Investigations on thermal, mechanical and tribological properties of ceramic/steel-joints

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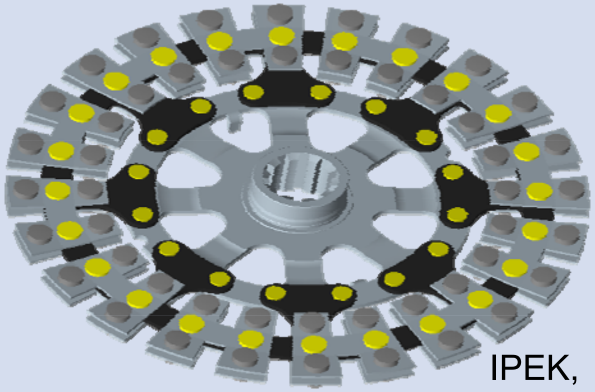
- motivation
- material properties
- results
  - microscopic compound analysis
  - shear testing
  - tribological testing
- conclusion

Motivation

Tribological application	Laser brazing	Mechanical characterisation

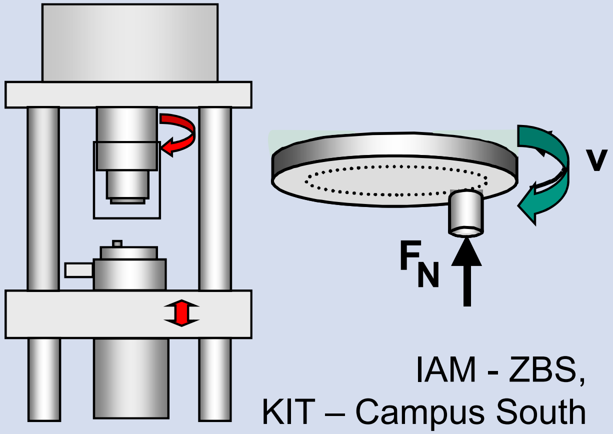
Tribological application

dry running clutch system



IPEK,
KIT – Campus South

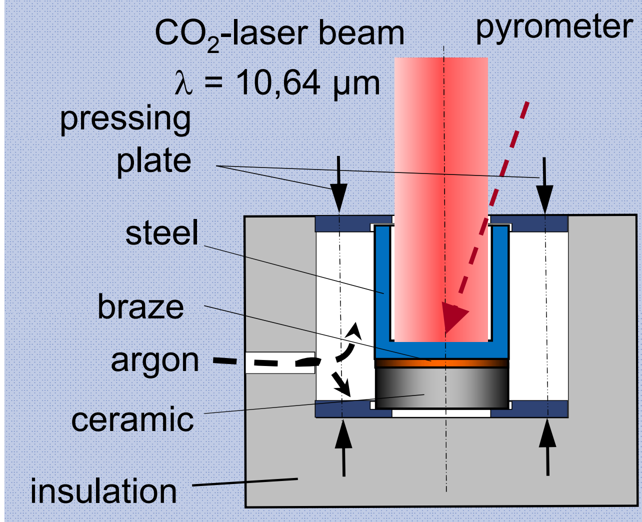
pin-on-disc experiment



IAM - ZBS,
KIT – Campus South

Laser brazing

process arrangement



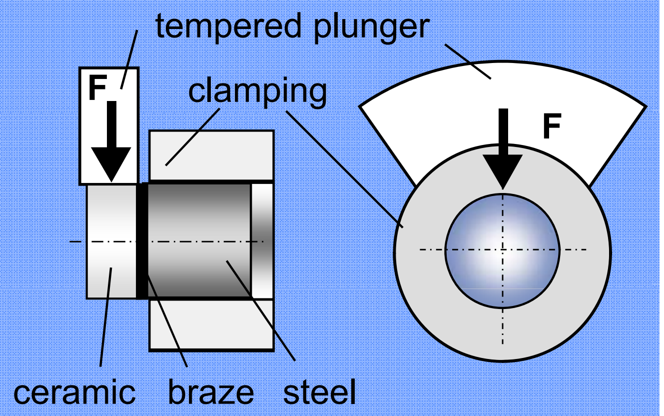
IAM-AWP, KIT – Campus North

process conditions

- laser output beam
- Argon stream ≥ 400 Nl/h
- pressure p ≥ 2 MPa
- temperature measurement

