Karlsruhe Institute of Technology

The effect of a homogenizing optic on residual stresses and shear strength of laser brazed ceramic/steel-joints

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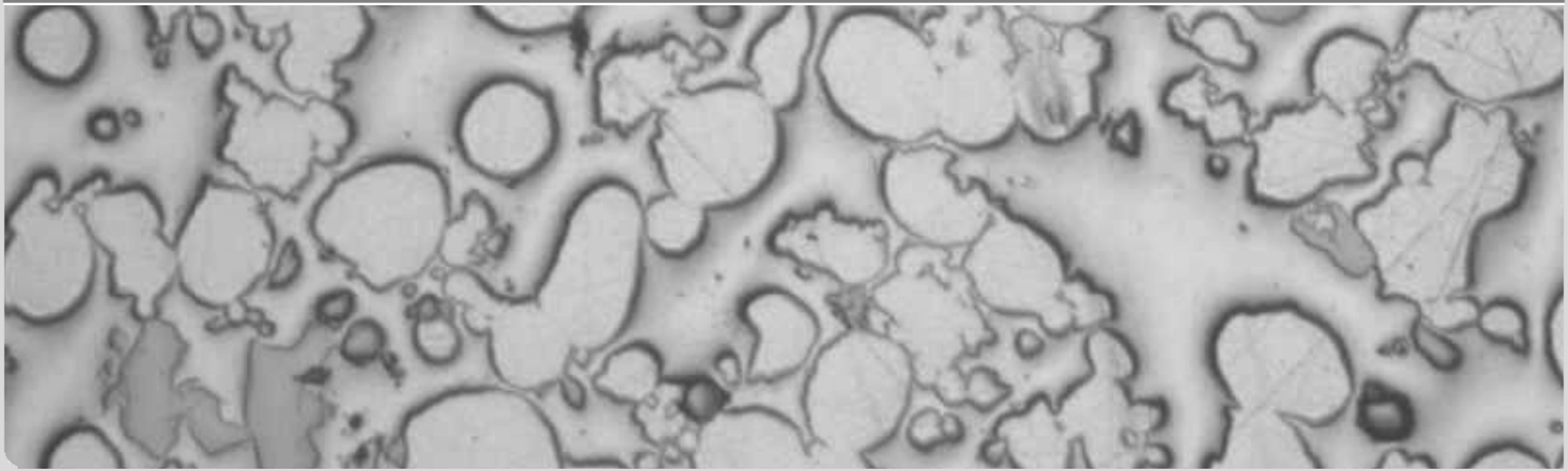


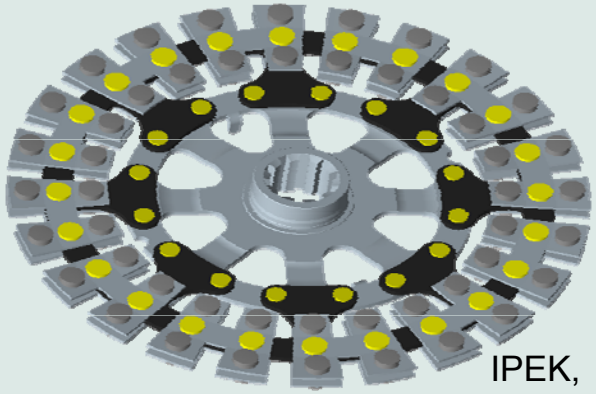
Outline

- motivation
- material properties
- results
  - microscopic compound analysis
  - thermal characterization of laser brazing process
  - fem-analysis of residual stresses
  - x-ray measurement of residual stress
  - shear testing
  - tribological testing
- conclusion

Motivation

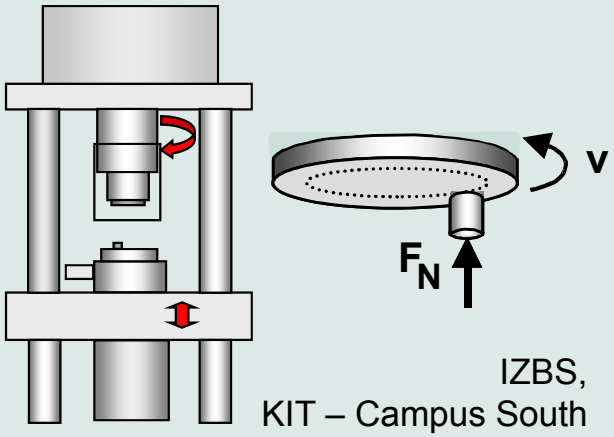
Tribological application

dry running clutch system



IPEK,
KIT – Campus South

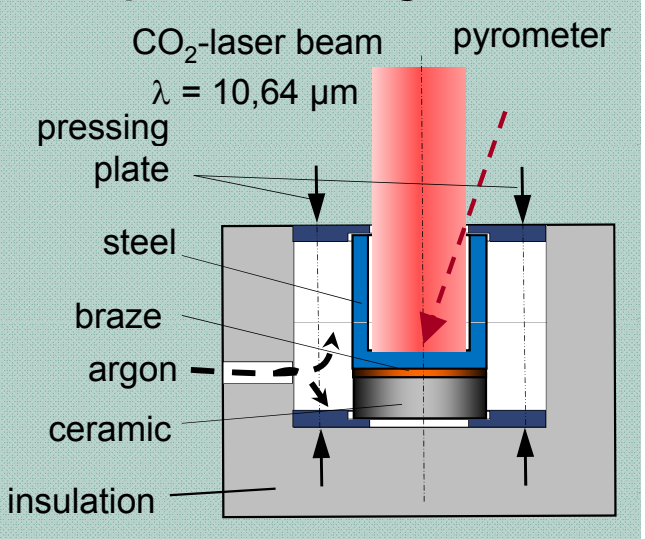
pin-on-disc experiment



IZBS,
KIT – Campus South

Laser brazing

process arrangement



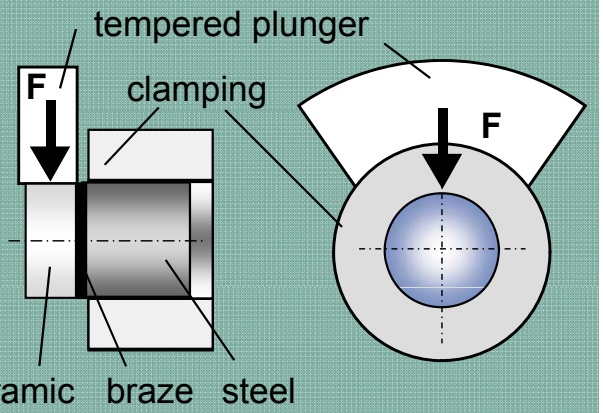
IMF I, KIT – Campus Nord

process conditions

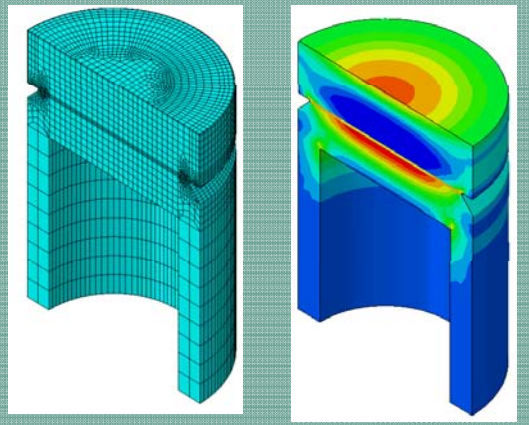
- laser output beam
- Argon stream ≥ 400 Nl/h
- pressure p ≥ 10 MPa
- temperature measurement

