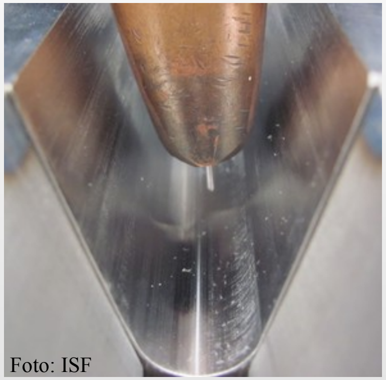
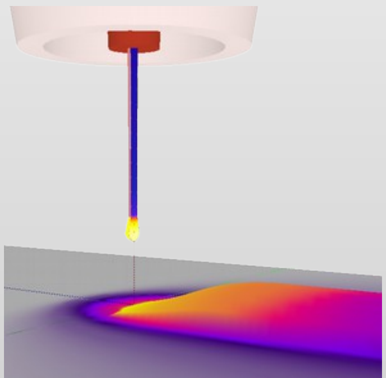
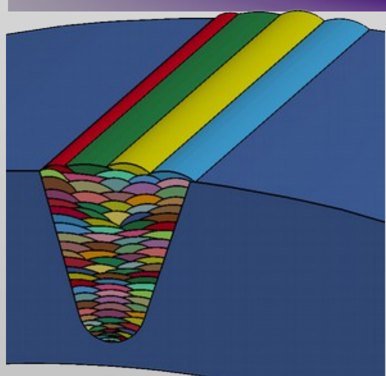


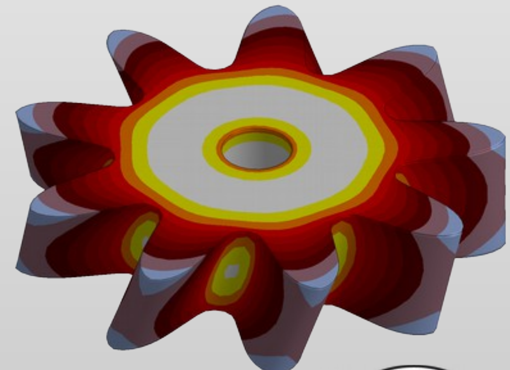
Foto: ISF





Basics of
Welding Simulation and Heat Treatment Simulation
Applications and Benefits

Infotag Schweißen und
Wärmebehandlung
14.04.2016
Zürich



Dr.-Ing. Tobias Loose
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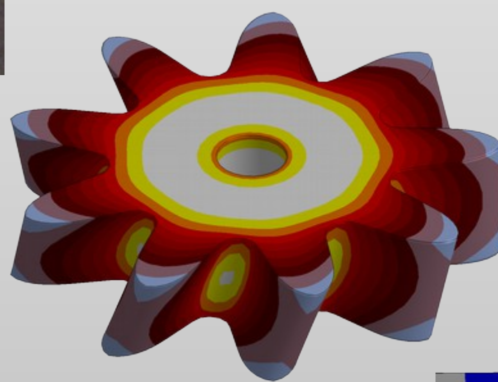
loose@tl-ing.de www.tl-ing.eu

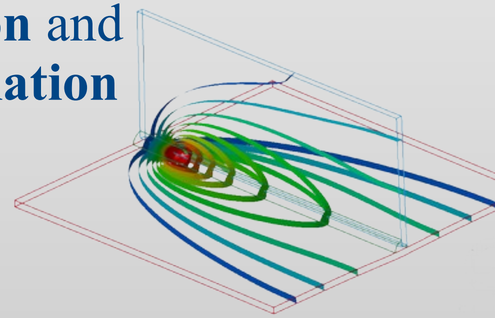
Herdweg 13, D-75045 Wössingen Lkr. Karlsruhe
E-Post: loose@tl-ing.de Web: **www.tl-ing.eu www.loose.at**
Mobil: +49 (0) 176 6126 8671 Tel: +49 (0) 7203 329 023 Fax: +49 (0) 7203 329 025

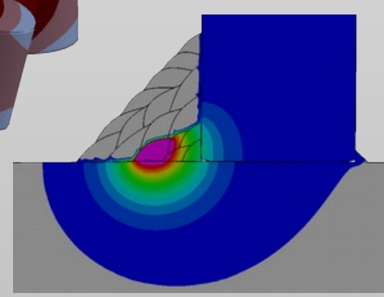
Numerical Simulation for Welding and Heat Treatment since 2004

- Consulting
- Training
- Support
- Software Development
- Software Distribution

for **Welding Simulation** and Heat **Treatment Simulation**



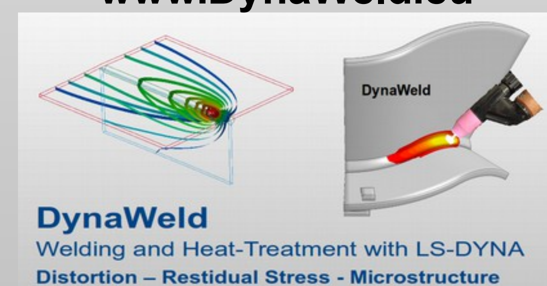




www.WeldWare.eu

www.SimWeld.eu

www.DynaWeld.eu

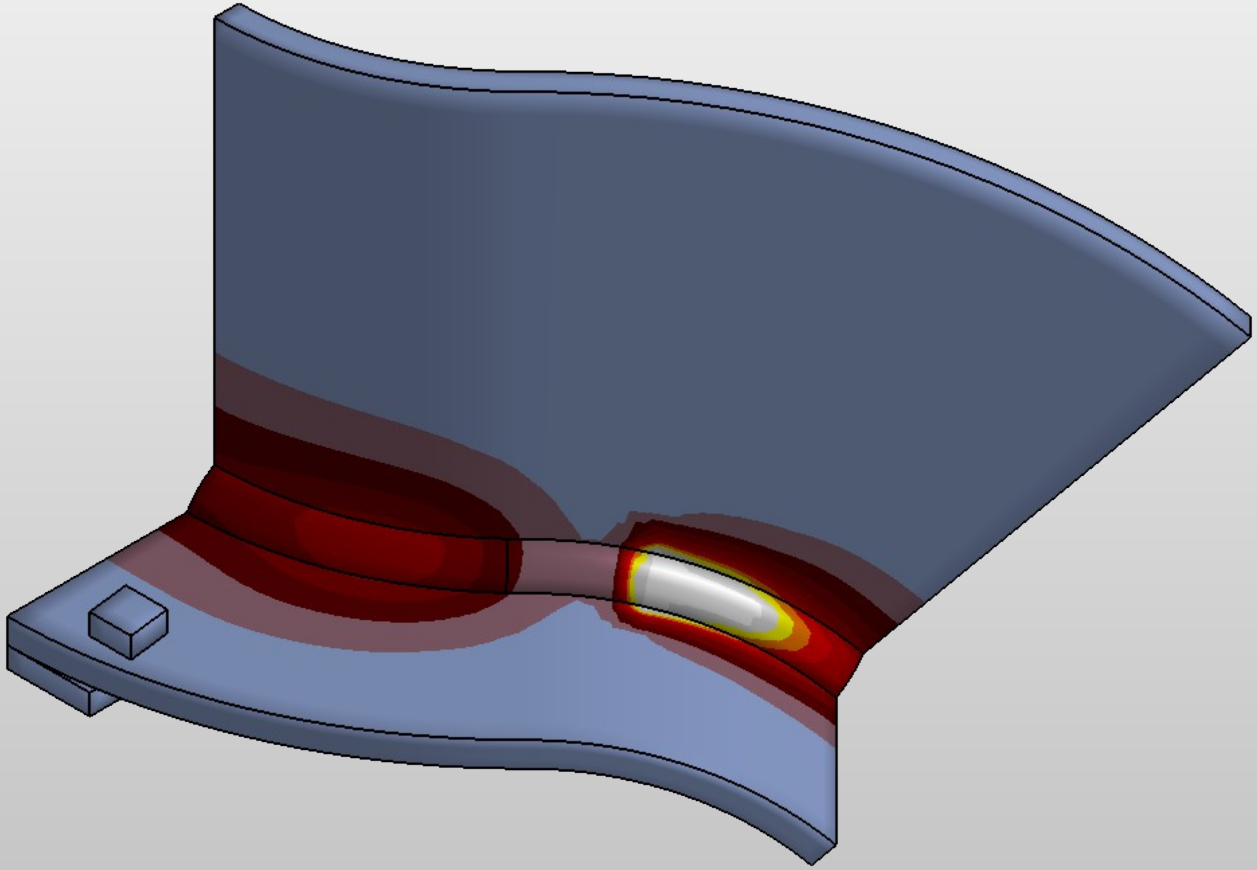


Internet:

DEeutsch: **www.loose.at**
ENglisch: **www.tl-ing.eu**
ESpañol: **www.loose.es**

Motivation

and Examples



Welding of a T-Joint

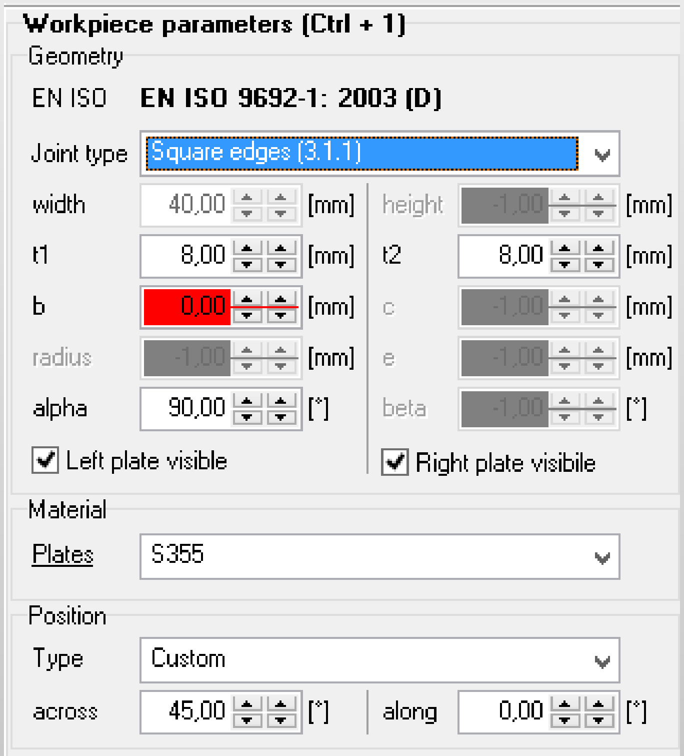
- Double sided T-Joint a = 4 mm
- Plate S355 thickness 8 mm
- 3 Tacks double sided
- Travel speed 80 cm/min
- Current: 390 A
- Voltage: 30 V

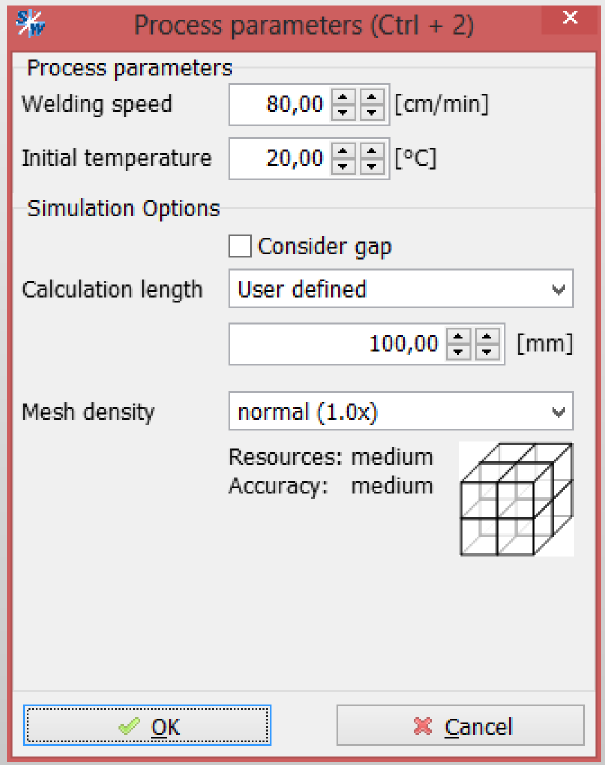
- Start Time Tack 1: 0 s
- Start Time Tack 2: 20 s
- Start Time Weld 1: 1000 s
- Start Time Weld 2: 1023 s
- Weld 1 and Weld 2 have the same travel direction

