Karlsruhe Institute of Technology

Institute for Applied Materials

Residual stresses and shear strength of laser brazed Al_2O_3/steel-joints

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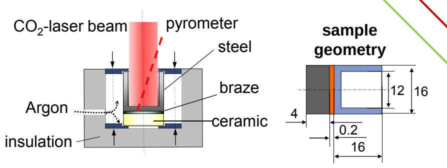
Laser Brazing Process



materials properties

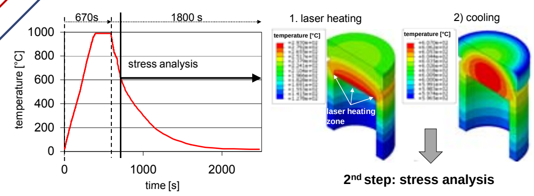
material / property	Al_2O_3	C45E	Incusil ABA Ag-Cu-In-Ti	CB4 Ag-Cu-Ti
company	Friatec AG	-	Morgan Chem.	Brazetec
density ρ / g/cm³	3.95	7.85	9.7	9.63
strength σ / MPa	350	560-710	338	72
Youngs modulus E / GPa	380	210	76	0.23*
thermal conductivity λ, W/mK	38	44	166	20*
CTE α, 10^{-6} m/K	8.4	11.0	18.2	170*

Youngs modulus, CTE, thermal conductivity and σ were implied as thermal dependent paramters.

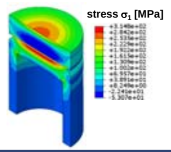
Motivation

Increase of shear strength by reduction of residual stresses in laser brazed Al_2O_3/steel-joints

Finite Element Modelling

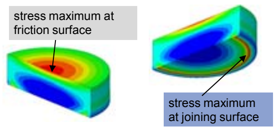


- **sequential temperature-stress-analysis:** calculated temperature distribution provides as loading for stress calculation
- **evaluation of calculated stress:** σ_1-stress in ceramic pellet are considered to be failure relevant

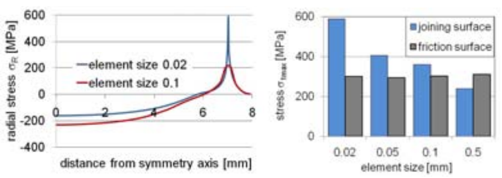


Stress Analysis

The ceramic pellet exhibits two areas of stress maxima:

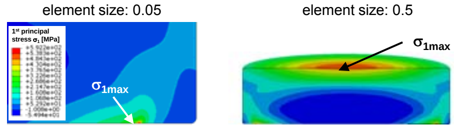


effect of element size on σ_{1max}



- value of σ_{1max} on joining surface is explicitly dependent on element size (singularity)
- value of σ_{1max} on the friction surface is independent of element size

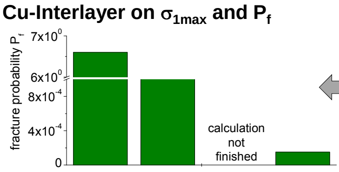
σ_1 - stress distribution (fem)



influence of Cu-Interlayer on σ_{1max} and P_f

Cu-interlayer lead to:

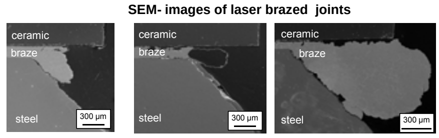
- reduction of σ_{1max}
- reduction of P_f
- ➡ conformity of experiments & models



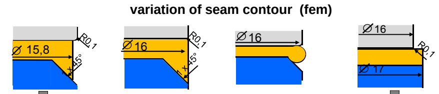
maximum of stress σ_{1max}	MPa	389	251	226	151
braze layer	µm	200	200	200	100
Cu-interlayer	µm	-	500	1000	1000

influence of seam geometry

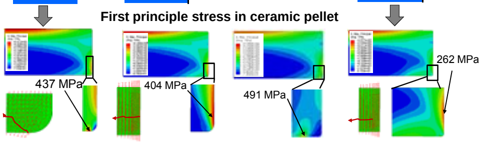
SEM- images of laser brazed joints



variation of seam contour (fem)

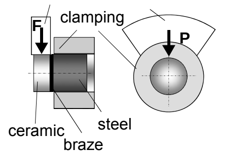


First principle stress in ceramic pellet



- value of σ_{1max} on joining surface is explicitly dependent on seam geometry

Shear Testing

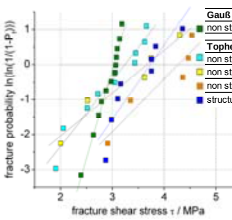


$$\tau = \frac{P_F}{\pi \cdot R^2}$$

$$F = \frac{i}{n+1}$$

P_F: fracture load
R: sample radius
τ: fracture stress
m: Weibull modulus
F: fracture probability
i: sample number
n: number of samples

Weibull evaluation of shear tests



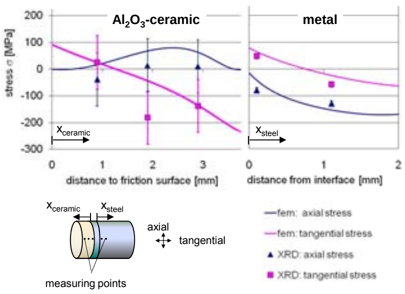
	τ_0*	m
Gauß laser profile	MPa	-
non structured	21	4.9
Tophead laser profile		
non structured	25	1.9
non structured + Cu-layer (500µm)	39	1.5
non structured + Cu-layer (1000µm)	71	1.7
structured steel	39	2.1

$*\tau_0 = \tau$ (F=63,2%)

increase of joint strength through:

- homogenized laser profile
- Cu-interlayer and
- structured steel surface

XRD-measurement



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

XRD measurement were carried out by IAM-WK, KIT – Campus South

Fracture Probability

input | **STAU**

finite-element modelling: geometry, loading

experimental: material parameter

spontaneous fracture: m, σ_0

crack growth: n, B, (p)

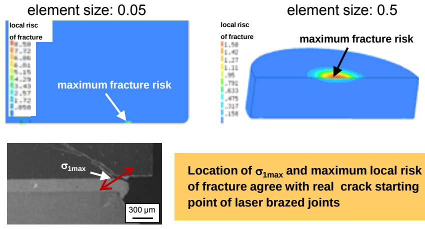
fe-interface

numerical integration

$$\iiint_{A,\Omega} \left(\frac{\sigma_{eq}}{\sigma_0}\right)^m d\Omega dA$$

output: P_f, V_{eff}

local risk of fracture (STAU)*



Location of σ_{1max} and maximum local risk of fracture agree with real crack starting point of laser brazed joints

Summary

Shear testing of laser brazed joints

- Increase of joint strength and reduction of reliability through
  - heating with homogenized laser intensity profile,
  - Cu-interlayer and
  - structured steel surfaces

Finite Element Modelling of laser brazing process

- A reduction of element size in the ceramic/braze interface affects an explicit increase of σ_{1max} (singularity)
- Thin metal carrier evoke bending of ceramic ➡ high σ_1-values
- Reduction of σ_{1max} through Cu-interlayer
- Seam geometry braze has an value of σ_{1max} singularity

XRD measurement of residual stress

- General compliance of measured and calculated axial and tangential stress, but large deviation according to textures in the ceramic

Calculation of fracture probability

- Agreement of calculated local risk of fracture and real crack configuration
- Reduction of calculated fracture probability through Cu-interlayer correspond to experimental results

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