Infoday Automotive and Aerospace Applications, Berlin, December 1st, 2022

Simulation of Resistive Heating of Ti64 Blanks

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In cooperation with

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

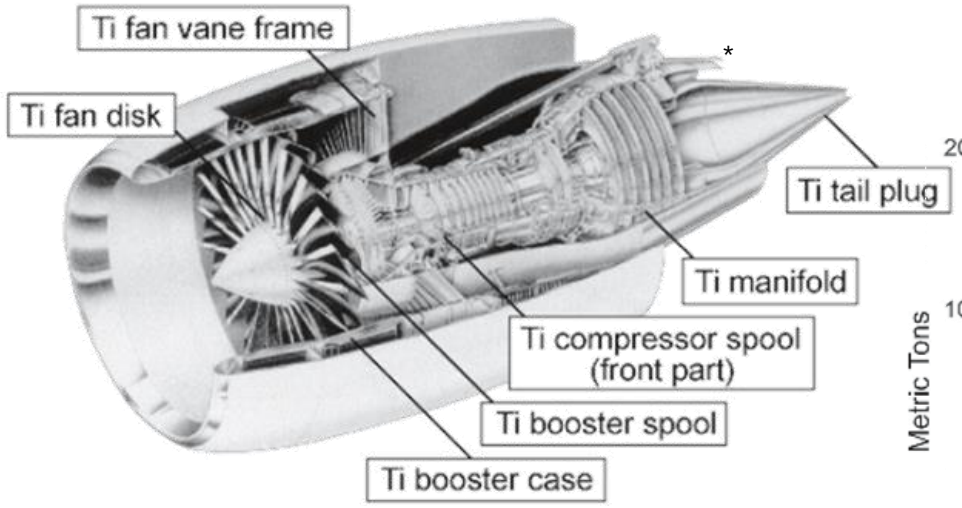
Agenda

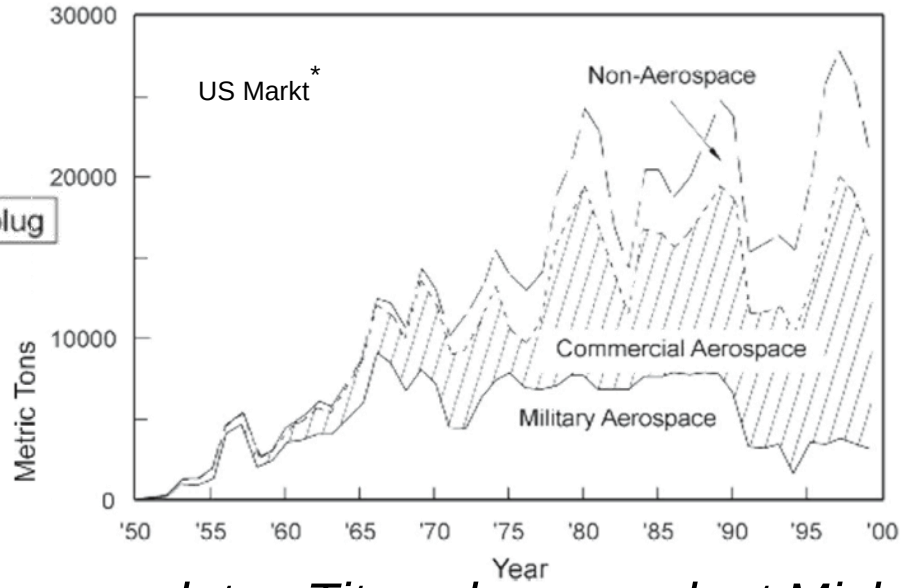
1) Introduction
2) Coupled Multi-Physics
3) Self-controlled Multi-Physics
4) Material Data
5) Summary

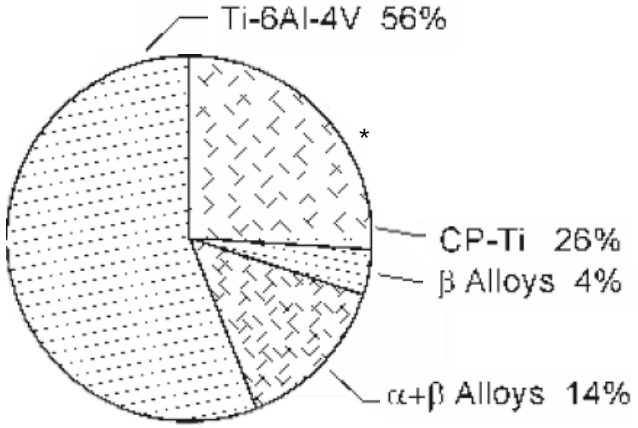
Introduction

Ti-6Al-4V

- Relative cheap raw material, relative expensive structural material







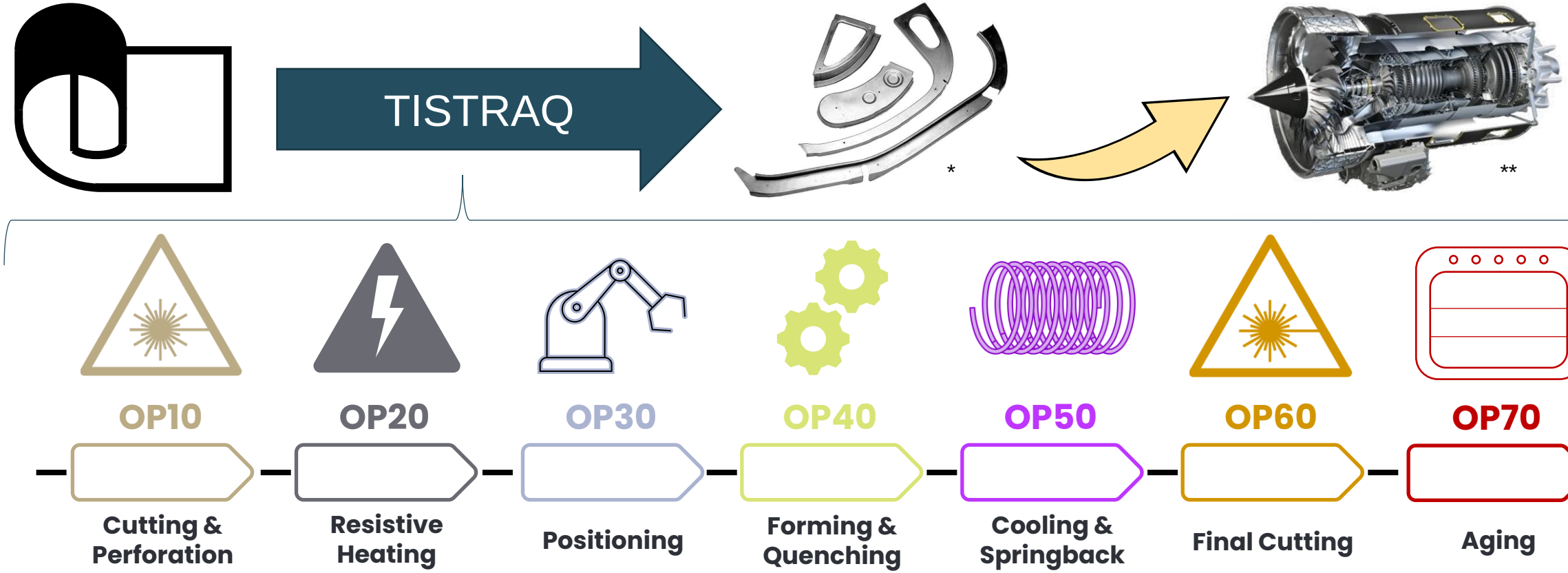
**Titanium, 2nd Edition, Lütjering & Williams, 2007, Springer Verlag*

- *„35 bis 40 Prozent des von Boeing verwendeten Titans kommen laut Michaels bisher vom russischen Zulieferer VSMPO-Avisma, der zu ein Viertel dem staatlichen Rüstungskonzern Rostec gehört. Bei Airbus stammen rund 50 Prozent des Titans aus Russland.“*
  „«Es gibt keinen einzigen Rest Titan mehr auf dem Markt, es wurde alles aufgekauft.» Solange der Konflikt nicht bis ins Jahr 2023 andauere, dürften sich die Folgen für die Luftfahrt noch in Grenzen halten.“ https://www.aerotelegraph.com/boeing-verzichtet-auf-russisches-titan-airbus-nicht (08.03.2022, zuletzt aufgerufen am 14.11.2022)

Introduction

TISTRAQ: TItanium Solution Treated and RApid Quenching

- **Scope:** *Development of a **predictable** quench-forming process for **energy** and **material** efficient production of **sheet metal parts** made of α+β-titanium alloys with **enhanced mechanical properties** compared to the delivery state due to a **process integrated heat treatment**.*