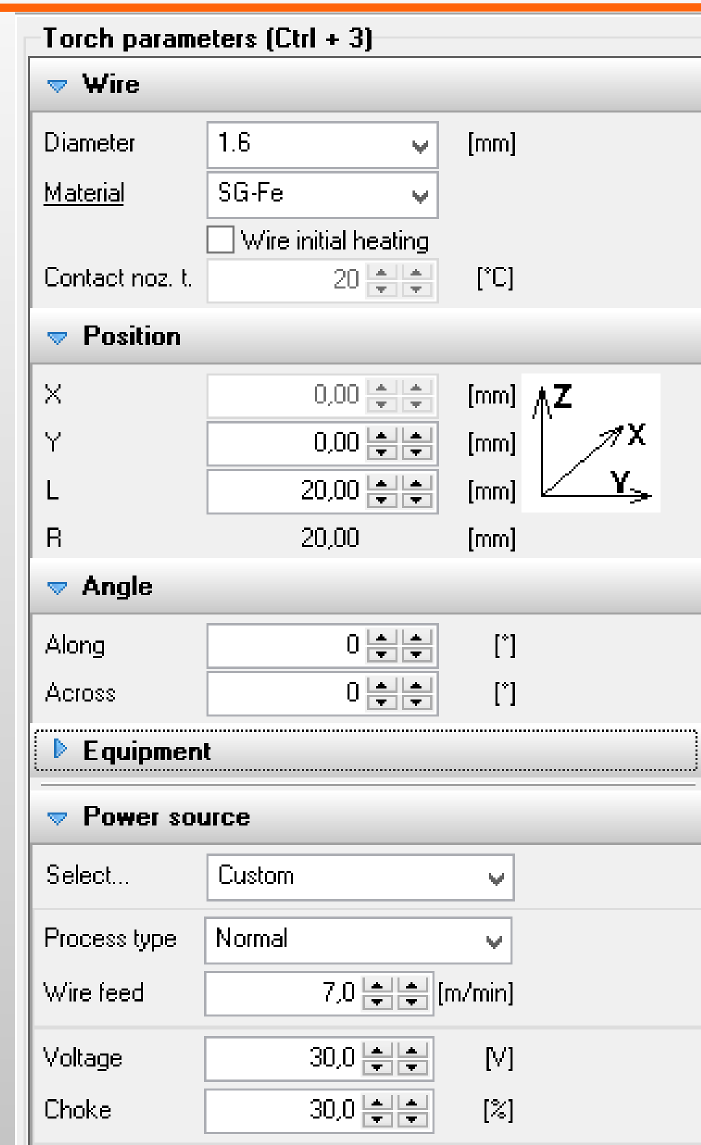

Foto: Volvo

Process Simulation with SimWeld

Input-Parameter SimWeld

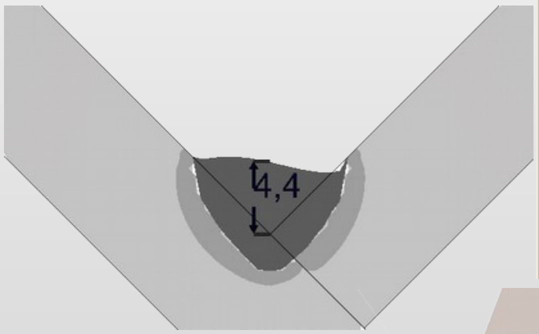




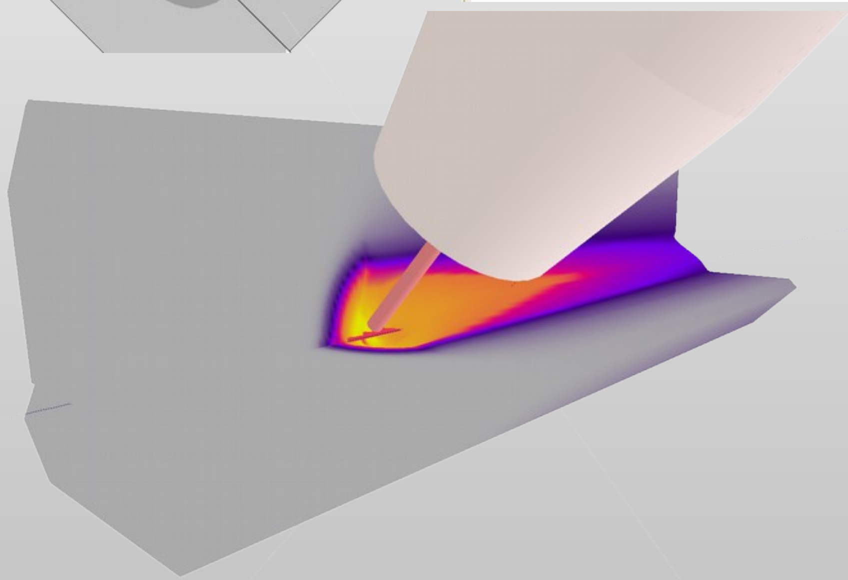


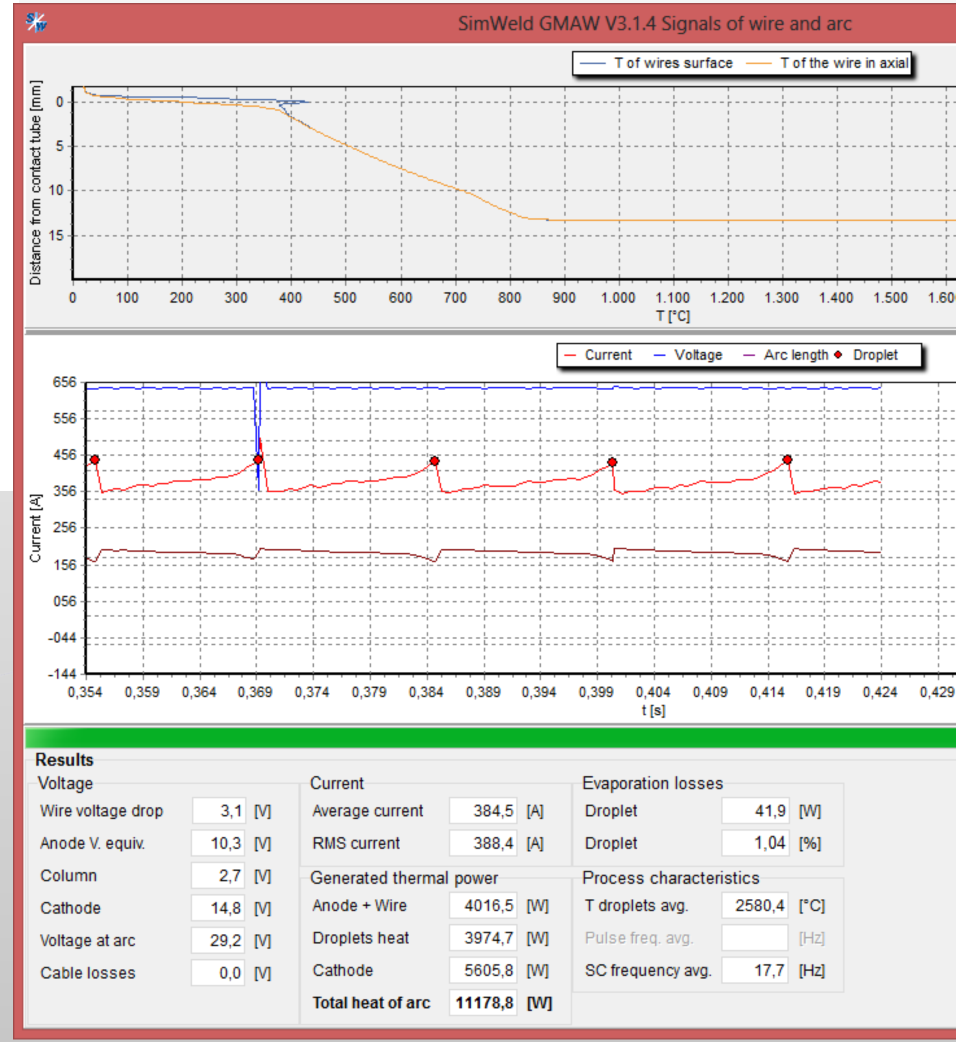
SimWeld Results

- a = 4,4 mm
- I = 390 A
- V = 29,2 V

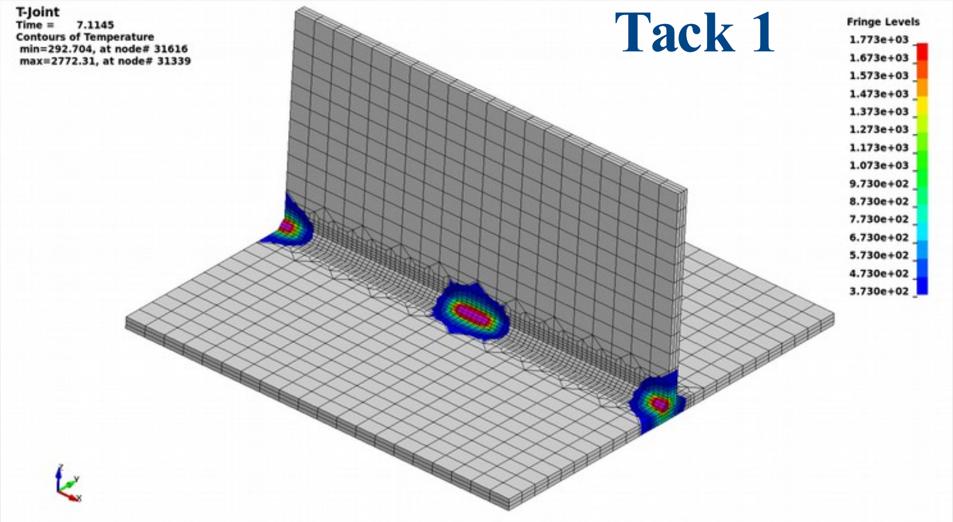


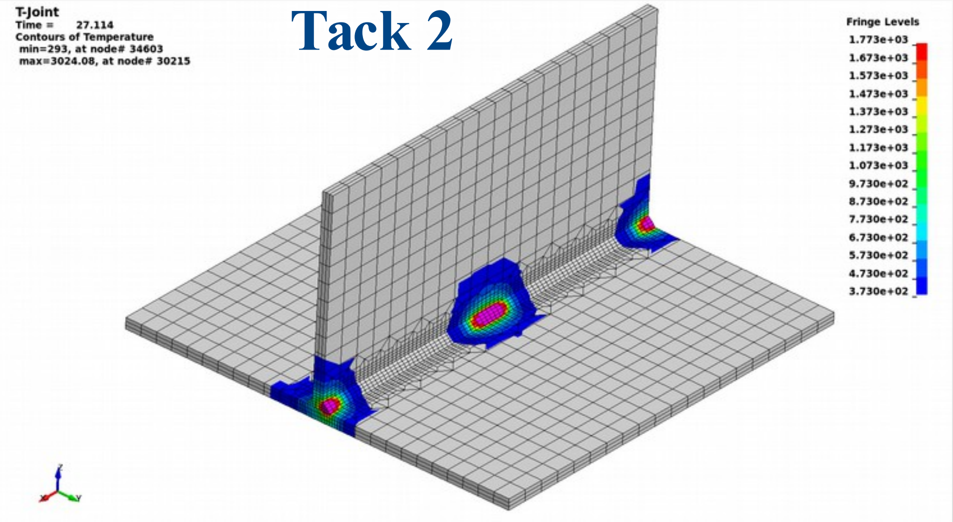

```
3D double ellipsoid source
10142,58600  //Q (W)
6005,89110  //Qf (W)
4136,69530  //Qr (W)
375,36136  //q0_front (W/mm3)
7,87233  //q0_rear (W/mm3)
2,58247  //af (mm)
31,54304  //ar (mm)
4,67305  //b (mm)
6,65324  //c (mm)
3,30435  //x0 (mm)
3,30435  //z0 (mm)
45,00001  //ay (degree)
80,00000  //vy (cm/min)
```

