing of zirconia-based (8YSZ) ceramic electrolyte through tape casting



Results \rightarrow effect of thickness on mechanical strength and ionic conductivity quantified

New mechanical testing setup for very thin 8YSZ electrolytes developed to avoid large deflections



M.Tech
Arijit Jana
Chair of Structural and Functional Ceramics
Department of Materials Science
arijit.jana@unileoben.ac.at

More information:

A. Jana et al, J. Eur. Ceram. Soc. 2025, 45 [2] 116929



In cooperation with:

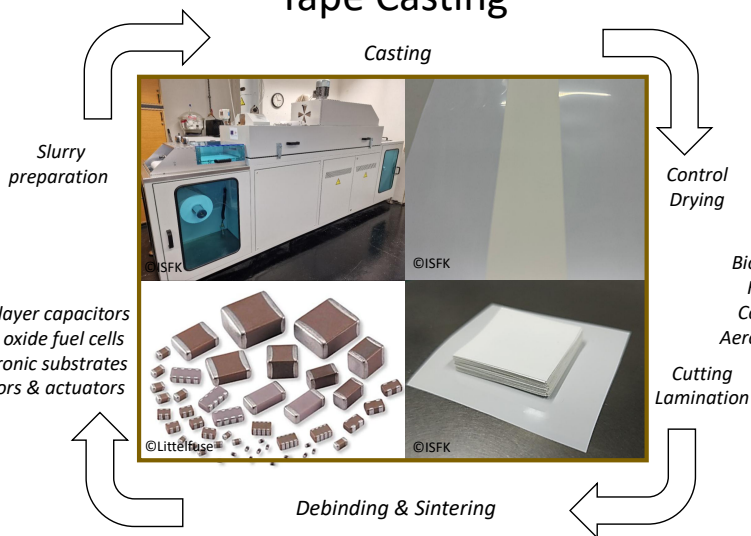


Design and processing of ceramic materials

Ceramic manufacturing & Microstructural Analysis

■ Ceramic manufacturing

Tape Casting



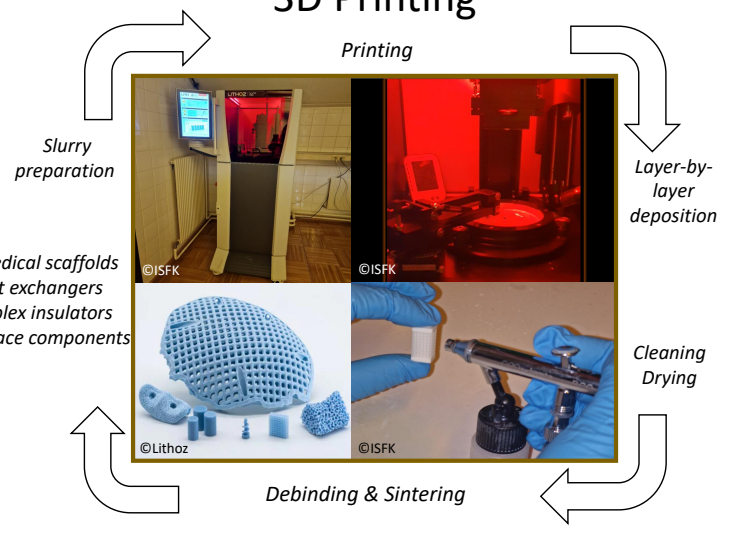
Key Advantages

- Excellent thickness control
- High throughput
- Suitable for multilayer structures
- Industrial scalability