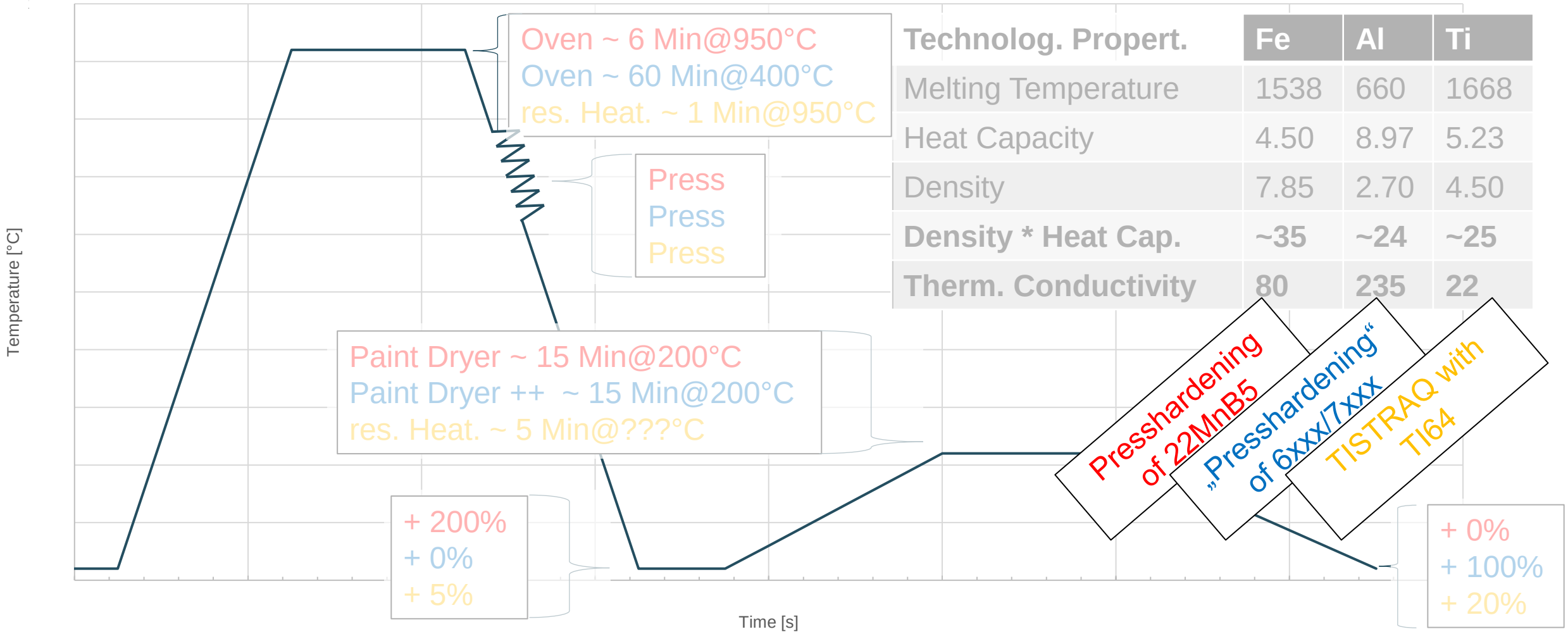


*Aerospace Sheet Metal Fabrication Low Cost | Premium Rapid & Mold (prmmold.com)

**Triebwerke werden digital | BDLI

Introduction

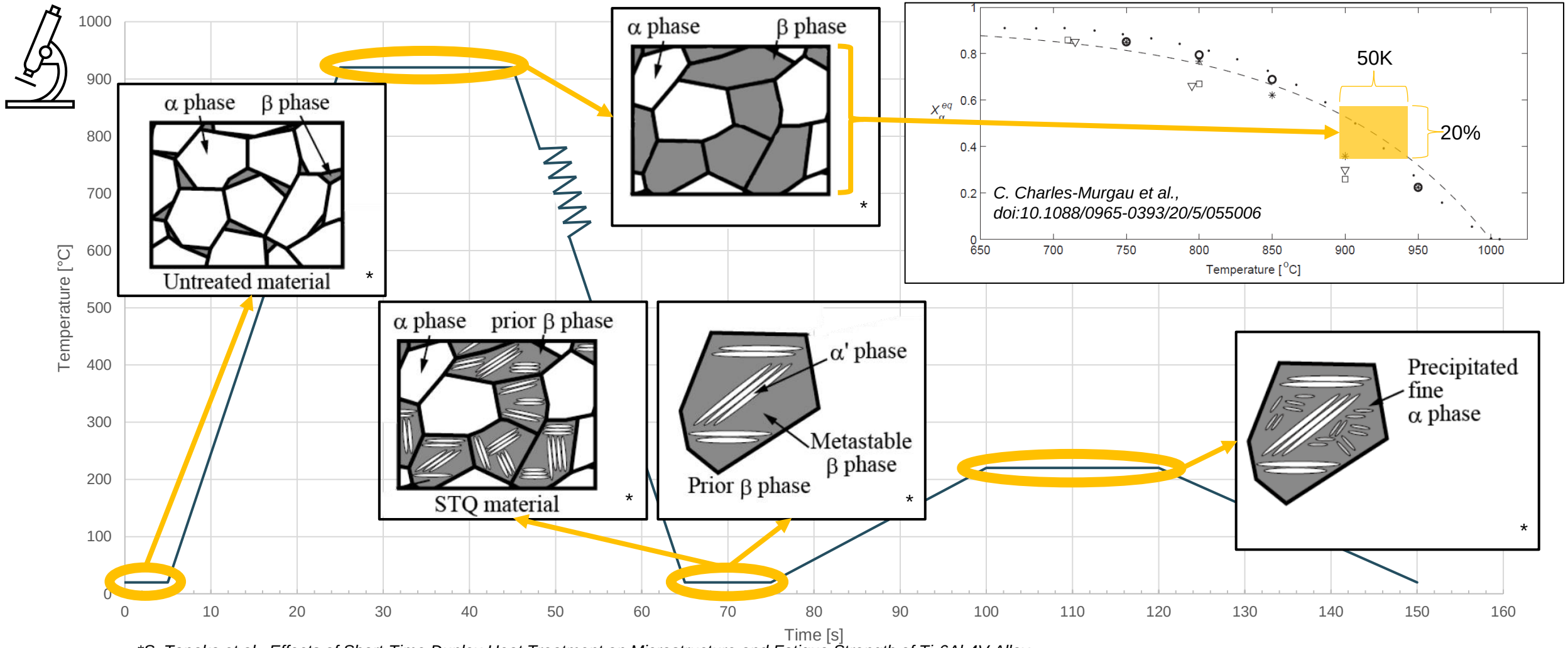
Schematic Heat Treatment – TISTRAQ compared to typical (automotive) processes



Technolog. Propert.	Fe	Al	Ti
Melting Temperature	1538	660	1668
Heat Capacity	4.50	8.97	5.23
Density	7.85	2.70	4.50
Density * Heat Cap.	**~35**	**~24**	**~25**
Therm. Conductivity	**80**	**235**	**22**

Introduction

Mikrostructural Changes due to TISTRAQ (working assumption)



S. Tanaka et al., Effects of Short-Time Duplex Heat Treatment on Microstructure and Fatigue Strength of Ti-6Al-4V Alloy, 13th International Conference on Fracture, June 16–21, 2013, Beijing, China;

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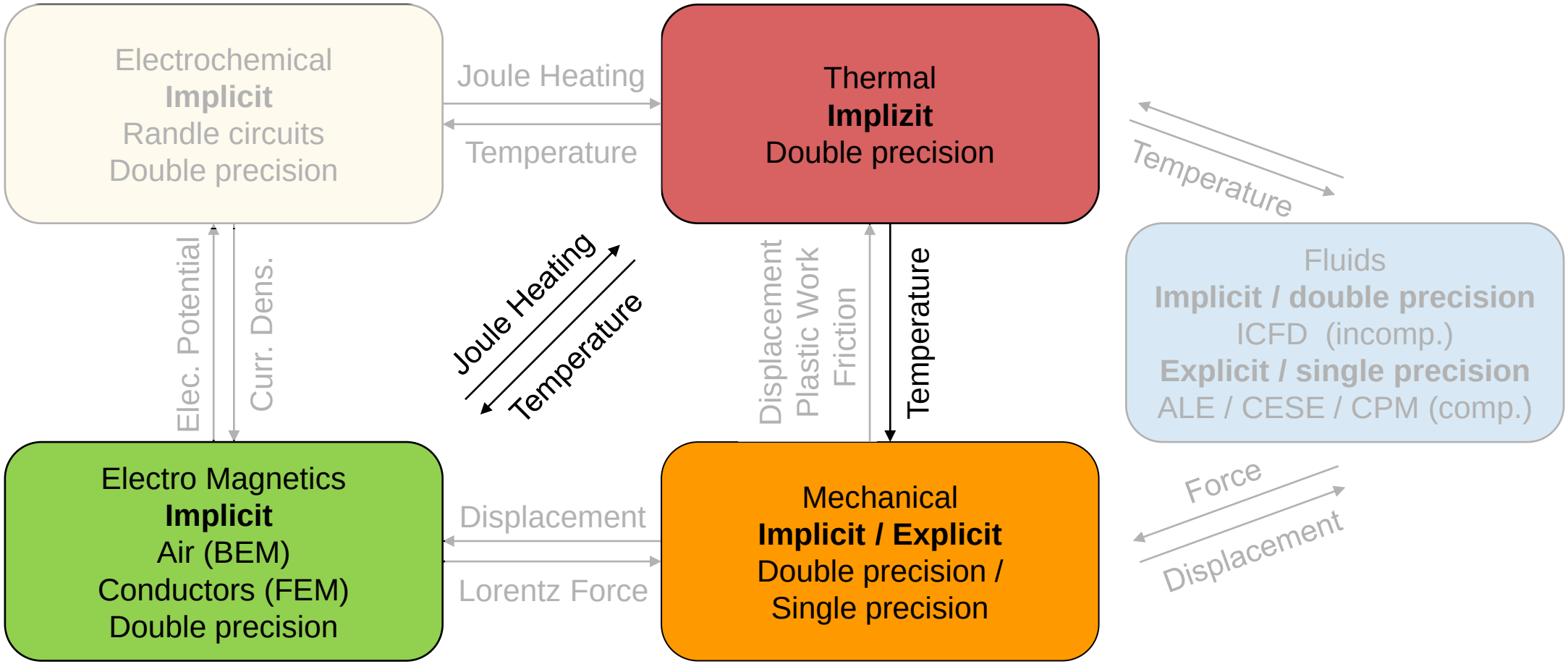
Coupled Multi-Physics