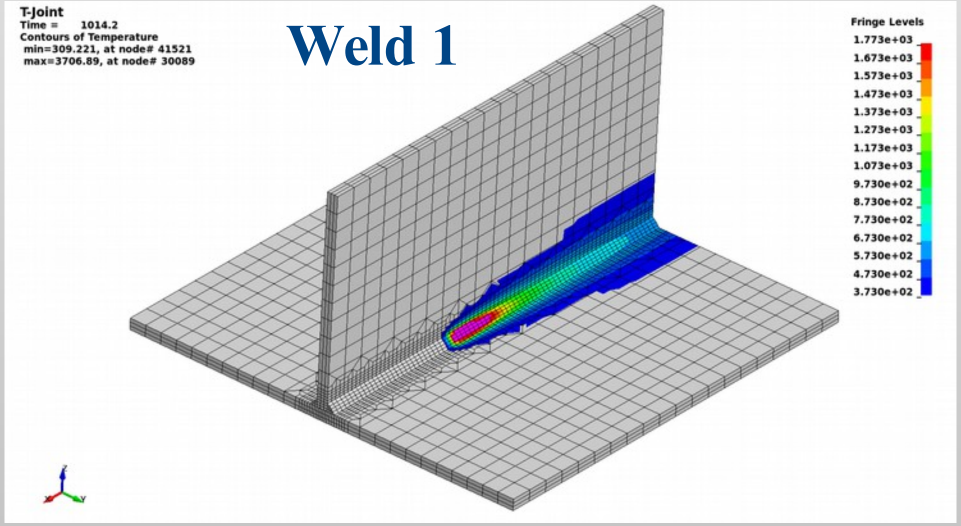


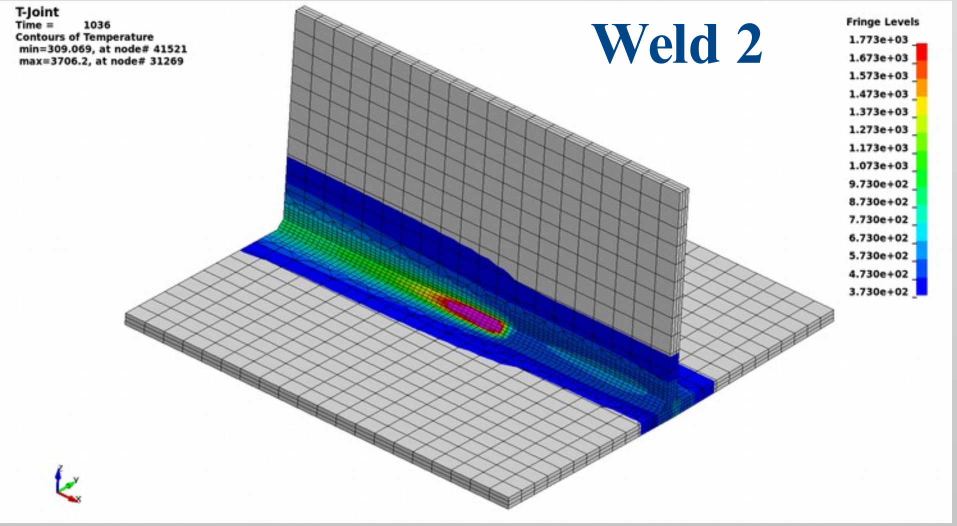


Temperature



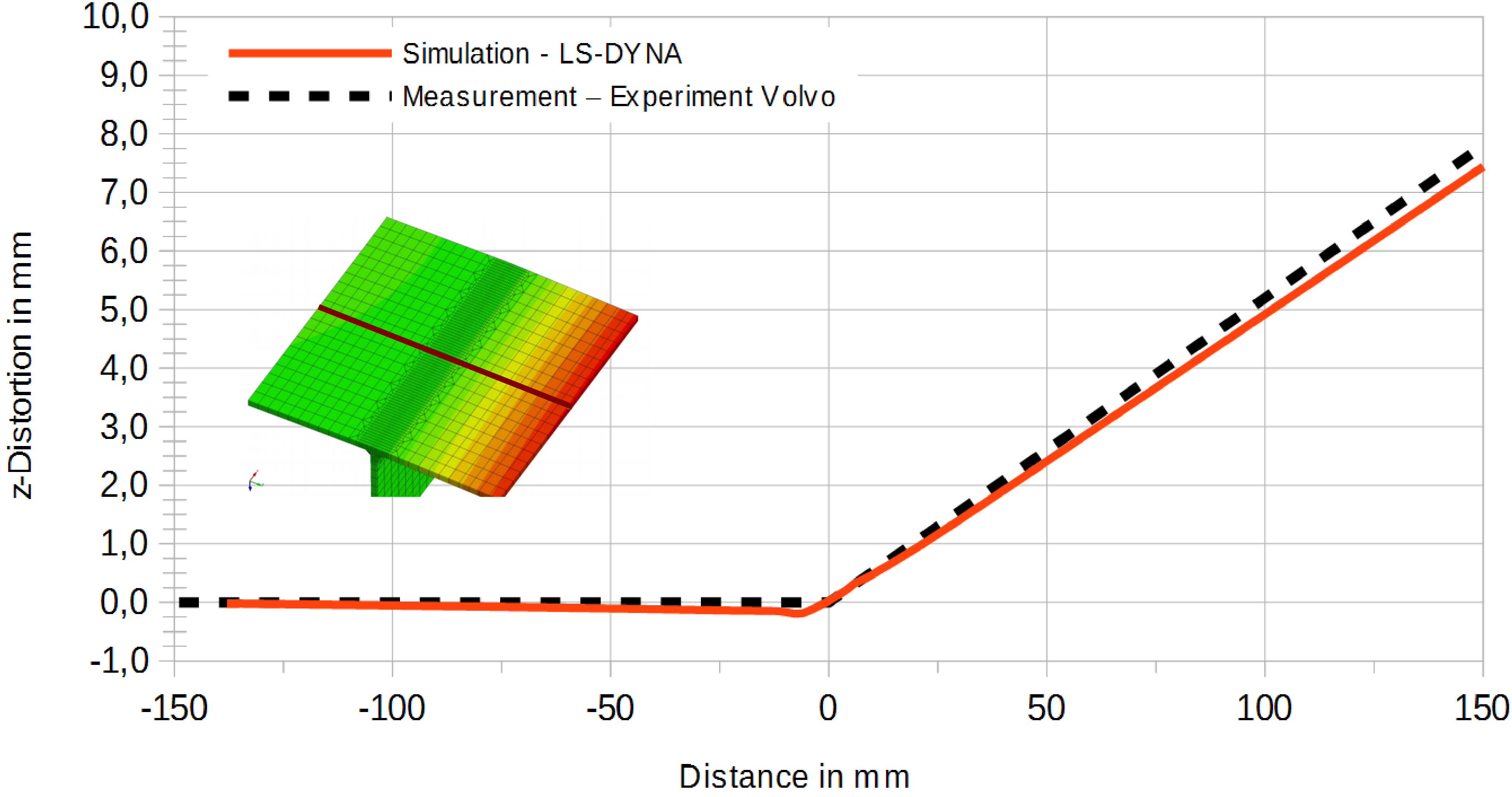




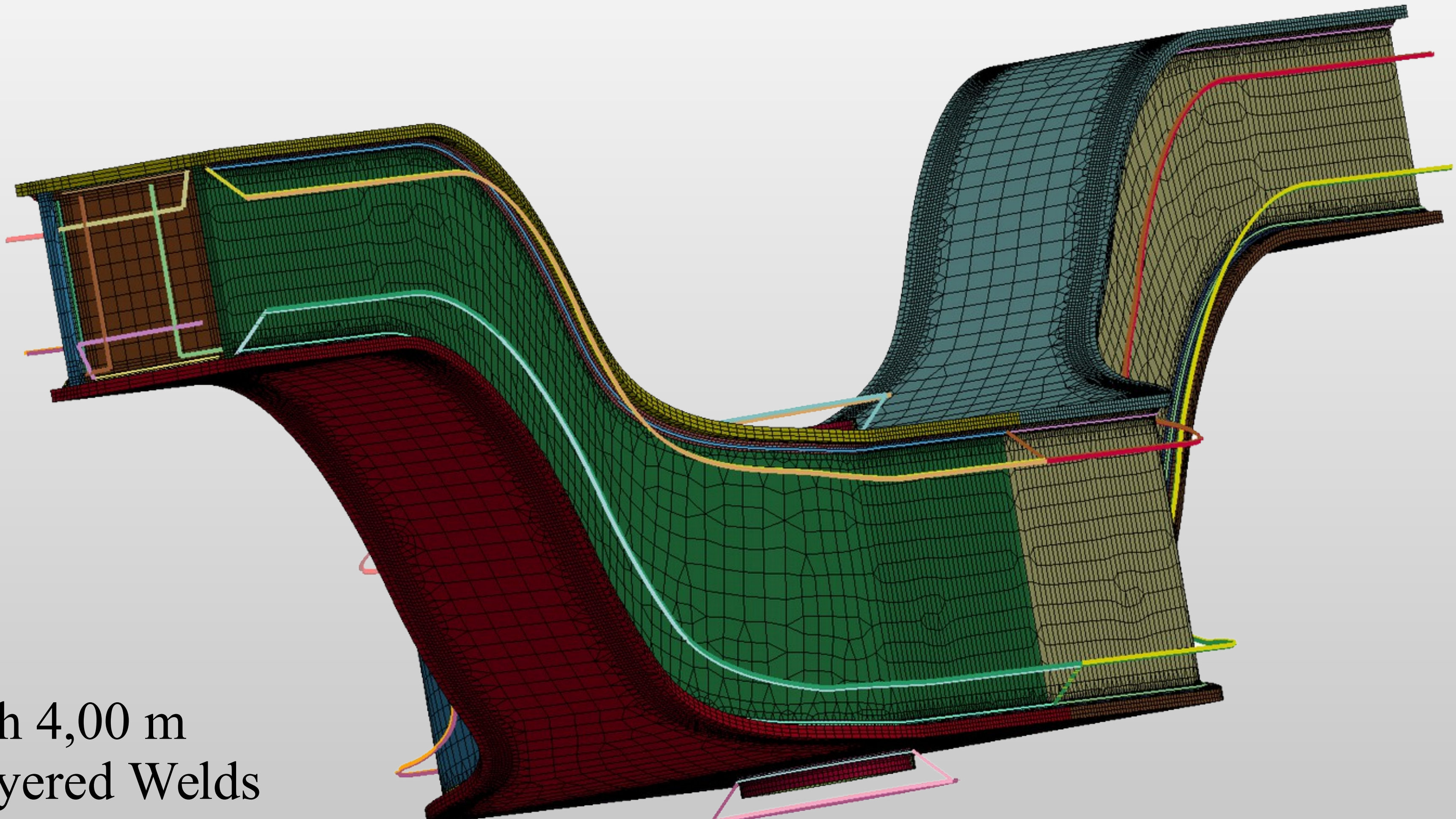


z-Distortion at Evaluation Path

transformed to flat left side

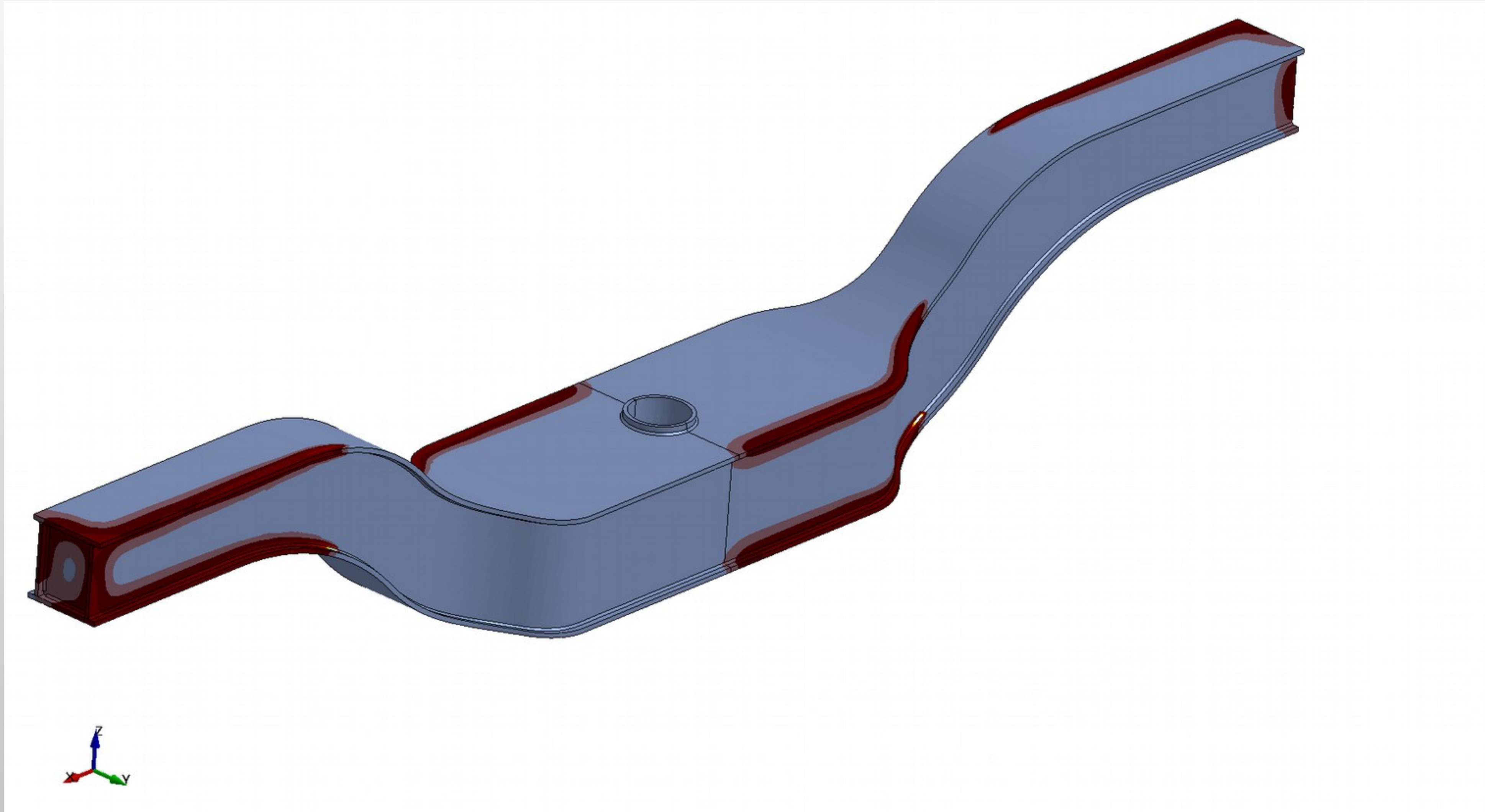


Curved Hollow Section Beam

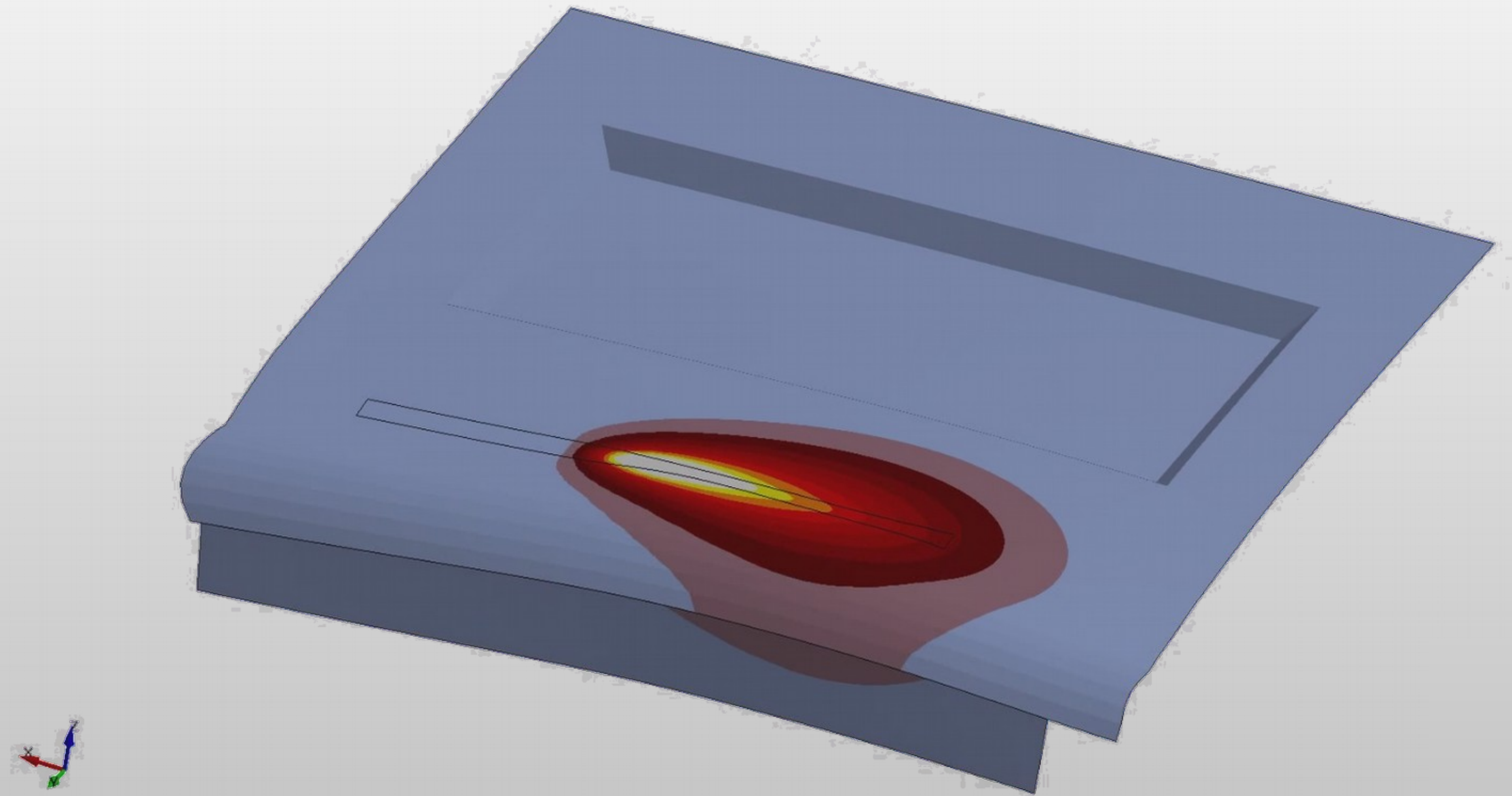


Length 4,00 m
8 2-layered Welds
12 single layered Welds

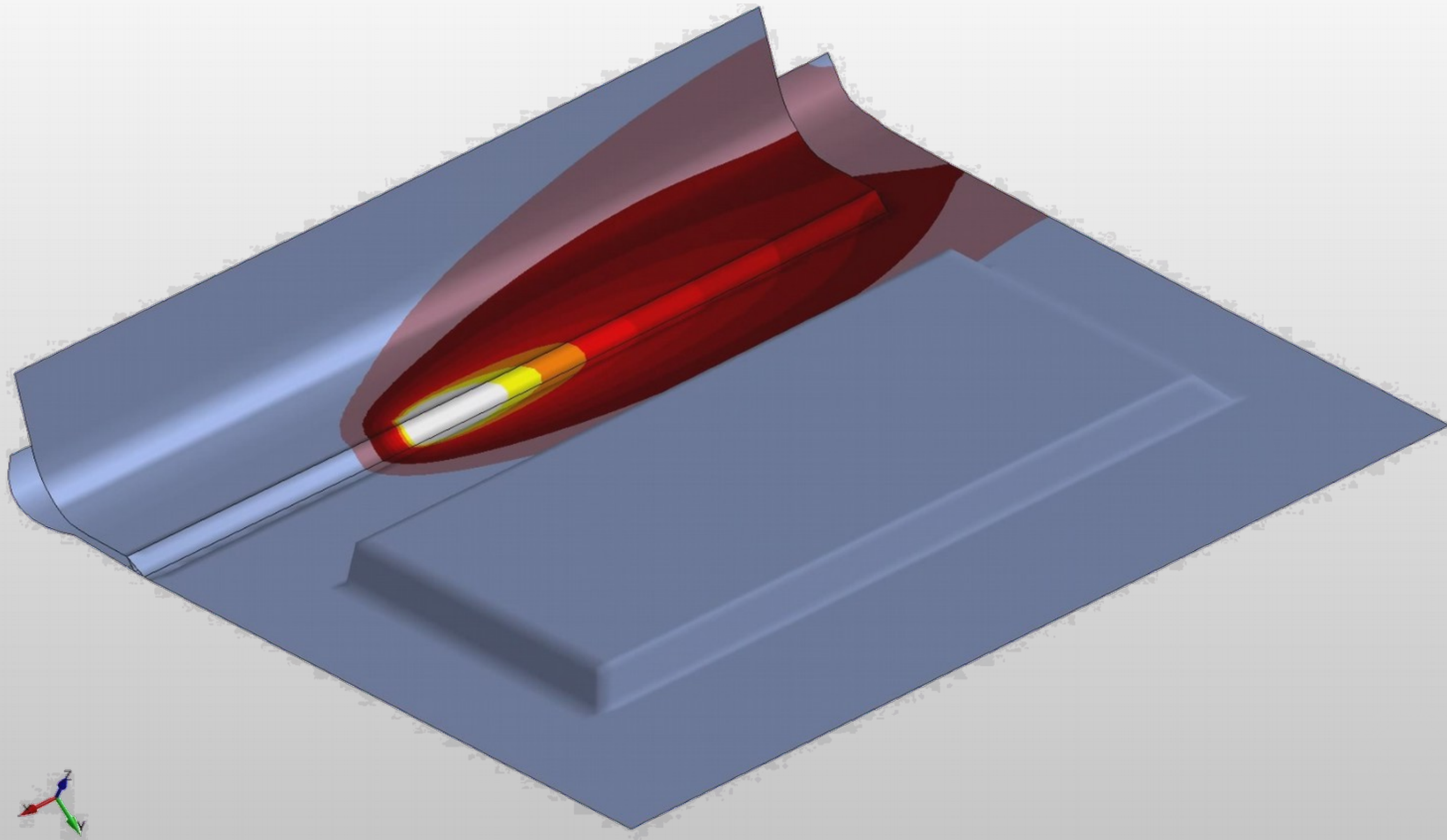
Curved Hollow Section Beam