Limitations

- Limited to flat geometries
- Additional lamination steps for complex parts

3D Printing



Key Advantages

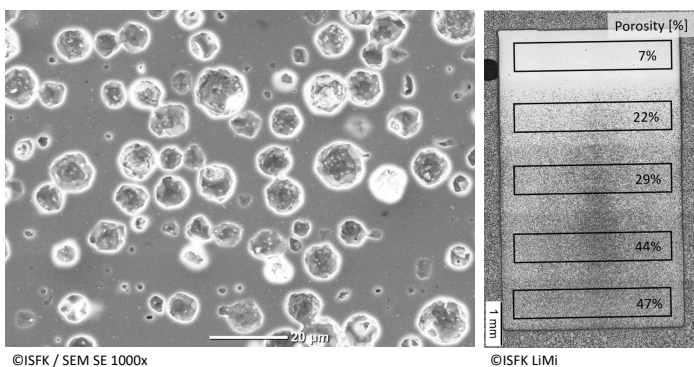
- High geometric complexity
- Design flexibility
- Low material waste
- Rapid prototyping capability

Limitations

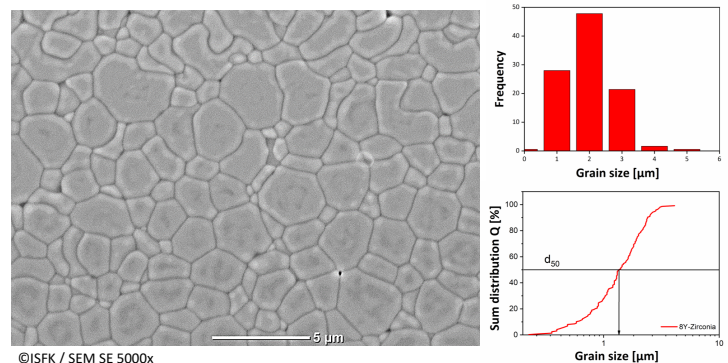
- Lower production rate
- Equipment cost
- Possible porosity defects

■ Microstructural Analysis

Polished surface / Porosity measurement



Etched surface / Grain size distribution



Dipl.-Ing.
Irina Krалеva
Department of Materials Science
Chair of Structural and
Functional Ceramics
irina.krалеva@unileoben.ac.at

More information:



In cooperation with:



Funded by
the European Union



European Research Council
Established by the European Commission

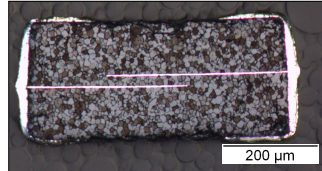
Characterization of ceramic materials

Lock-in Infrared Microscopy (LIIM)

Characterization of microelectronic ceramic components

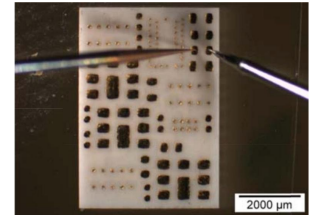
Multilayer varistor:

Zinc oxide-based (voltage dependent VARIABLE RESISTOR) used for surge and overvoltage protection of devices [1]



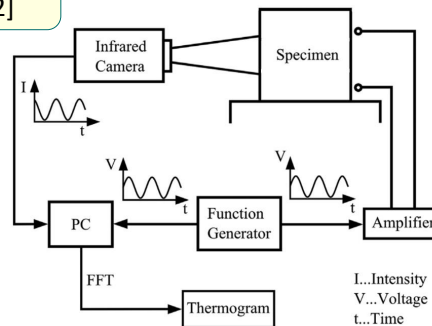
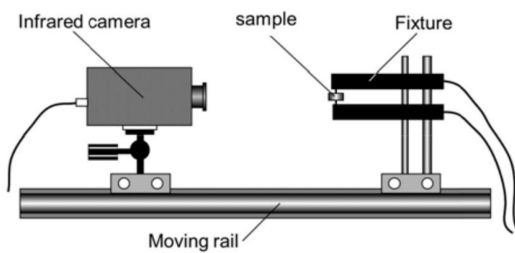
LTCC module:

Hybrid integrated circuit based on LTCC (low temperature co-fired ceramics) [2]



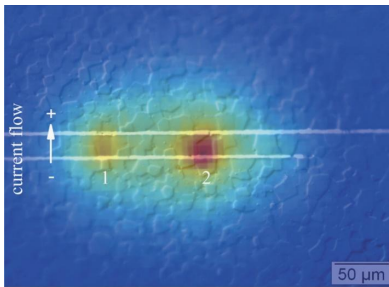
Method

Schematic of an IR camera mounted on a rail track in front of the sample [2]