Mechanical characterization

shear strength

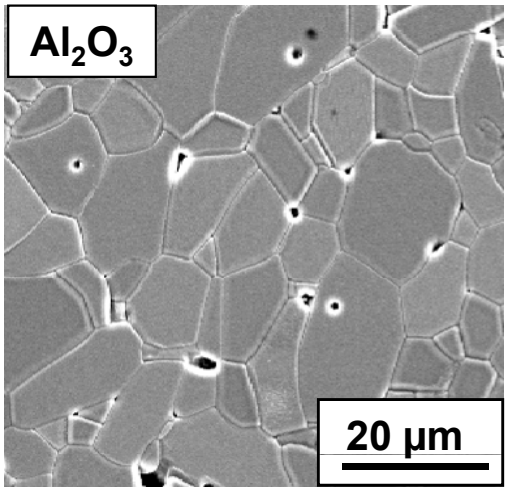


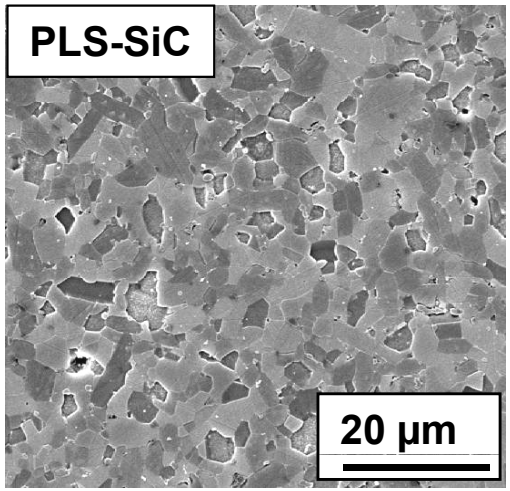
residual stresses

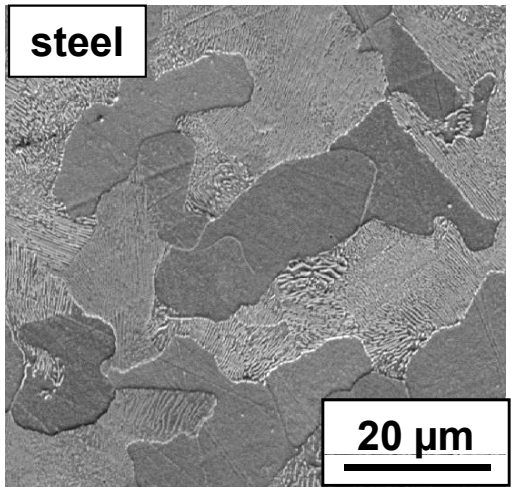


Material properties

Properties \ Material	Al_2O_3	PLS-SiC	Steel	Incusil-braze	Sn50 50Sn48Ag2Ti
Company	Friatec AG	ESK Ceramics	-	Morgan Chem.	KIT, IMF I
Density ρ / g/cm³	3.9-3.95	3.0	7.85	9.7	8.3
Strength σ / MPa	3501	400	560-710	338	-
Youngs modulus / GPa	380	410	210	76	68
Thermal conductivity λ, W/mK	38	145	44	166	-
Coefficient of thermal expansion α, 10^{-6} m/K	8.4	4.1	11.0	18.2	-

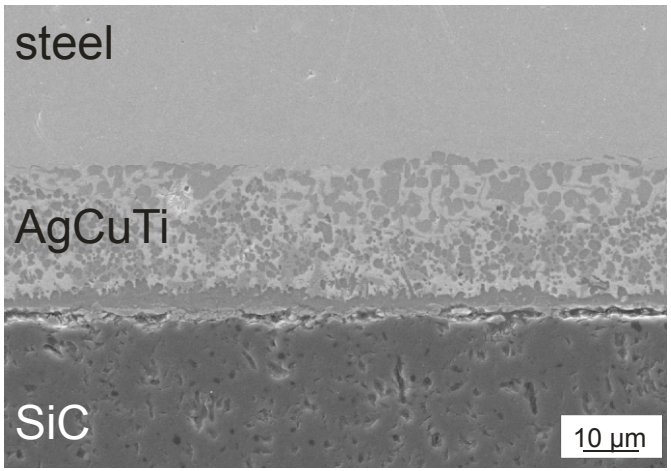




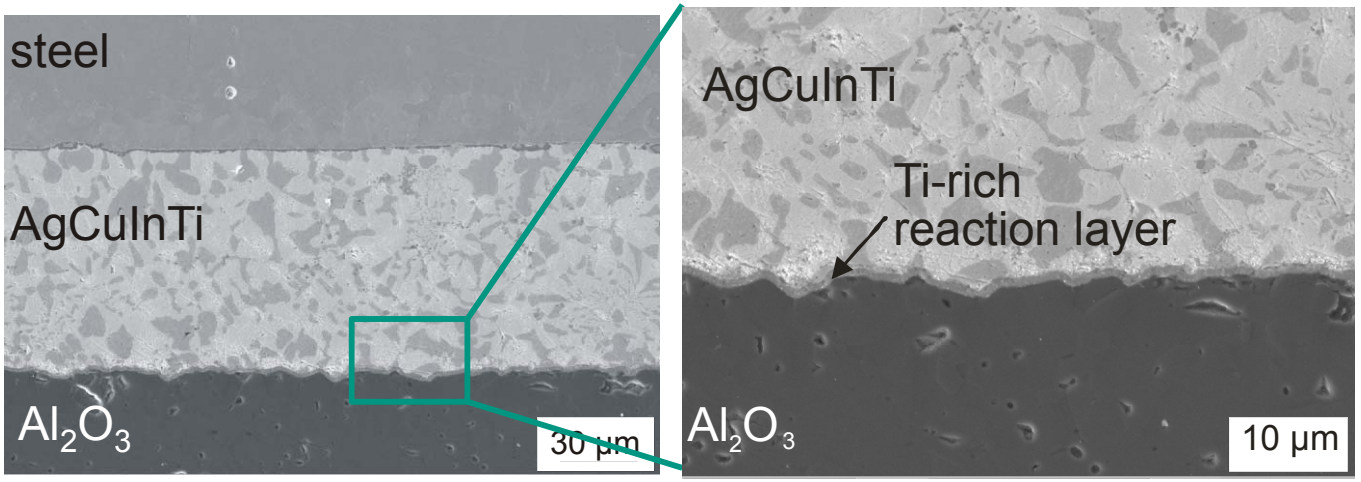


SEM-images of ceramic/AgCuTi/steel-joints

SiC / AgCuTi / steel



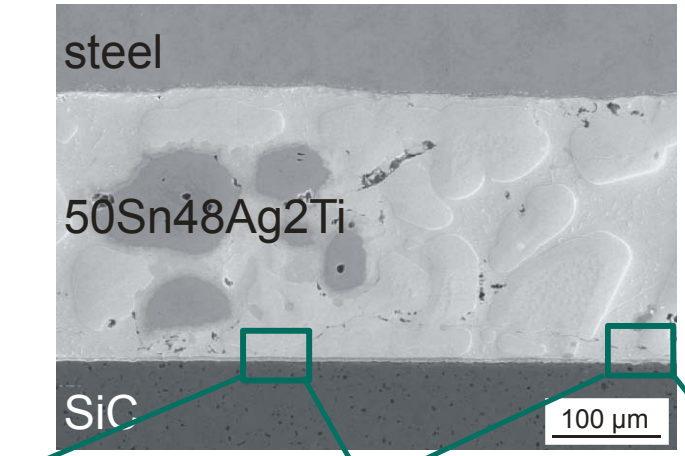
Al_2O_3 / AgCuTi / steel

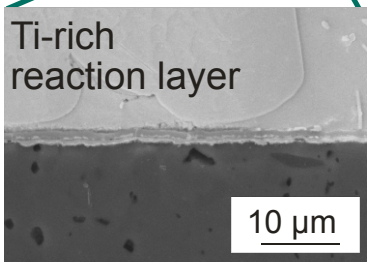


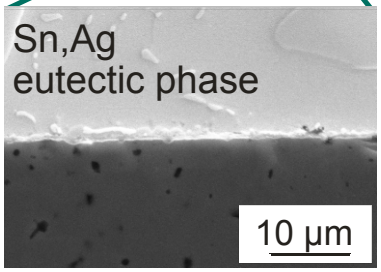
- inomogenous or no wetting of SiC mit AgCuTi- and AgCuInTi-filler despite a Ti-rich reaction zone
- homogenous, seamless wetting and explicit Ti-rich reaction layer on Al_2O_3 with AgCuTi- and AgCuInTi-filler