Autobody Sheet

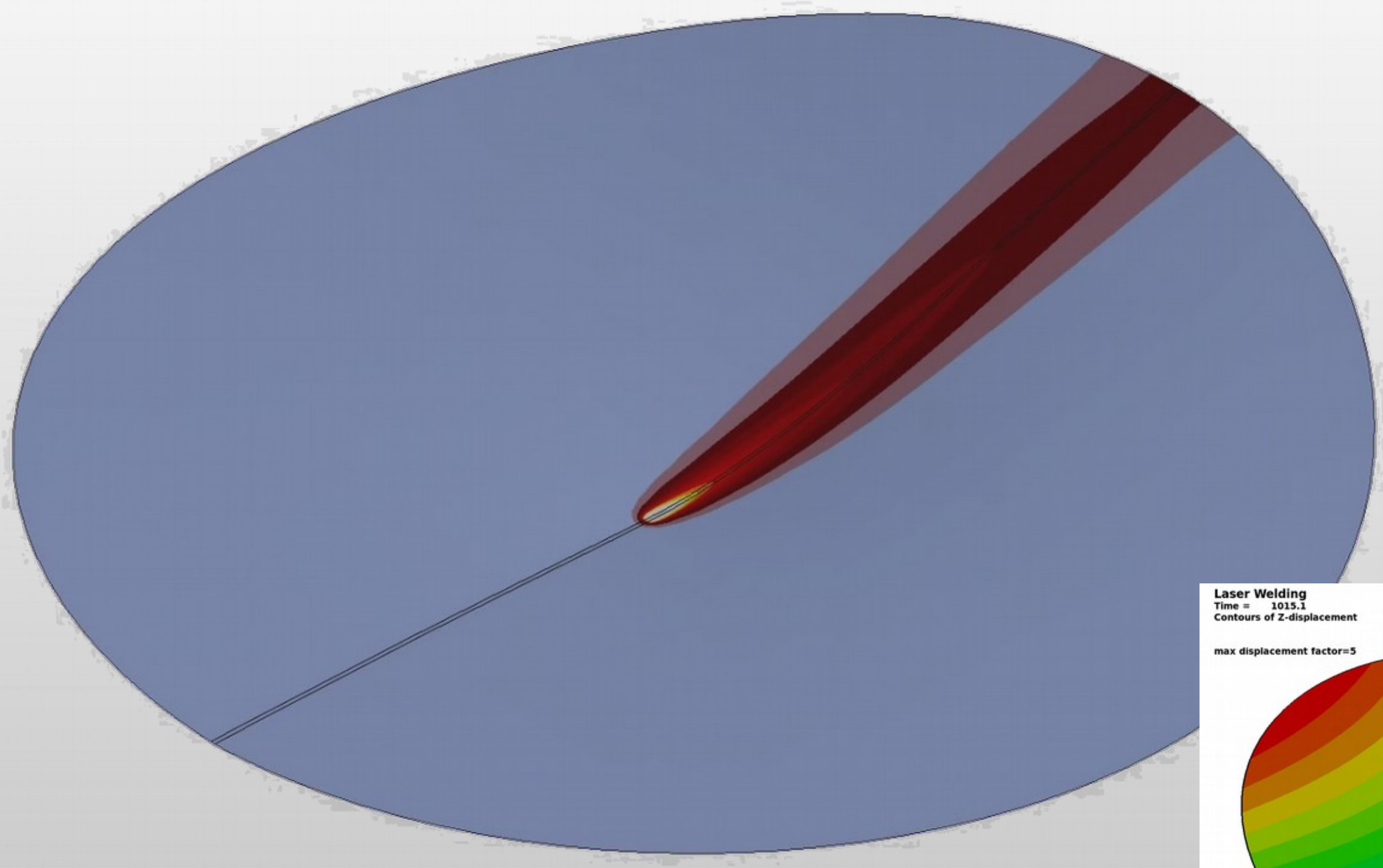


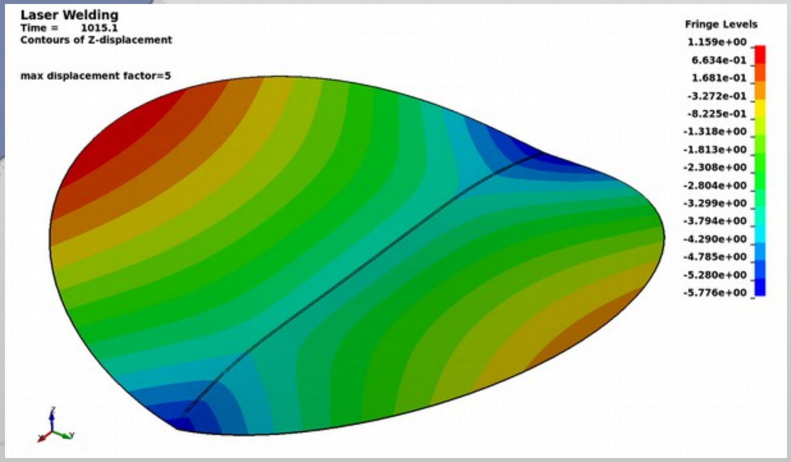
Autobody Sheet



Welding

z-displacement 5-times scaled

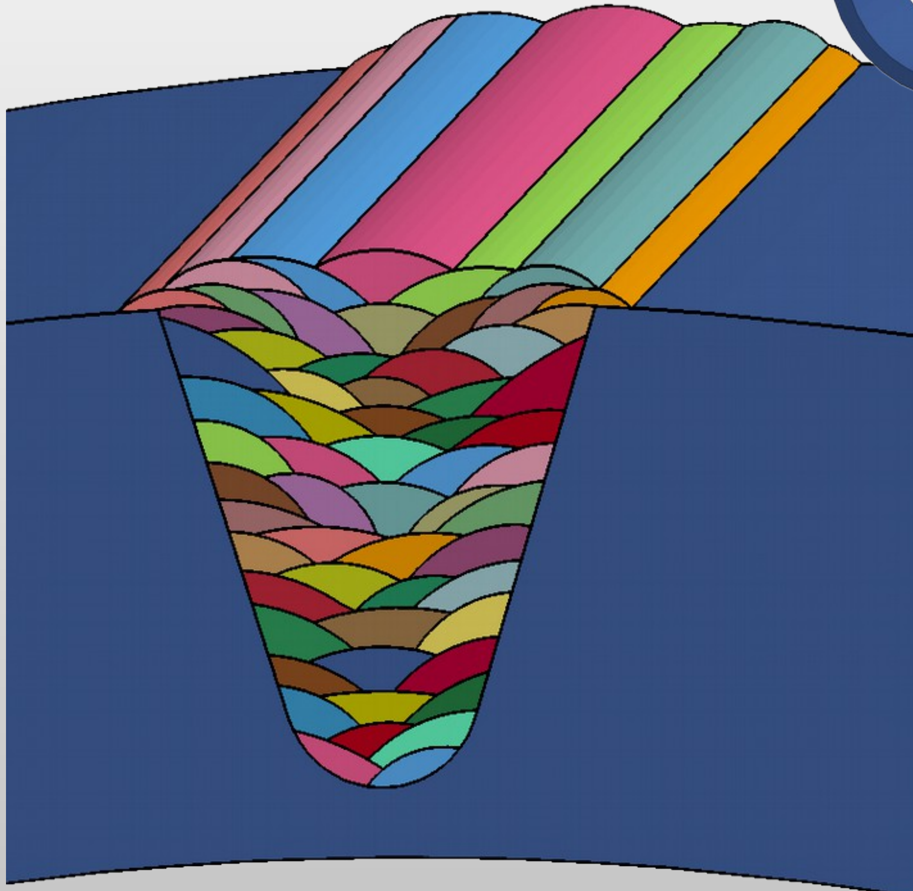


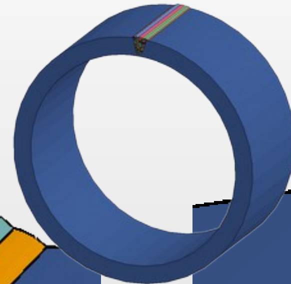


Weld of a Pipe with 40 mm Wall Thickness

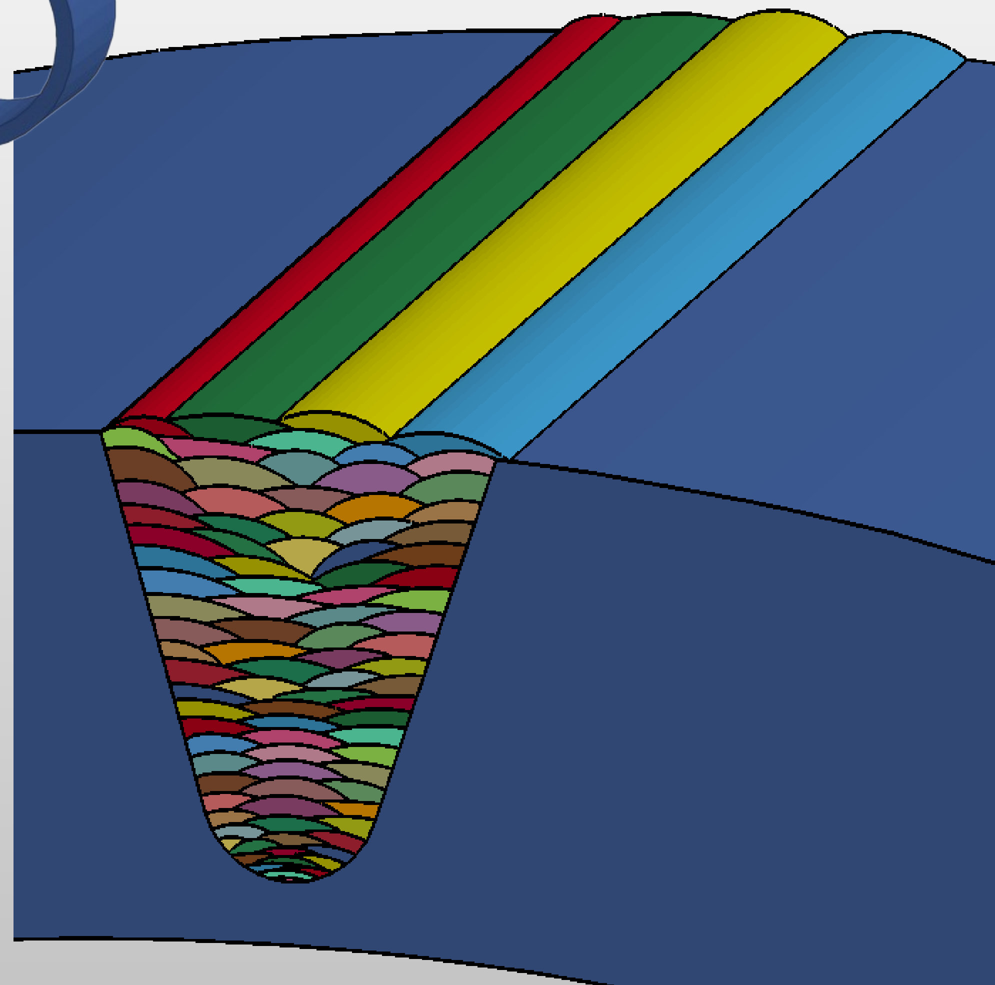
made of Alloy 625

60 Layer - GMAW





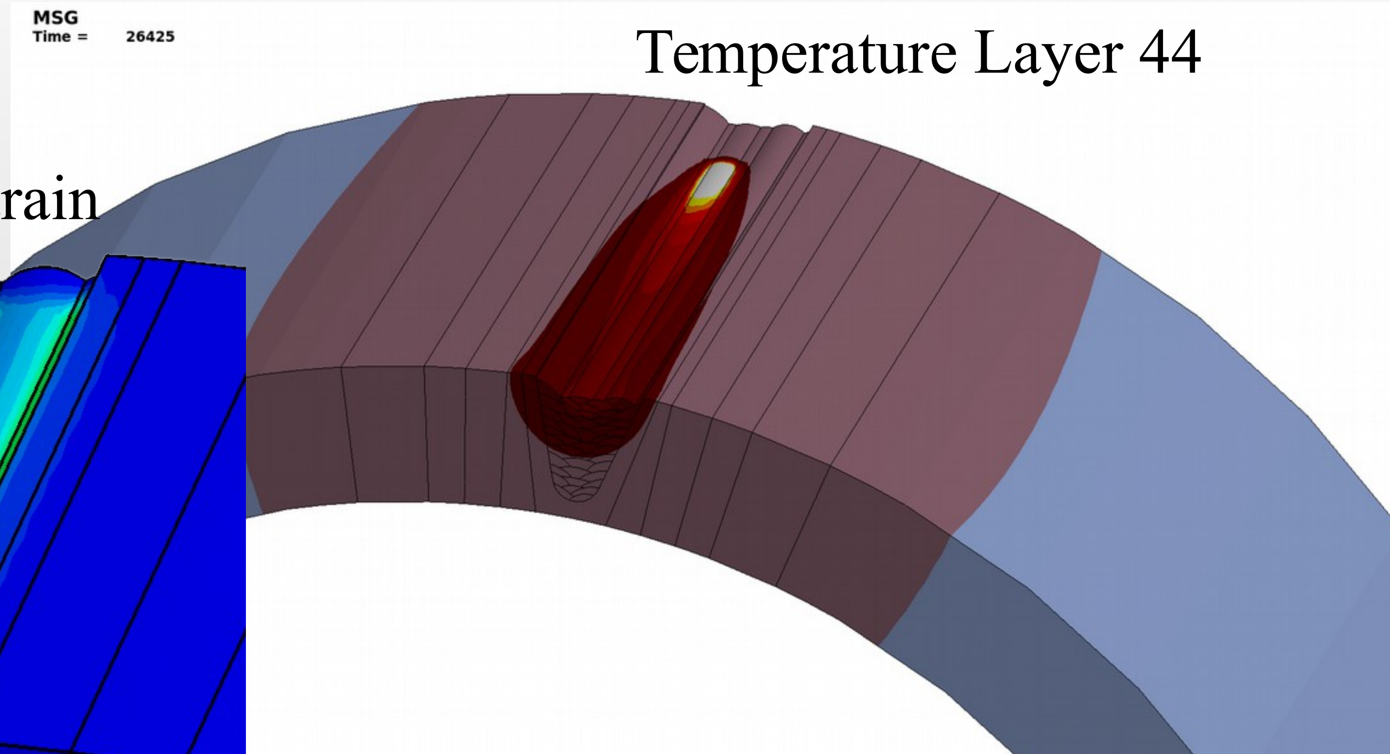
93 Layer - TIG



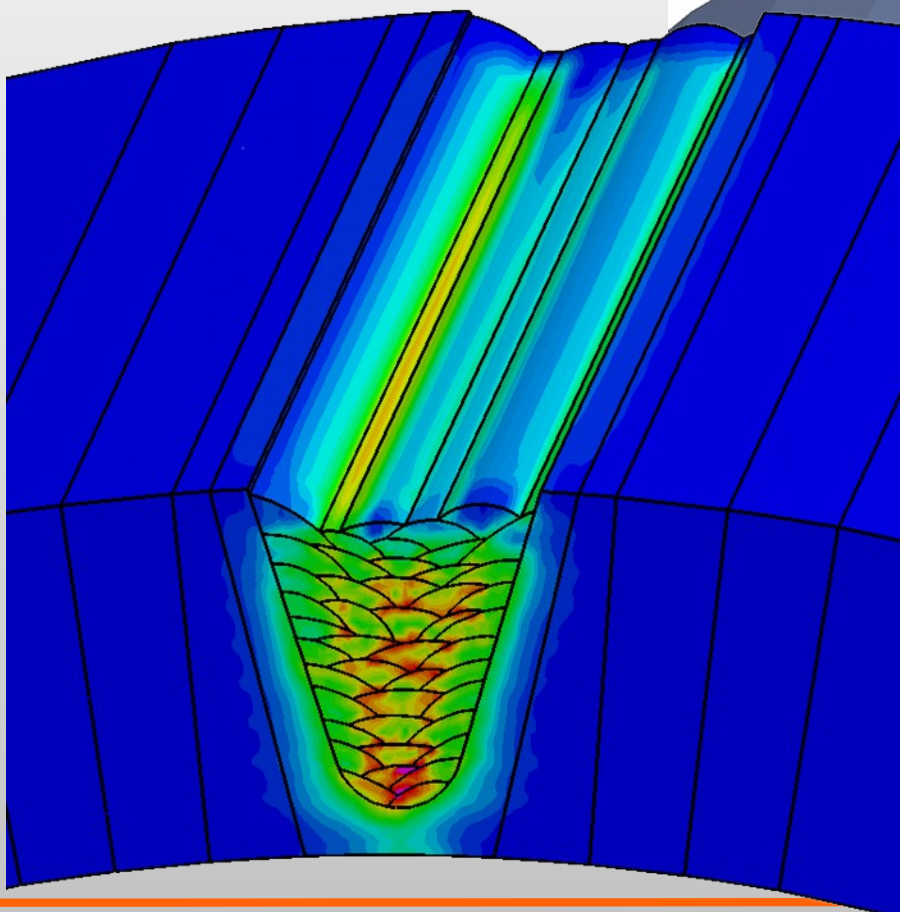
Weld of a Pipe with 40 mm Wall Thickness