A sinusoidal voltage is applied to the specimen. An infrared camera records the resulting periodic heating. The thermogram is evaluated by Fourier Transformation [1]

Thermograms

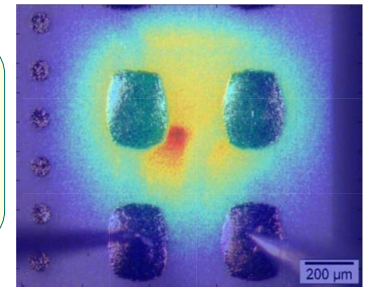


Varistor thermogram

Two distinct areas with current paths between electrodes are detected by the Lock-in system [3]

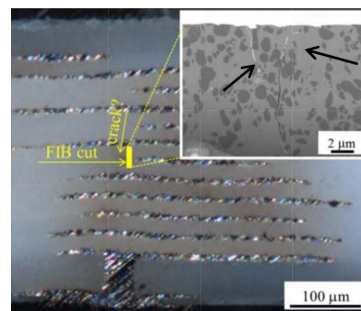
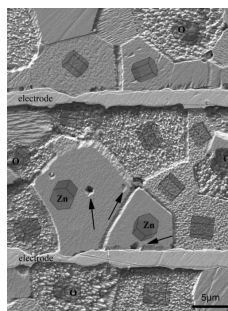
Hot spot in LTCC module

Heat generation caused by leakage current in the LTCC module is detected by the Lock-in system [2]



Results

Lock-in IR microscopy can be used as a tool for microscale current detection to reveal the device dominating junctions in electroceramic varistors [3]



After hot spot detection a crosssection of the sample reveals the source of error current: cracks partially filled with electrode material [2]



Josef Kreith

Department of Materials Science
Chair of Structural and
Functional Ceramics
josef.kreith@unileoben.ac.at

More information:



References:

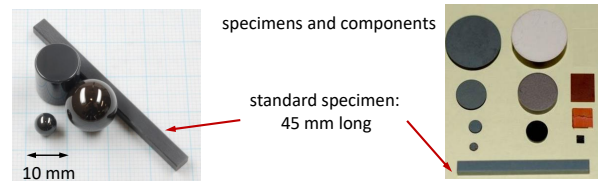
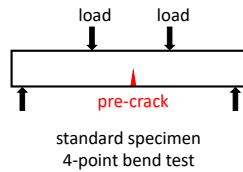
- [1] N.Raidl et. al. *Adv. Eng. Mater.* 19 [4] (2017)
- [2] S.Röhrig et. al. *J. Ceram. Sci. Tech.* 6 (2015)
- [3] M.Hofstätter et. al. *Microscopy and Microanalysis* 21 (2015)

Characterization of ceramic materials

Fracture toughness tests for components

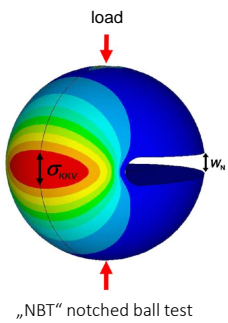
- ❑ **Fracture Toughness** is a material property that tells us how difficult it is to propagate an existing crack in a component. It is measured by breaking specimens with **artificial pre-cracks**.

- ❑ **Problem:** Many parts are too small to make standard specimens.

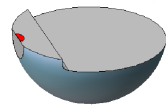


- ❑ **Solution:** New tests which use the parts directly have to be developed. The Finite-Element-Method has to be used to evaluate results.