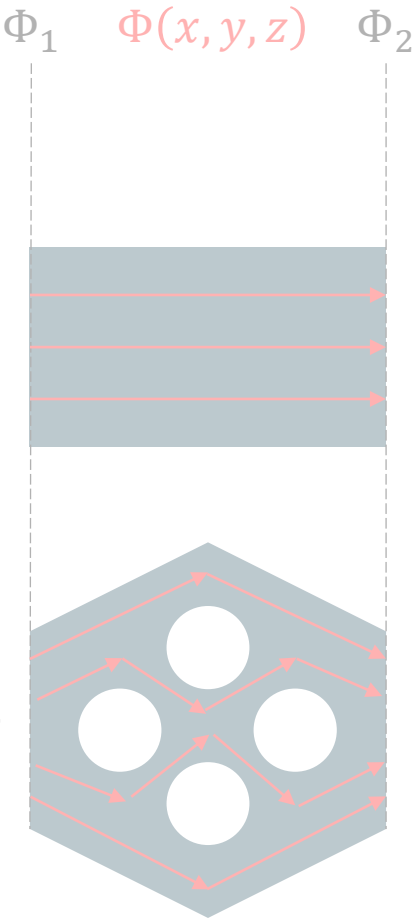
„The scalable Code for Multi-Stage and Multi-Physics“



Coupled Multi-Physics

Physical Basics for resistive Heating (electro-static)

- Equations
  - Electr. Potential: $0 = div(grad\ \Phi)$
  - Electr. Field: $E = -grad\ \Phi$
  - Current Flow: $J = \sigma E$
  - Joule‘s Law: $Q = \iiint \rho\, J^2\, dV$
- Properties
  - Φ Potential
  - E Electr. Field
  - J Current Flow
- Material Properties
  - σ Electr. Conductivity
  - ρ Spec. electr. Resistivity $(1/\sigma)$



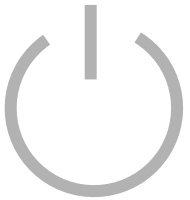
Current Flow in different **Conductors** within the Potentialfield between two **Iso-Potential Φ_1 und Φ_2**

Coupled Multi-Physics

Integration in existing thermo-mechanical Model

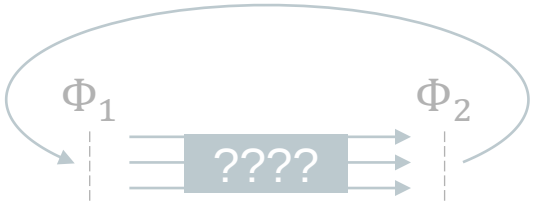
- Add-on to an existing Model and Adjustment of Modeling

```
*EM_CONTROL
$#   emsol                          dim                        NCYCLFEM  NCYCLBEM
         3                        &dim                               1         1
*EM_CONTROL_TIMESTEP
$#  tstype     dtcons       lcid
         1    &dtcons
```



```
*EM_MAT_001
$#  em_mid      mtype      sigma        eos
         1          2  &em_cond          1
*EM_EOS_TABULATED1
$     EOSID       LCID
         1       1600
```

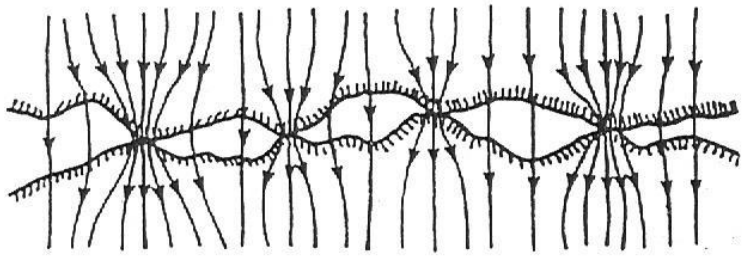
```
*EM_ISOPOTENTIAL
$#   isoid    settype      setid
         1          2          1
*EM_ISOPOTENTIAL
$#   isoid    settype      setid
         3          2          3
*EM_ISOPOTENTIAL_CONNECT
$#   conid    contype     isoid1     isoid2        val       lcid
         1          4          1          3                   51
```



Coupled Multi-Physics

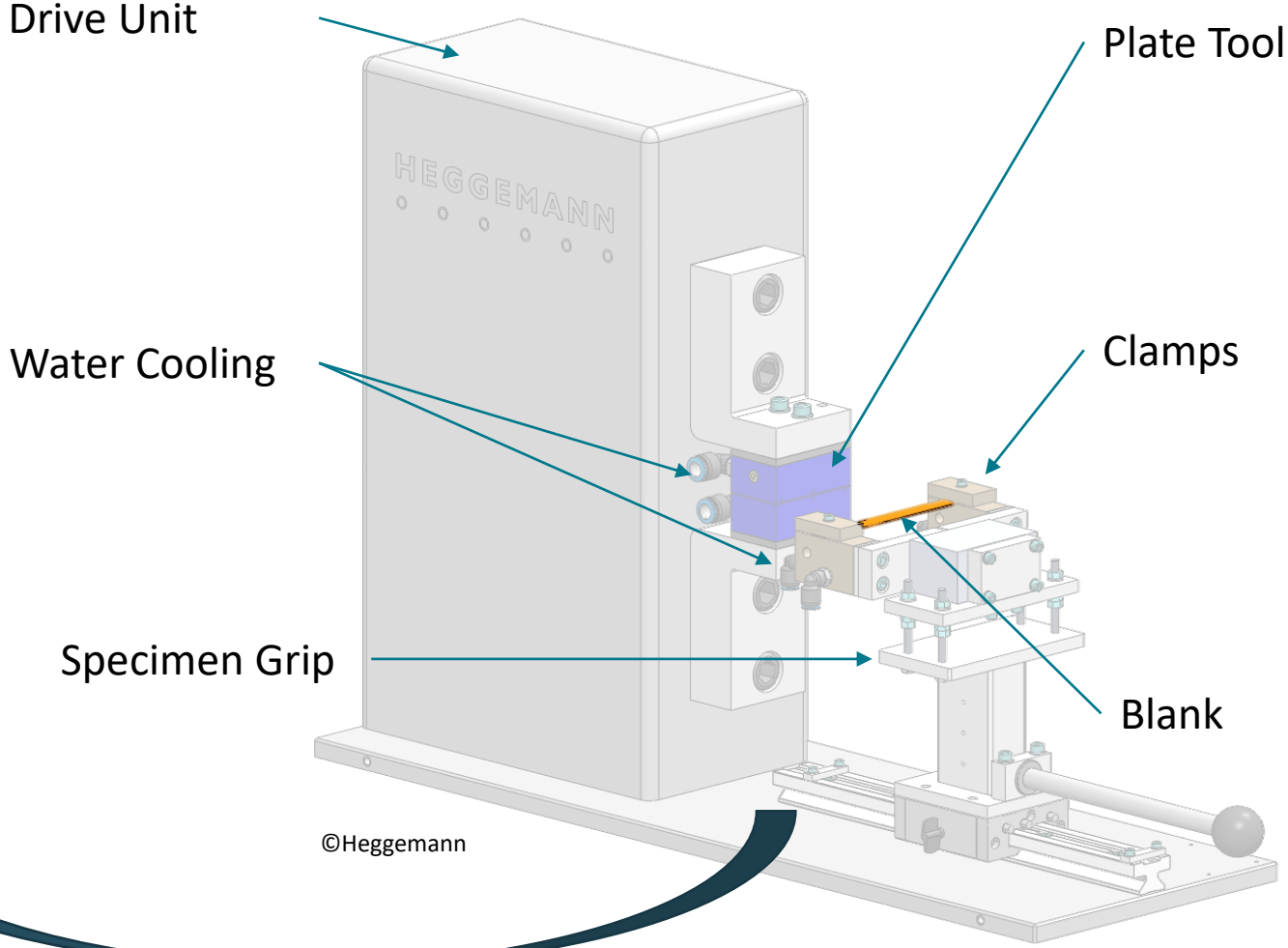
First Try: HTC Test Facility

- Facility to identify Pressure dependent Heat Transfer Coefficients:



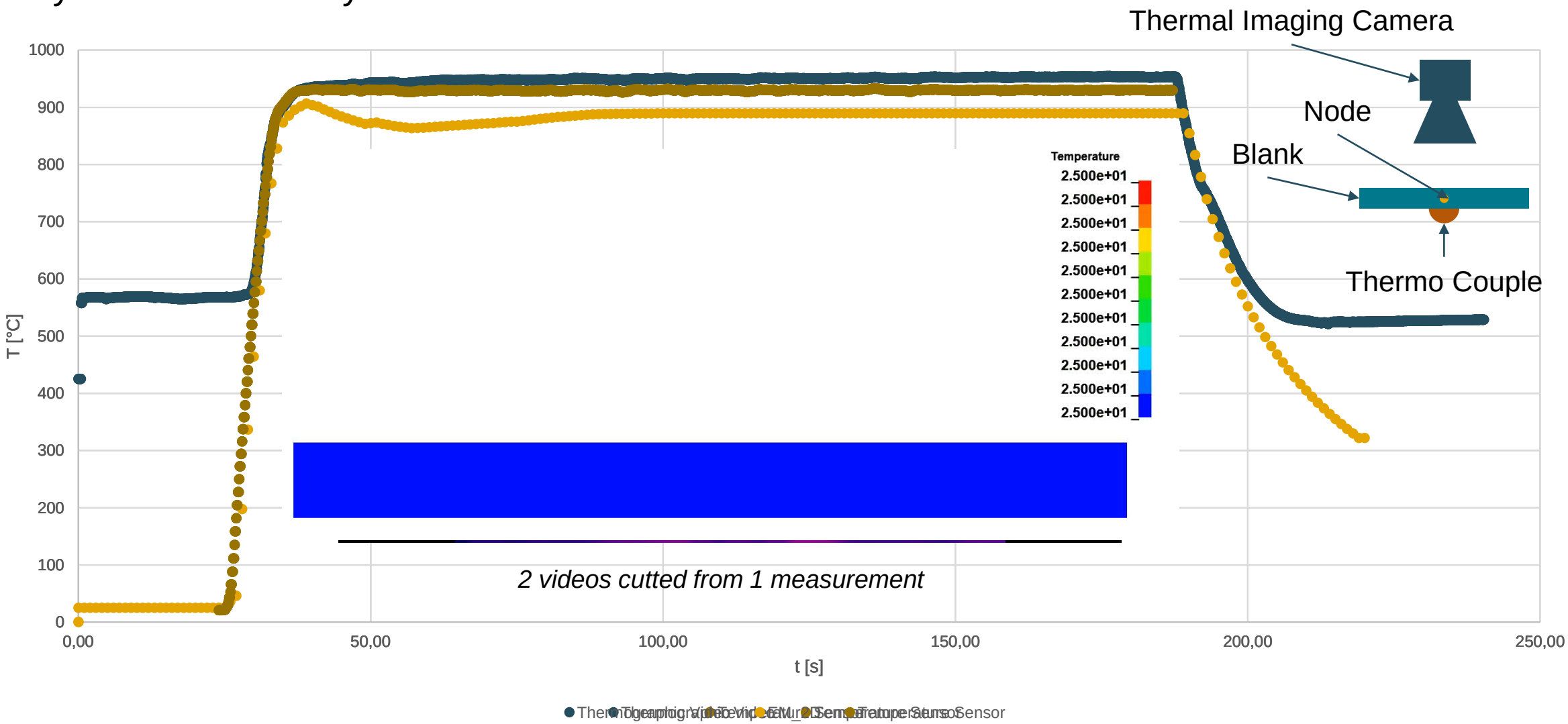
- Installation for Resistive Heating added
- Usage for Close-to-Process Microstru-cture Simulation
- Reduced Model for Heating Simulation

  - + Cooling to Air/Clamps



Coupled Multi-Physics

First Try: HTC Test Facility



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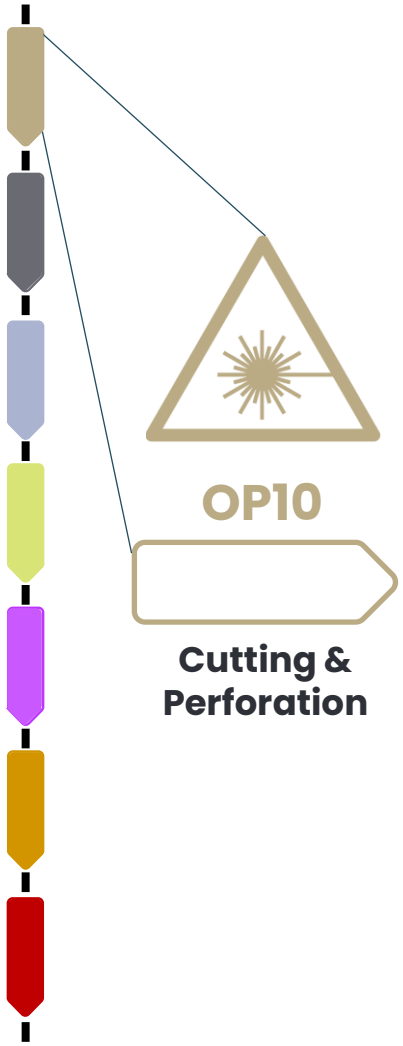
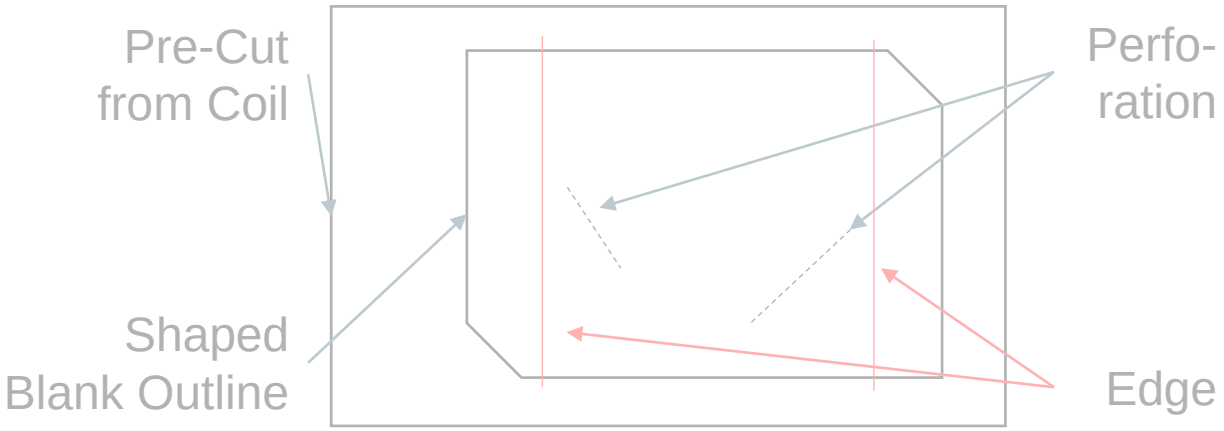
Self-controlled Multi-Physics

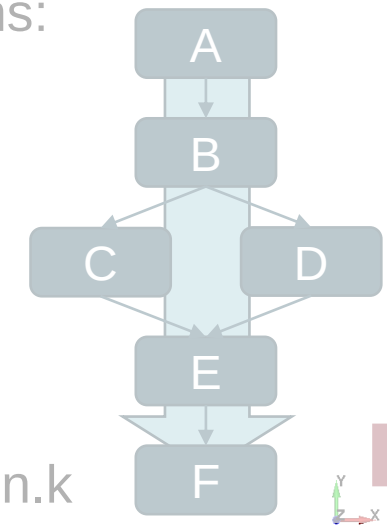
Semi-automatic Preparation of the Blank for TISTRAQ-Simulation

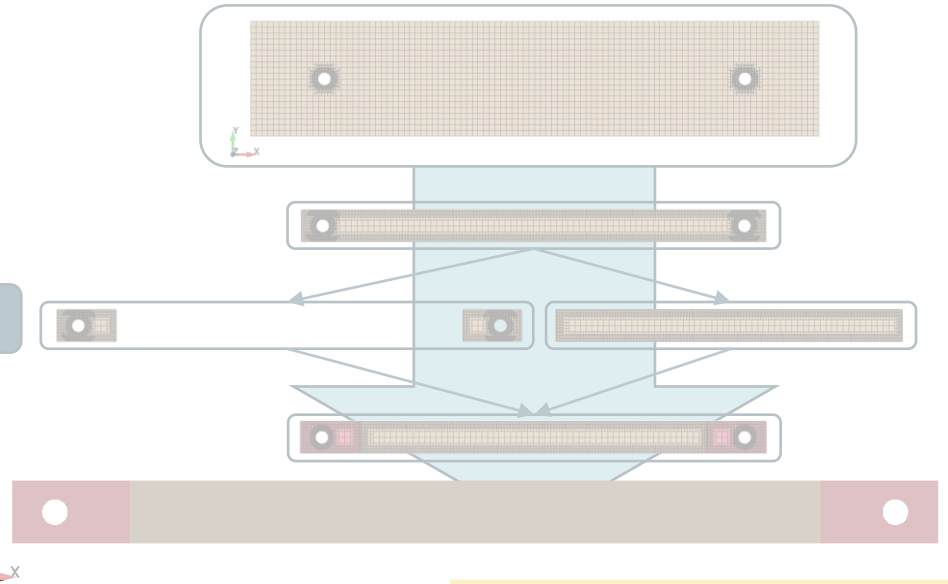


- Input Data
  - Mesh of the Pre-cutted Blank
  - IGES of the shaped Blank
  - IGES of the clamping Edges
  - Optional: Perforation



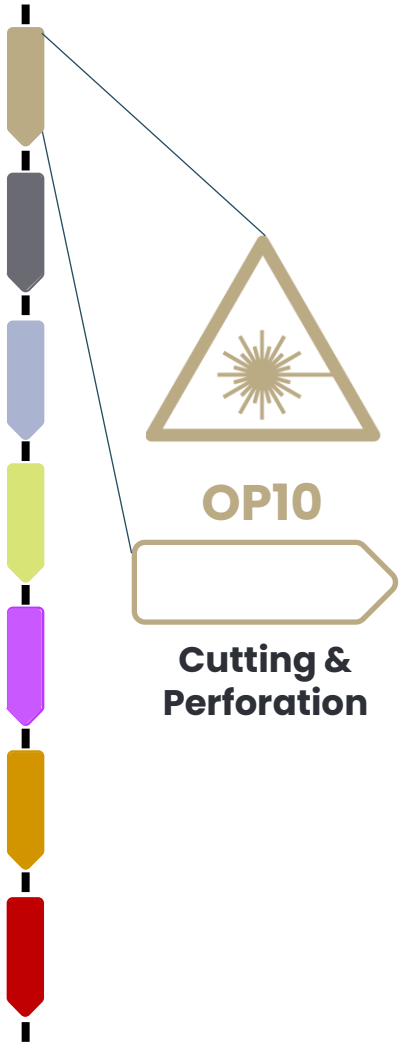
- Workflow with LS-DYNA runs:
  - 00_A_Inner_Trim.k
  - 00_B_Outer_Trim.k
  - 00_C_Clamp_Trim.k
  - 00_D_Free_Trim.k
  - 00_E_Merge.k
  - Optional: 00_F_Perforation.k



