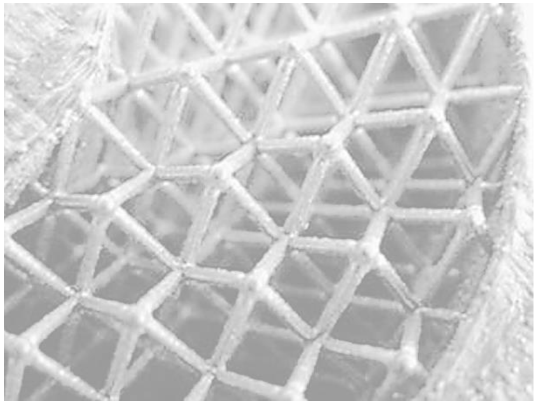
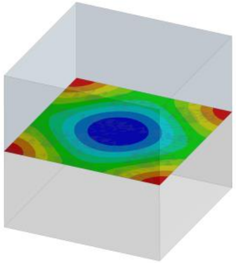
Günter-Köhler-Institut für Fügetechnik und Werkstoffprüfung

Simulation of a Diffusion Bonding System





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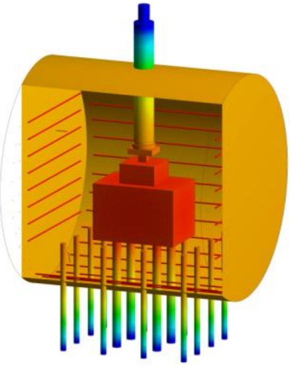
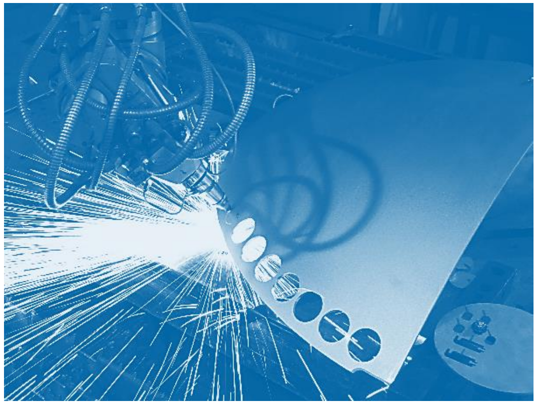




Outline

- ifw-Jena
- Motivation
- Vacuum furnace
- Simulation process
  - Material Properties
  - Simulation models
  - Boundary conditions
  - PI temperature control
- Results
  - Thermal analysis
  - Structural analysis
- Summary and outlook

ifw Jena – location

Germany

Thuringia

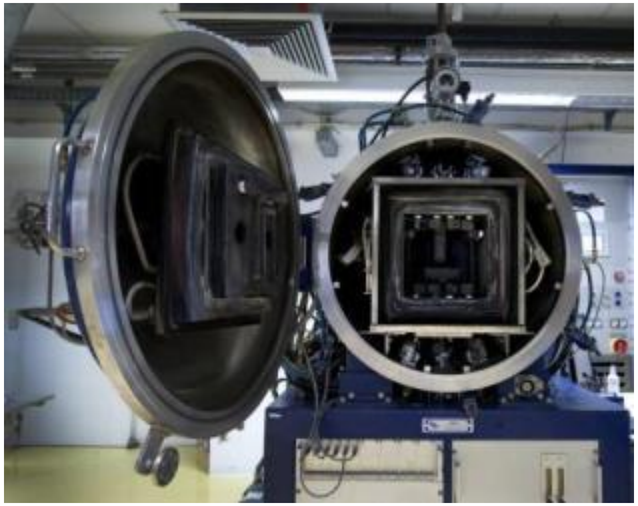
Research areas – topics

	brazing / welding	diffusion bonding	PBF	USP laser processing	adhesive bonding
glass / ceramic					
material testing					
smart manu-facturing					

Additive Manufacturing

Laser material processing

Furnace Systems – ifw (Diffusion Bonding, Brazing, HT)



	GERO	MUT	PVA
heater made of	graphite	molybdenum	molybdenum
max. temperature	1800°C	1550°C	1300°C
press load	2 kN	60 kN	1500 kN
atmosphere	vacuum $1 \cdot 10^{-1}$ mbar gases N_2, Ar	vacuum $1 \cdot 10^{-5}$ mbar gases N_2, Ar, H_2	vacuum $1 \cdot 10^{-5}$ mbar gases N_2, Ar
max. part volume	200x200x200 mm³	450x450x600 mm³	250x300x500 mm³

Motivation

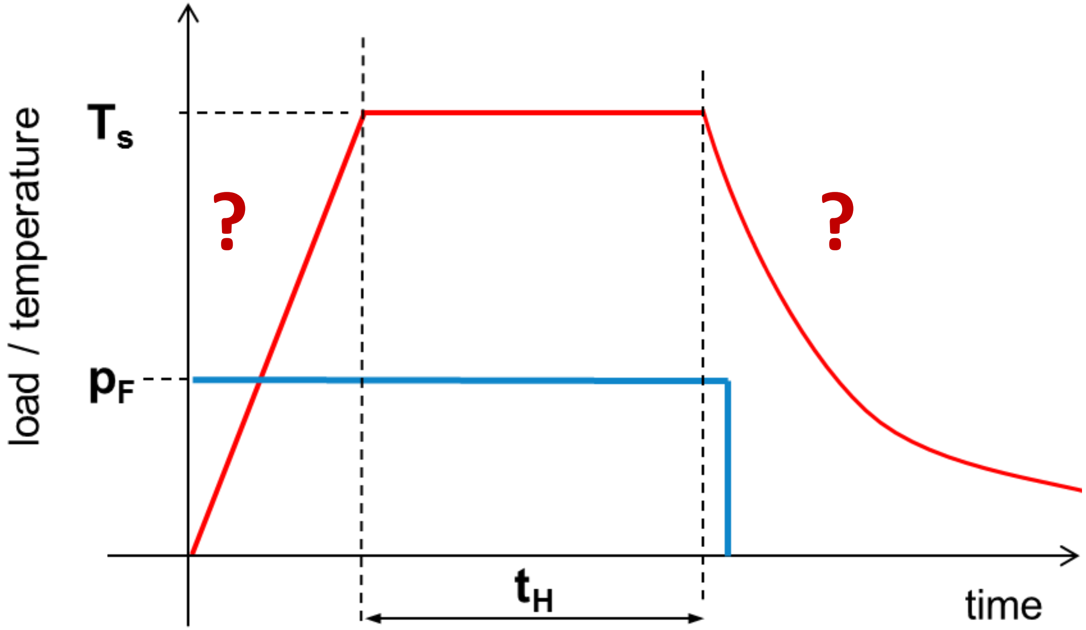
Relevant process parameters:

- **Pressure (Load) -> p_F = 2-20 MPa**
- **Temperature -> T_S = 0,6-0,9 T_M**
- **Dwelltime -> t_H = 0,5-4 h**

Example:

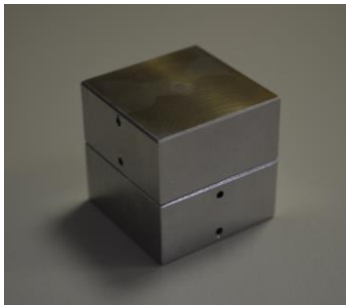
Stainless Steel 304L

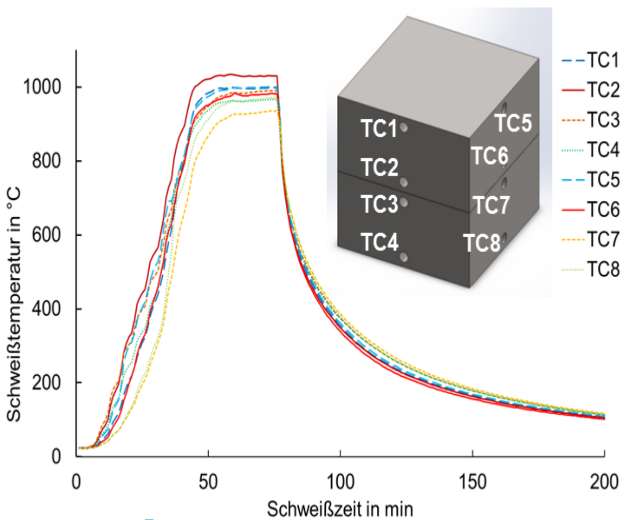
- **6 MPa**
- **1050°C**
- **1h**



Motivation

Cube 30x30x30 mm³





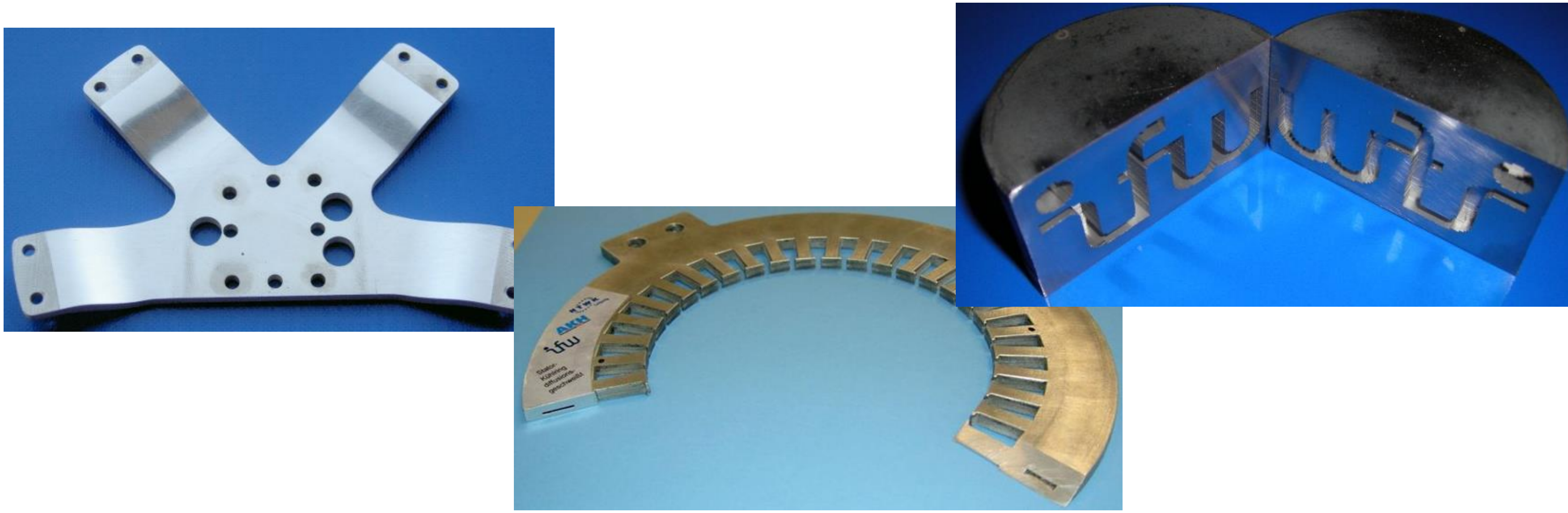
→10K/min, FC

Block 250x450x80 mm³

- **Heating rate ?**
- **Temperature homogeneity**
- **Load distribution**

→ Determination based on expierence carried out by experiment

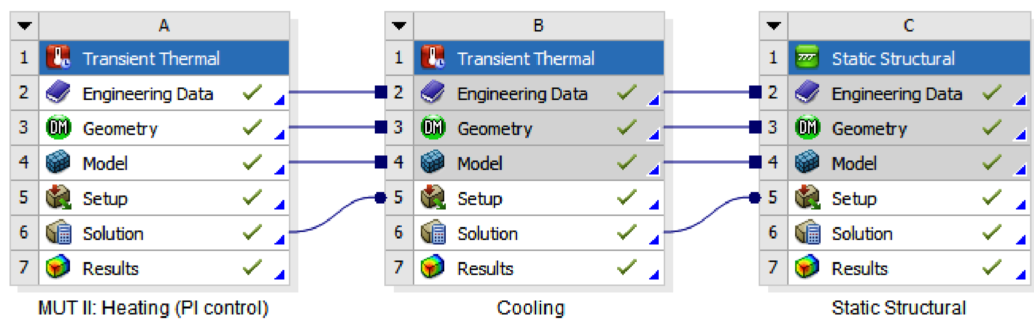
Motivation



Generating new knowledge about the process

⇨ Reducing the amount of pretests and experiments

Coupled thermal-structural-analysis

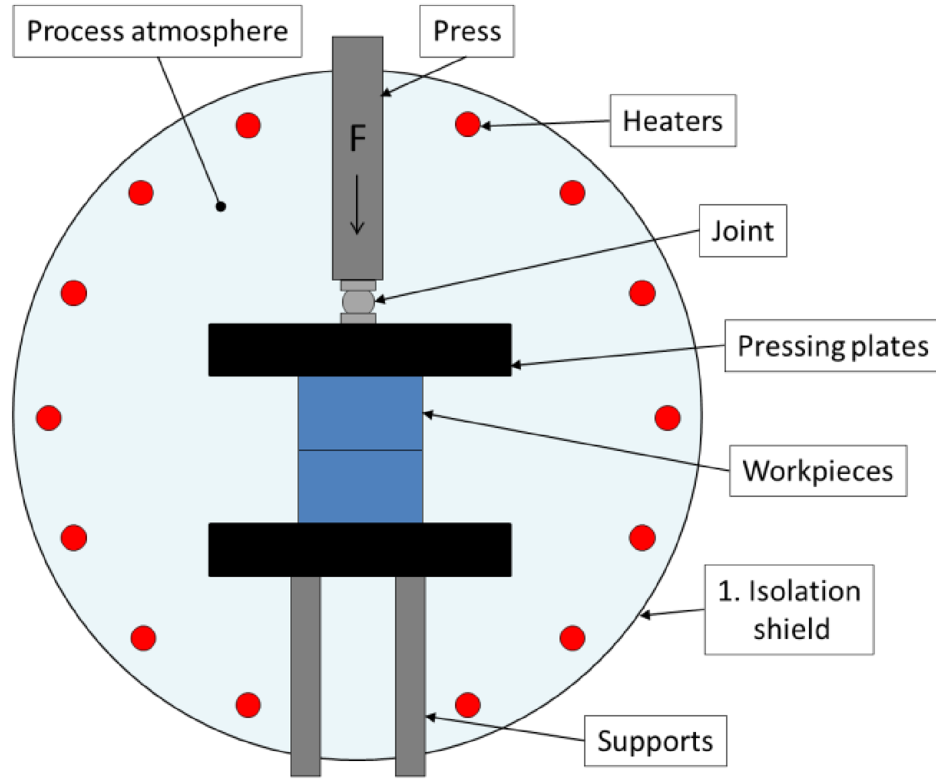


Coupled systems

State of the art

Significant process parameters for diffusion bonding

- Joining temperature
- Holding time
- Process force (Load)



Principle of the diffusion bonding

Simulating radiation (vacuum)

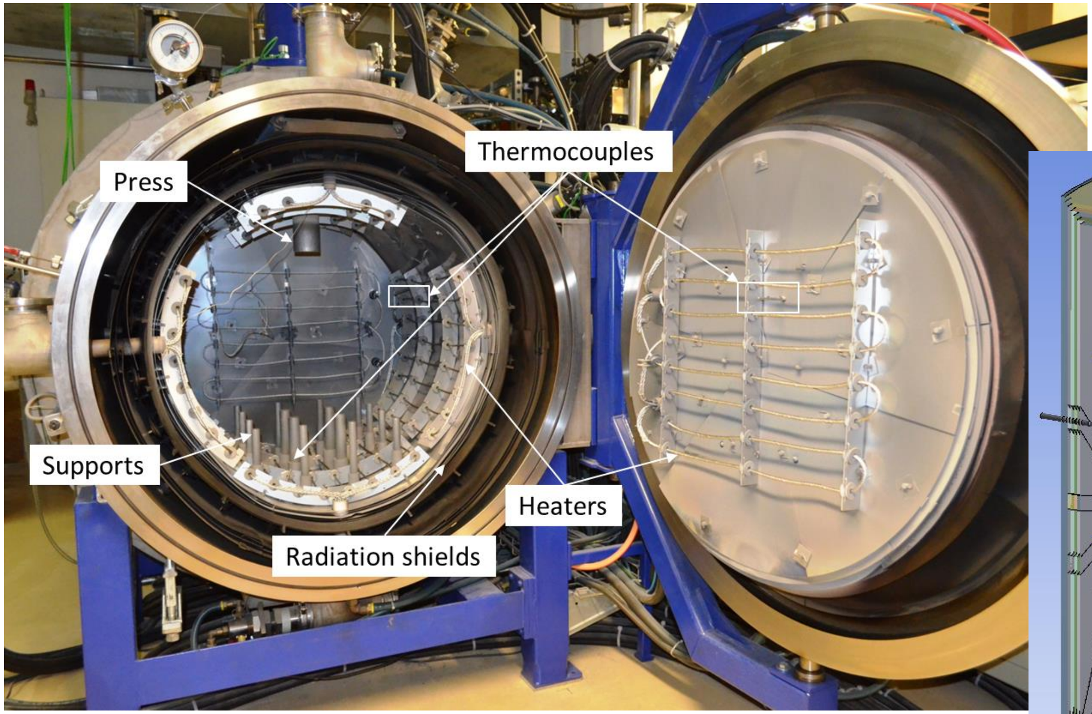
$$\dot{Q} = A_i \cdot f_{ij} \cdot \varepsilon_i \cdot \sigma \cdot \left(T_i^4 - T_j^4\right)$$