SEM-images of laser brazed ceramic/steel joints

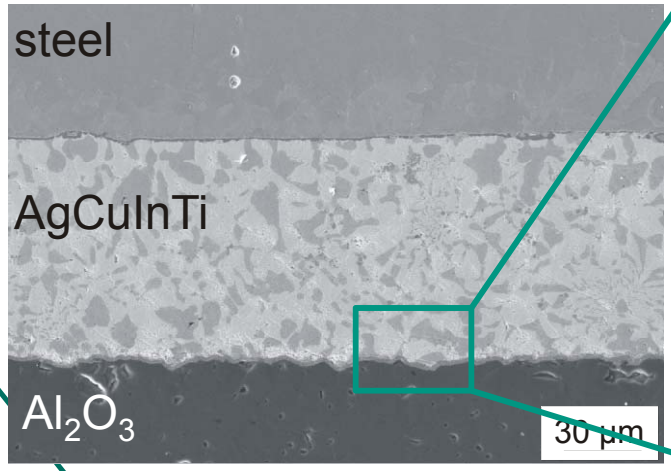
SiC / SnAgTi / steel

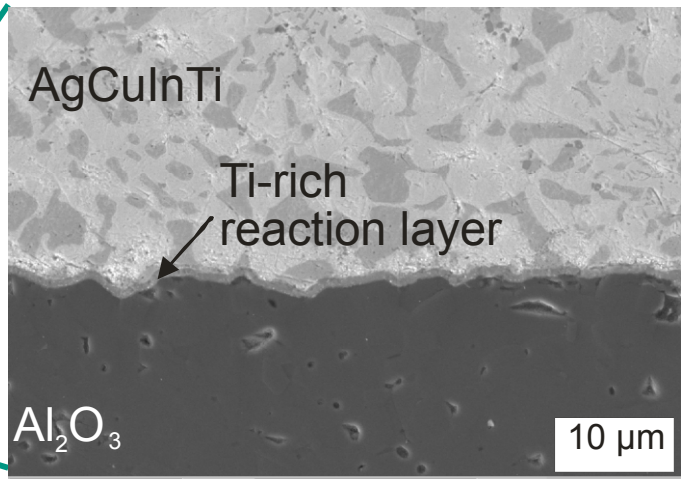






Al_2O_3 / AgCuTi / steel

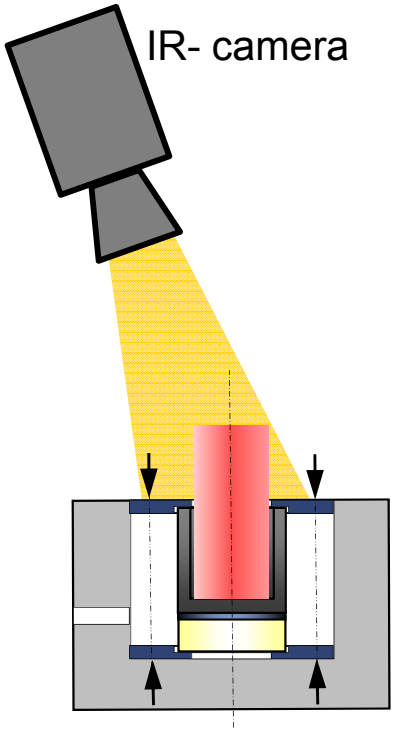


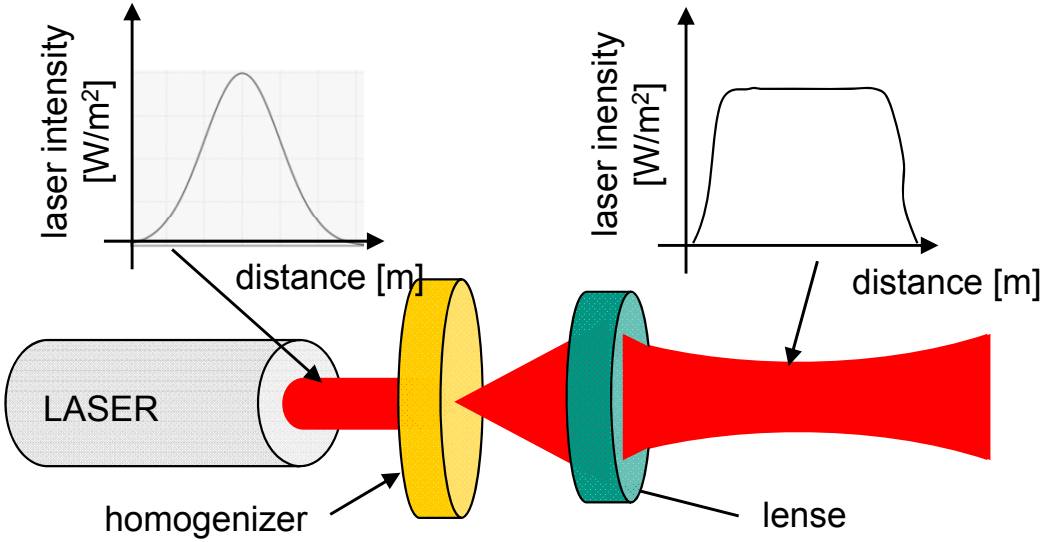


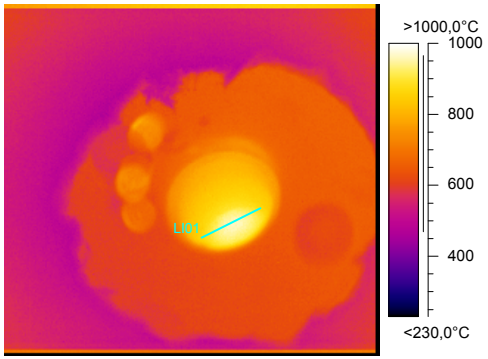
- homogenous wetting of SiC with SnAgTi-filler for Sn ≥ 30wt% at T ≥ 900°C
- seamless wetting but inhomogenous Ti-rich reaction layer

Infrared camera: Images of temperature distribution

temperature measurement

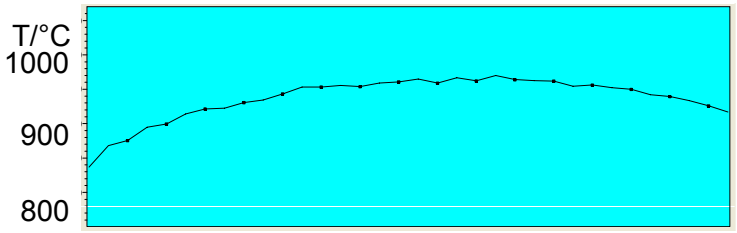






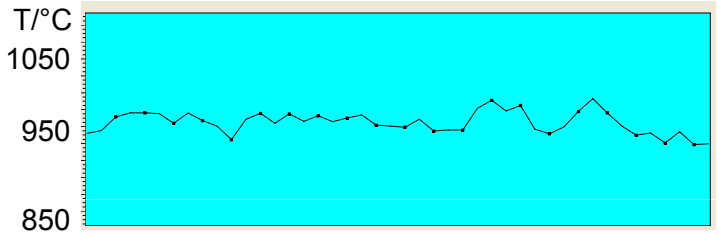
Laser output beam

Gauß profile



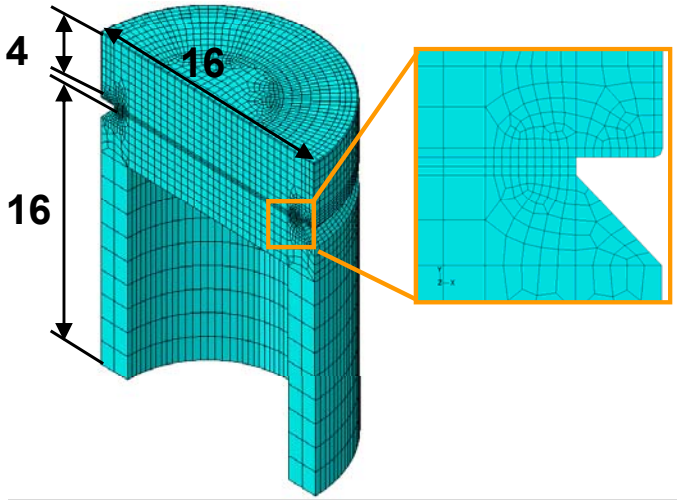
Homogenized laser output beam

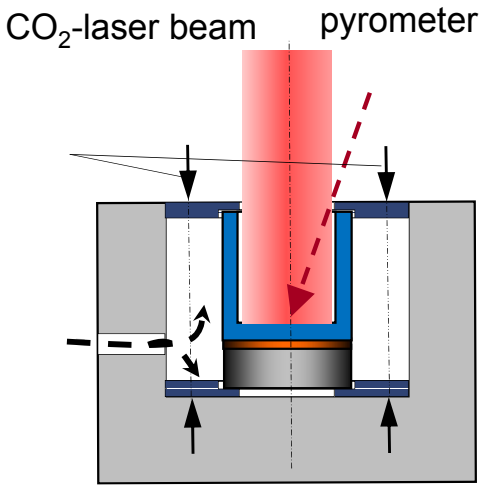
top head profile

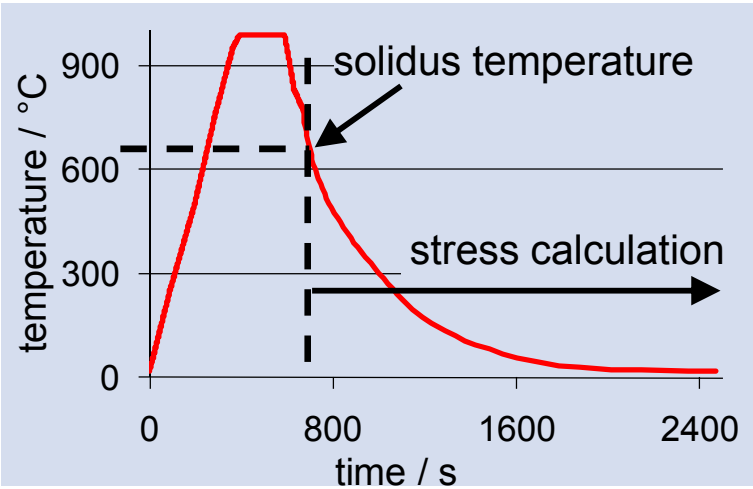


FEM-calculation: Sequential temperature/stress analysis

Step 1: Calculation of temperature distribution laser heating profile

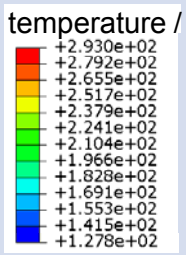


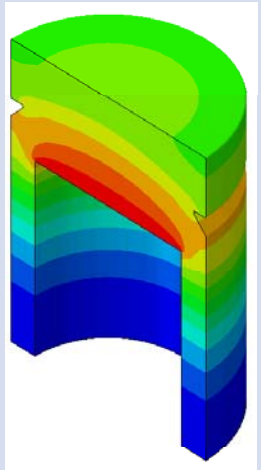




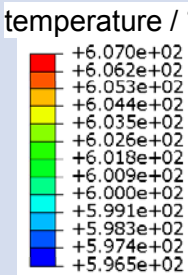
Step 2: Calculation of expansion and stress according to temperature profile