made of Alloy 625 - 60 Layer GMAW

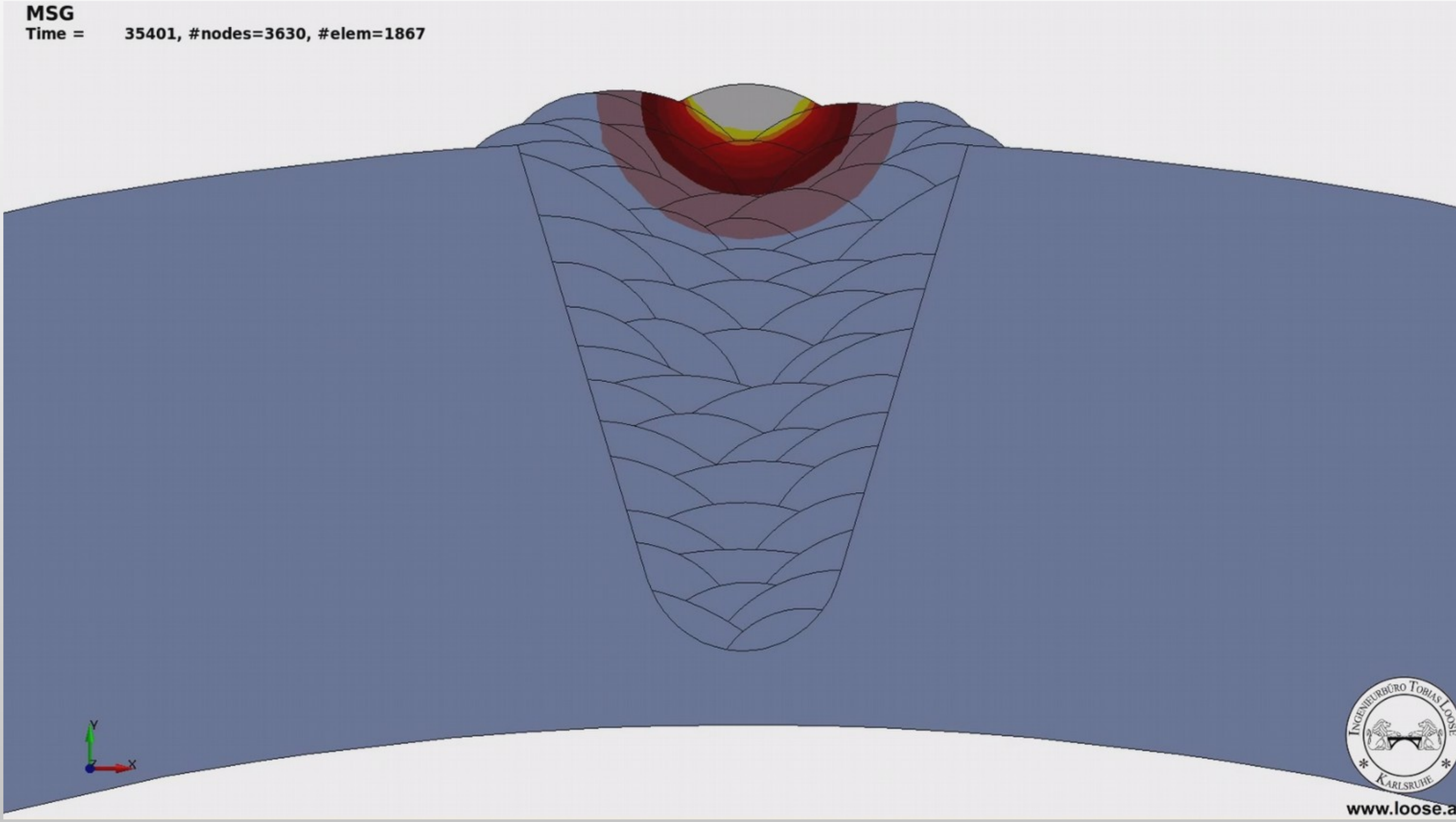
Temperature Layer 44



Equivalent Plastic Strain



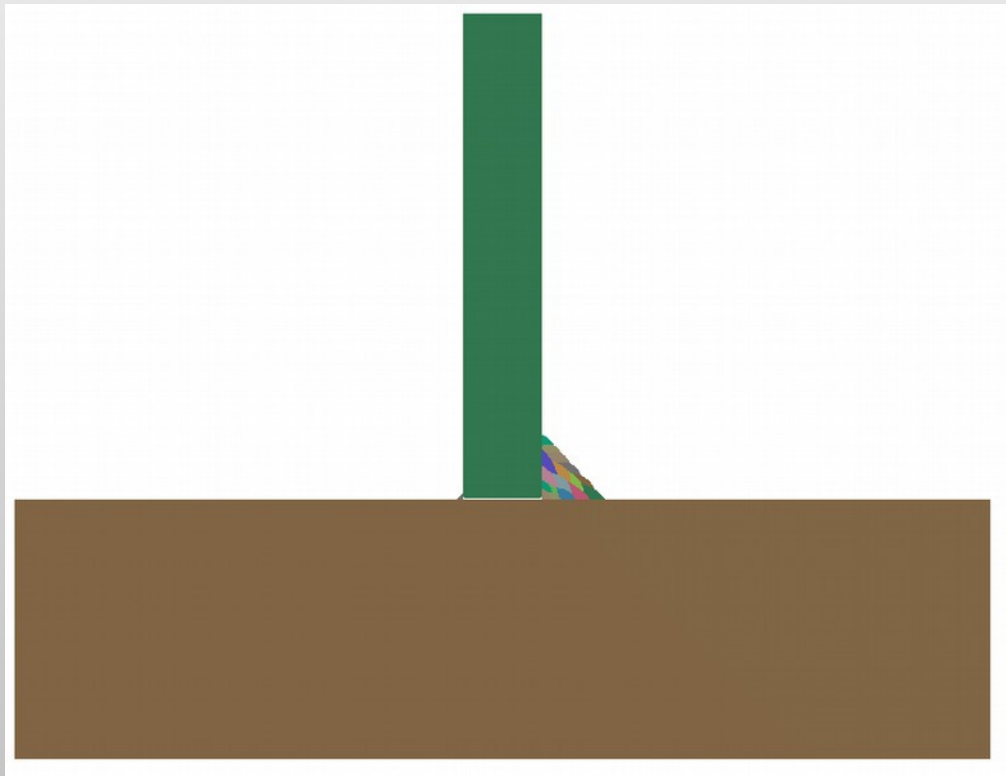
Temperature Field Multilayered Weld
2D Metatransient

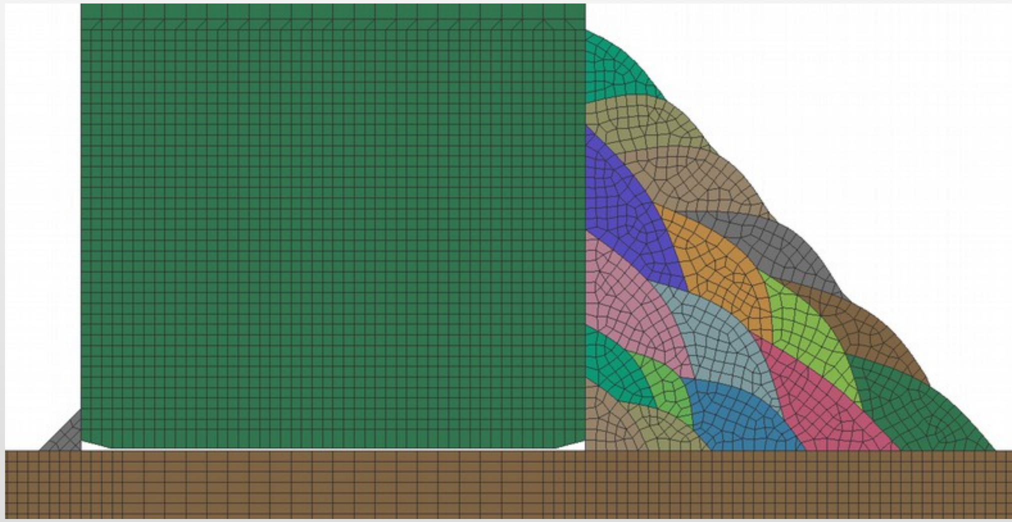


Multilayererd Weld T-Joint with large Plate Thickness

2D-Analysis LS-DYNA

2D plain strain
Plate: 300 x 80 mm
Stiffner: 150 x 24 mm
Fillet Weld: a = 13 mm
Material: 1.4301



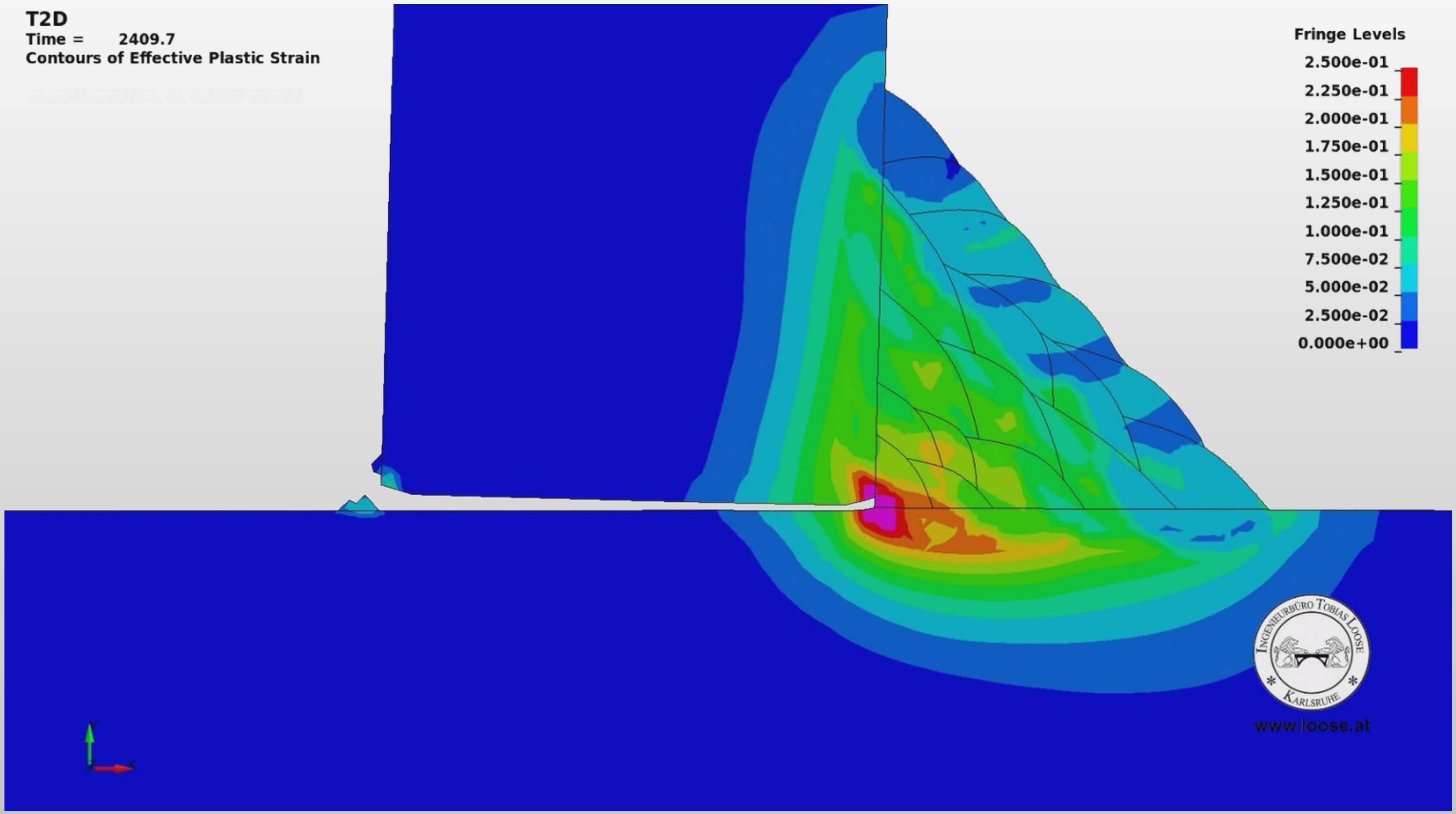


Tack a = 1,4 mm
with failiure on strain KFAIL = 0,25 m/m

Initial gap between stiffner and plate:
0,1 mm

Symmetry boundary contitions on left and right side.

Multilayererd Weld T-Joint with large Plate Thickness
2D-Analysis LS-DYNA – plastic strain



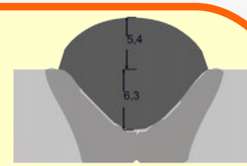
Prediction of Weld Quality

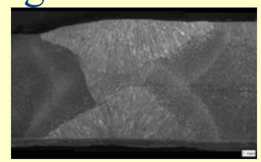
Microstructure and Mechanical Properties

Material Specification
Chemical Composition

WeldWare®

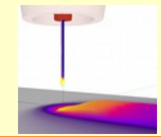
- Weld-Pool
- HAZ
- Microstructure
- Yield Strength
- Ultimate Strength
- Hardness
- Ultimate Elongation