$$\dot{Q} = C_{Str} \cdot \left(T_i^4 - T_j^4\right)$$

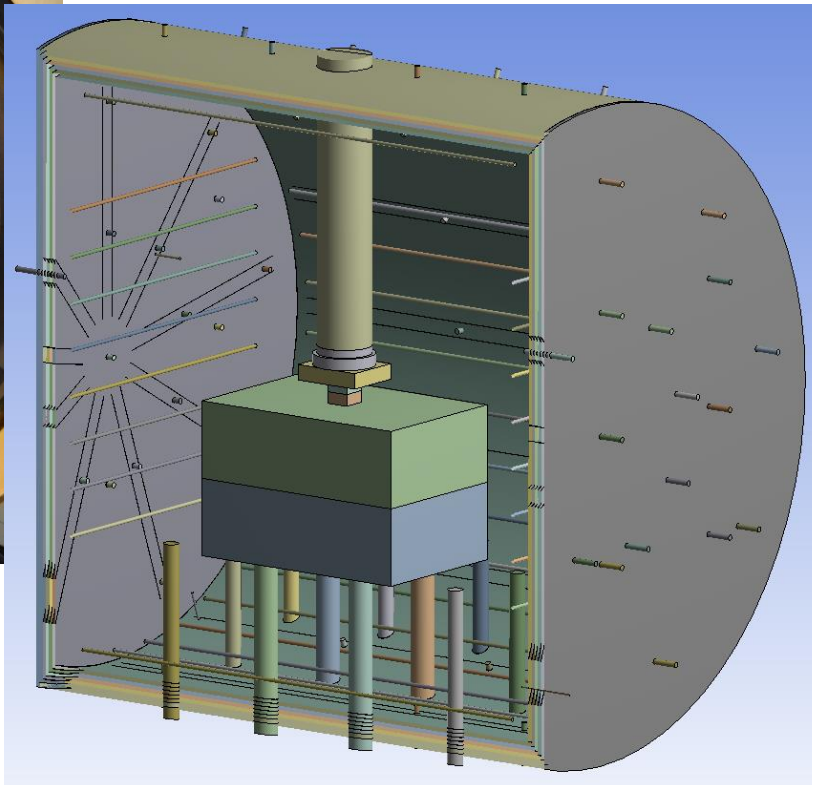
$\dot{Q}$	Heat flow [W]
A_i	Area of element i [m^2]
ε_i	Emissivity of area i
f_{ij}	Shape factor between area i and j
σ	Stefan-Boltzmann-Constant: 5,67 10^{-8} [$W/m^2\ K^4$]
C_{Str}	Radiation exchange coefficient [W/K^4]
T_i	Temperature of area i [K]
T_j	Temperature of area j [K]

Simulation Process

1. Creation of CAD Model



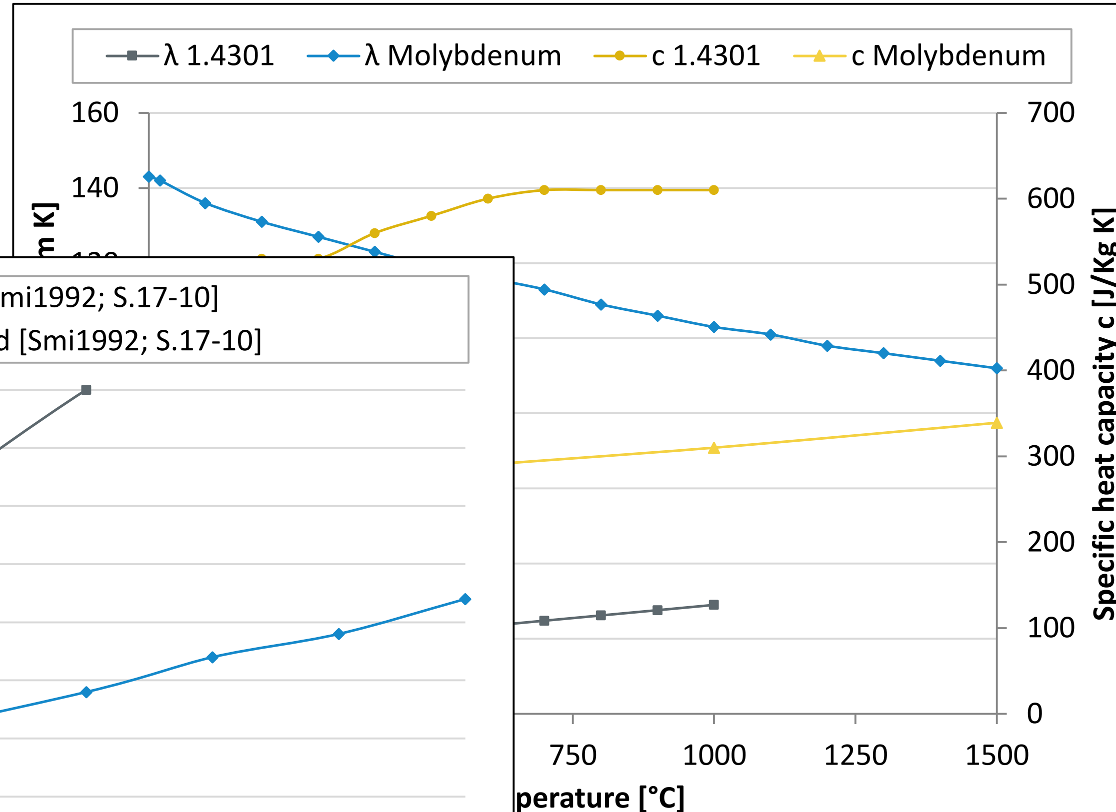
model including all features that influence heat transfer



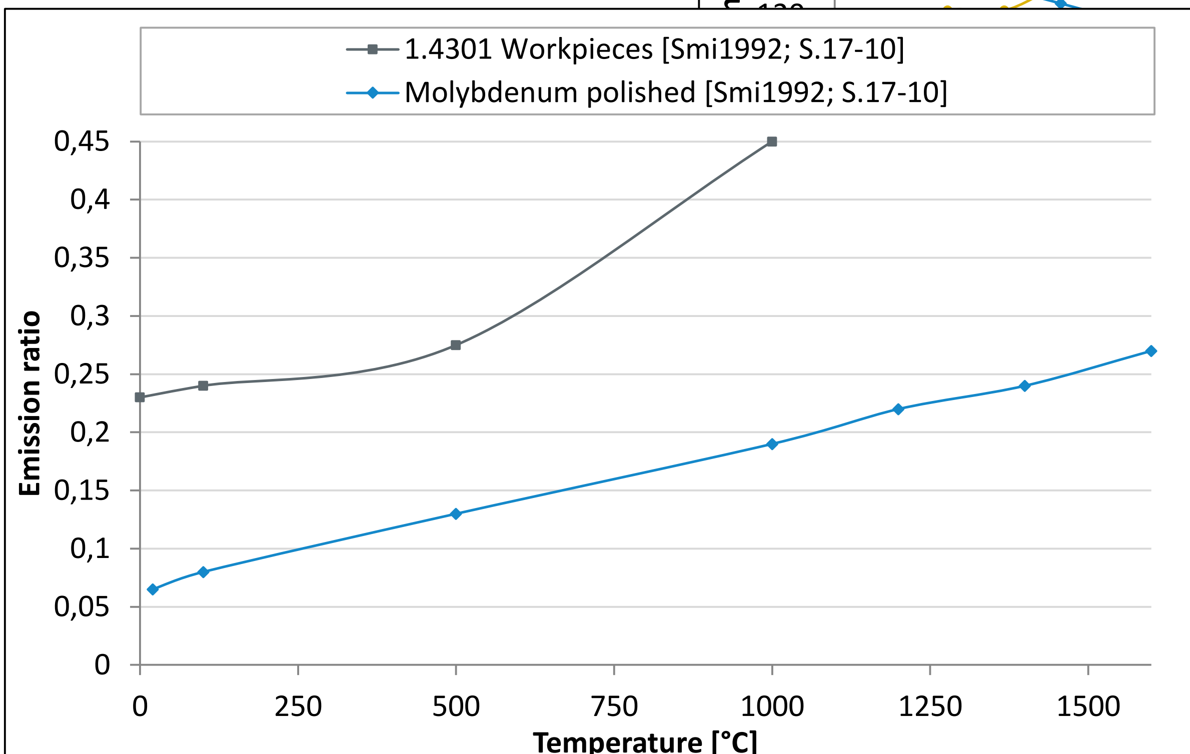
- All metal furnace (Molybdenum)
- Tmax:1500°C
- Dimensions: 450x450x600 mm³
- Load: 60 kN