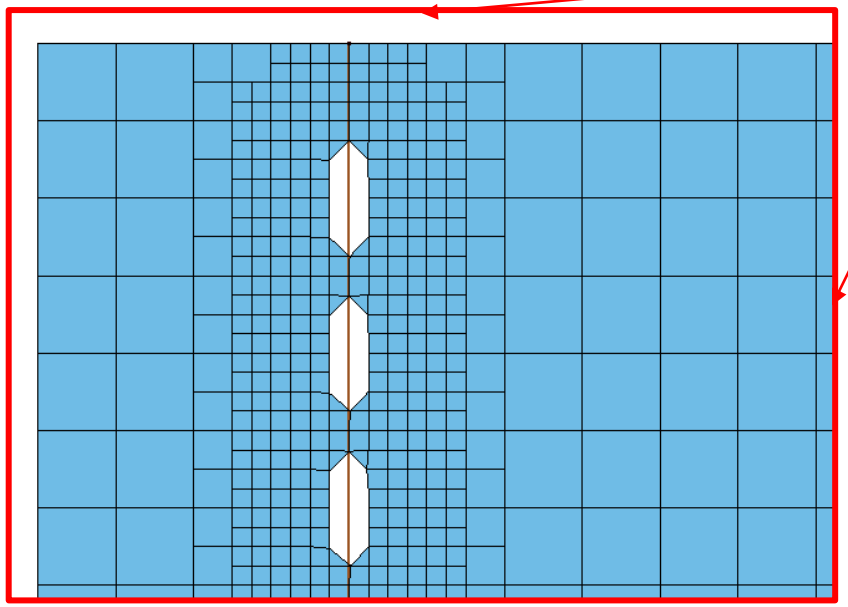


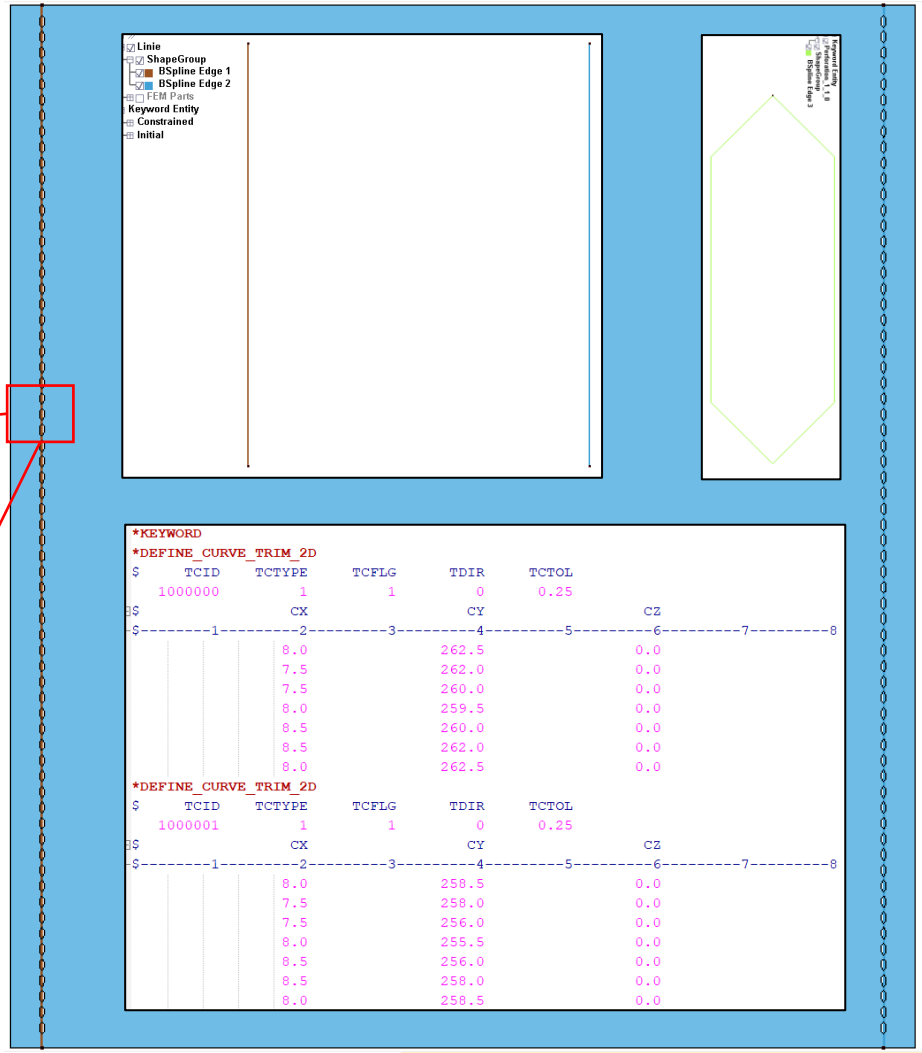
Self-controlled Multi-Physics

Semi-automatic Preparation of the Blank for TISTRAQ-Simulation



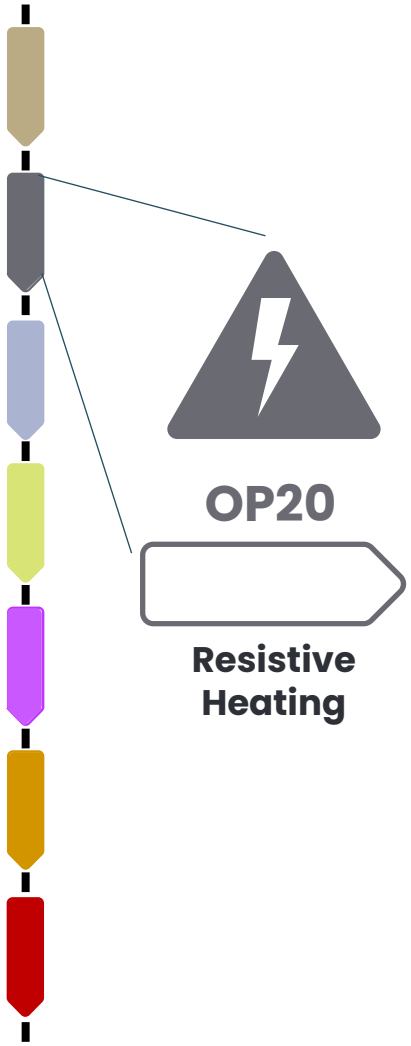
- Patented Perforation (by Heggemann AG)
- To influence the Current Flow and thus the Temperature Evolution
- Script to generate necessary Input
- ***CONTROL_FORMING_TRIMMING**