Bearing balls – NBT-KIc

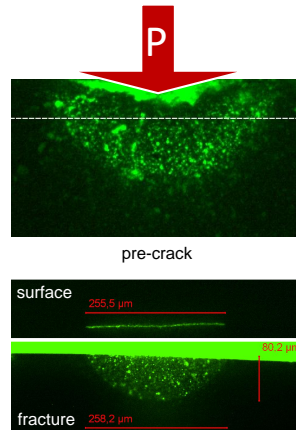


„NBT“ notched ball test

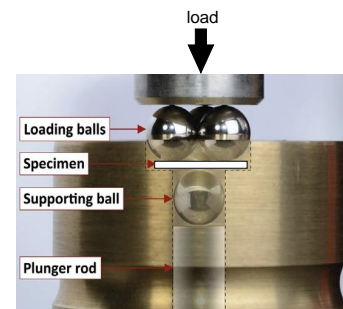


NBT-test: ball with artificial pre-crack

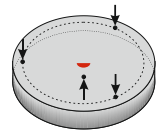
Precracking with Knoop indenter



Discs and Plates – B3B-KIc

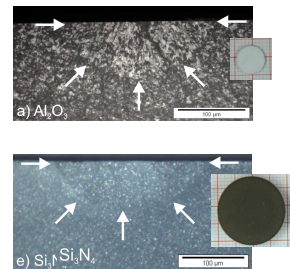
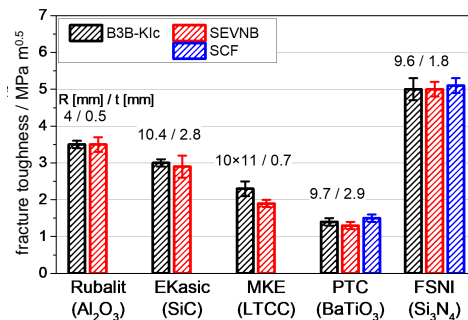
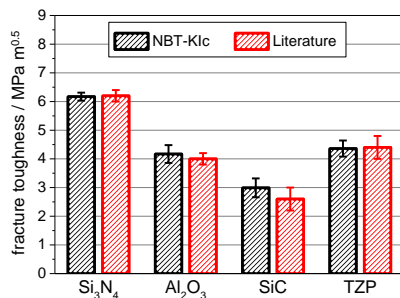
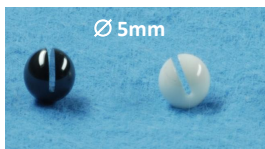


„B3B“ ball-on-3-balls test



B3B test: disc with artificial pre-crack

- ❑ **Verification:** Correct values can be measured with new methods.



ao. Univ. Prof. Dr.
Tanja Lube

Chair of Structural and Functional Ceramics
Department of Materials Science
tanja.lube@unileoben.ac.at



In cooperation with:



S. Strobl, T. Lube, O. Schöpl: *JECs* 34 (2014), 1881-1892
S. Strobl, P. Supancic, T. Lube, R. Danzer: *JECs* 32 (2012), 1163-1173
T. Lube, S. Rasche, T.G.T. Nindhia: *JaCers* 99 [1] (2016), 249-256

Fracture toughness measured on curved surfaces

Laser notching of silicon nitride bearing balls

Laser notching

Laser Pulse

Heat affected Zone

Very little heat accumulation due to the ultra short laser pulse

1 ns

microPREP™ PRO FEMTO

- The use of a femtosecond laser system is ideal for the preparation of reproducible, sharp and small notches
- Ultra short pulsed lasers induce only little heating of the material, and the material below is not damaged
- Notches that mimic real cracks can be made, and used for the determination of the fracture toughness
- Setting of the laser parameters is crucial to obtain a smooth notch root

Fluence = 49.7 Jcm⁻²

Fluence = 16.6 Jcm⁻²

Notch Flank

Fracture Surface

5 μm

Testing

Notch

∅ 23 mm

114 μm

33 μm

13 μm

Real Testing Setup

Notch

Dry Lubricant

- Semi-elliptical notches are ablated directly into the original curved surface of specimens, which are cut from silicon nitride bearing balls that can be seen on the top left
- The notches are 1/100 of the specimen height
- To fracture the specimen, a loading situation is used to induce the maximum stress at the location of the notch
- Dry lubricant is used to minimize friction