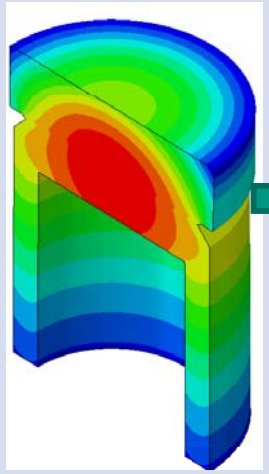
temperature during heating



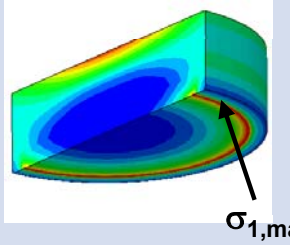


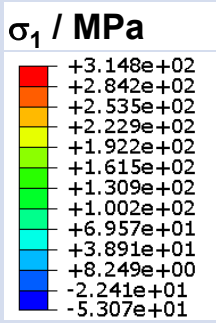
temperature during cooling

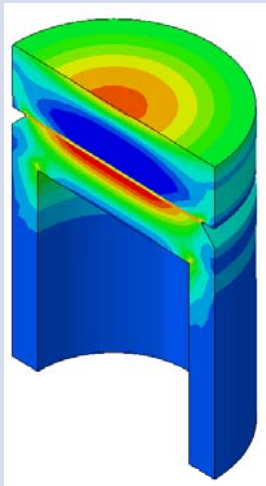




residual stress after brazing at RT

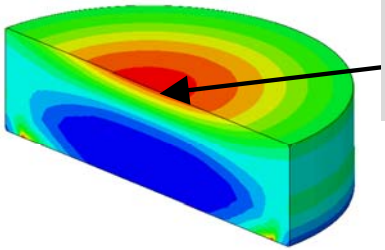






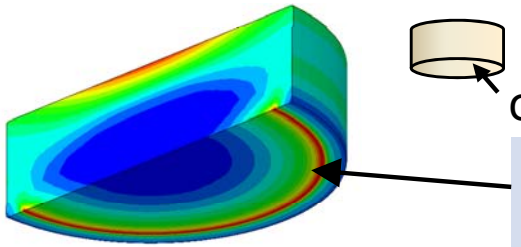
Residual stress σ_1 in ceramic pellet

influence of element size on residual stress