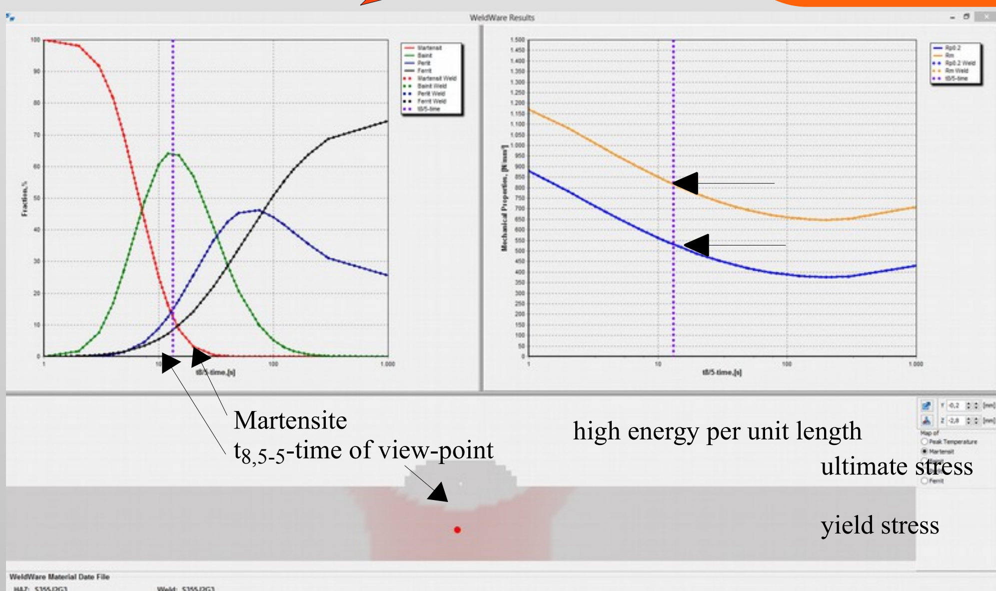


WPS
Welding Procedure Specification

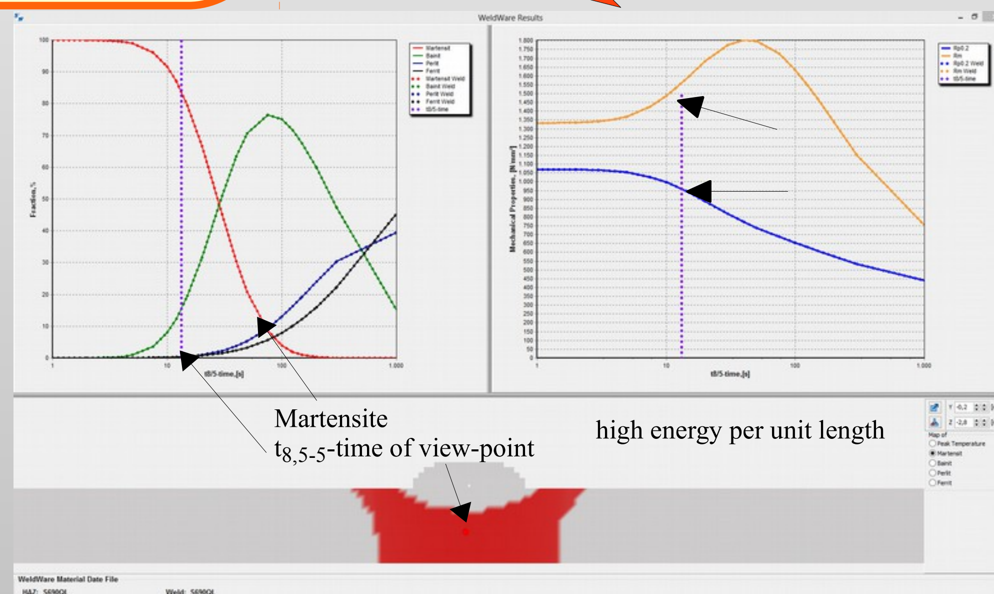
SimWeld®



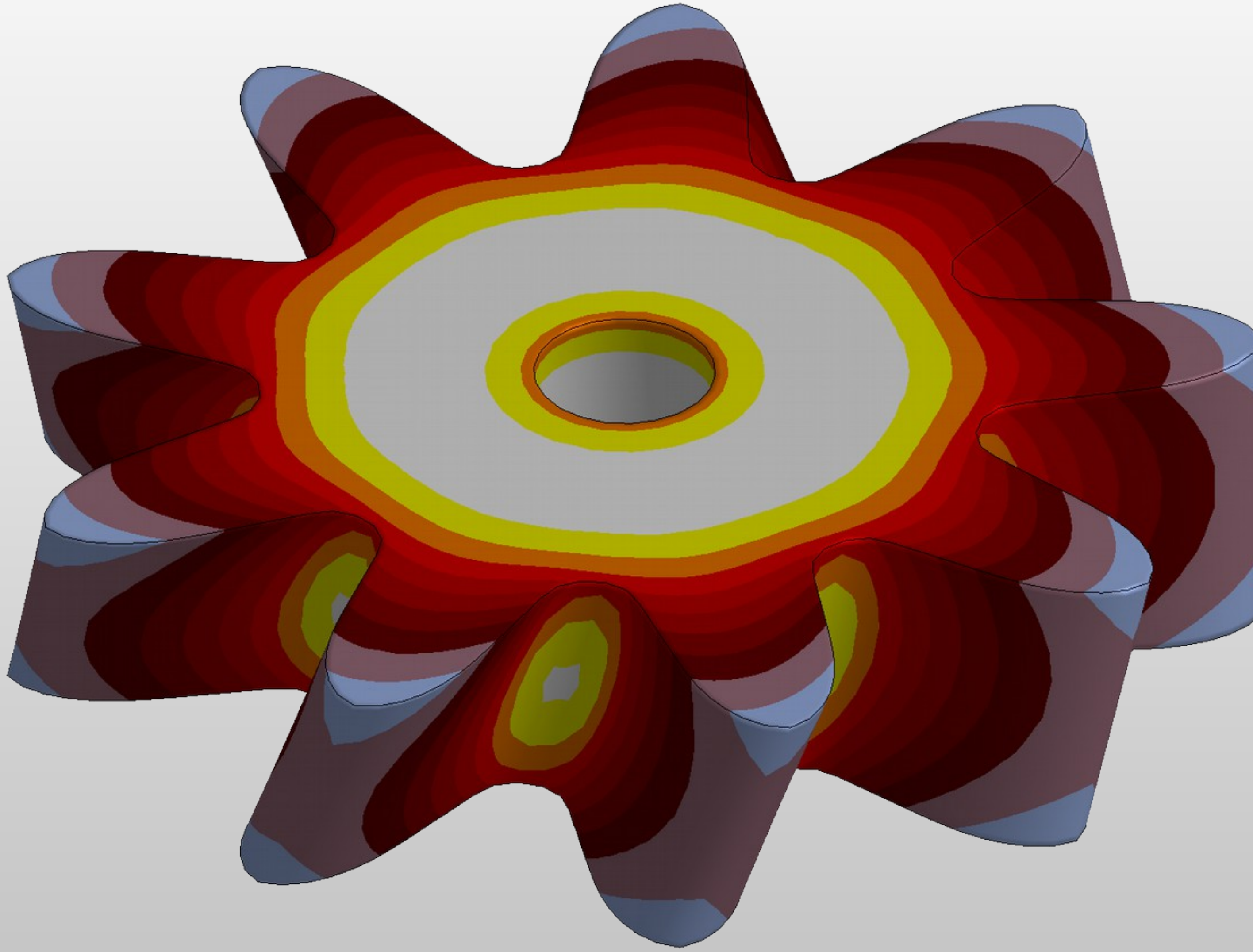
S355



S690

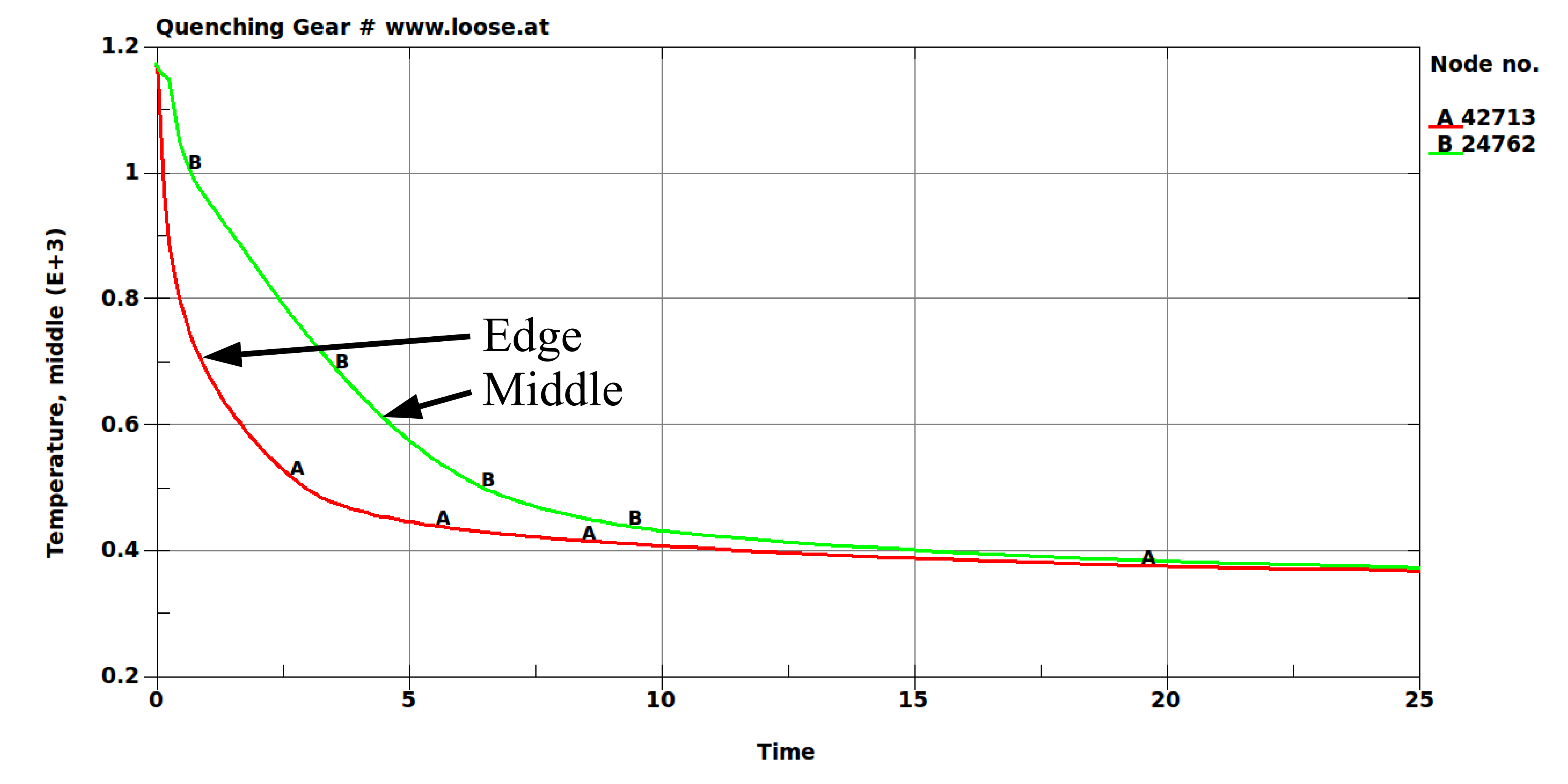


Quenching



Quenching of a Gear made of S355

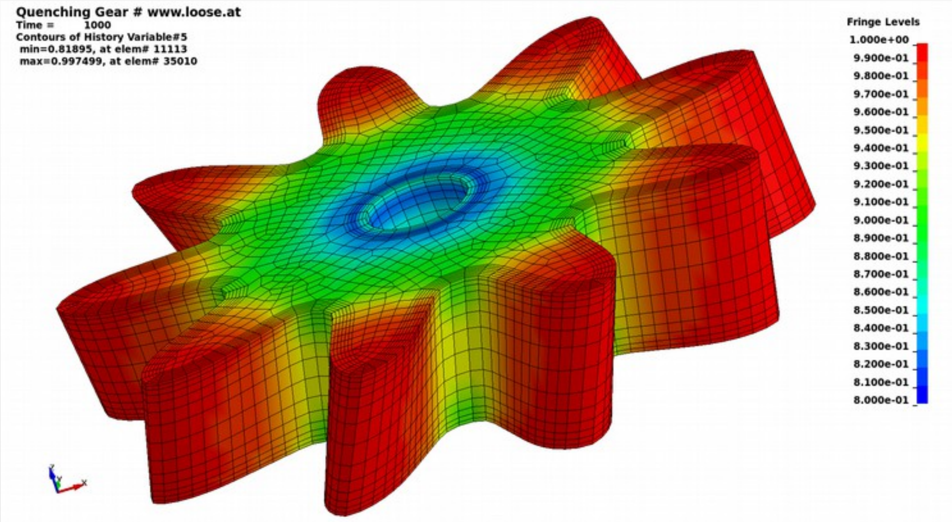
Temperature Curve

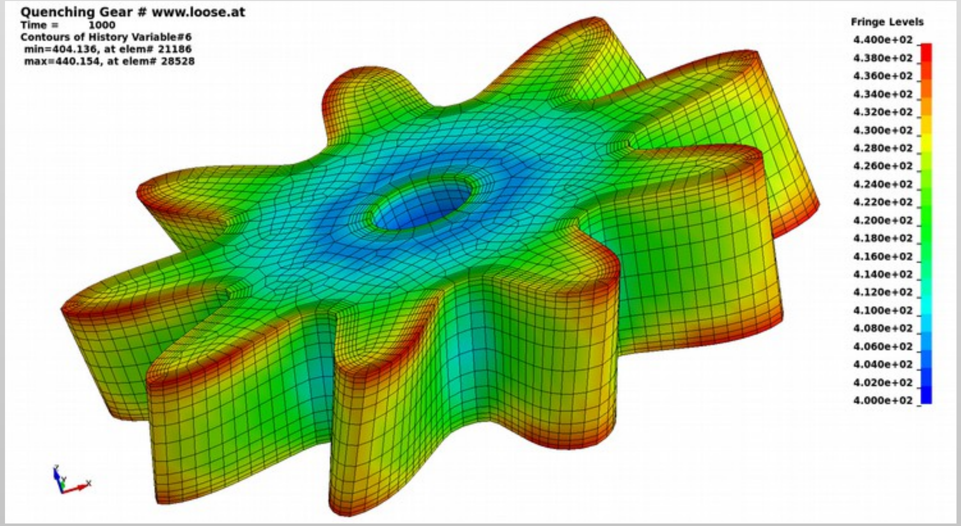


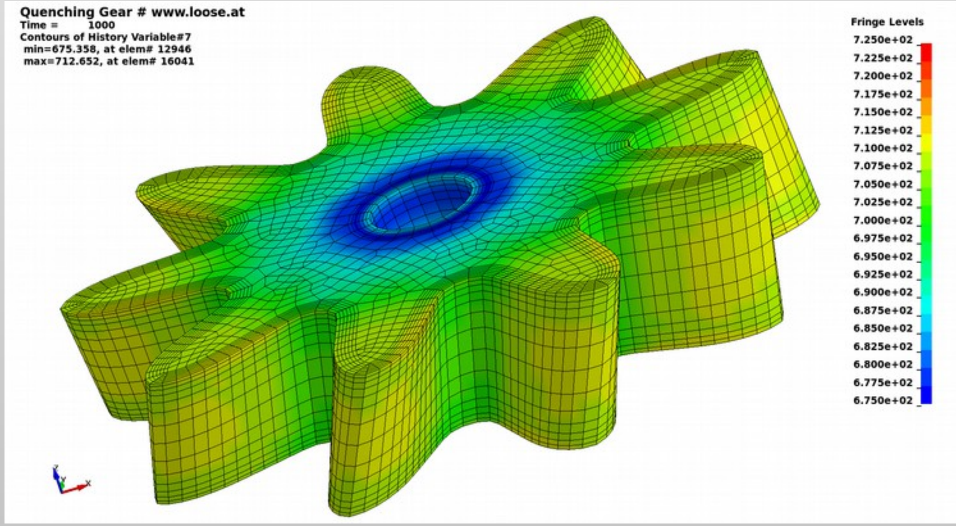
Quenching of a Gear made of S355

Results of Heat Treatment Simulation

Martensit (right)
Hardness HV (bottom left)
Yield (bottom right)







Validation

IIW Round Robin Versuch

- Plate with the dimensions
  270 x 200 x 30 mm^3
  with V/U-shaped notch
- Austenitic stainless steel
  (316LNSPH, Re = 275 MPa)
- 2 Layer welding of the notch with same material: 316L
- TIG Welding with
  U = 9 V, I = 155 A, v = 0,67 mm/s