Results

Top View – Fracture Origin

1 mm

Fracture Origin – Close Up

500 μm

curved surface

bulk

Crack Model

4.3 ± 0.1 MPam^{0.5}

4.3 ± 0.3 MPam^{0.5}

3.9 ± 0.1 MPam^{0.5}

Δ 10 %

- Fracture originates in all cases from the laser ablated notches, as can be seen on the left
- Simulation of the notched specimen subjected to the loading situation above is required to determine the fracture toughness, as can be seen on the right
- The fracture toughness for both specimen geometries that include the curved surface is the same
- Measuring the fracture toughness in the bulk of the bearing balls with the same laser notches results in a different value



Dipl.-Ing.
Maximilian Munz
Chair of Structural and Functional
Ceramics
Department of Materials Science
maximilian.munz@unileoben.ac.at

More information:



In cooperation with:

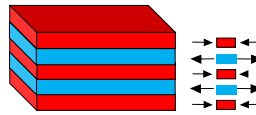


Design and processing of ceramic materials

Sintering of additively manufactured ceramic multi-materials

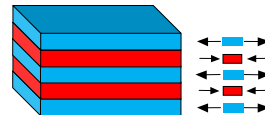
- ❑ **Ceramic multi-materials** may enhance mechanical properties such as strength and/or damage tolerance through tailored residual stresses and architecture

“mechanical resistance”



- ✓ scratch resistance
- ✓ contact applications

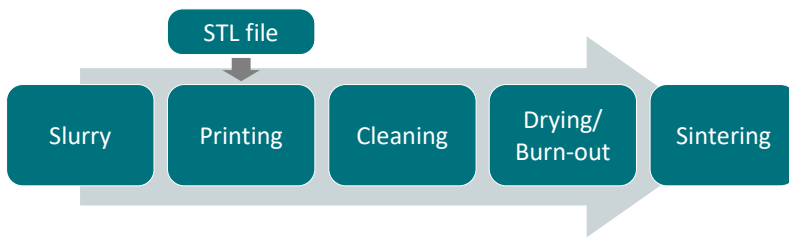
“damage tolerance”



- ✓ crack arrest
- ✓ damage tolerance

The **goal** of this work is to understand the **sintering** of ceramic **multi-materials** and to enable material combinations in complex shapes with specific mechanical properties.

- ❑ **Additive manufacturing (AM)** is a way of forming ceramics with complex geometry. The combination of different materials in XY- and Z-direction is possible



<https://www.lithoz.com/>



- ❑ **Sintering** is one of the most important steps in the processing of ceramics, whereby inorganic powders densify forming a microstructure, giving the material its properties

Sintering within minutes
(instead of hours)

Setup for rapid sintering

A.-K. Hofer et al., Addit. Manuf. 59 (2022) 103141.

Rapid Sintering	Conventional Sintering
2 μm	2 μm

With rapid sintering, fine grained microstructures can be realized

Ceramics have **high hardness** and **strength**, but **brittle behavior**.

By tailoring the microstructure in individual layers of the **multi-layered ceramic**, the **damage tolerance** can be enhanced.

- ❑ **Rapid-sintered multi-layered designs** with embedded textured layers show enhanced damage tolerance

Multi-layered design with equiaxed (EA) and textured (TA) alumina (Al_2O_3) layers

- ✓ Successful rapid sintering of layered design
- ✓ Strong & distinct interface
- ✓ Crack deflection & arrest in TA-layers for **limitation of crack length** in laminate

T. Prötsch et al., J. Am. Ceram. Soc. 108 (2025) e20706.

Crack depth laminate

EA, TA, EA



Dipl.-Ing.
Tobias Prötsch

Chair of Structural and Functional Ceramics
Department of Materials Science
tobias.proetsch@unileoben.ac.at

More information:



In cooperation with:



Characterization of ceramic materials

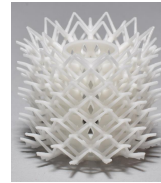
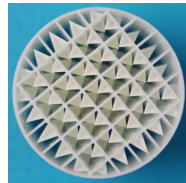
Strength testing of additively manufactured structures

□ Stereolithographic manufacturing opens new possibilities

Static mixer



Catalytic support structures

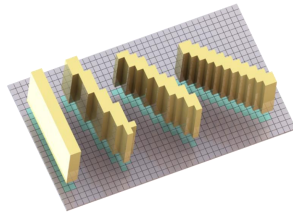


Heat exchangers

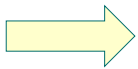


□ Challenges → Orientation-dependent surface structures

Aliasing effect of
DLP-module



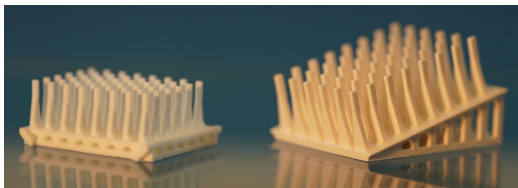
Rough surface due to
layered manufacturing



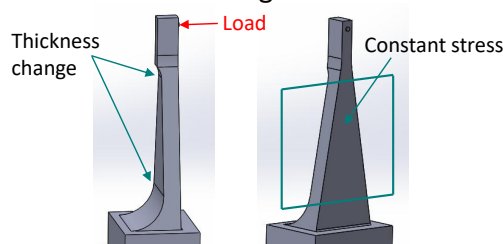
- **Problem:** Surface quality depends on surface orientation in relation to the building direction
- **Need for new testing methods** to reliably assess influence of surface orientation

□ Novel test specimen

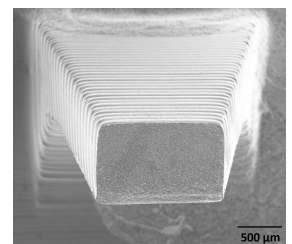
48 bending bars on a baseplate, different configurations (upright, inclined)



Region of constant stress on bending bars

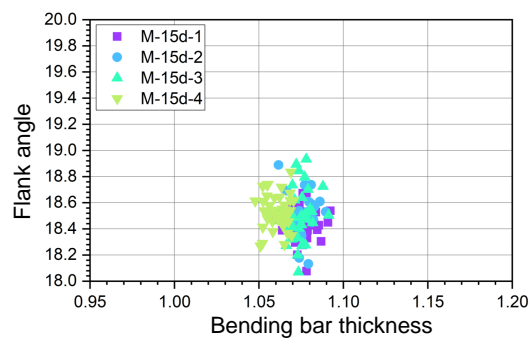
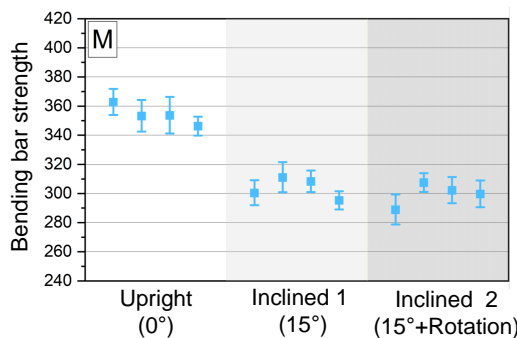


Fractured specimen with surface structures

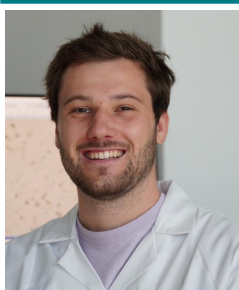


□ Results

Strength depends significantly on surface orientation



Exceptional dimensional reproducibility



Dipl.-Ing. Dr.
Maximilian Staudacher
Chair of Structural and Functional Ceramics
Department of Materials Science
Maximilian.staudacher@unileoben.ac.at

In cooperation with:



More information:



Mechanical characterization of glass

Bending strength of thin glass substrates

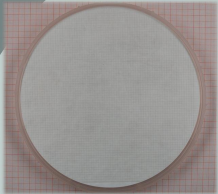
Thin glasses

The glass industry is capable of producing high-quality thin or ultra-thin glass substrates with thicknesses ranging from 30 μm to approximately 0.5 mm. For example, such glasses can be used as substrates for microelectronic components by matching their thermal expansion to that of silicon.