Simulation process

2. Material properties:



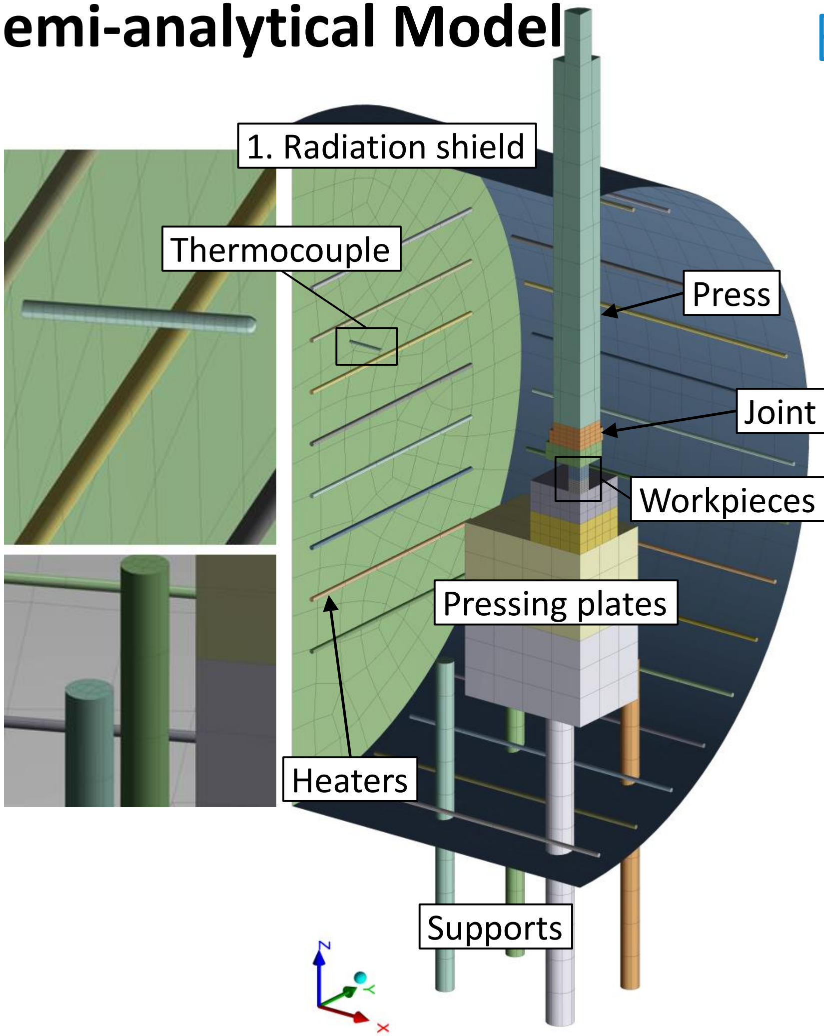
perties of molybdenum and 1.4301



Emission ratio of molybdenum and 1.4301

Simulation process

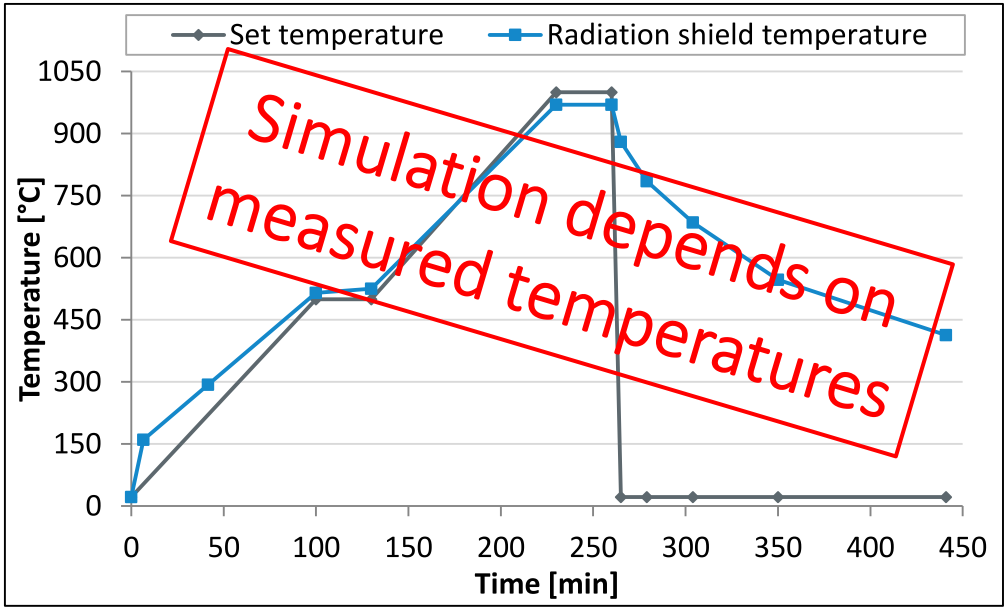
Semi-analytical Model



Discretized and symmetrized geometry

Boundary conditions:

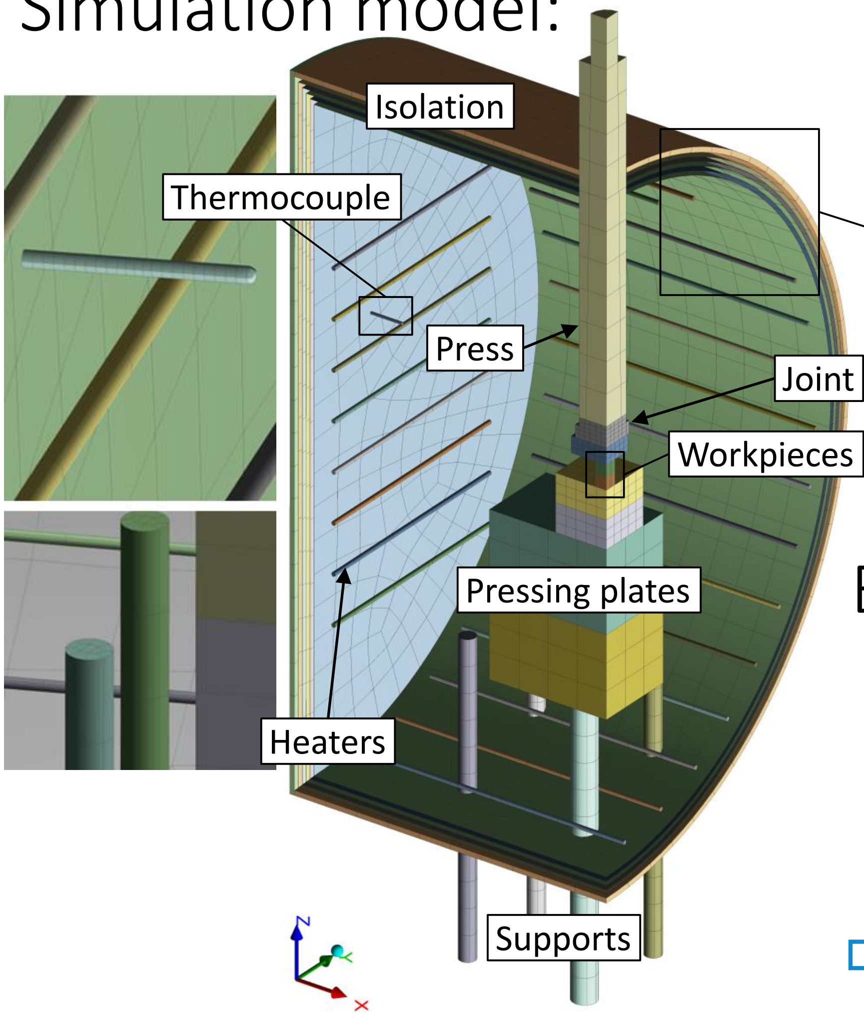
- Radiation (all surfaces)
- Press and supports are cooled (23 °C)
- Furnace set temperature curve
- Determined radiation shield temperature