Mechanical characterisation

shear strength



Shear strength

$$\tau = \frac{P_F}{\pi \cdot R^2}$$

P_F: Fracture load

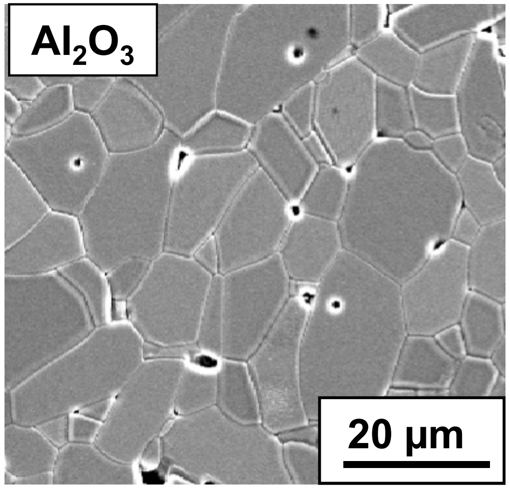
R: sample radius

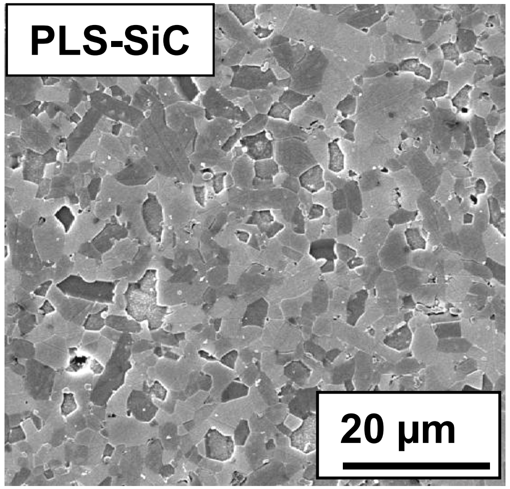
τ: fracture stress

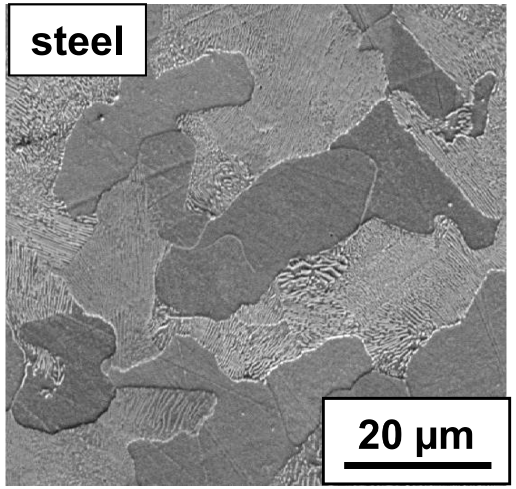
m: Weibull modulus m

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	-

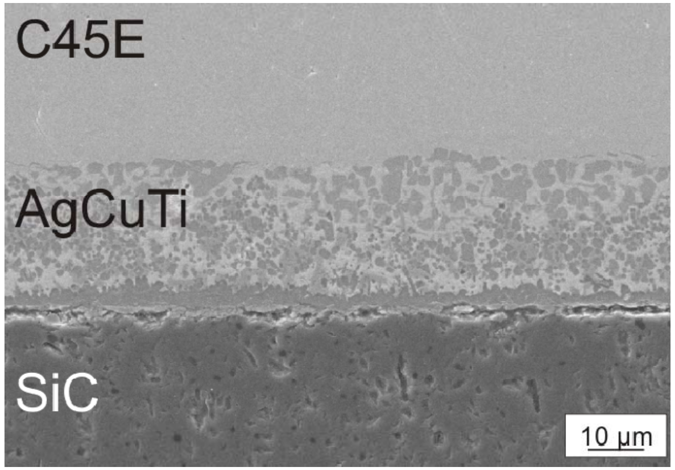




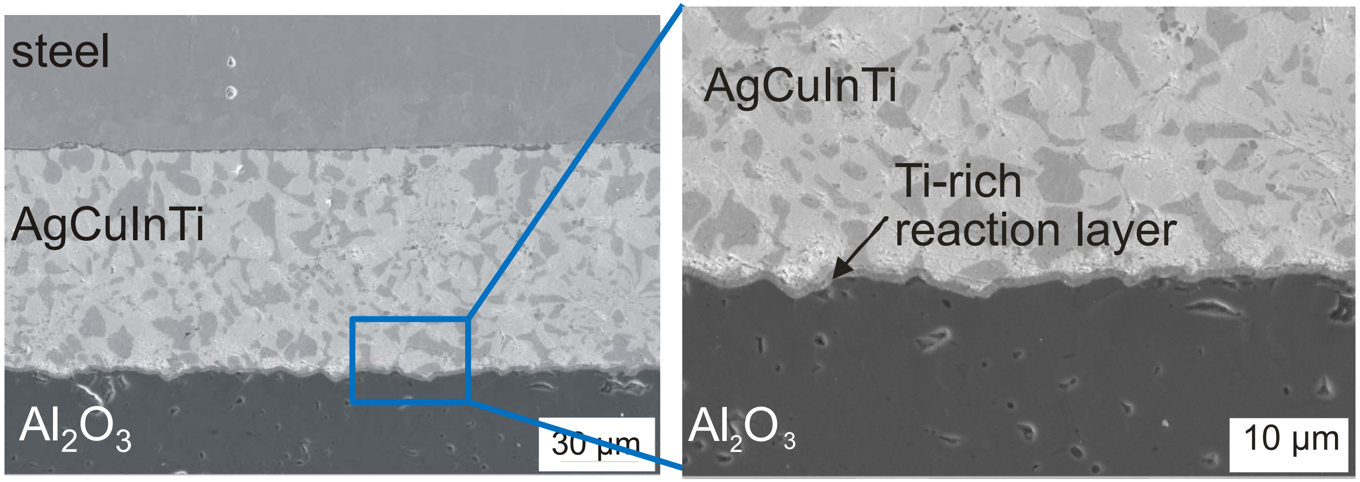


SEM-images of ceramic/AgCuTi/steel-joints

SiC-AgCuTi-steel



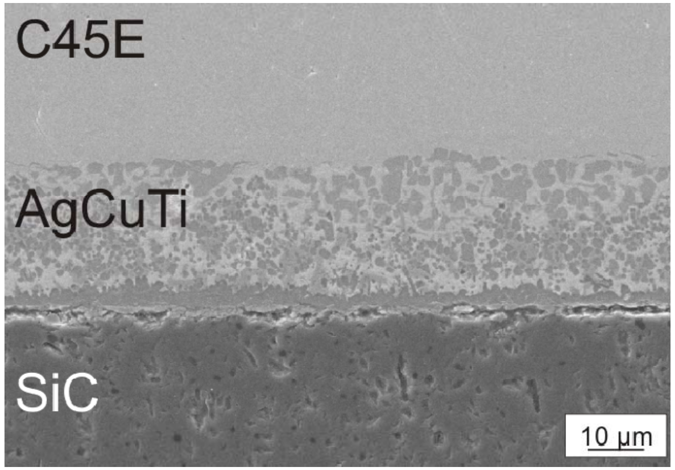
Al_2O_3 / AgCuTi / steel



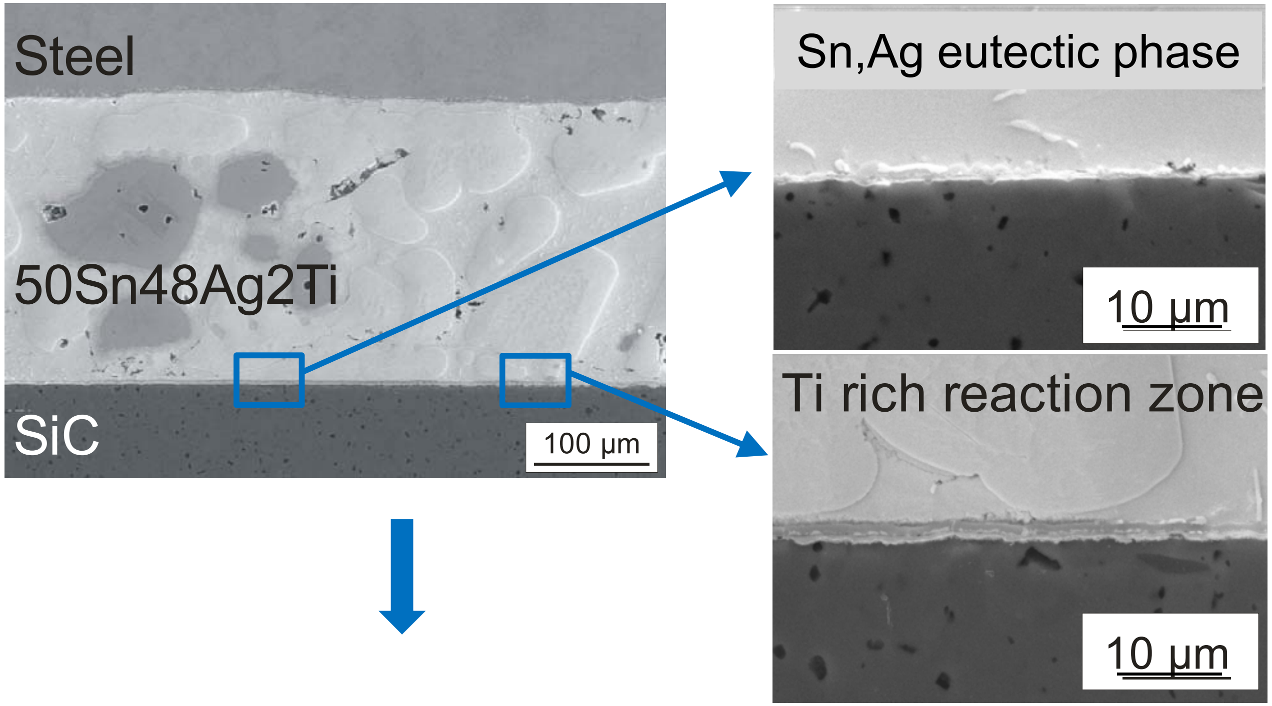
- inhomogeneous or no wetting for AgCuTi- and AgCuInTi-brazing filler on SiC despite a explicit Ti rich reaction zone
- homogenous, seamless wetting and Ti-reach reaction zone on Al_2O_3 with AgCuTi- and AgCuInTi-filler

SEM images of SiC-steel joints

SiC-AgCuTi-steel



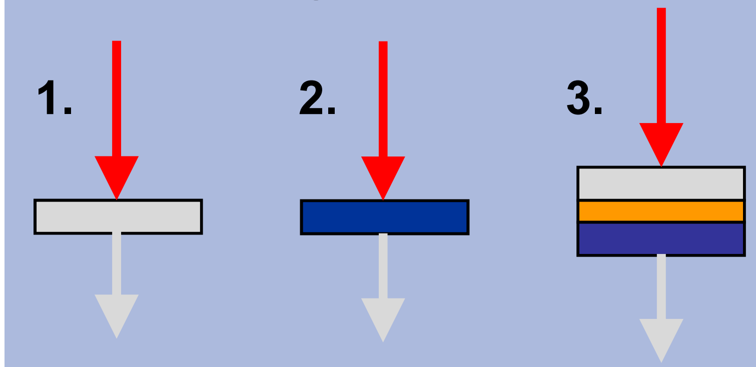
50Sn48Ag2Ti



- good seamless wetting for SnAgTi-alloys with Sn ≥ 30wt% above T ≥ 900°C
- thin, inhomogeneous Ti rich reaction zone
- large Ti-particles in inner braze region