stress maximum at friction face

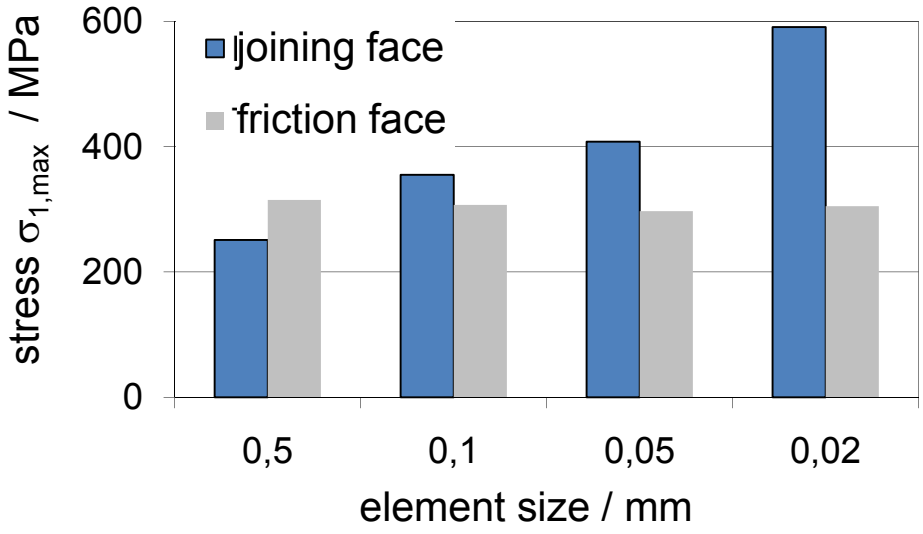
$\sigma_{1,T}$

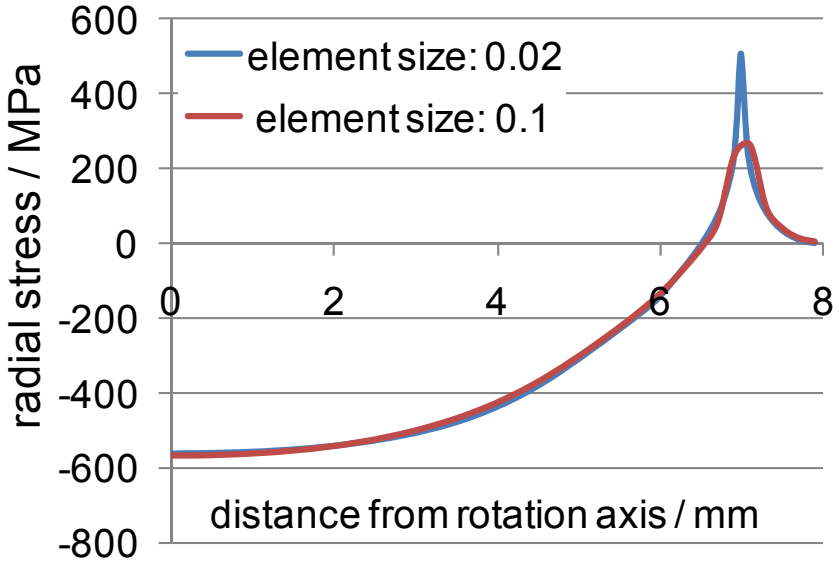


$\sigma_{1,F}$

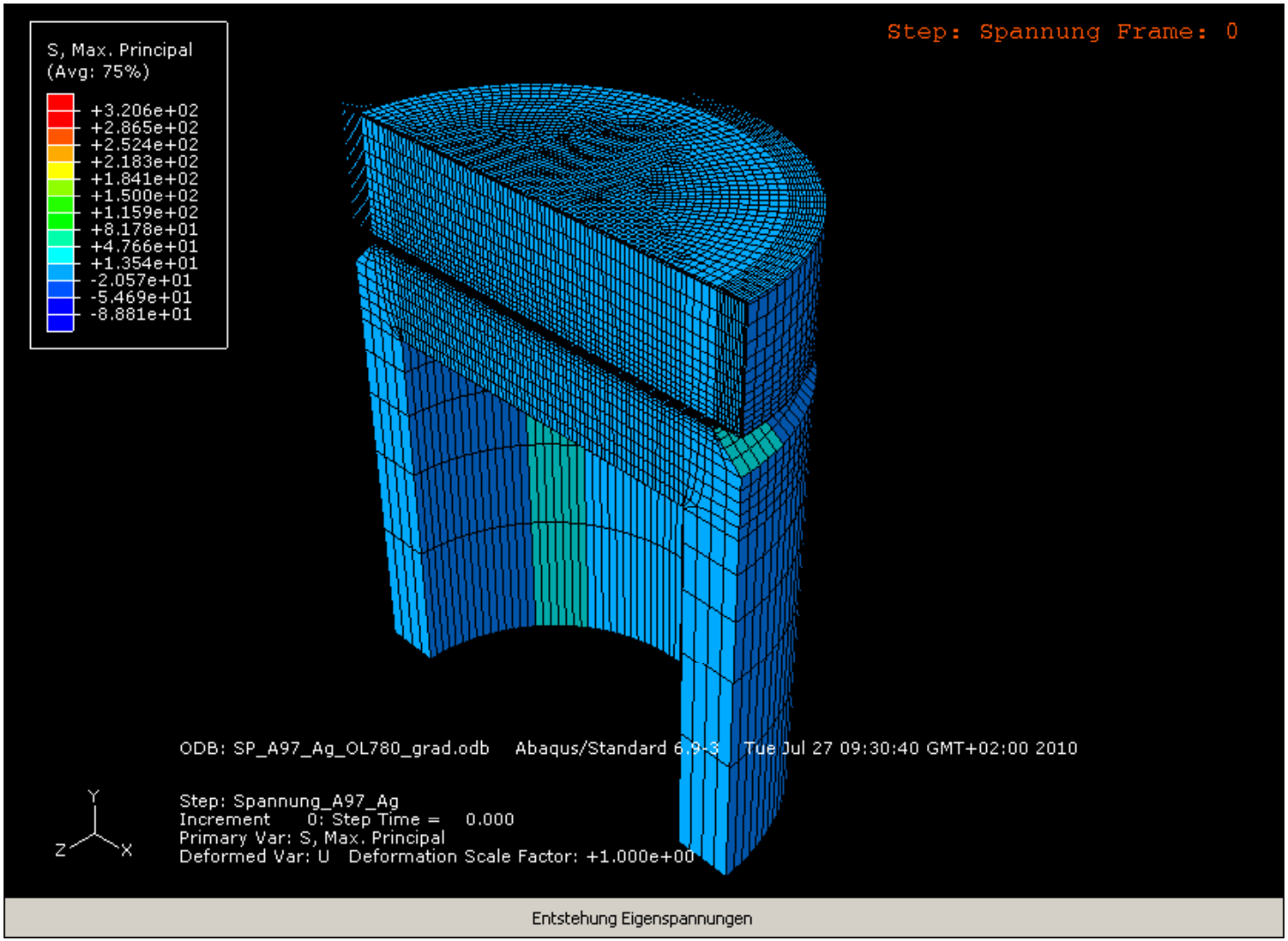
stress maximun at ^the joining face

influence of element size on residual stress

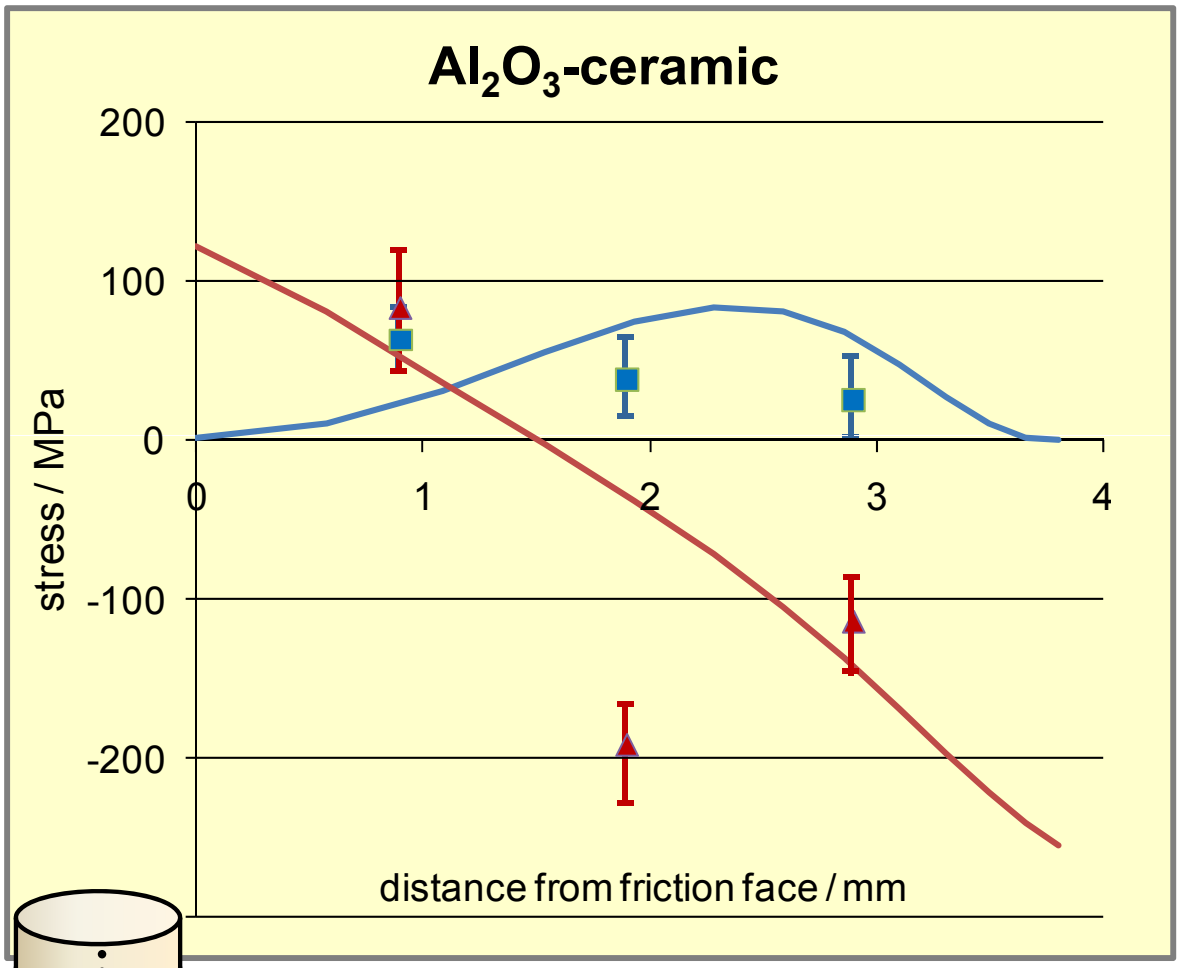


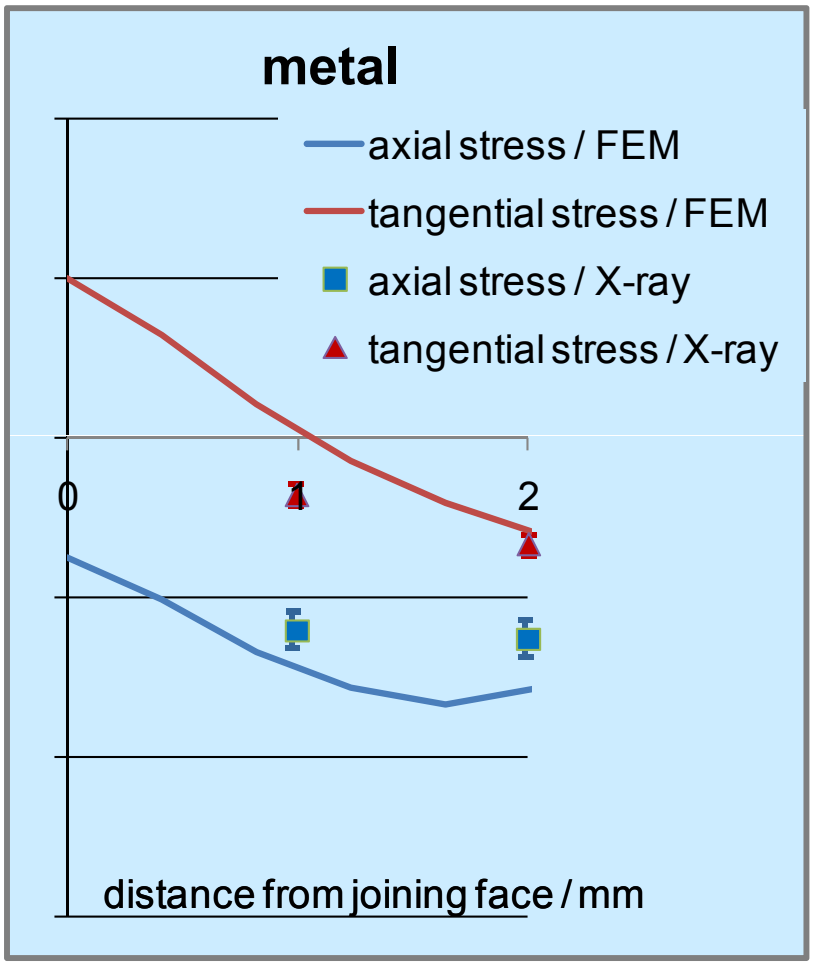


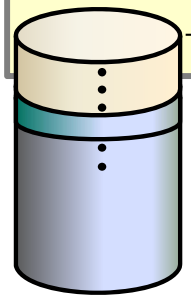
Residual stress σ_1 in ceramic pellet