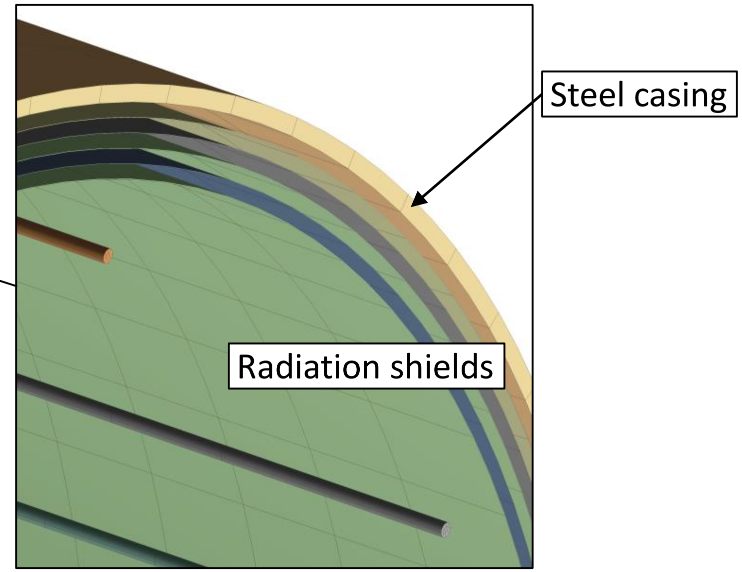


Set furnace and radiation shield temperature

Simulation process

Simulation model:





Discretized and symmetrized geometry with Isolation

Boundary conditions:

- Radiation (all surfaces)
- Press and supports are cooled (23 °C)
- Furnace set temperature curve

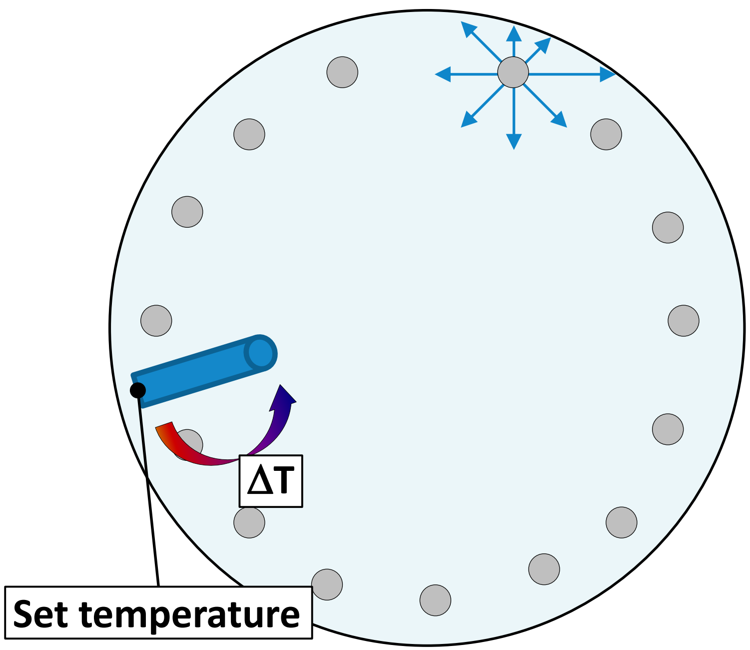
⇨ Simulation does not depend on measured temperatures

Simulation process

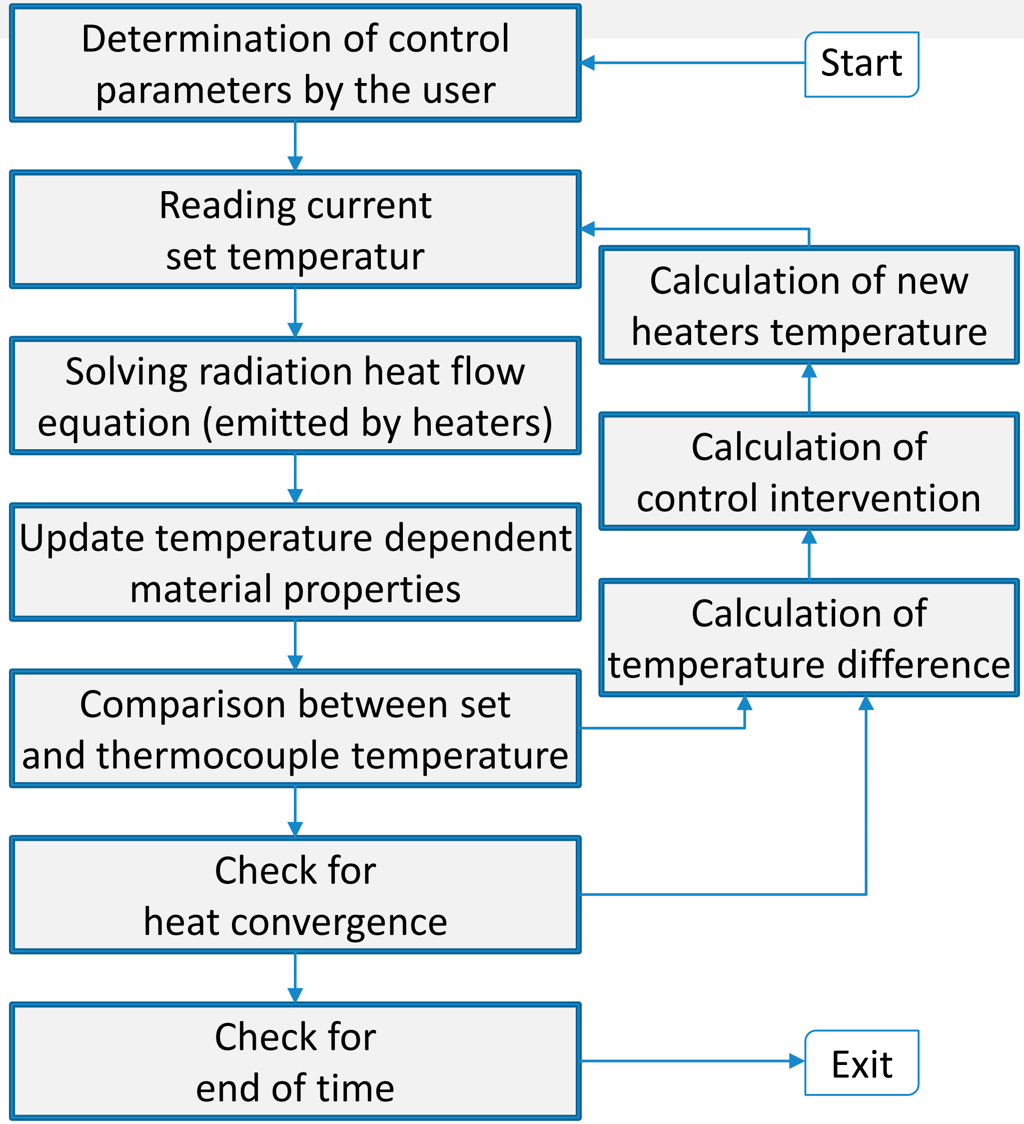
PI temperature control:

- Using a command snippet

$$\dot{Q} = A_i \cdot f_{ij} \cdot \varepsilon_i \cdot \sigma \cdot \left(T_i^4 - T_j^4\right)$$



Function of the PI temperature contol



Simulation process

Structural boundary conditions:

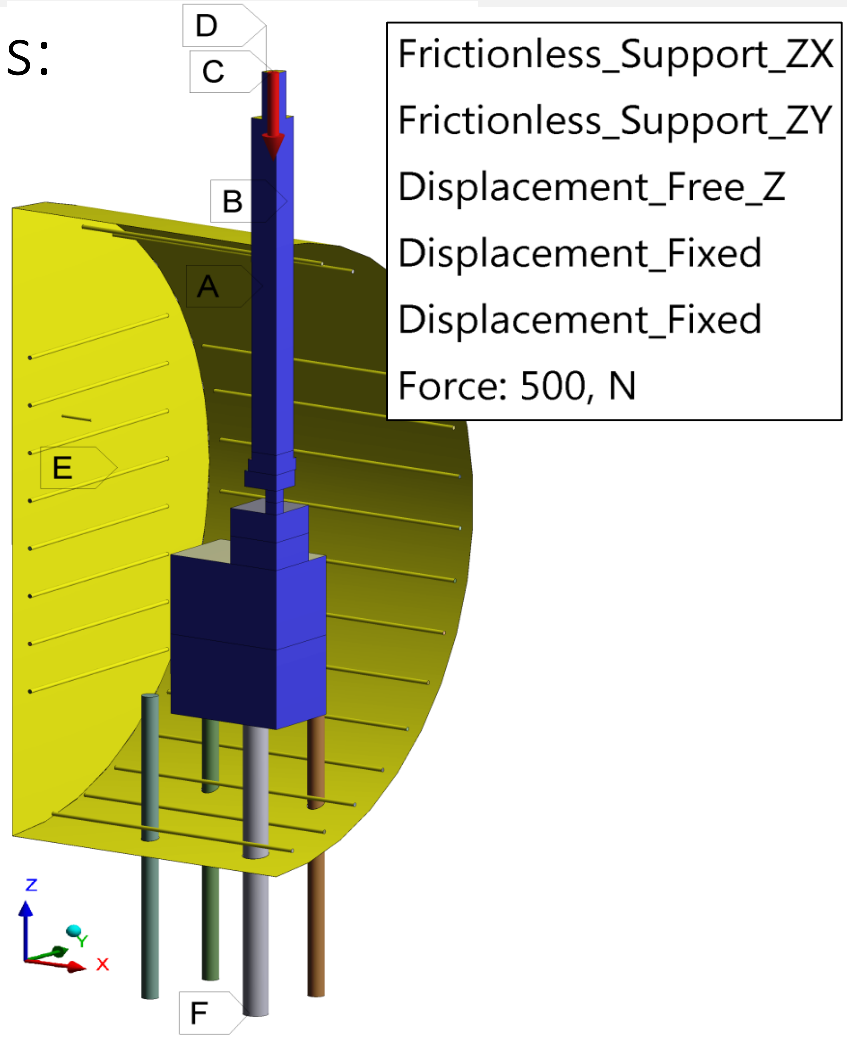
- Using symmetry function
- Fixing not moving parts
- Loading the press

$$F = p \cdot A$$

$$F = 2{,}2\bar{2}\frac{N}{mm^2} \cdot 15mm \cdot 15mm$$

$$F = 500\ N$$

F	Force [N]
p	Surface pressure in the joining zone [N/mm²]
A	Area of the joining surface [mm²]



Structural boundary conditions

Experimental verification:

- Same batch allignment as simulated
  - Material
  - Geometry
- Same furnace set temperature curve as simulated
- Additional thermocouples
- Running a whole cycle

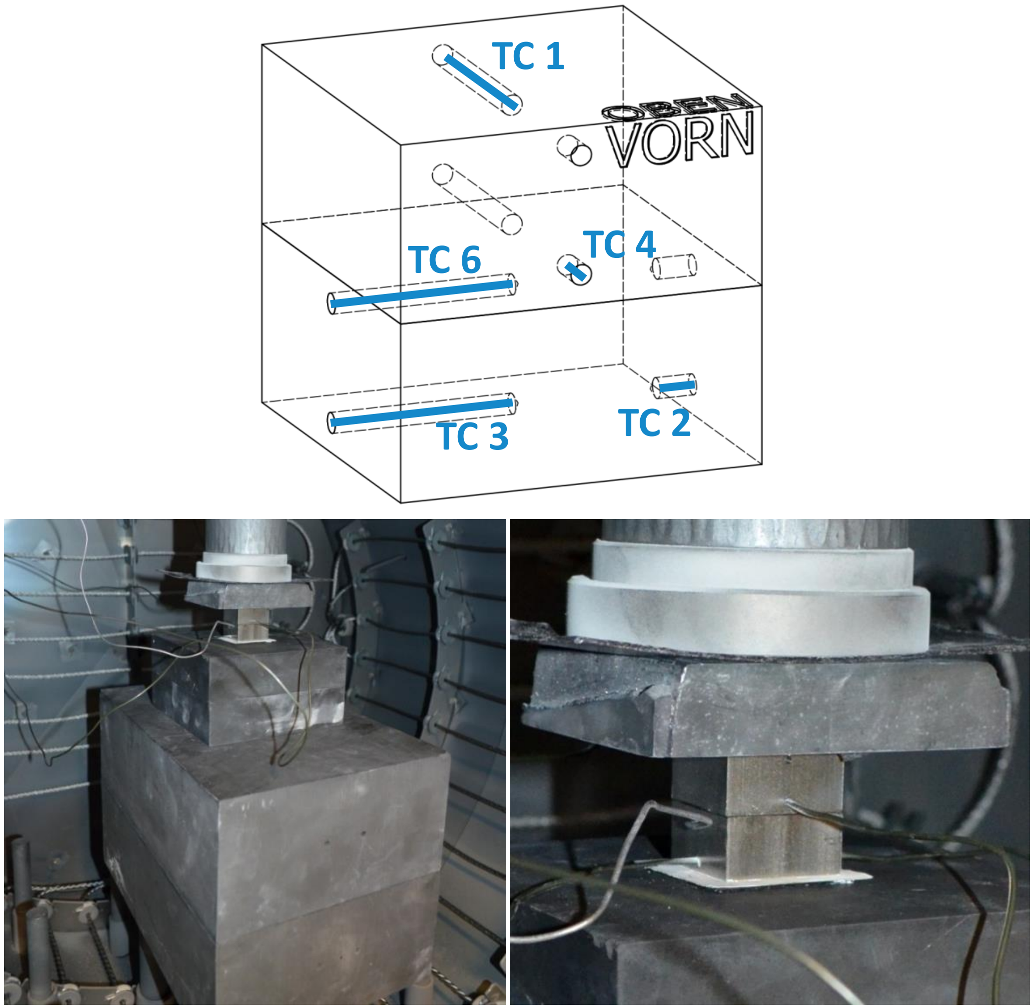
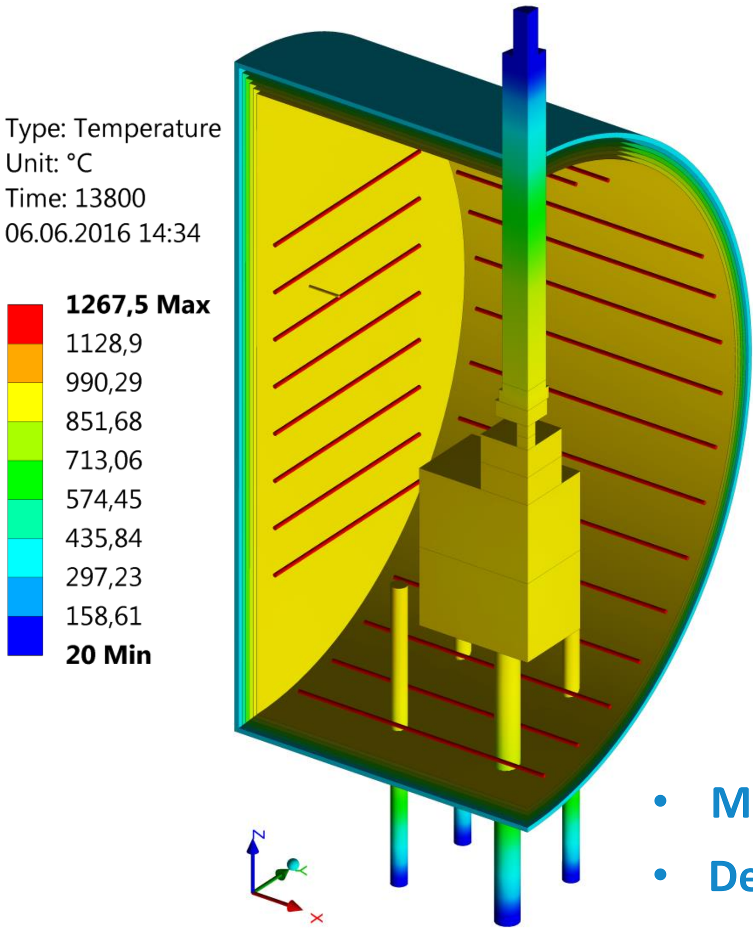