Thermal resistance of ceramic-steel joints

measuring principle of LFA



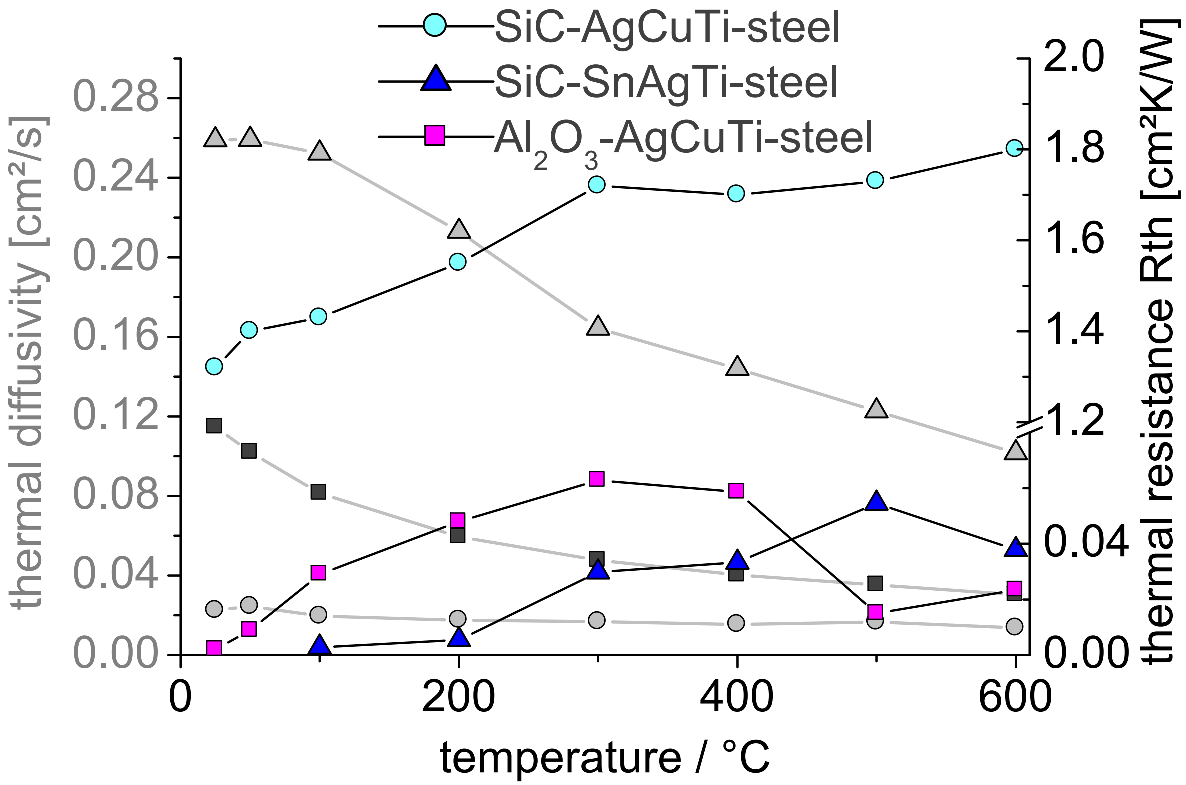
measuring of T = f(t) ➡ α(T)

$$\lambda = \alpha \cdot c_P \cdot \rho$$

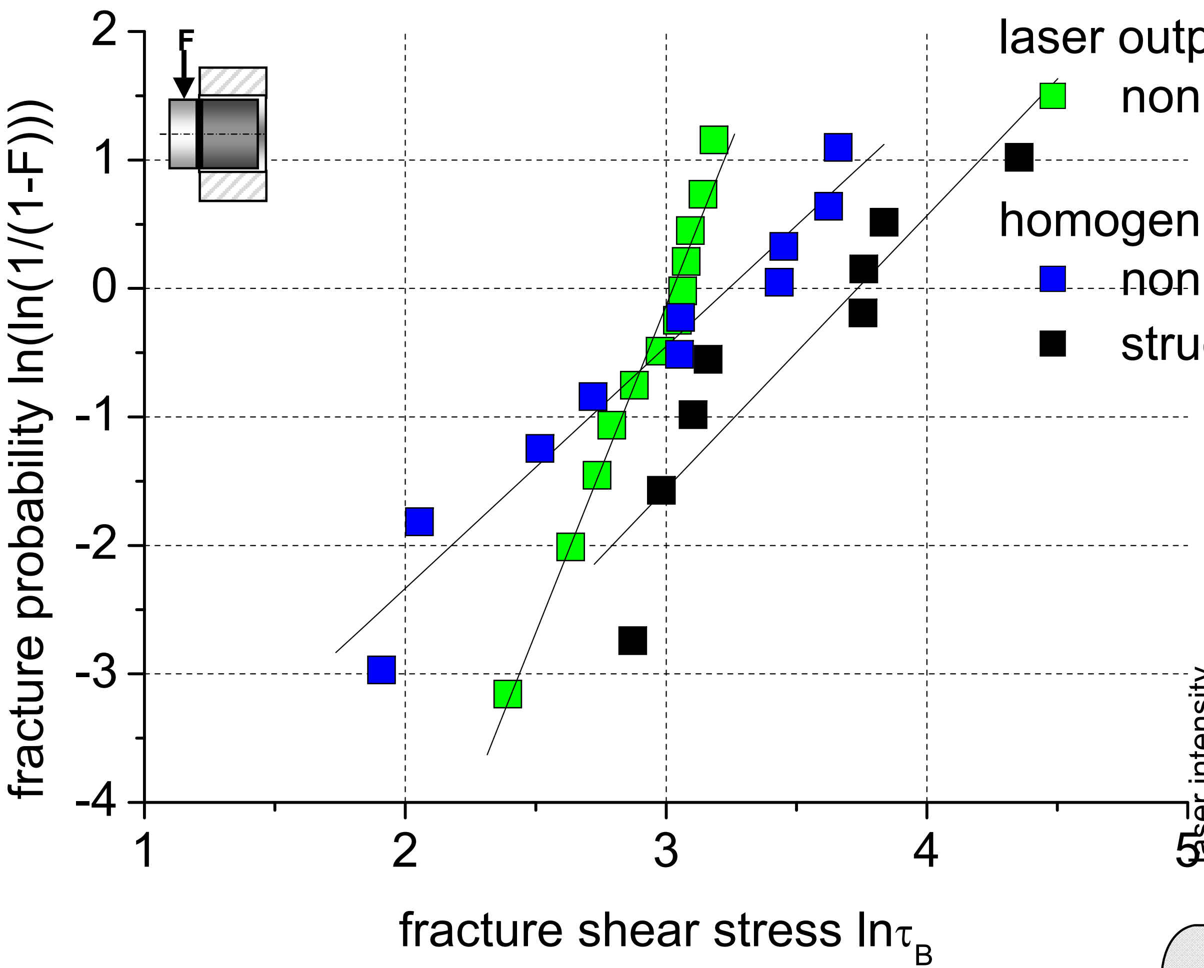
calculation of R_{th}

$$\frac{s_{joint}}{\lambda_{joint}} = \frac{s_{ceramid}}{\lambda_{ceramic}} + \frac{s_{steel}}{\lambda_{steel}} + \underbrace{\frac{s_{interface}}{\lambda_{interface}}}_{R_{th}}$$

thermal diffusivity and thermal resistance of brazed joints



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



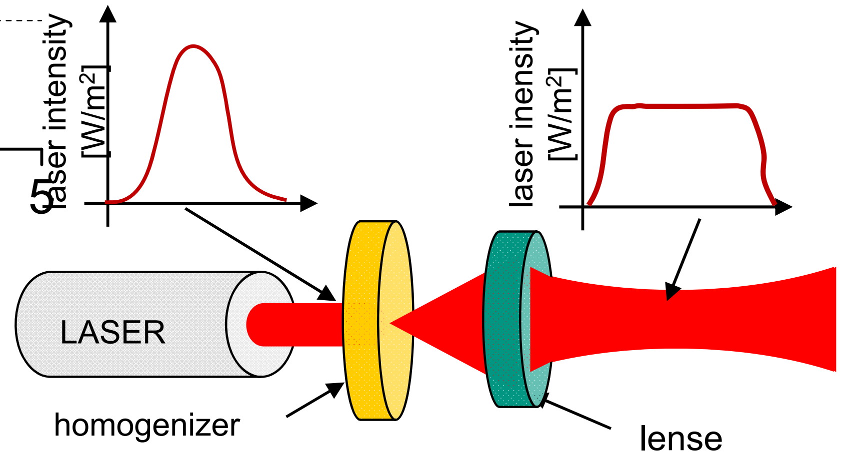
laser output beam:

- 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

homogenizing optic



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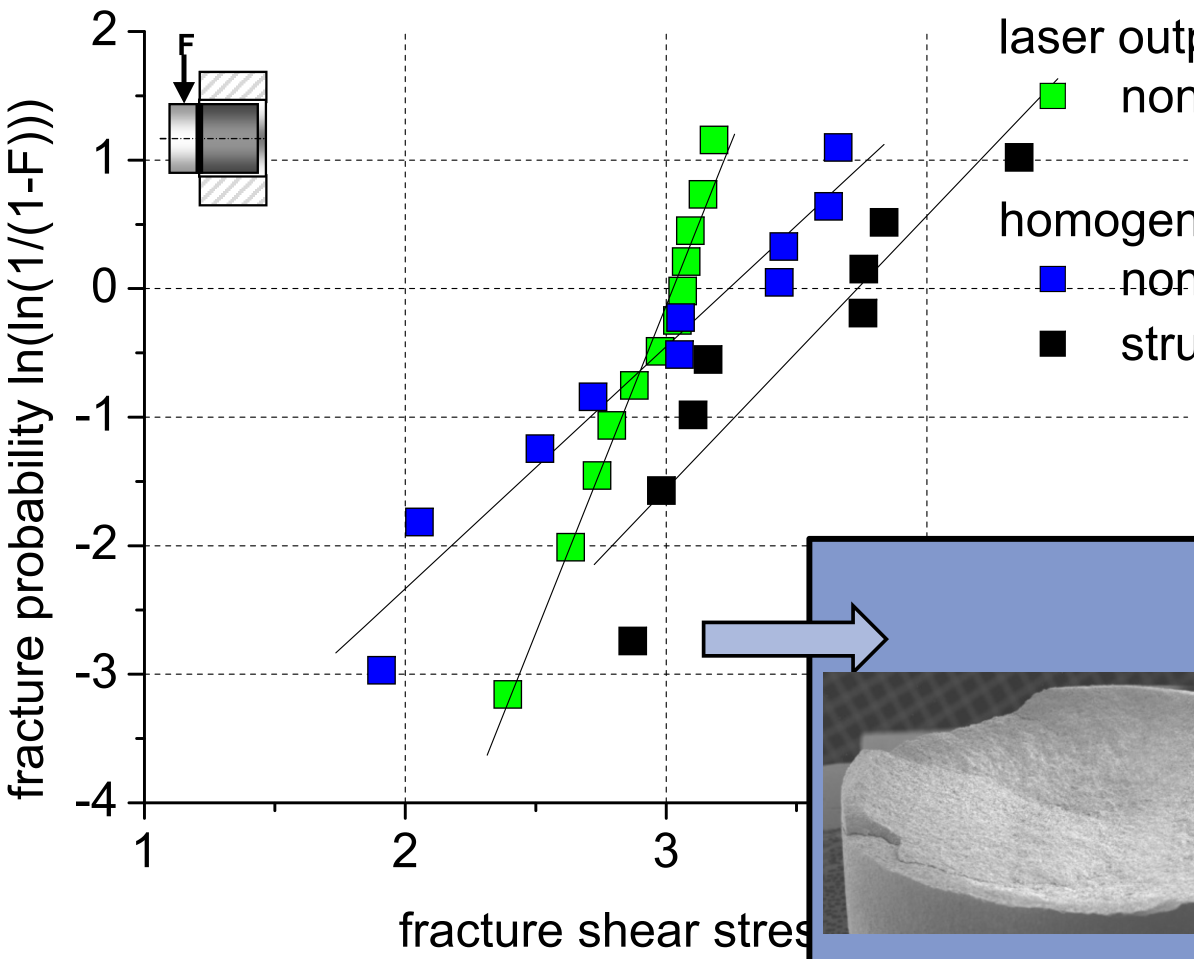

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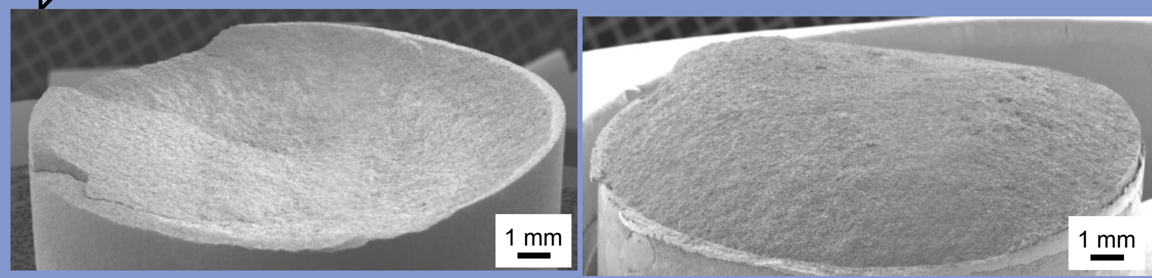
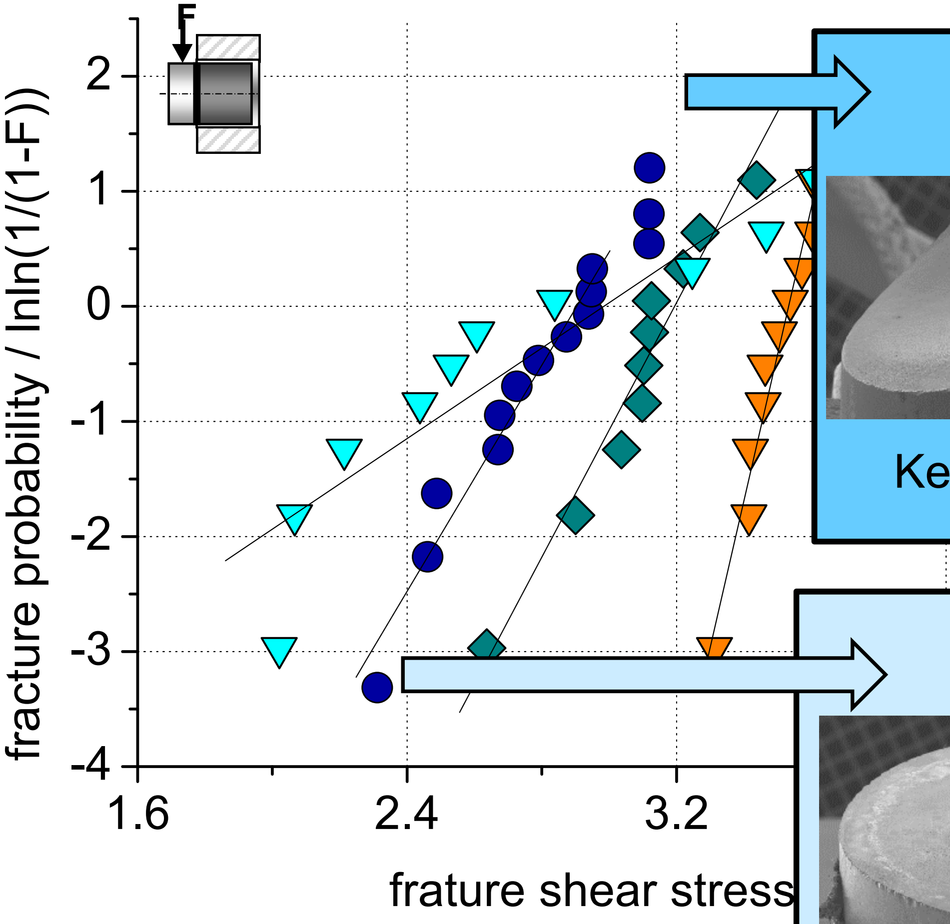
fracture surface