Comparison residual stress FEM / X-ray measurement





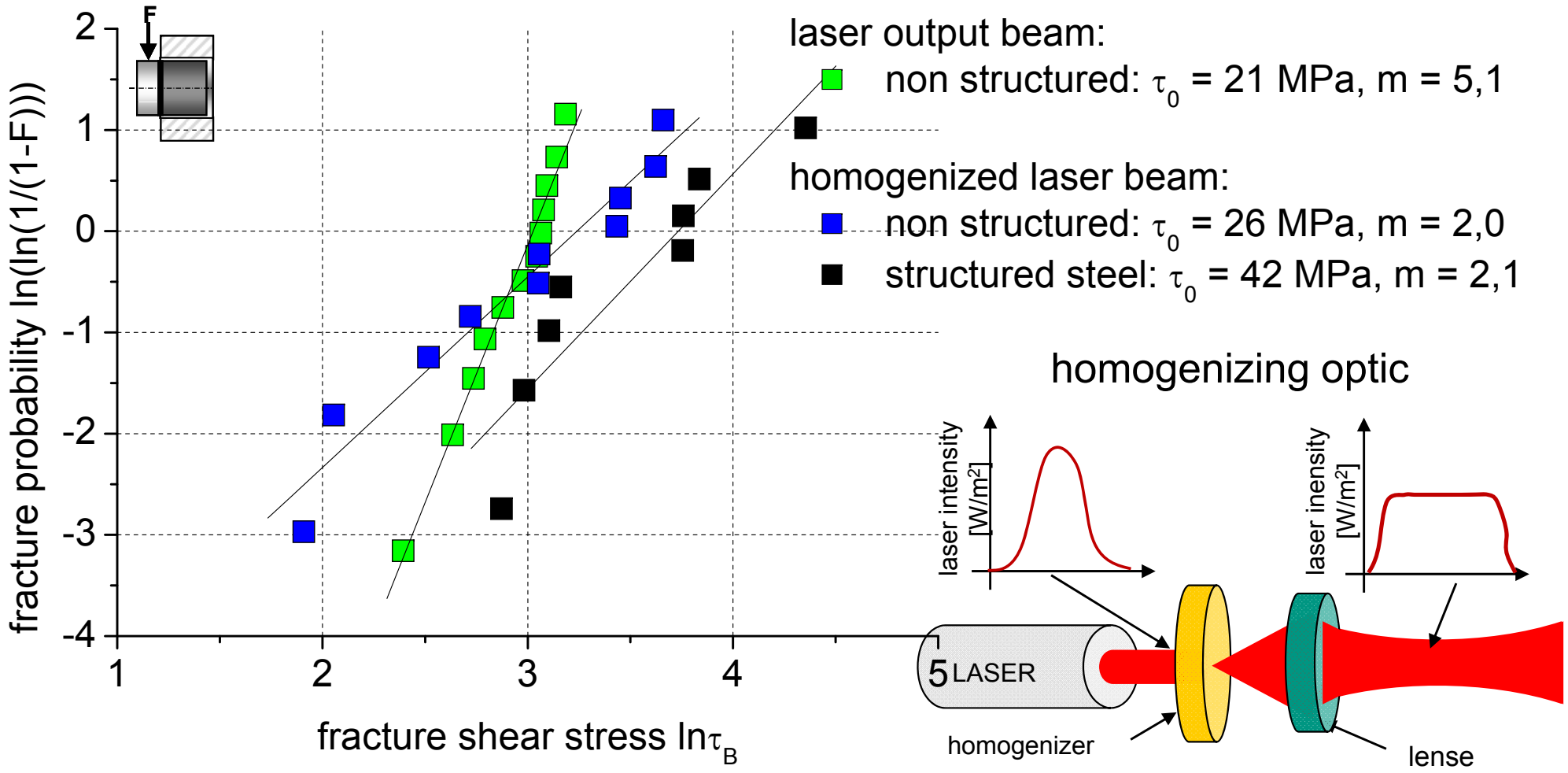


axial

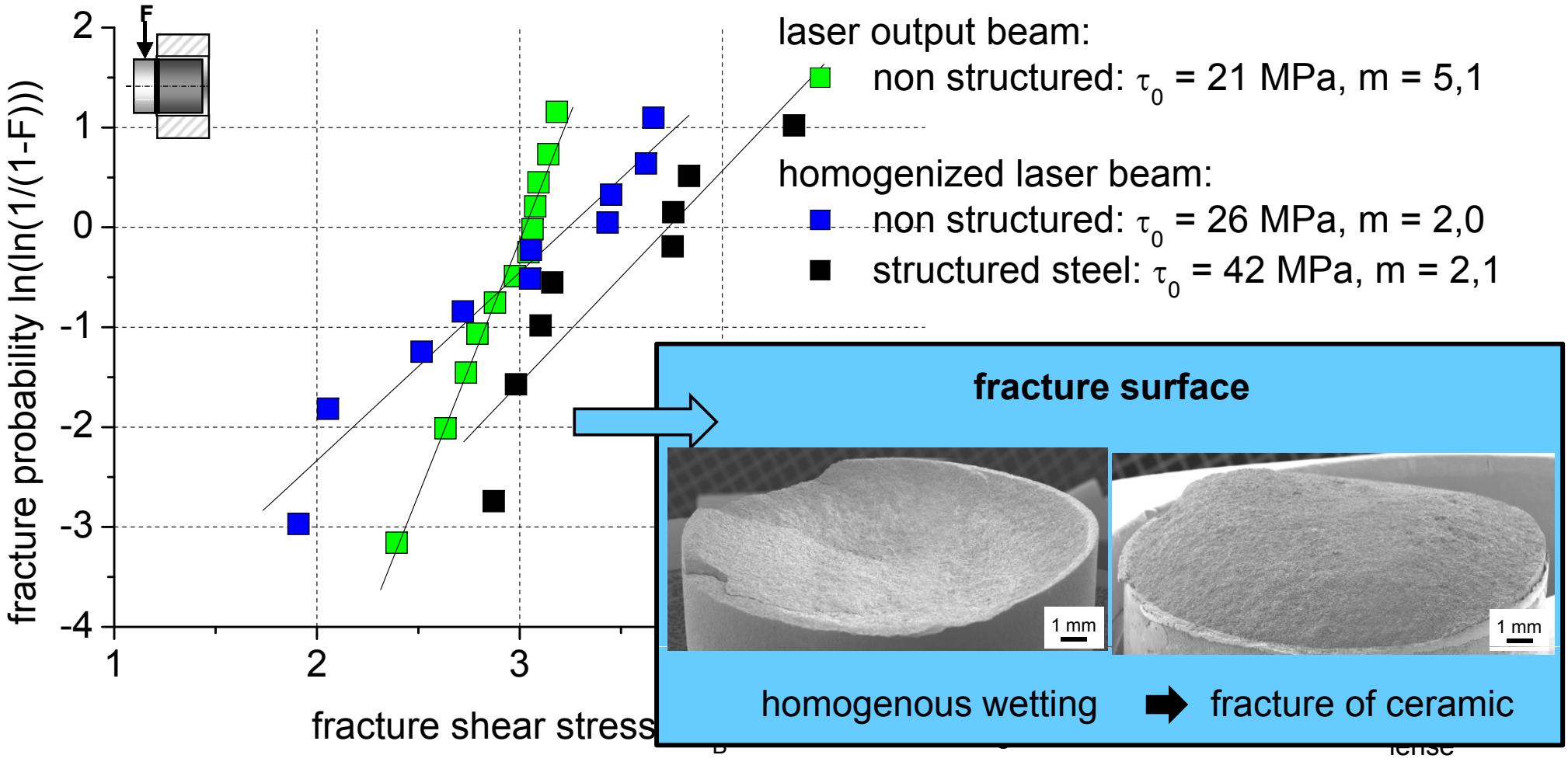
tangential

- textures in ceramics lead to large inhomogenites of x-ray signals
- general compliance of calculated and measured residual stresses

Shear strength of laser brazed Al_2O_3/AgCuInTi/steel-joints



Shear strength of laser brazed Al_2O_3/AgCuInTi/steel-joints



laser output beam:

- non structured: τ_0 = 21 MPa, m = 5,1

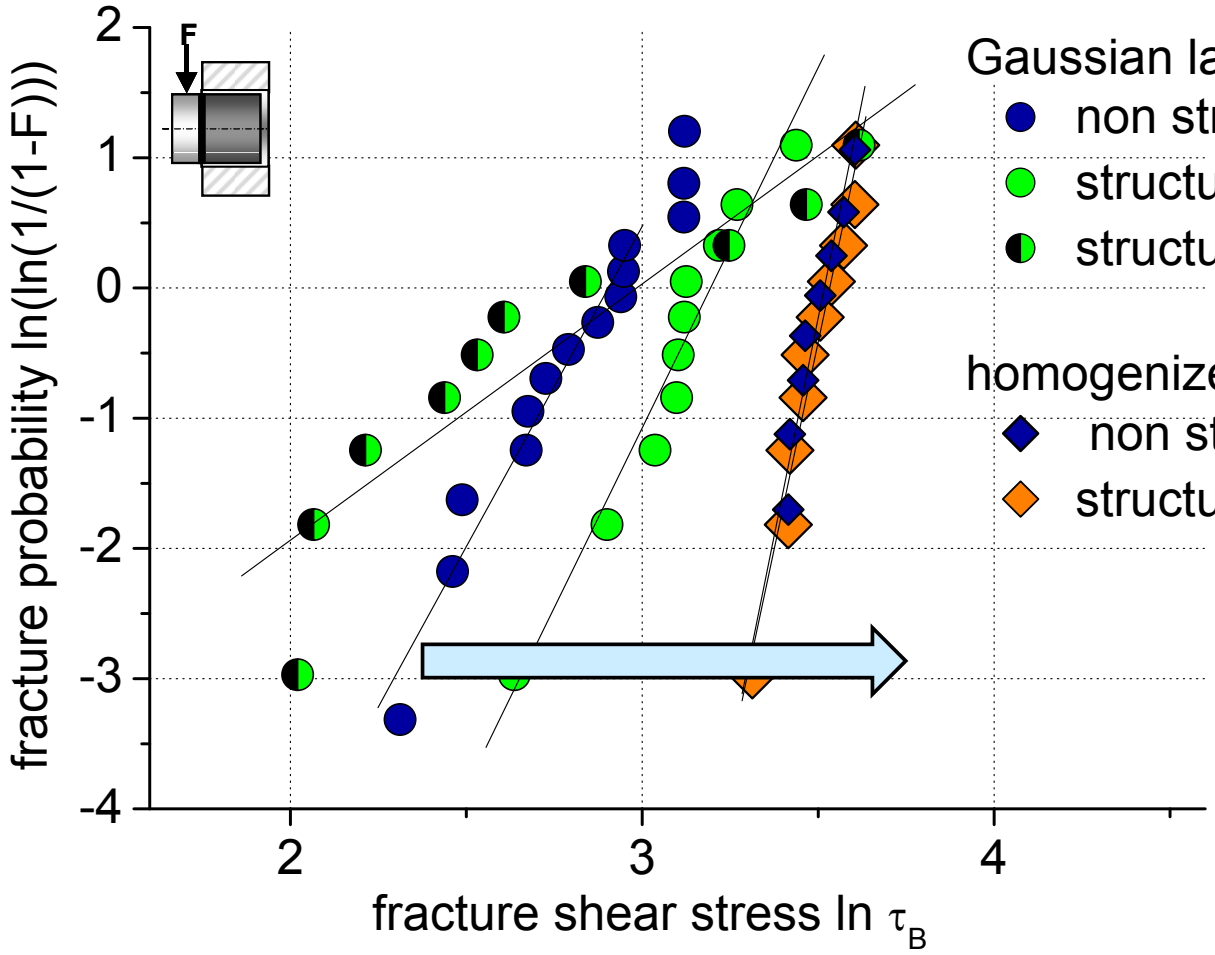
homogenized laser beam:

- non structured: τ_0 = 26 MPa, m = 2,0
- structured steel: τ_0 = 42 MPa, m = 2,1

fracture surface

homogenous wetting ➡ fracture of ceramic

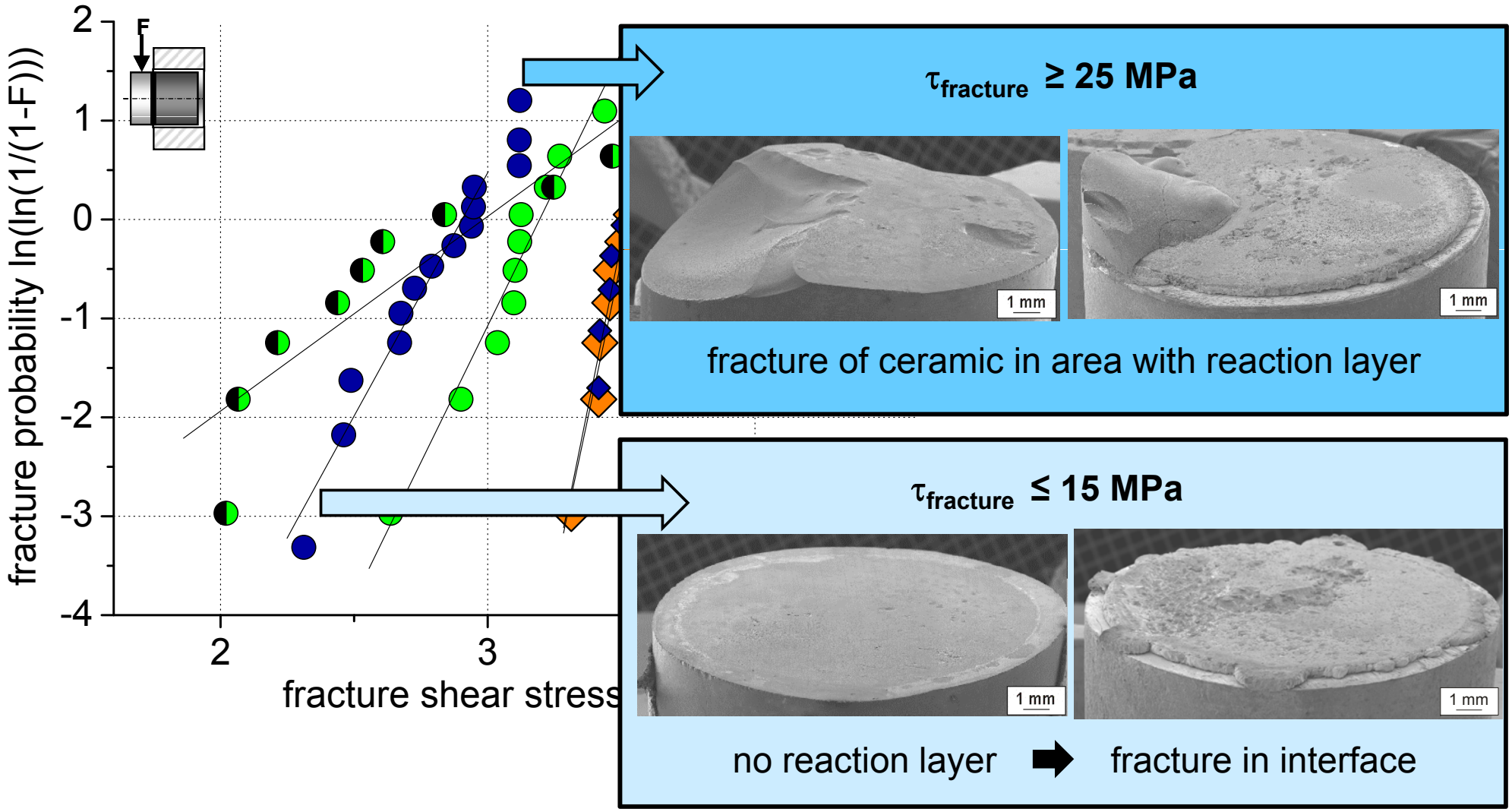
Shear strength of laser brazed SiC/SnAgTi/steel-joints



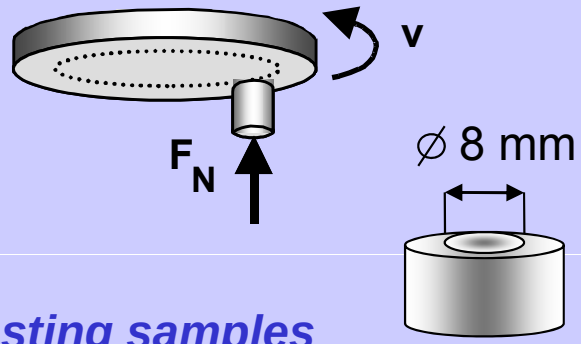
Gaussian laser beam
- non structured: τ_0 = 19 MPa, m = 4.9
- structured SiC: τ_0 = 24 MPa, m = 5.1
- structured steel: τ_0 = 20 MPa, m = 2.1

homogenized laser beam
- non structured: τ_0 = 34 MPa, m = 13.3
- structured steel: τ_0 = 35 MPa, m = 12.7