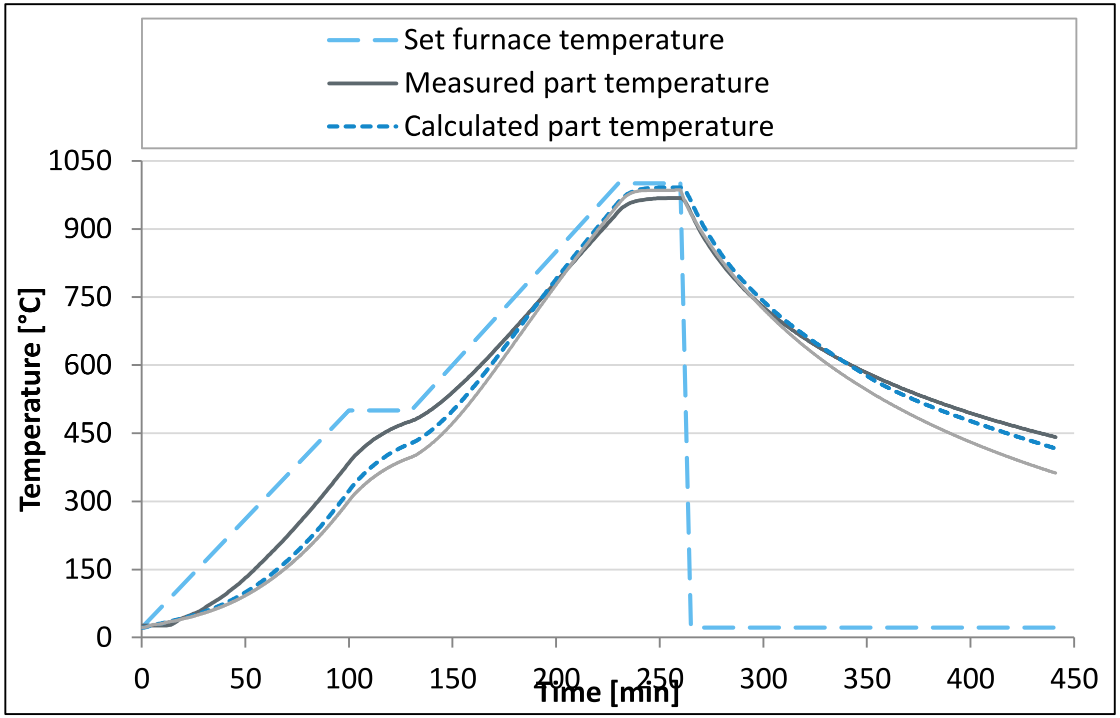
Fig. 12. Experimental verification

Results

Thermal analysis:



Thermal results (Isolation)

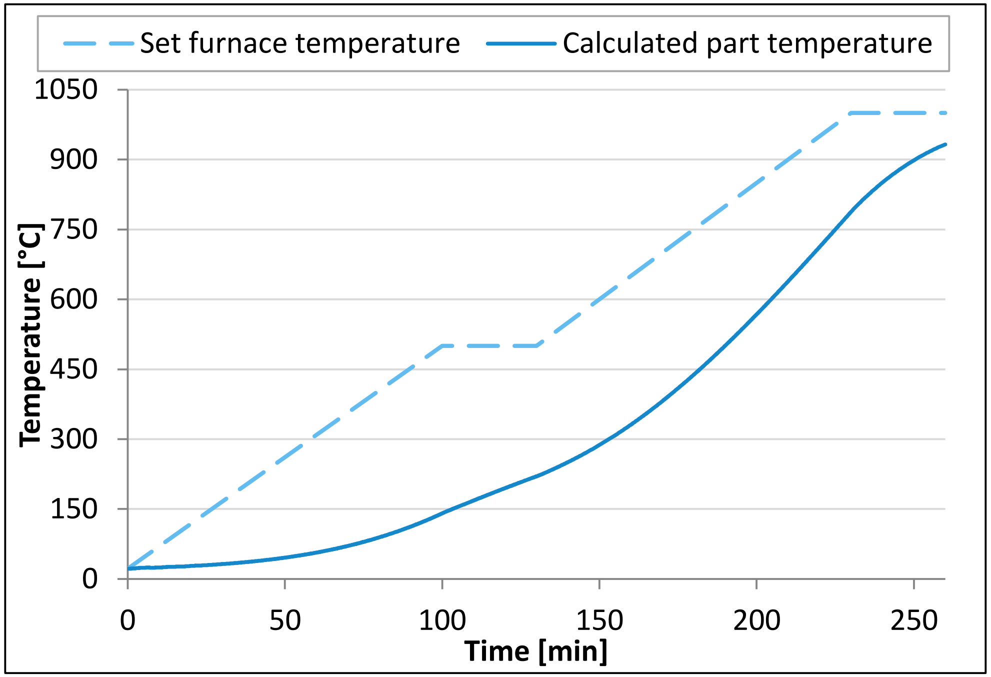


Comparison between simulated and measured temperatures (Isolation)

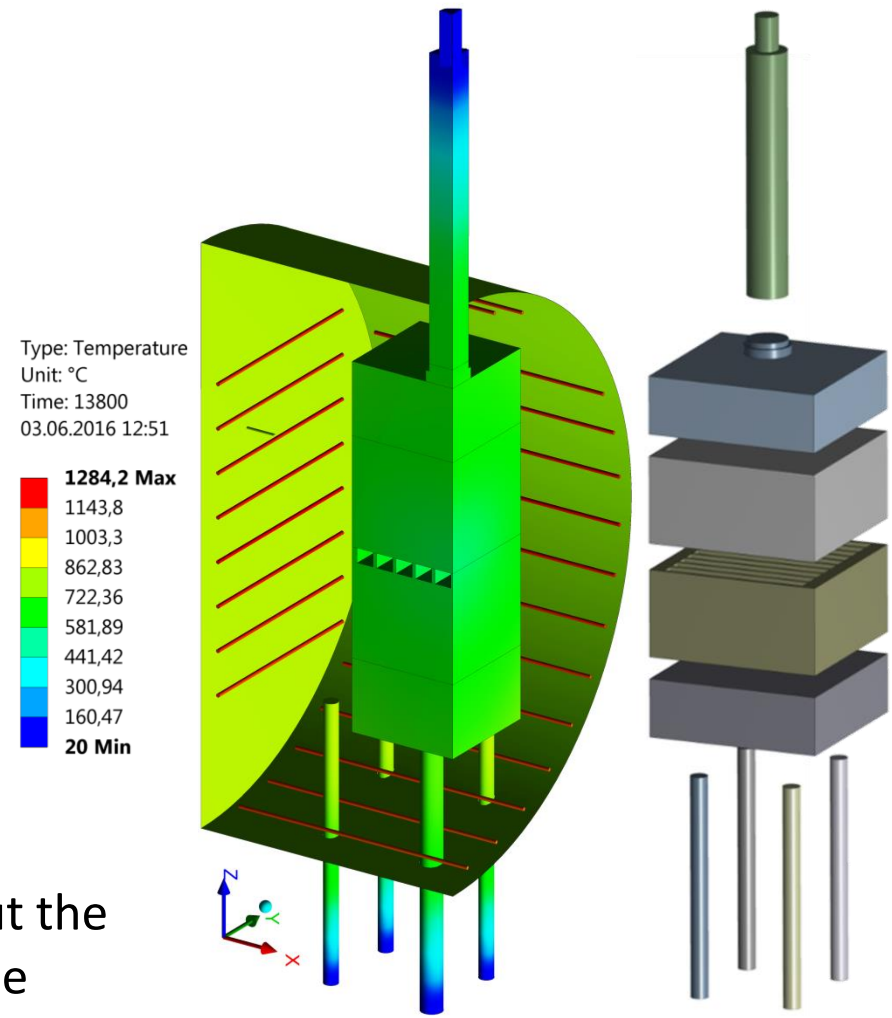
- **Maximum temperature difference of 25 K above 600 °C**
- **Deviations occur on the basis of imprecise emission ratios**

Results

Thermal analysis: „Big part“



Thermal results heating up (Big part)