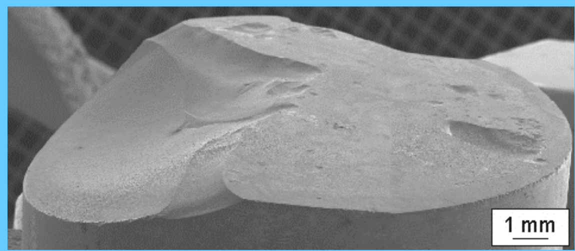
homogeneous wetting ➡ fracture of ceramic

Shear tests of laser brazed SiC-SnAgTi-steel joints

variation laser beam profile

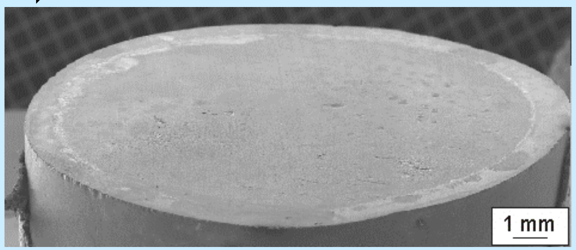


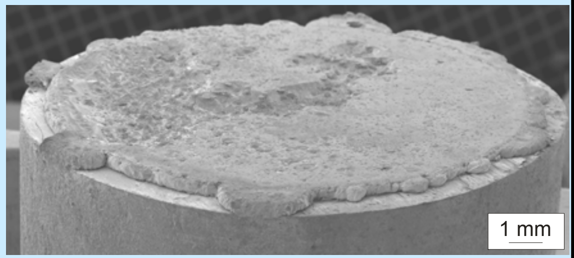
τ_{Bruch} ≥ 25 MPa



Keramikbruch in Bereichen mit Reaktionsschicht

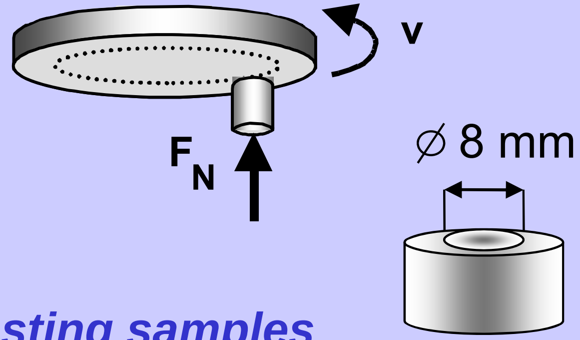
τ_{Bruch} ≤ 15 MPa





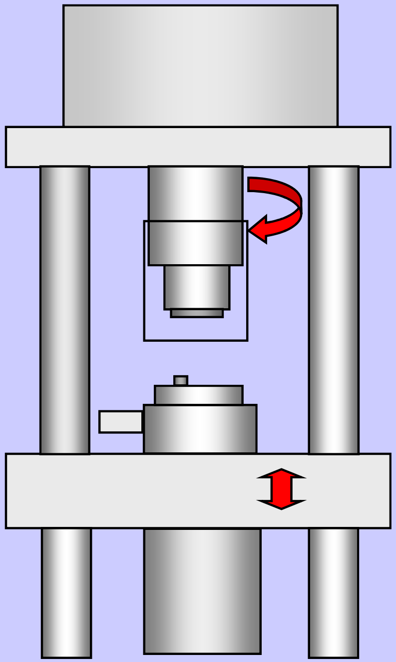
Keine Reaktionsschicht ➡ Bruch in der Grenzfläche

Tribological testing



testing samples

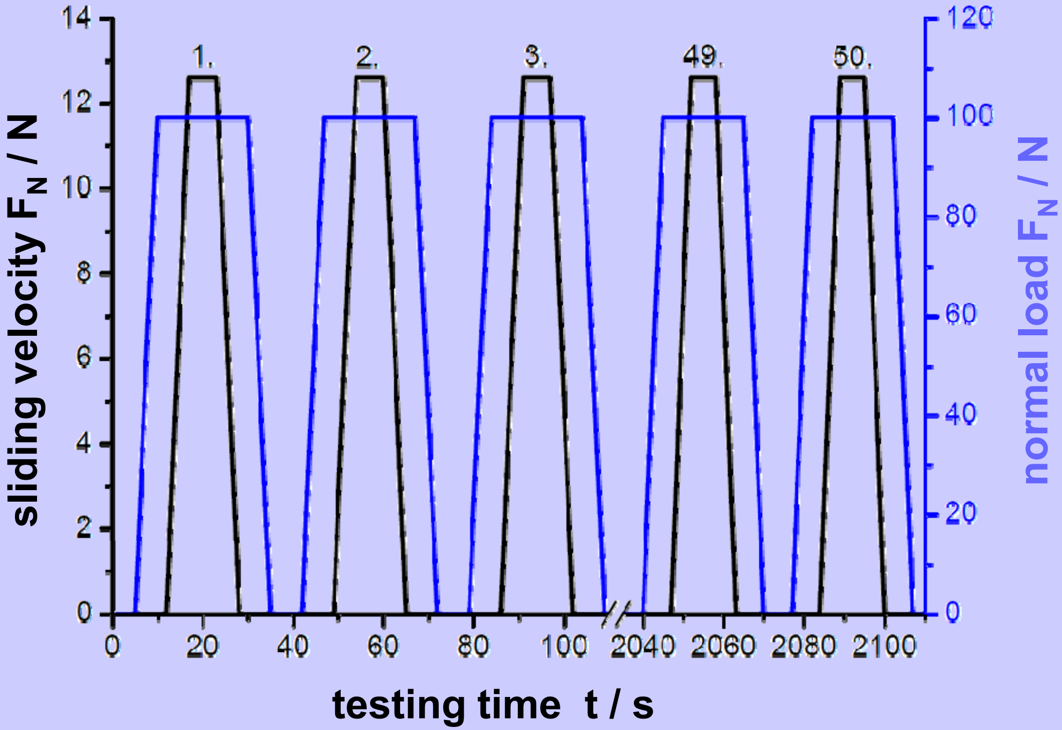
disc	steel AISI 1045 (normalised), 206 HV30
pin	Al_2O_3 : monolithic, brazed
	PLS-SiC : monolithic, brazed