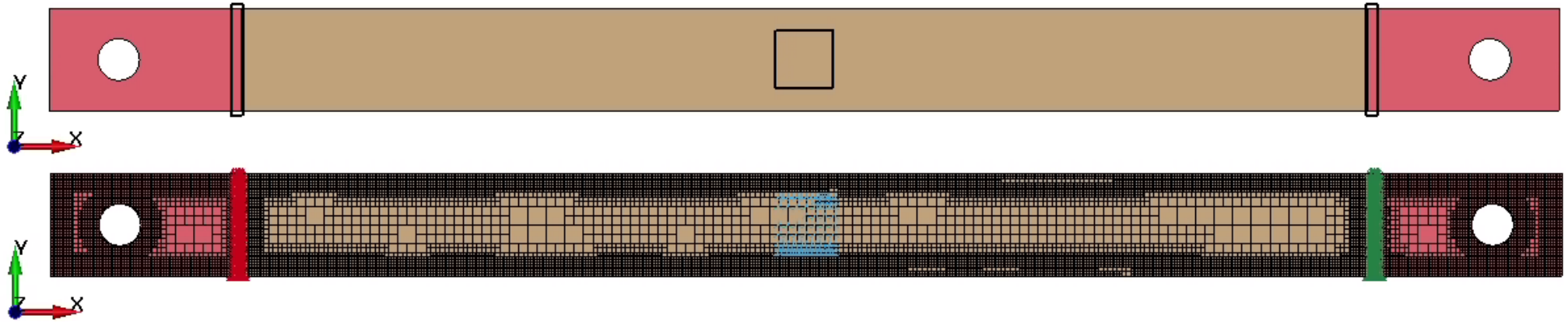


Self-controlled Multi-Physics

Semi-automatic Preparation of the Blank for TISTRAQ-Simulation



- ***SET_NODE** with **_GENERAL**

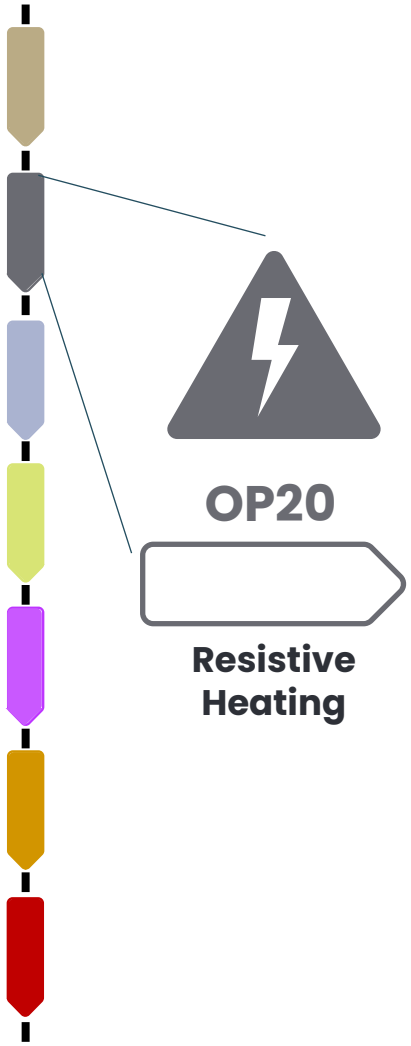


- 3x Boxes ***DEFINE_BOX**
  - 2x Isopotentiale
  - 1x „Virtual Thermo-Element“

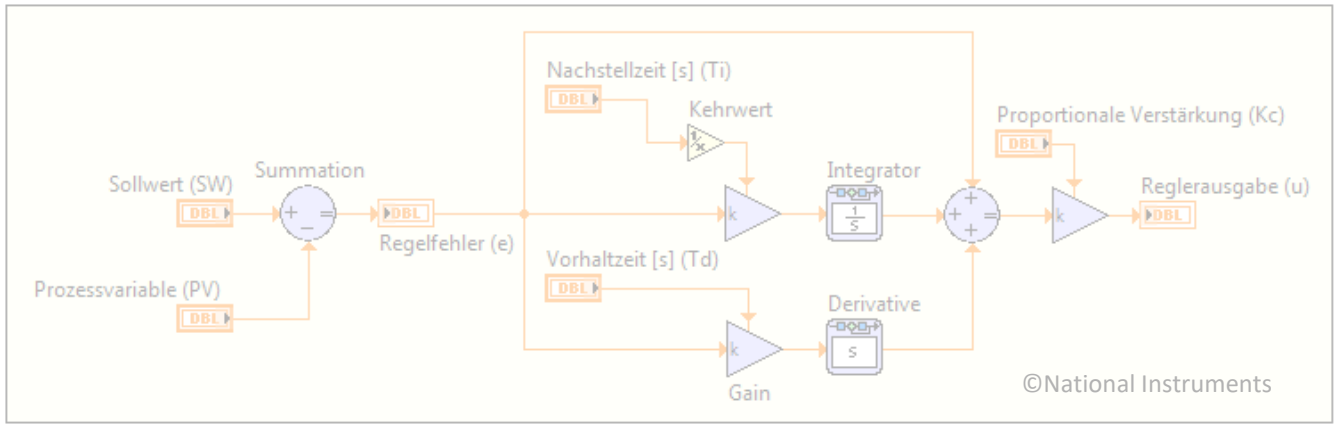
```
$ Sensorbox
*DEFINE_BOX
$    BOXID       XMN       XMX       YMN       YMX       ZMN       ZMX
         2      -3.1       3.1      -3.1       3.1      -1.0       1.0
*SET_NODE_GENERAL
$       SID
         2
$    OPTION        ID
       BOX         2
*SENSOR_DEFINE_NODE_SET_UPDATE
$    SENSID     NODE1     NODE2       VID                 CTYPE     SETOPT
         2         2                                       TEMP        AVG
$     BIRTH     DEATH    UPDATE
       0.0    &t_end   &tdtmin
```

Self-controlled Multi-Physics

Set up



- Real World Process is controlled
- PID Values are obtained iterativly



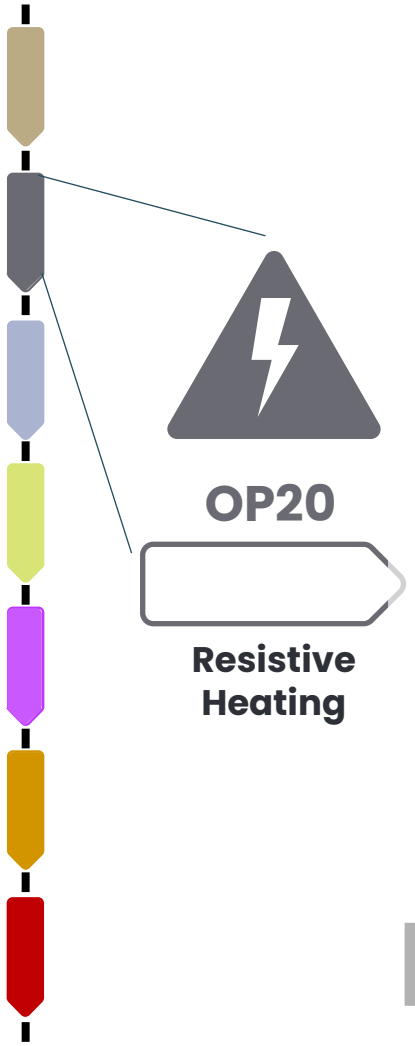
- Idea: Use Simulation to get a good first try
  - Reduce Material Usage

- LS-DYNA Keyword:
  ***DEFINE_CURVE_FUNCTION**

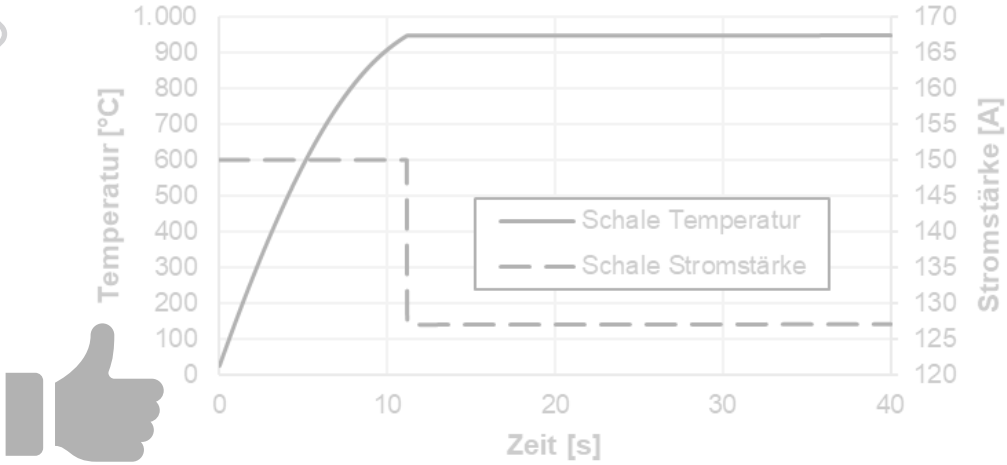
```
*EM_ISOPOTENTIAL_CONNECT
$    conid   contype    isoid1    isoid2       val      lcid
         1         4         1         3                   51
*DEFINE_CURVE_FUNCTION
$     LCID
        51
PIDCTL(SENSORD(2),&ref,&kp,&ki,&kd,&tf,&ei0,&sint,&umin,&umax)
```

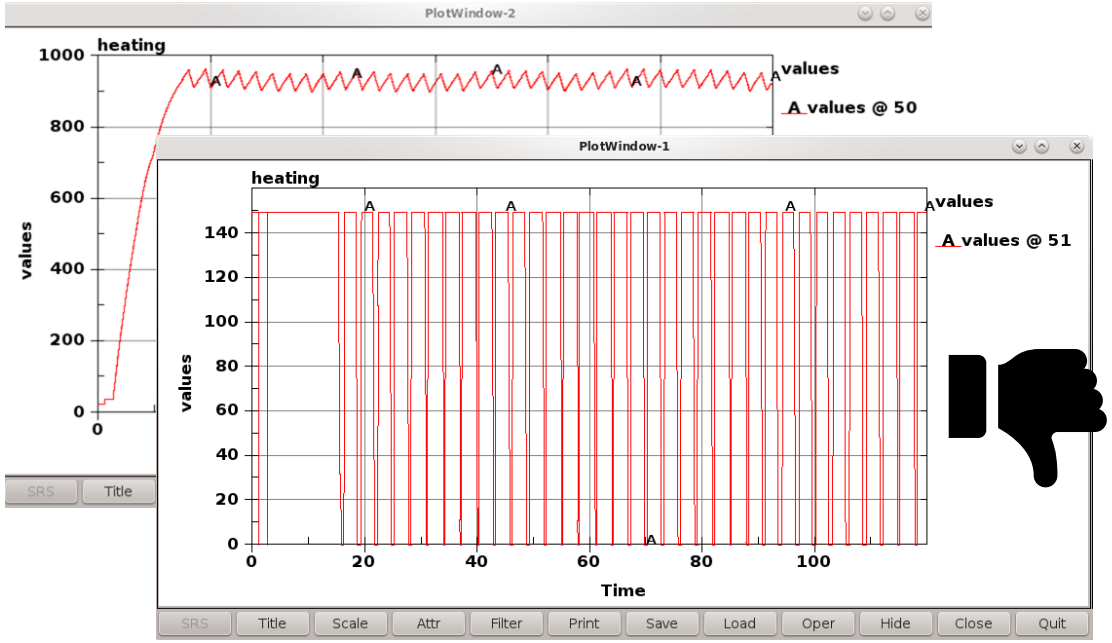
Self-controlled Multi-Physics

Results and Findings



- Controlled (weak) Coupling requires small Timesteps
- „Unknown Boundary Condition“ as Result of Simulation
- Latent Heat neglected here
- Potential for Improvement