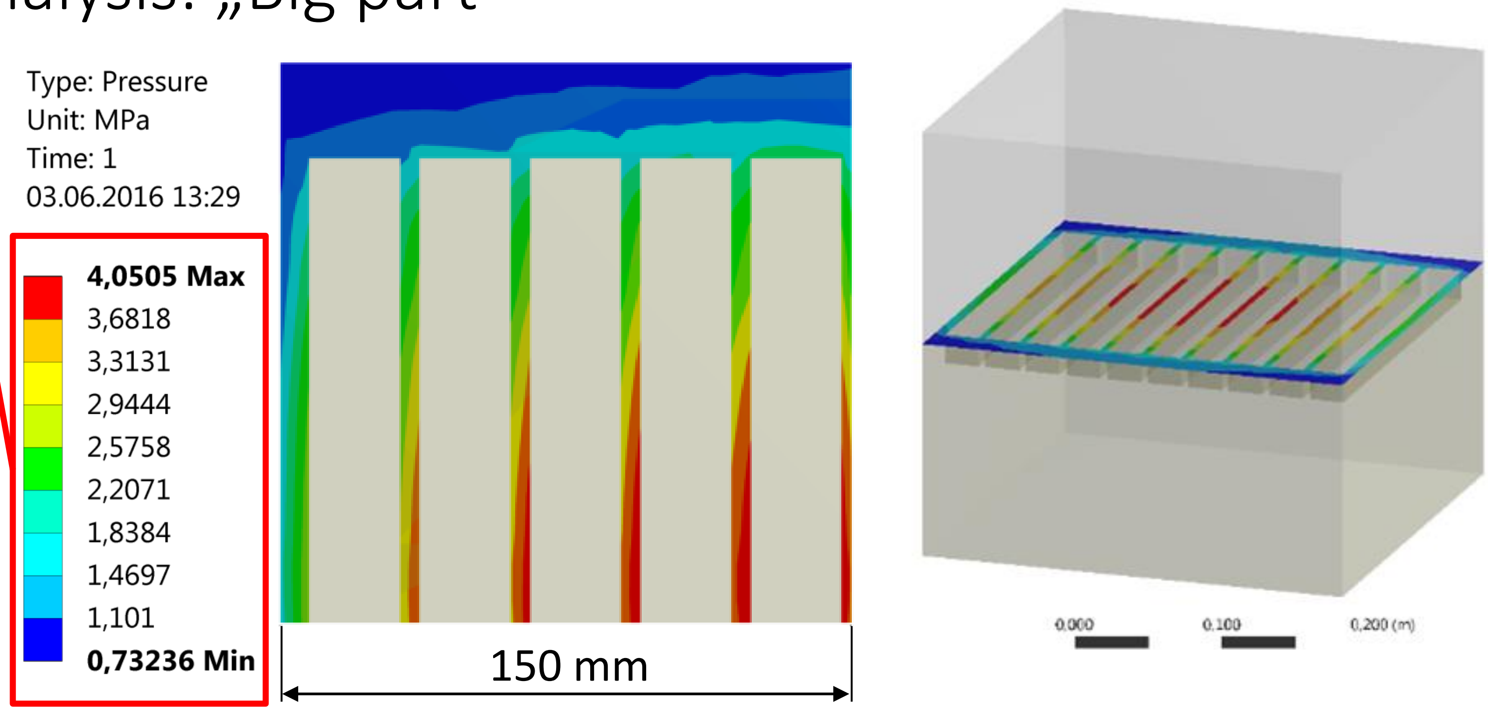
Geometry and thermal results of the “big part”

⇨ Thermal results leads to findings about the set temperature curve and joining time

Results

Structual analysis: „Big part“

$$p = 2{,}00\ \frac{N}{mm^2}$$



Structural results surface pressure big part

- Structural results leads to new findings about the surface pressure in the joining zone
- New findings for designing the batch alignment

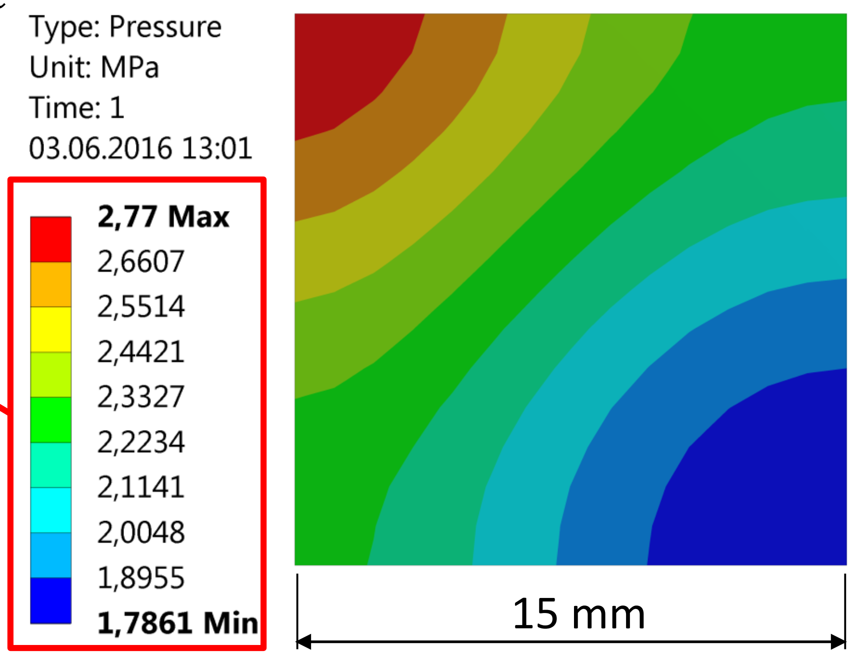
Results

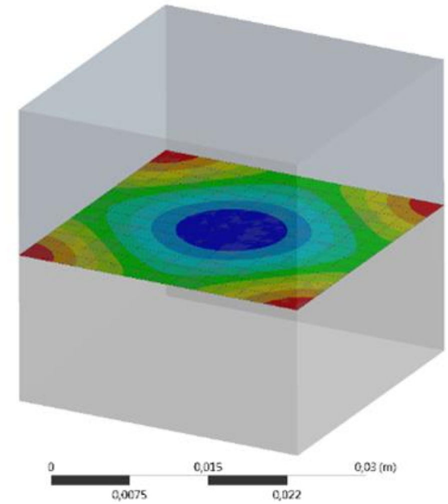
Structual analysis (30mm cube):

$$p = \frac{F}{A} = \frac{500\ N}{15\ mm \cdot 15\ mm}$$

$$p = 2{,}2\bar{2}\,\frac{N}{mm^2}$$

Structural results surface pressure





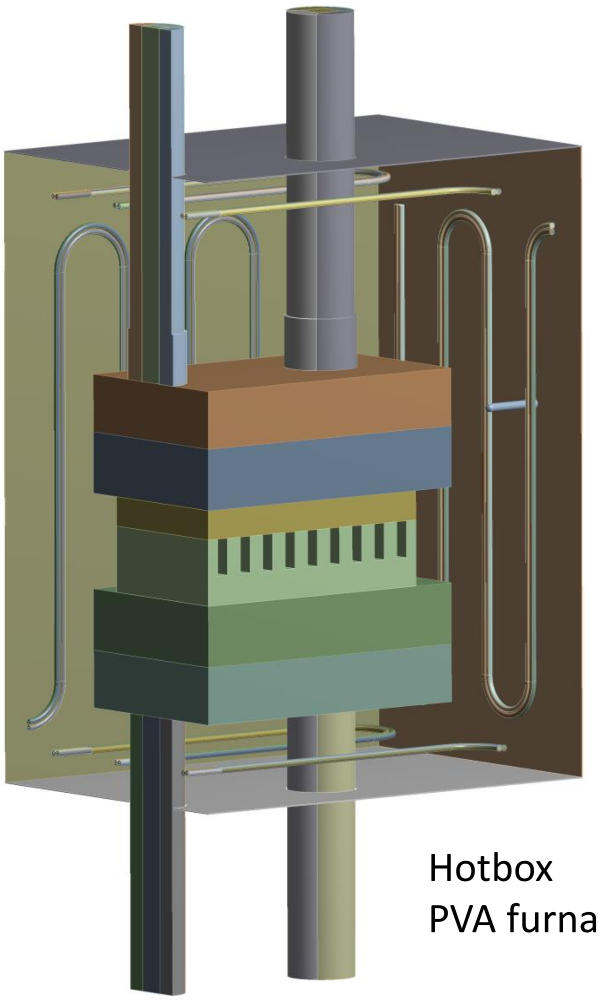
Deformation of the press plates leads to an uneven surface pressure in the joining zone

Summary

- A furnace based model for a diffusion bonding system was developed
- Thermal analysis allows to determine the process parameters simulative
  - Joining temperature and joining time can be calculated
  - Simulation reduced the amount of pretests
- Structural analysis leads to new findings about the batch allignment
  - Surface pressure in the joining zone can be calculated

Outlook

- Creating a cfd simulation (computational fluid dynamics) to calculate the diffusion bonding process under inert gas
- Set up models for all ifw furnaces
- Ehance model by means of
  - Performance
  - Contacts definition
  - Emssivity
- Combine with „microscale“ calculations (creep, diffusion, ..)?



Hotbox
PVA furnace