F_N = 100 N (2 MPa)

air, rel. hum.50%

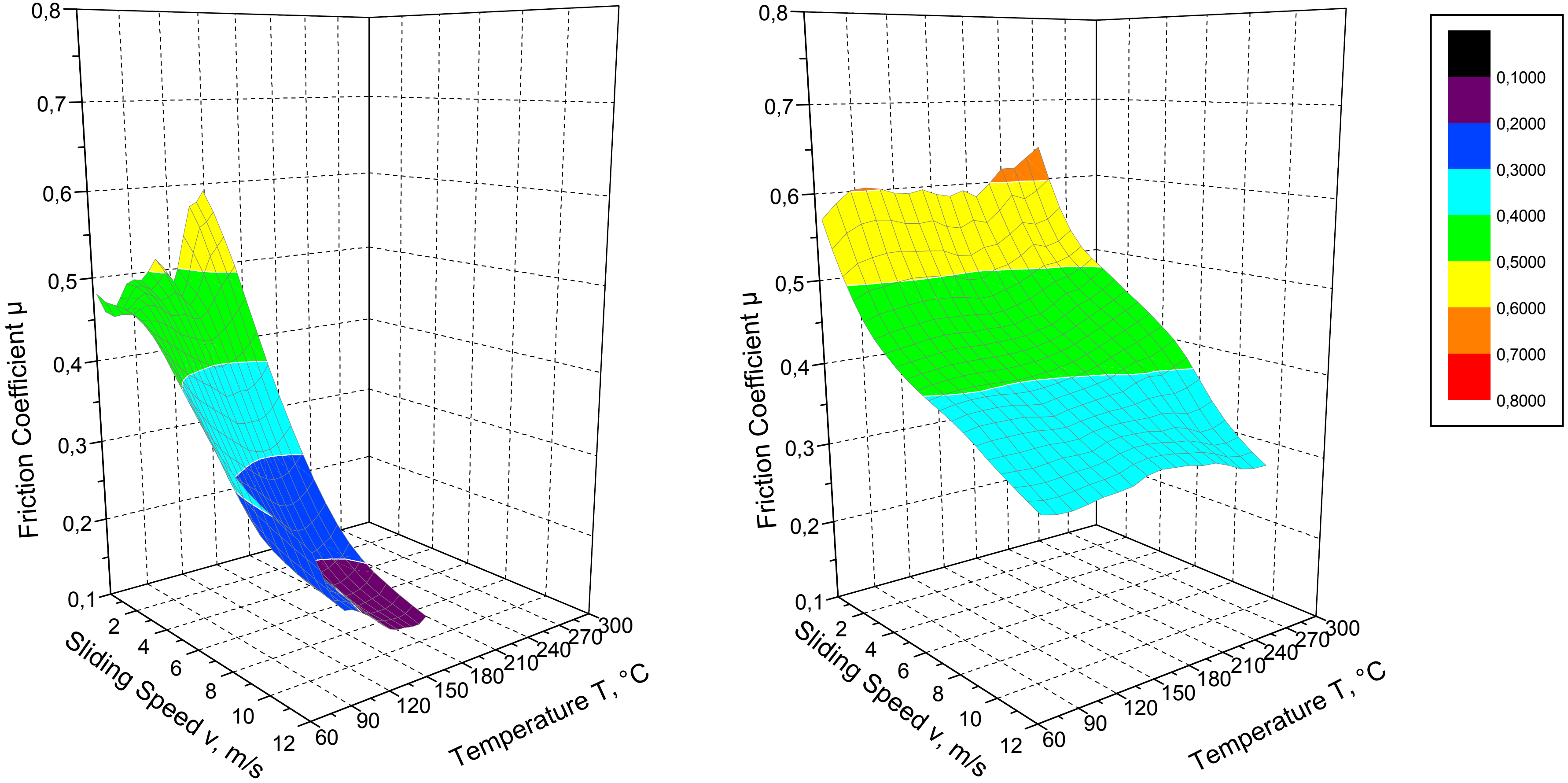
50 cycles (≙ 6300 m)
- loading
- 5 s ramp
- 5 s holding
- 5 s slow down
- unloading
- 5 s pause
- ...



Tribological characterisation of Al_2O_3 and PLS-SiC

Al_2O_3 / steel

PLS-SiC / steel

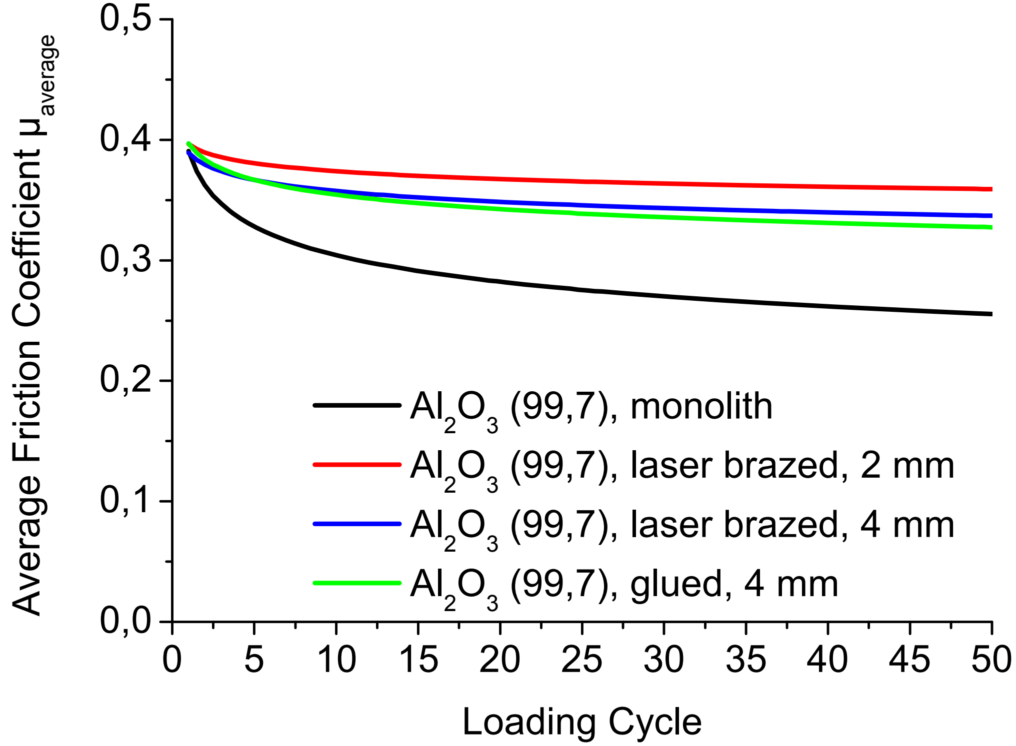


- PLS-SiC exhibits compared to Al_2O_3
  - a higher friction coefficient,
  - a lower and more constant friction gradient and
  - the highest temperatures.