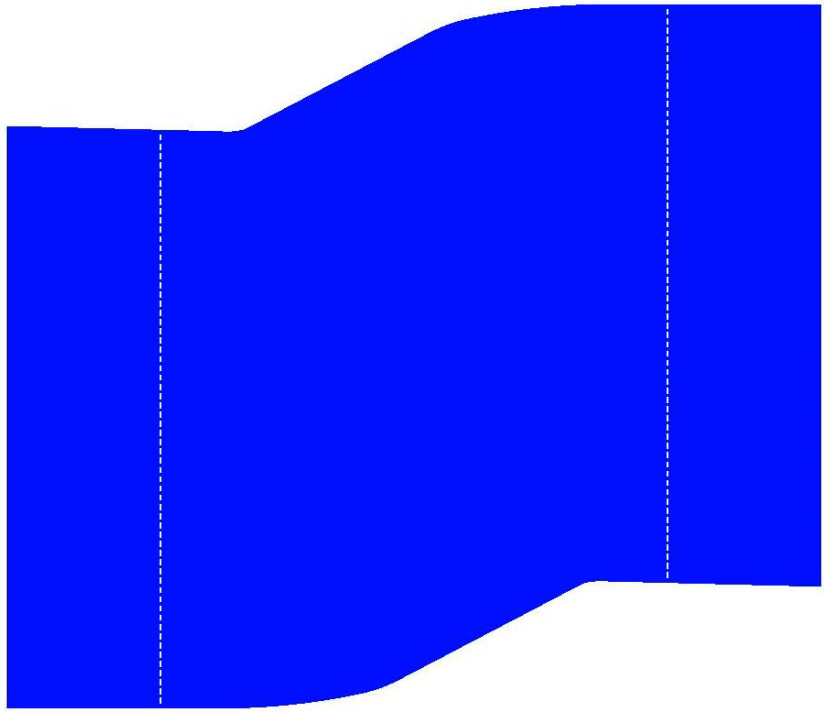


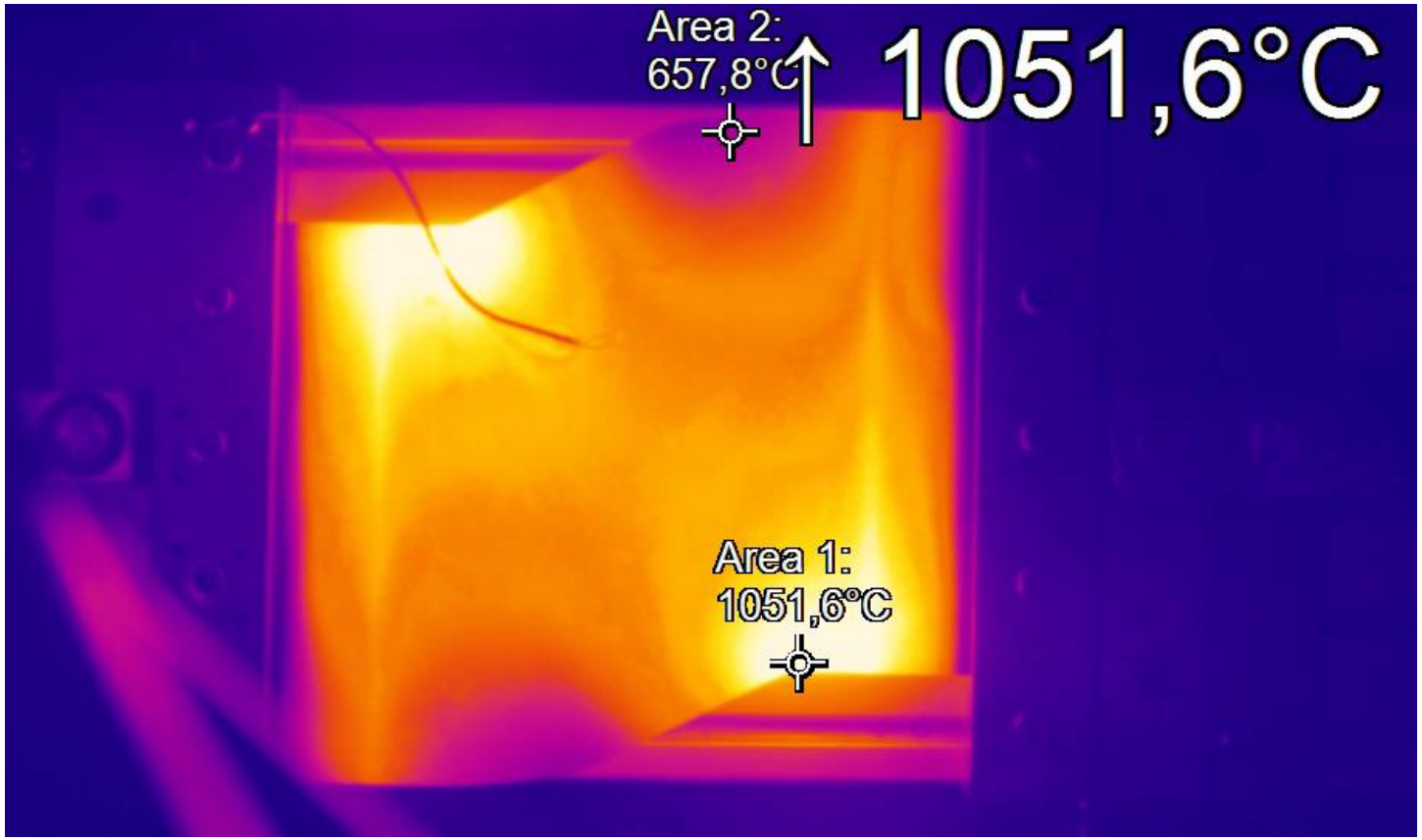


Self-controlled Multi-Physics

Results and Findings

- Application on a Demonstrator with 1mm thickness
- Blank approx. A4-sized





Self-controlled Multi-Physics

Results and Findings

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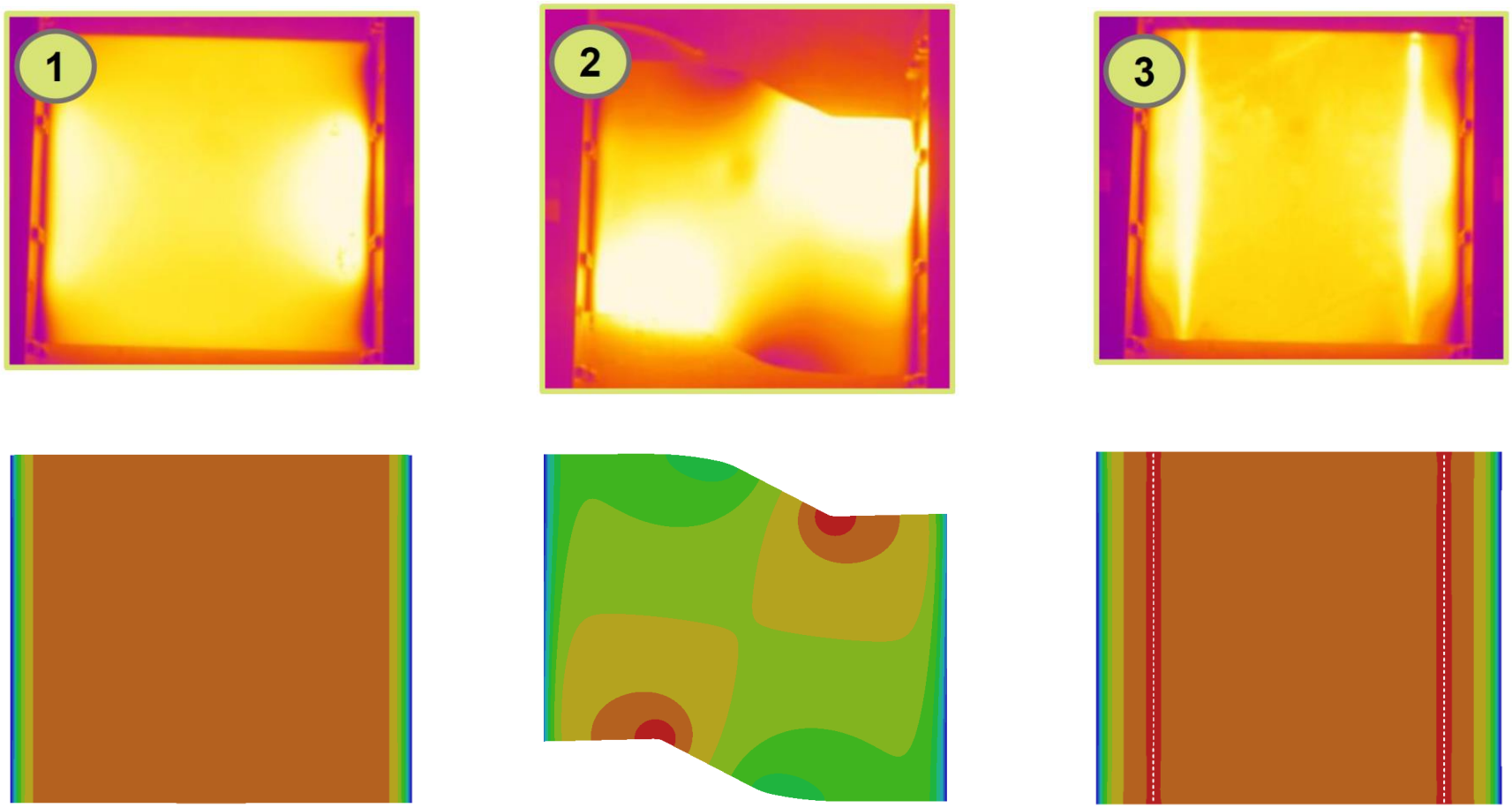