How strong are thin, flexible glasses?

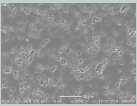


Samples

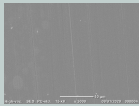


Glass wafer
6 inch diameter
SCHOTT AF 32[®] eco
Young's modulus: 74.8 GPa
Poisson's ratio: 0.24
diced in plates: 2x2x0.13 mm

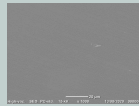
specimens with 3 different surface qualities



(i) ground

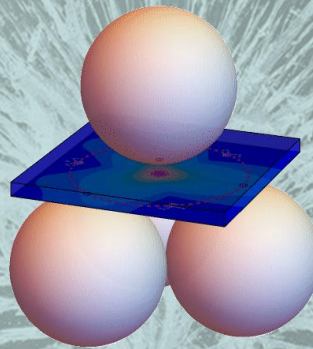


(ii) fine ground



(iii) polished, etched

Ball-on-Three Balls Test (B3B)

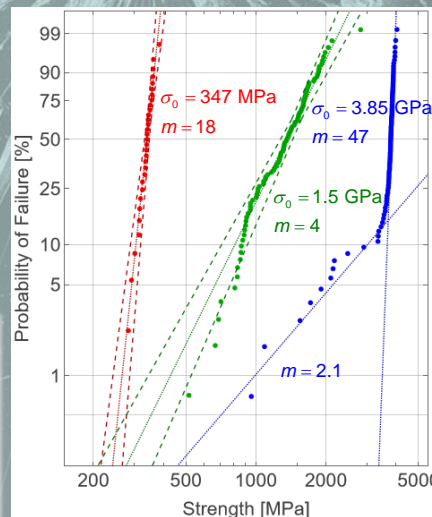


Glas specimen 2 mm \times 2 mm
Diameter support ball: 1.4 mm

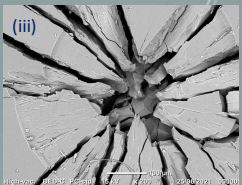
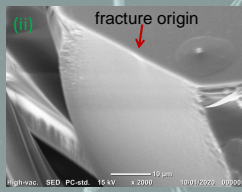
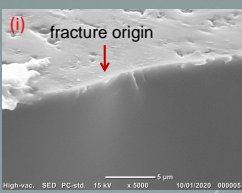
$$\text{Evaluation: } \sigma_{\max} = f_{\text{FEM}} \cdot \frac{F}{h^2}$$

σ_{\max} .. strength
F .. fracture force
h .. thickness (0.13 mm)
 f_{FEM} .. geometric factor
(calculated by FEM; ca. 2.15)

Results: Weibull plot of strength



Results: Fractography



In case of (i) and (ii) typical fracture origins are scratches and grinding marks (sub-surface damage).

In case of the high strength tail of (iii) a complete fragmentation of the central zone is observed.

Results: Summary

- The bending strength of commercial glass wafers was measured with a miniaturized B3B-Test.
- The observed strength distributions (from 300 MPa up to 4 GPa) showed a strong dependence on the surface quality.
- The failures in the low strength range between 300 MPa and 3 GPa were caused by clearly detectable surface defects.
- The fracture mode of the strongest specimens (ca. 4 GPa) changed to complete fragmentation, with reduced scatter ($m=47$).



ao. Univ. Prof. Dr.
Peter Supancic

Chair of Structural and Functional Ceramics
Department of Materials Science
peter.supancic@unileoben.ac.at



In cooperation with:

SCHOTT
glass made of ideas

P. Supancic, F. Maurer, R. Danzer: *Journal of Non-Crystalline Solids* 639 (2024) 123067.