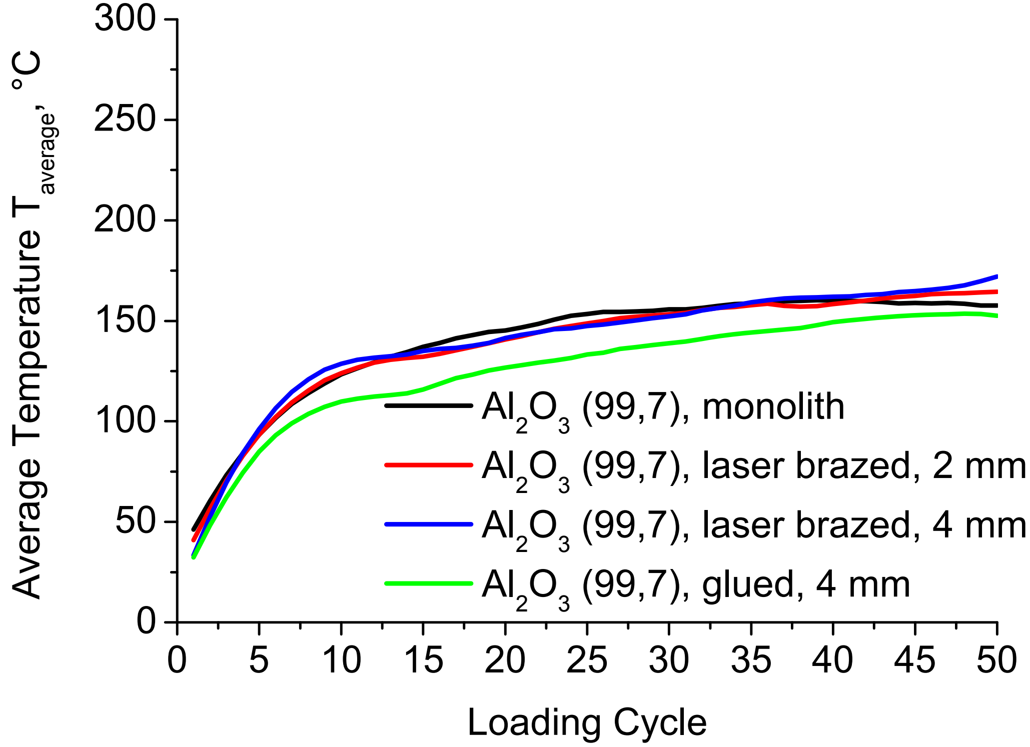
Tribological characterisation

Al_2O_3/steel-joints

average friction coefficient $\mu_{average}$



average temperature $T_{average}$

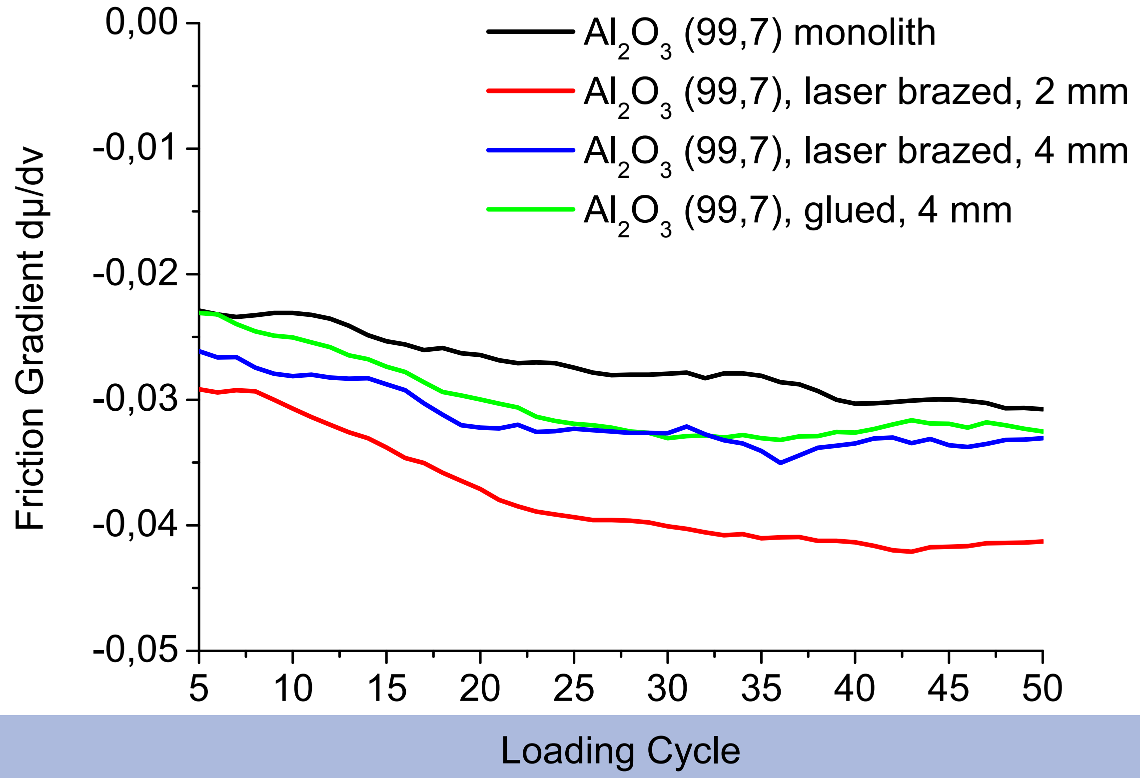


- **Al_2O_3-joints exhibit higher average friction coefficients than the Al_2O_3-monolith.**
- **only few differences of average temperature between monolith and joint**

Tribological characterisation

Al_2O_3/steel-joints

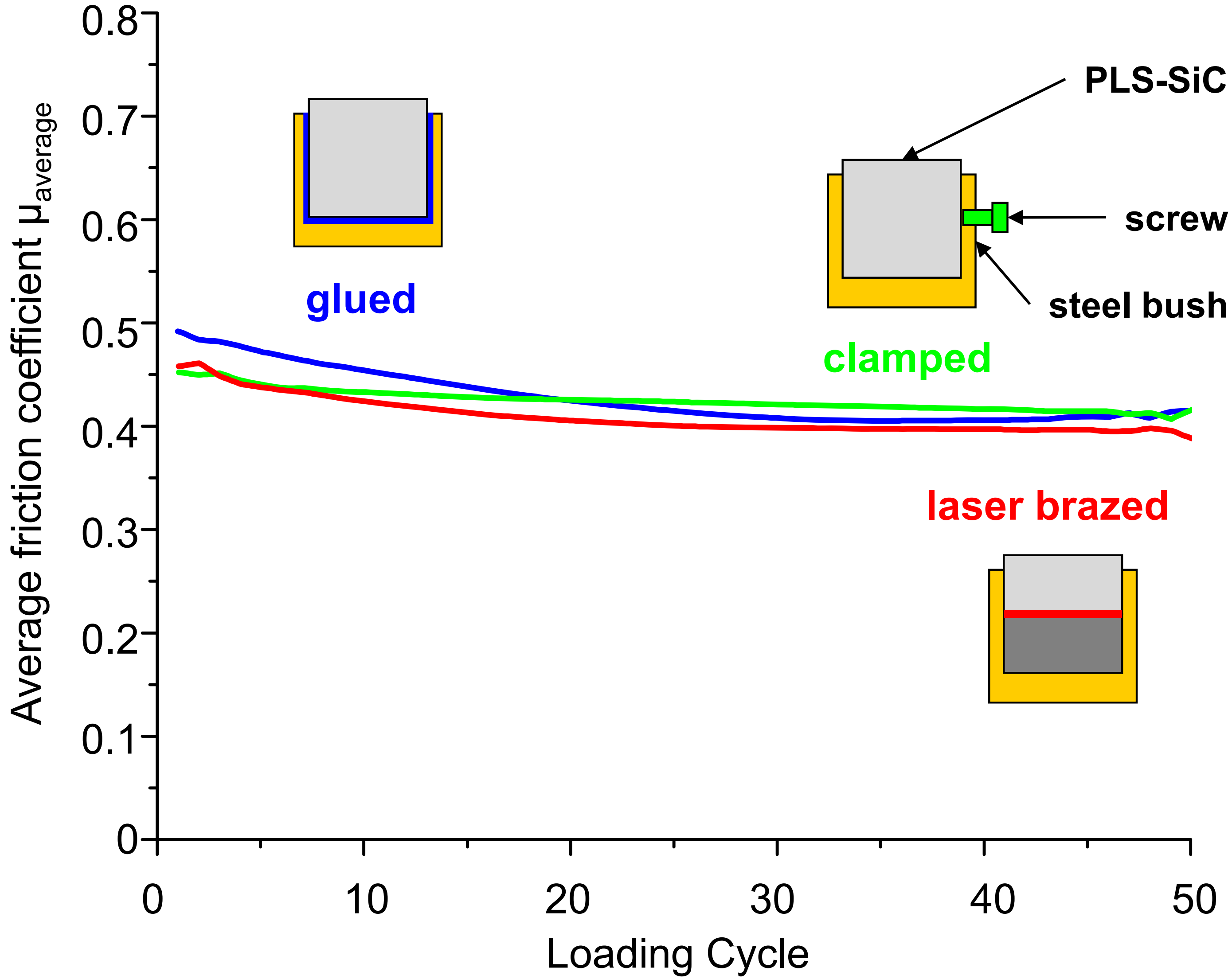
friction gradient dμ/dv



- **Al_2O_3-monolith exhibits the lowest friction gradient dμ/dv compared to Al_2O_3-brazing joints.**