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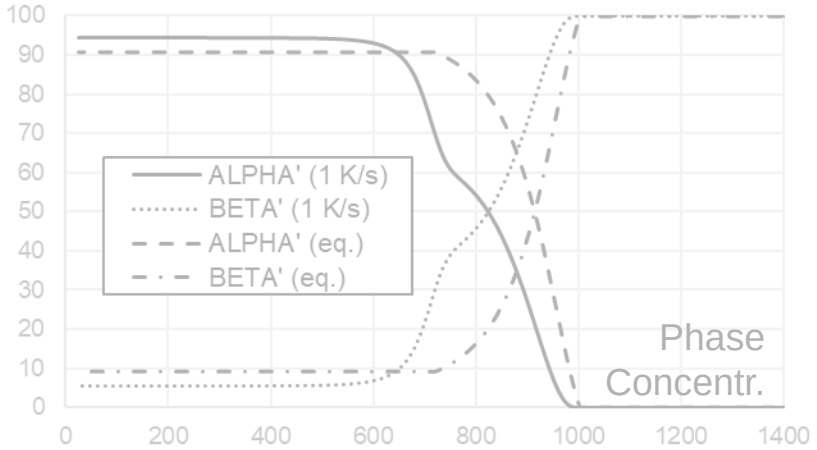
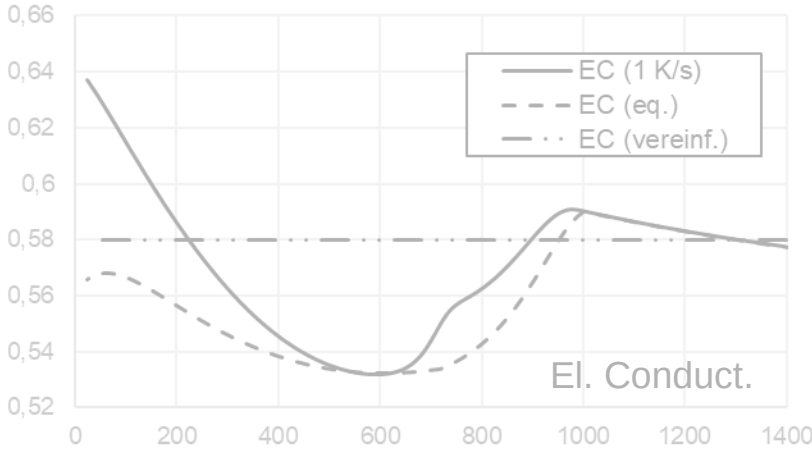
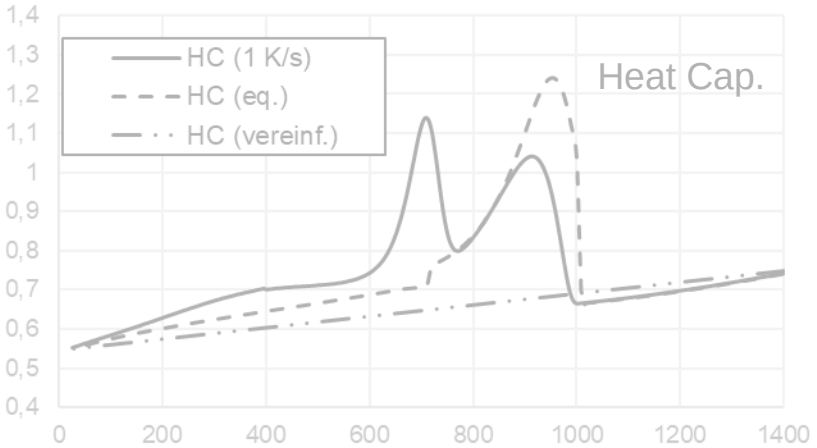
Material Data – Process dependent Properties

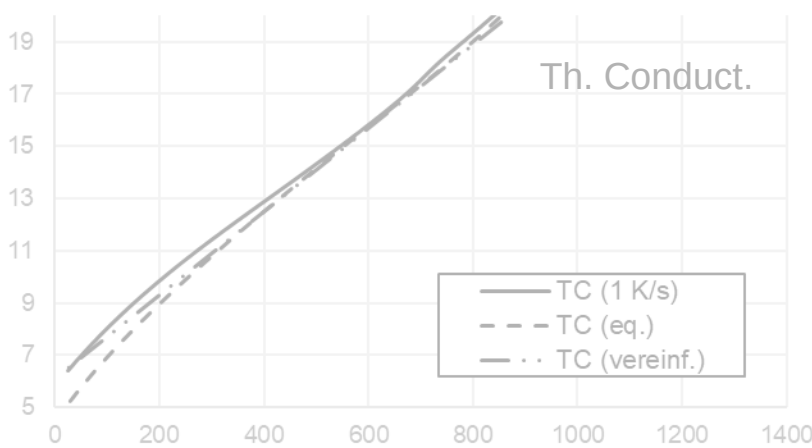
Are Temperature dependent Properties sufficient?

- Data from JMatPro (Demo Version)
- Phase Composition depends on Temperature and Time
- Potential Improvement for process dependent Properties
- (Allready available in Structural Solver: Yield Curve, Youngs M., …)





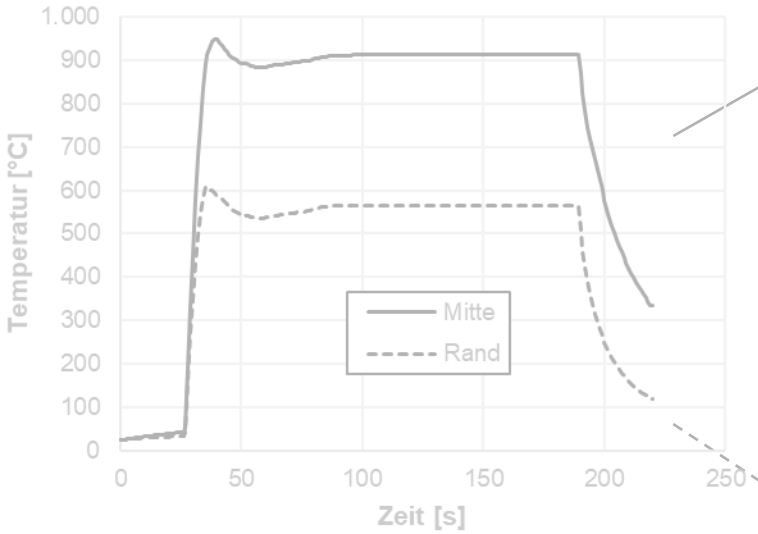


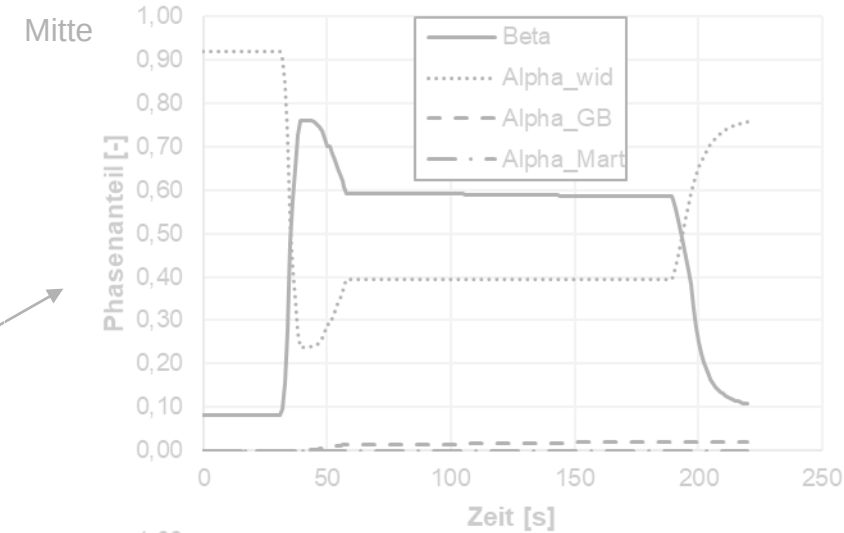


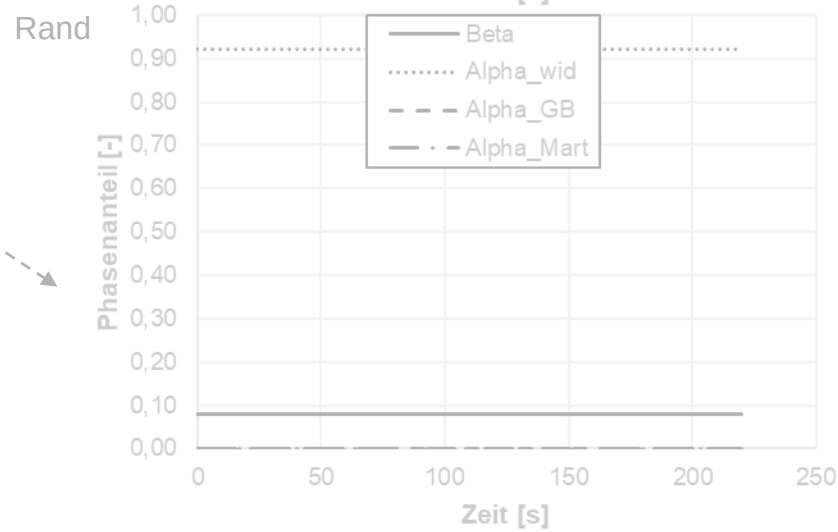
Material Data – Process dependent Properties

Simulation of Phase Transformations

- ***MAT_GENERALIZED_PHASECHANGE** to simulate complex Material behaviour with Phase Transformations
- Application of ***MAT_254** from *“Simulating Ti-6Al-4V with *MAT_254 in LS-DYNA”, Klöppel et al, 23. ESAFORM, Cottbus, 2020* (with doubts …)
- Phase Composition over Time







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Summary

3 potential Scenarios for Multi-Physics in TISTRAQ

1. Homogeneity of Temperature Field History
   - (and thus Mechanical Properties of the later Part)
   - Very fast thanks to 2D-EM, Thermal thin Shells & Shells (with all nodes constrained)
   - Checking Blank Outlines & Perforations & Cooling Conditions (Not showned yet)

2. Self-Controlled Simulation
   - Get a Current Profile to compare with Real World Production and potentially identify QA issues
   - At the Moment very long Run Times due to small Timesteps

3. Simulation with Process dependent Properties
   - At the Moment very unlikely,

Thank You

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