Shear strength of laser brazed SiC/SnAgTi/steel-joints



Tribological testing

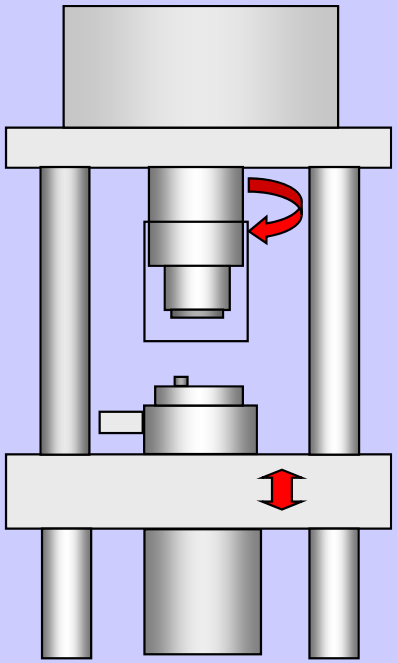


testing samples

disc steel AISI 1045(normalized), 206 HV30

pin Al_2O_3 : monolithic, brazed

SSiC: monolithic

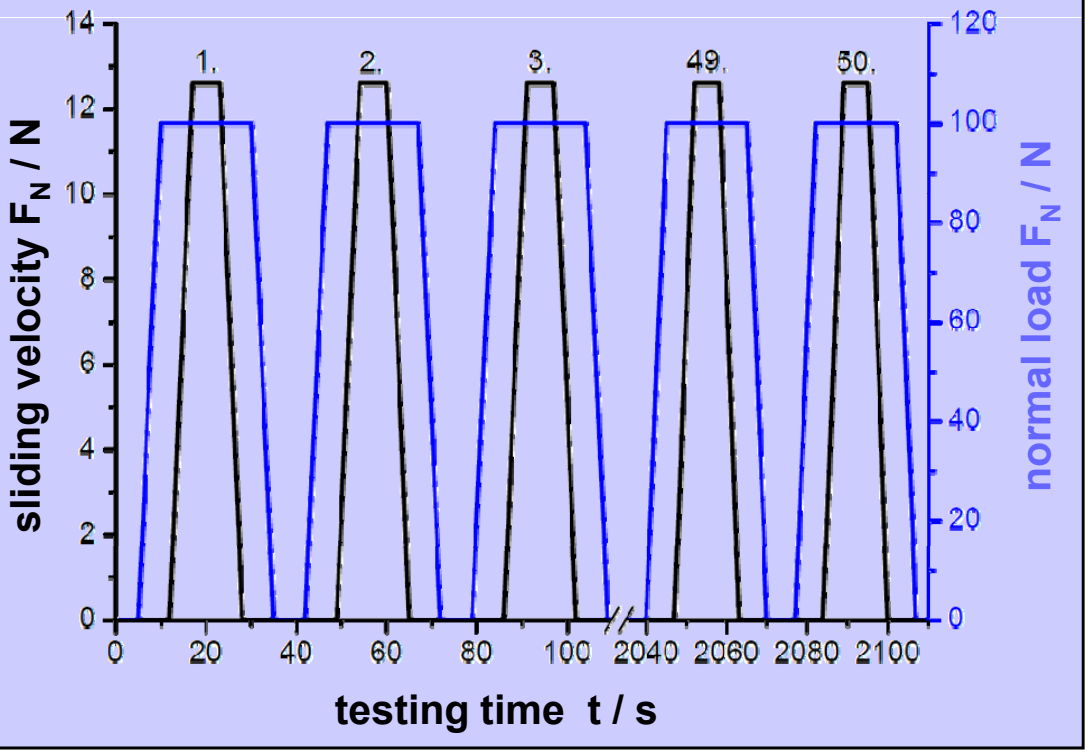


F_N = 100 N (2 MPa)

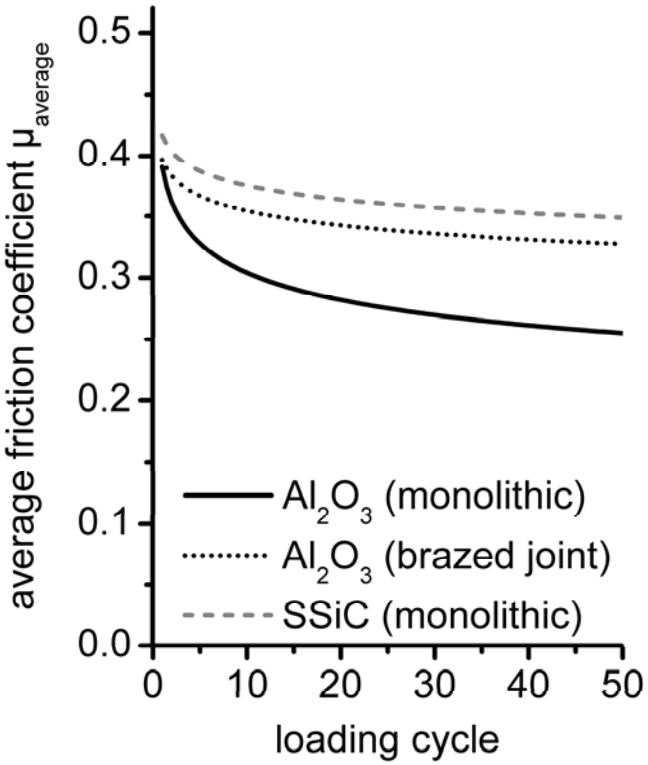
air, rel. hum.50%

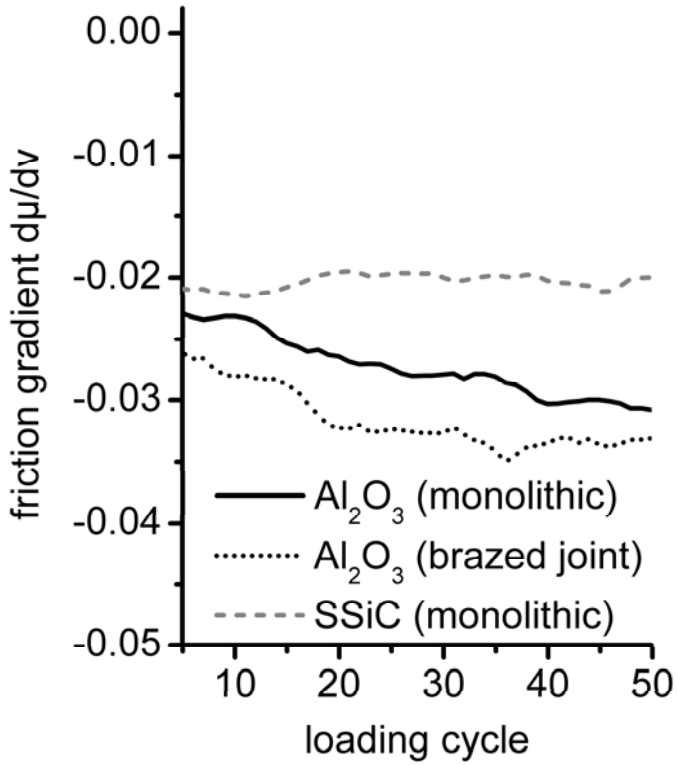
50 cycles (≙ 6300 m)

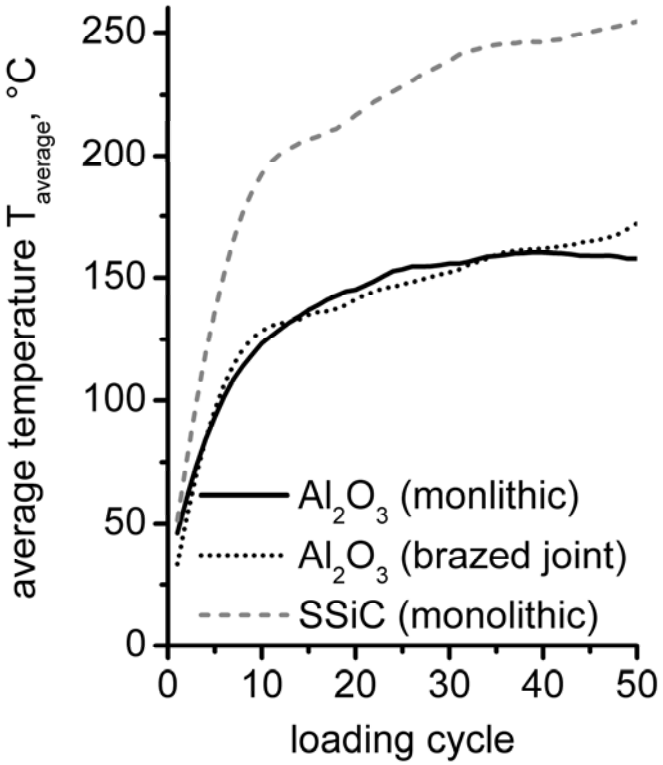
- loading
- 5 s ramp
- 5 s holding
- 5 s slow down
- unloading
- 5 s pause
- ...



Tribological testing







conclusions

- no reproducable wetting of SiC with AgCuTi-filler
- good wetting of SiC was only achieved with SnAgTi-fillers for Sn fraction ≥ 30wt%

  but inhomogenous Ti-rich reaction layer
- increase of compound strength of ceramic/steel joints with homogenizing optic
  - SiC/SnAgTi/steel-joints: from 20 MPa (m = 5) to 35 MPa (m = 12)
  - Al_2O_3/AgCuInTi/steel-joints: from 20 MPa (m = 5) to 42 MPa (m = 2)
- measurement of residual stress in Al_2O_3/AgCuInTi/steel-joints difficult, but possible

  ➡ general compliance of measured and calculated stress
- influence of brazing layer on tribological behaviour
- improvement of the Ti rich reaction zone necessary
- further investigations of residual stresses for improvement of joint strength

Thank you for your attention!

The authors thank the Deutsche Forschungsgemeinschaft for suppporting the Sonderforschungsbereich 483 „High performance sliding and friction systems on the basis of engineering ceramics“.