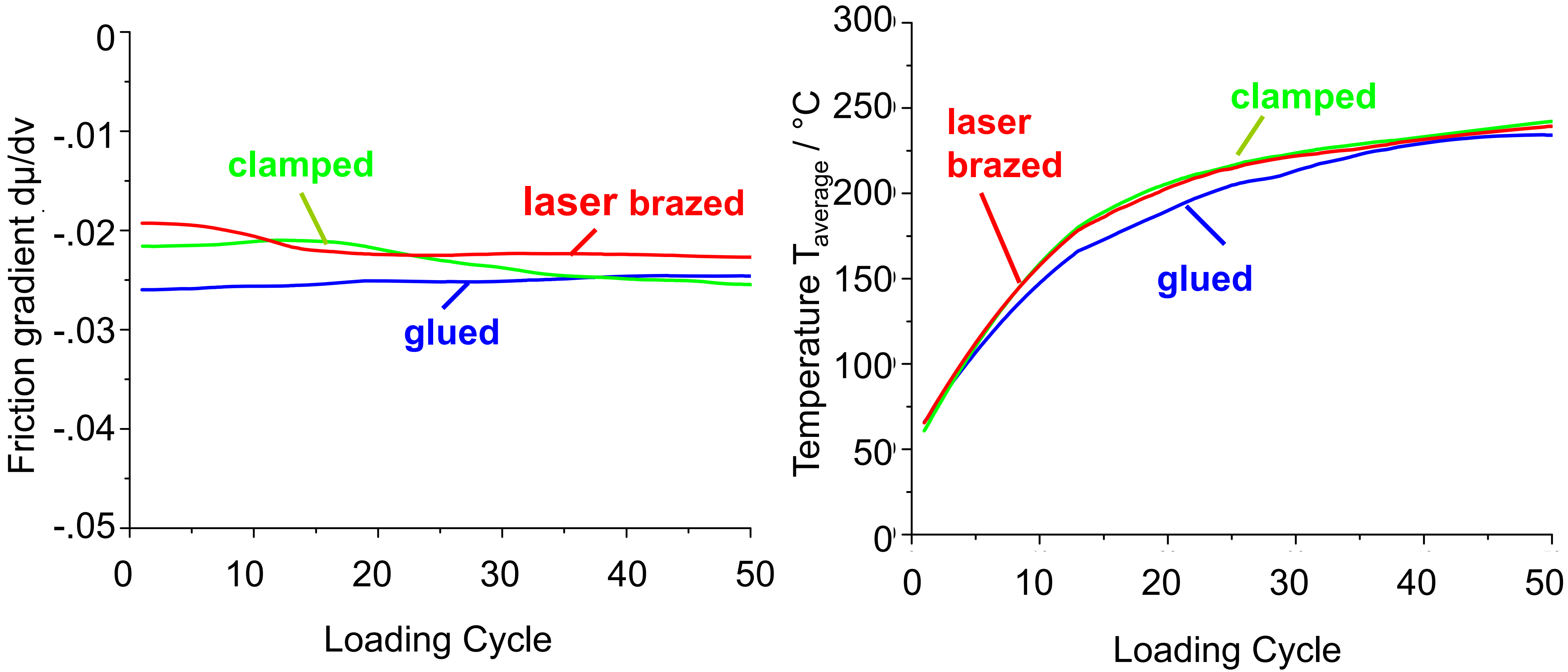
Tribological characterisation

PLS-SiC/steel-joints: variation of joining technique



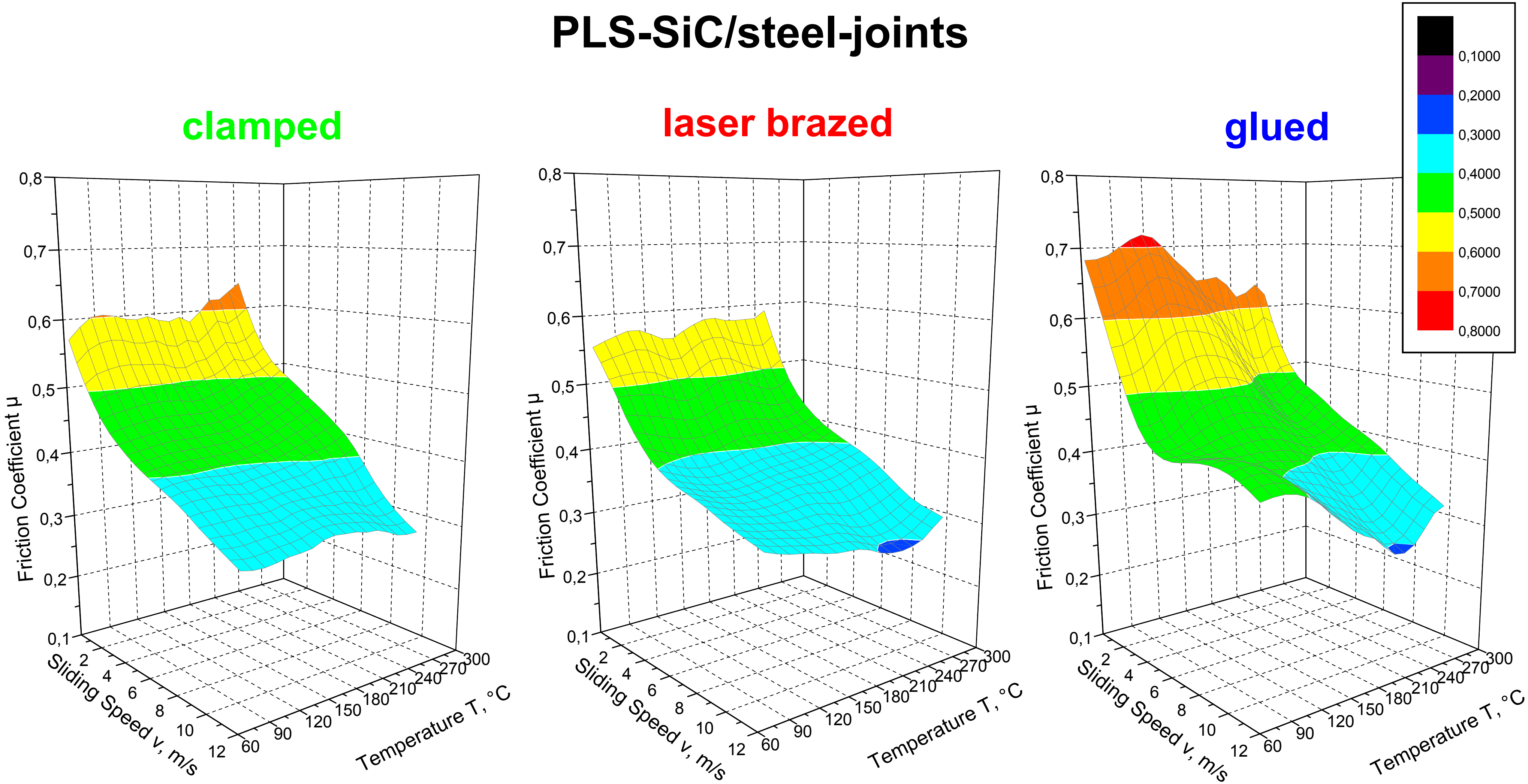
Tribological characterisation

PLS-SiC/steel-joints: variation of joining technique



Tribological characterisation

PLS-SiC/steel-joints



summary

Brazing results

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

  but inhomogeneous Ti-rich reaction layer
- increase of compound strength of ceramic/steel joints with homogenizing optic
  - Al_2O_3/AgCuInTi/steel-joints: from 20 MPa (m = 5) to 42 MPa (m = 2)

Tribological results

- SiC shows a higher and more constant friction coefficient than Al_2O_3

  ➡ higher temperatures of 250°C
- influence of joining technique on tribological behaviour

Thank you for your attention!

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