Mesuread and calculated results

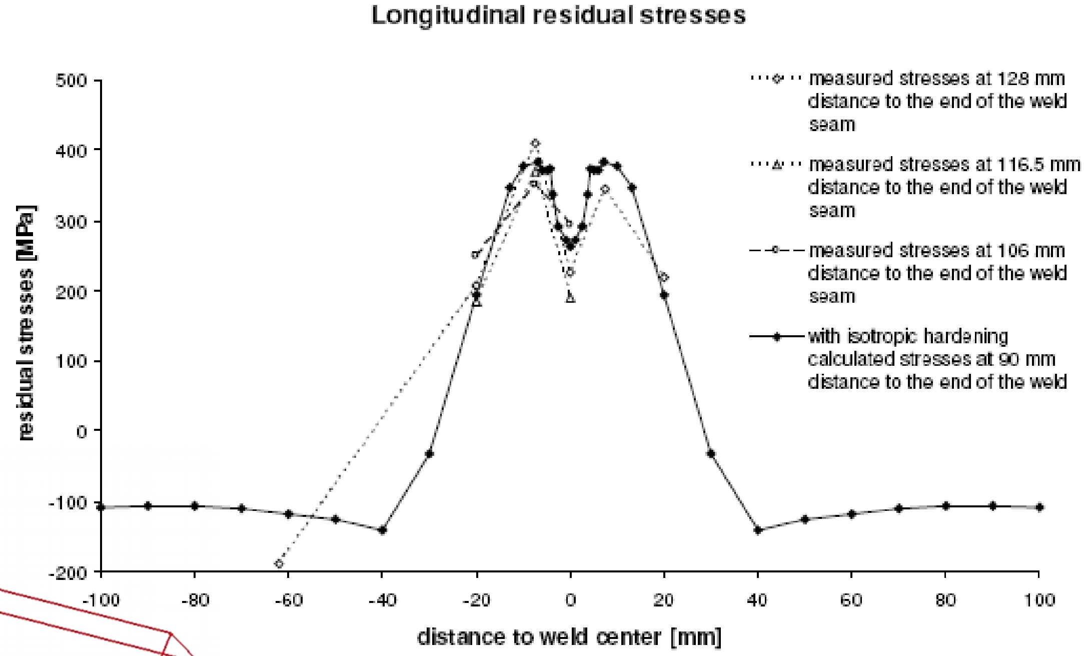


Fig. 9 Measured and calculated longitudinal residual stresses along a line transverse to the weld seam

9th International Seminar
Numerical Analysis of Weldability
Graz – Seggau, Austria

Kenneth Easterling Best Paper Award

Given to the paper

New 3D-calculations of residual stresses consistent with measured results of the IIW round robin programme

T. Loose, J. Sakkiettibutra, H. Wohlfahrt

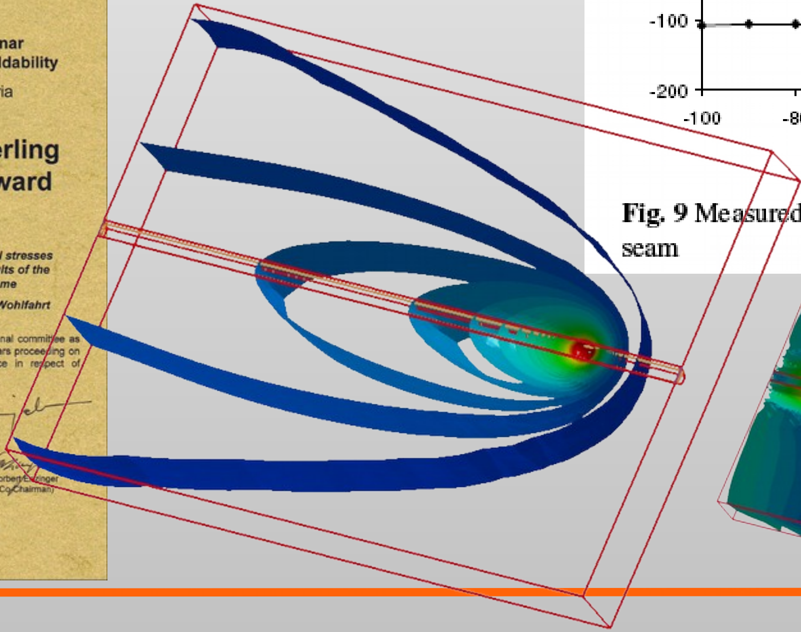
This paper has been valued by an international committee as the best contribution made over the three years proceeding on the advancement of knowledge or practice in respect of mathematical modeling of weld phenomena.

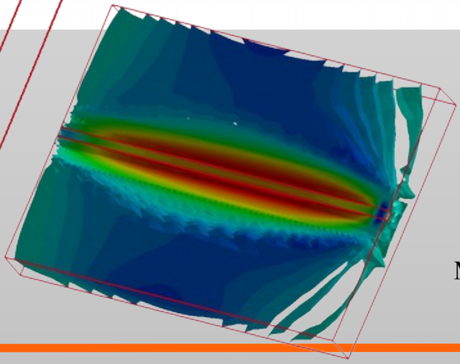
Horst H. Cerjak
(Chairman)

Christof Sommitsch
(Head of the Institute)

Norbert Enzinger
(Co-Chairman)

Graz Seggau, September 2009





Loose, T. ; Sakkiettibutra, J. ; Wohlfahrt, H. :
New 3D-Calculations of residual stresses consistent with measured results of the IIW Round Robin Programme.
In: Cherjak, H. (Ed.) ; Enzinger, N. (Ed.) :
Mathematical Modelling of Weld Phenomena Bd. 9,
Verlag der Technischen Universität Graz, 2010

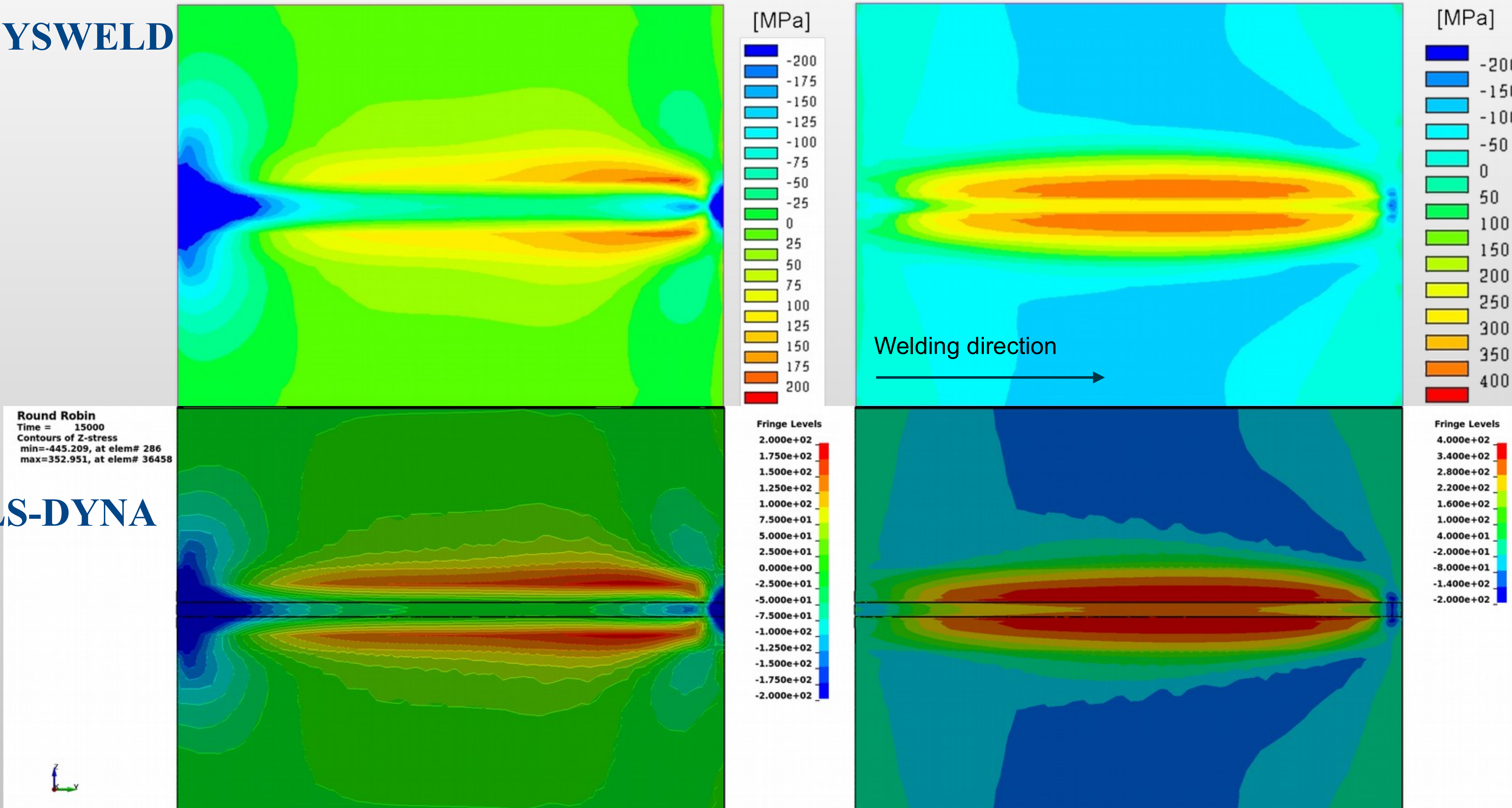
Validation

IIW Round Robin Versuch

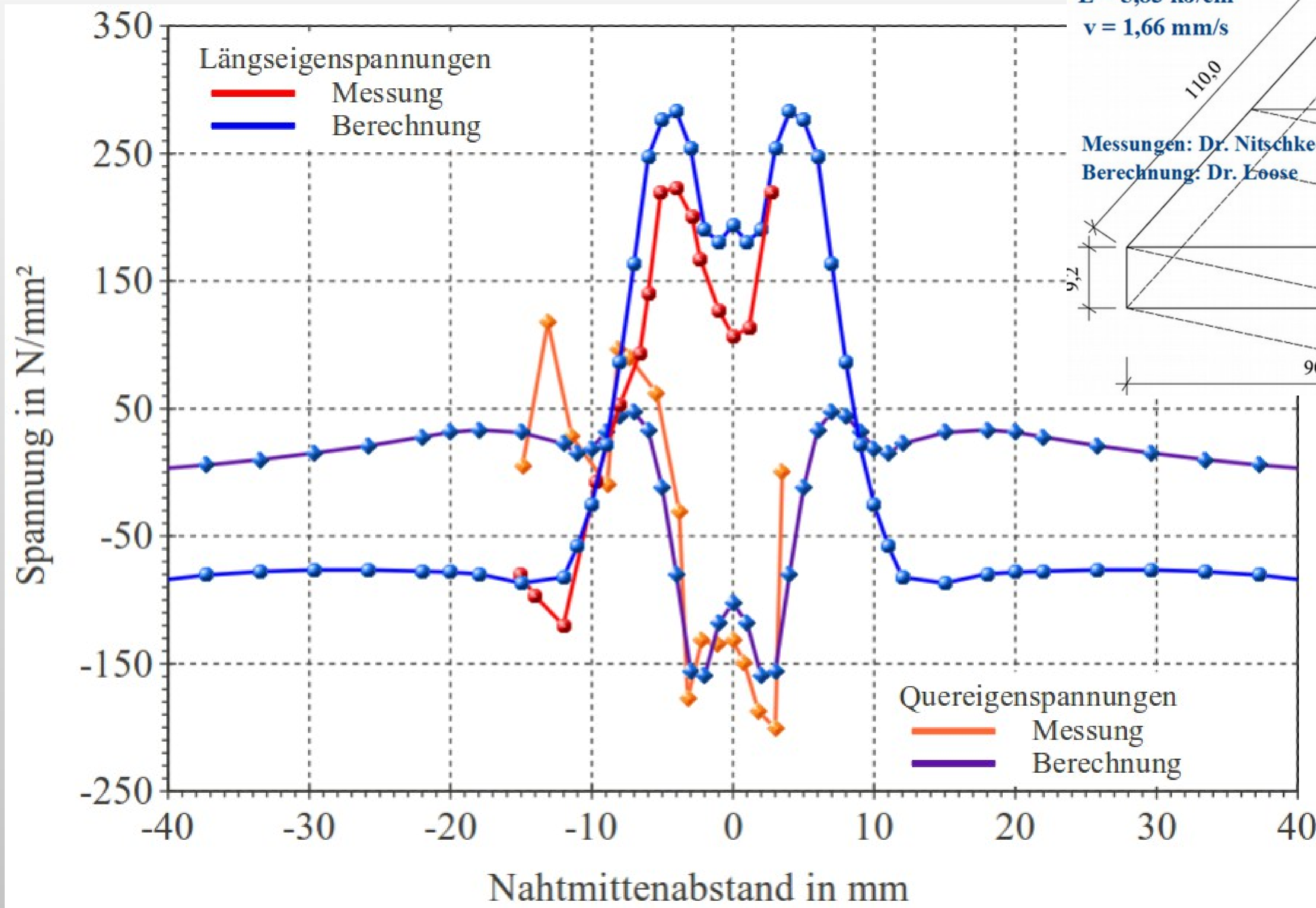
Transversal Stress / Longitudinal Stress

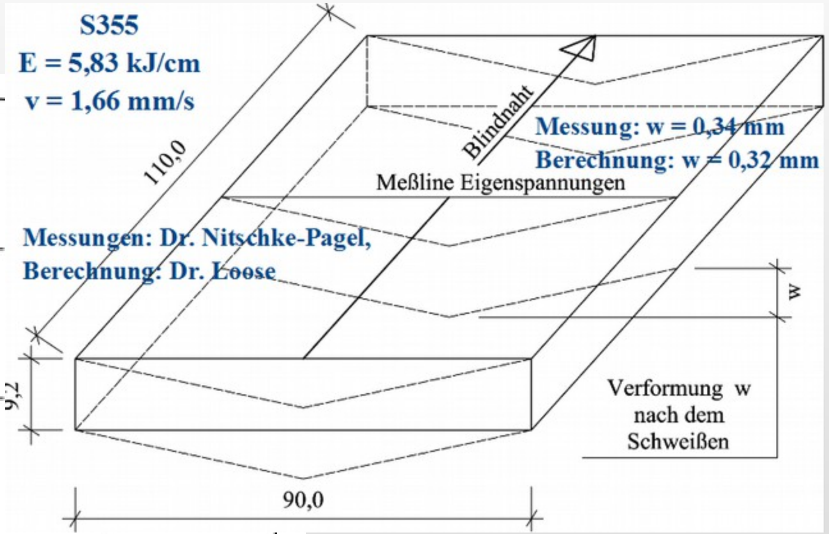
SYSWELD

LS-DYNA



Validation Nitschke-Pagel Test



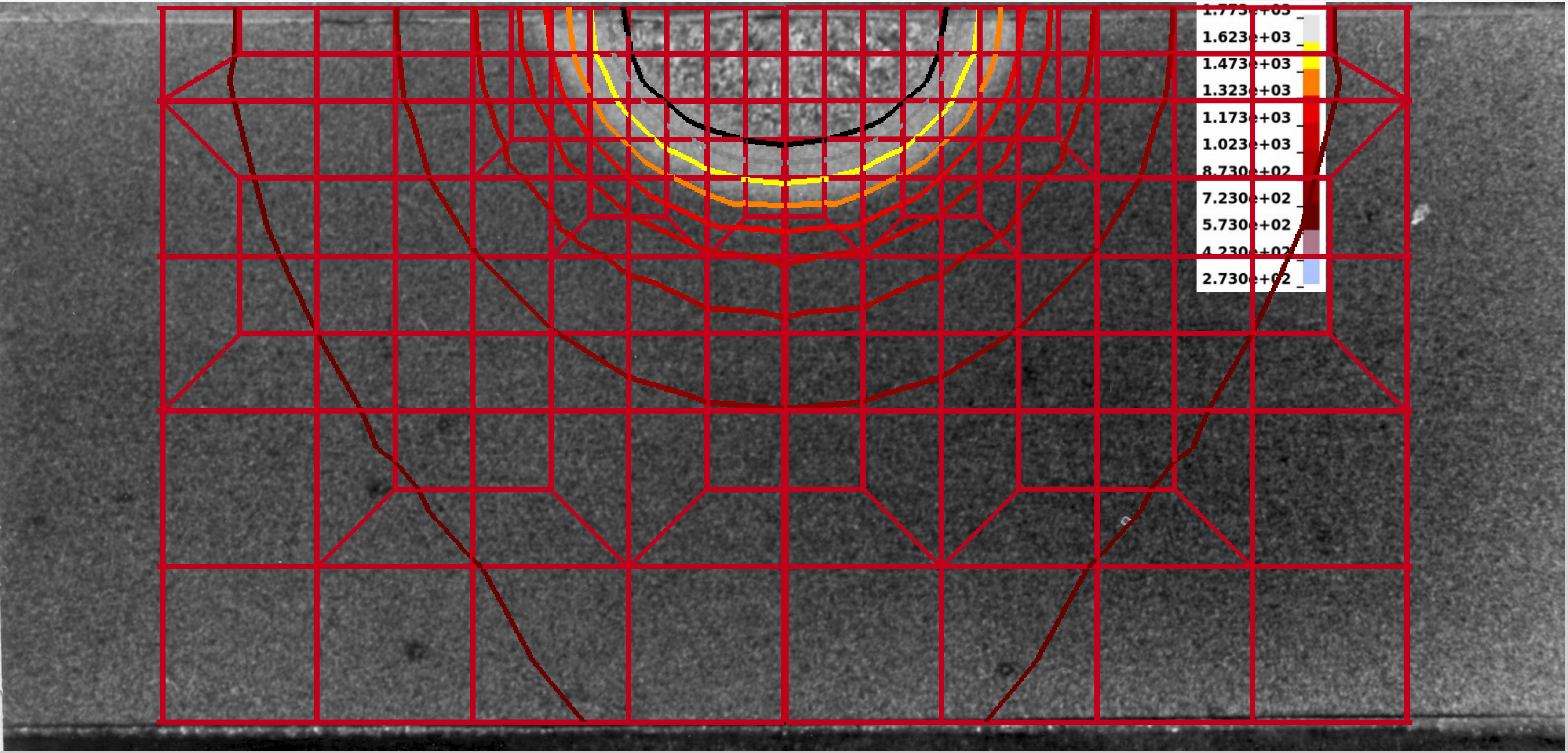


Distortion w:

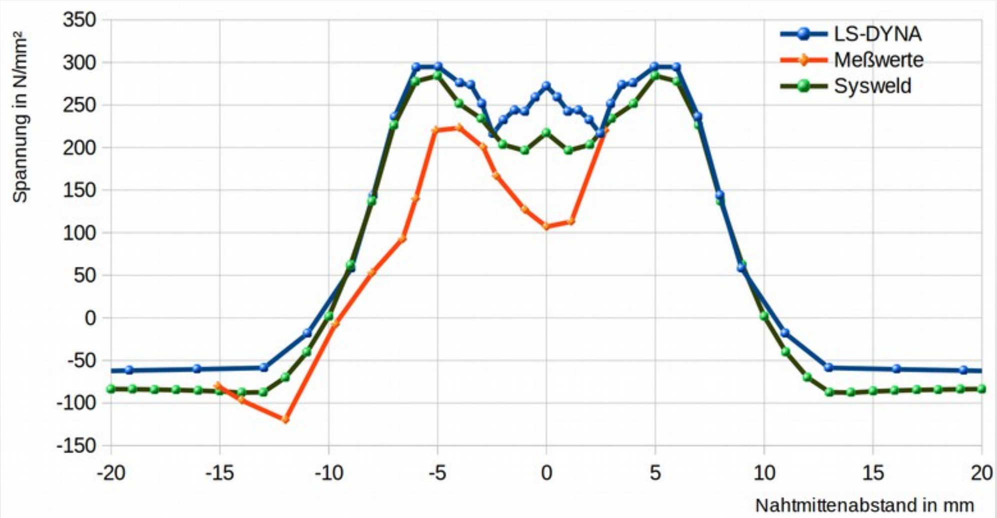
Experiment:	0,34 mm
Sysweld:	0,32 mm
LS-DYNA:	0,34 mm

Loose, T.: Einfluß des transienten Schweißvorganges auf Verzug, Eigenspannungen und Stabiltiätsverhalten axial gedrückter Kreiszylinderschalen aus Stahl, Diss, Karlsruhe, 2008

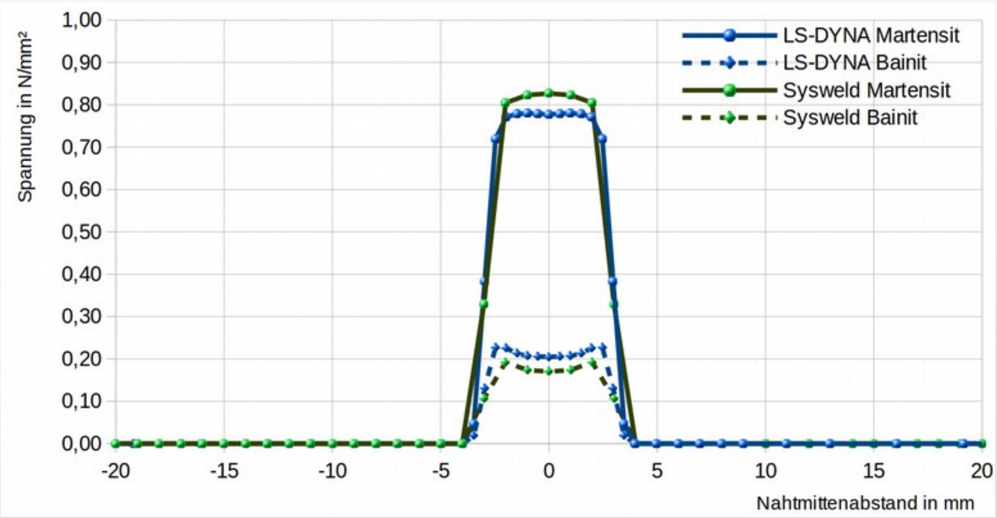
Makrosection
Temperature: 100 .. 1500 °C



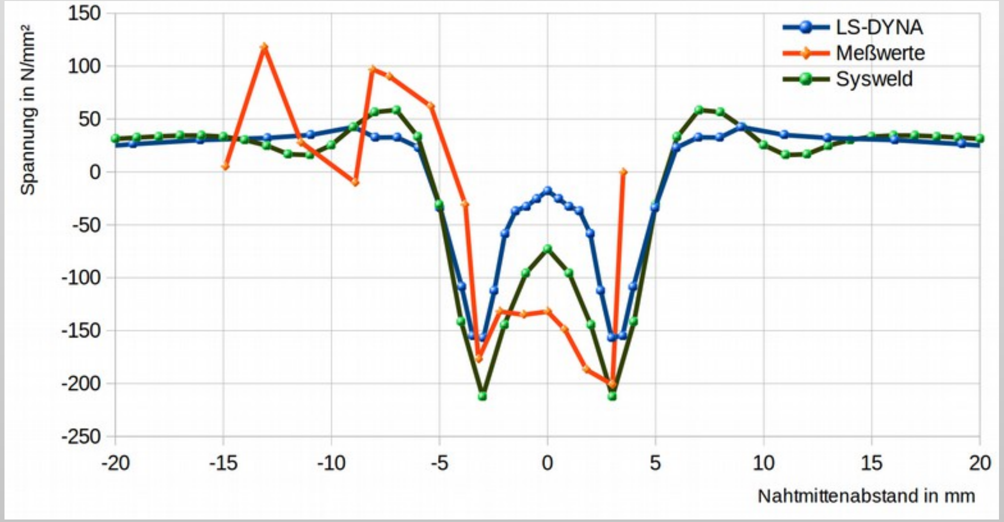
Result



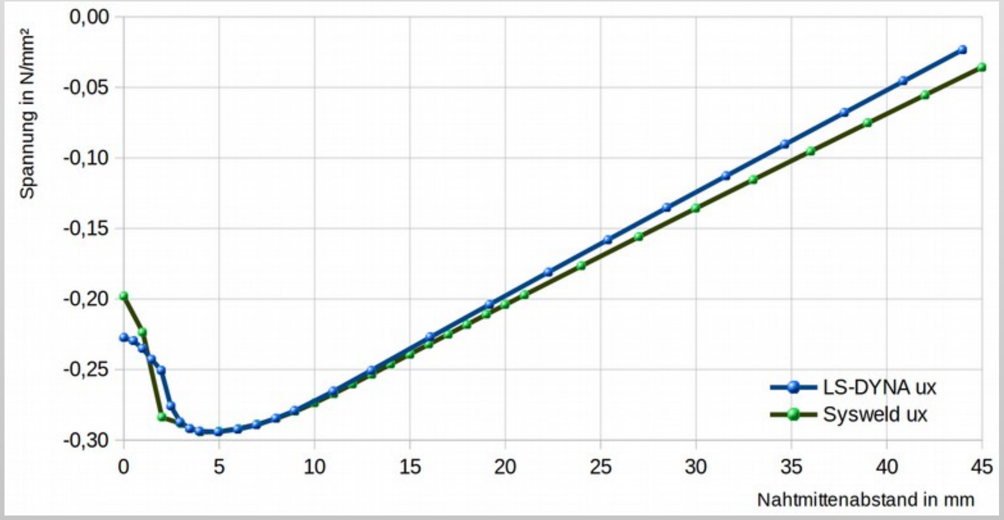
Spannung in N/mm²
LS-DYNA
Meßwerte
Sysweld
Nahtmittenabstand in mm



Spannung in N/mm²
LS-DYNA Martensit
LS-DYNA Bainit
Sysweld Martensit
Sysweld Bainit
Nahtmittenabstand in mm

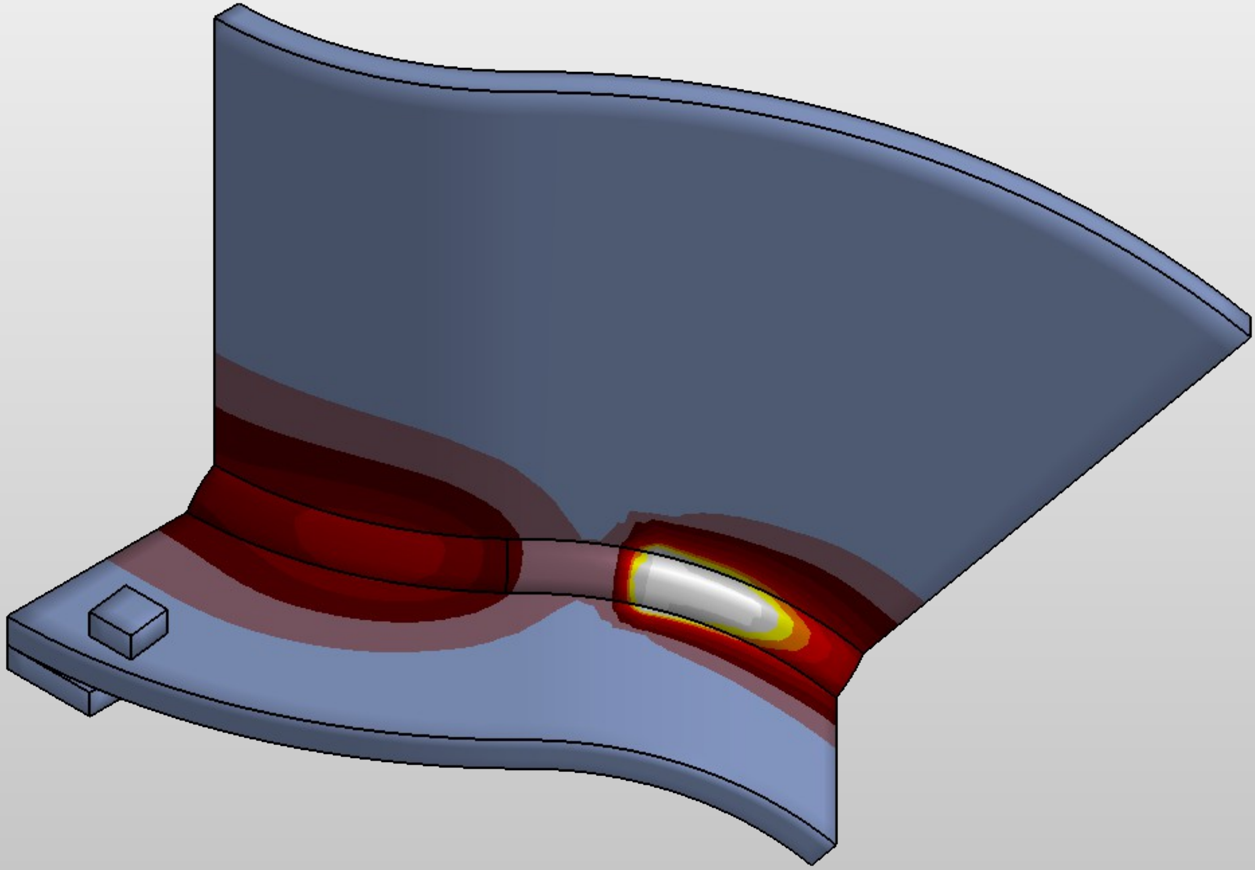


Spannung in N/mm²
LS-DYNA
Meßwerte
Sysweld
Nahtmittenabstand in mm



Spannung in N/mm²
LS-DYNA ux
Sysweld ux
Nahtmittenabstand in mm

Benefits



Results from Simulation of Welding and Heat Treatment

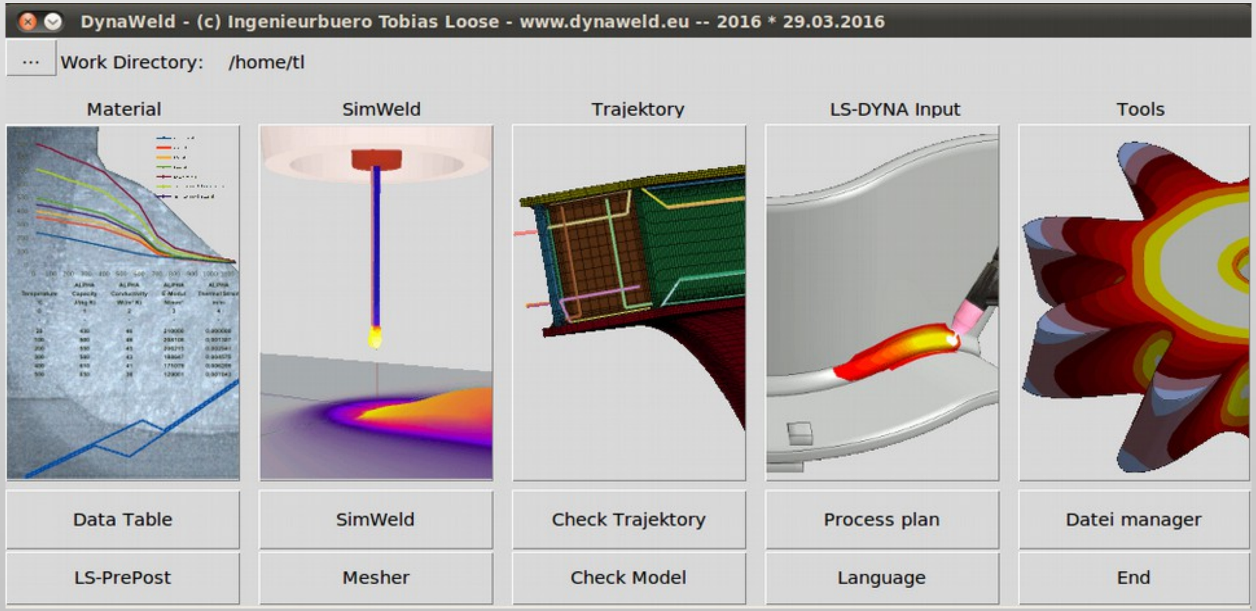
- Process simulation welding (SimWeld)
  - weld pool formation
  - heat input / heat generation
  - local temperature field, cooling time in the weld and heat affected zone
- Structure simulation welding (DynaWeld)
  - temperature field in the whole assembley during welding, cooling time
  - distortion during welding and cooling
  - clamping forces and bearing reactions
  - plastic strains, strain hardening
  - residual stresses, elastic or plastic reserves
  - microstructure / areas with change of microstructure
- Heat treatment simulation
  - temperature during quenching
  - carburization and depht of arburization for case hardening
  - microstructure and hardness
  - distortion / distortion after hardening

Benefits from Simulation of Welding and Heat Treatment

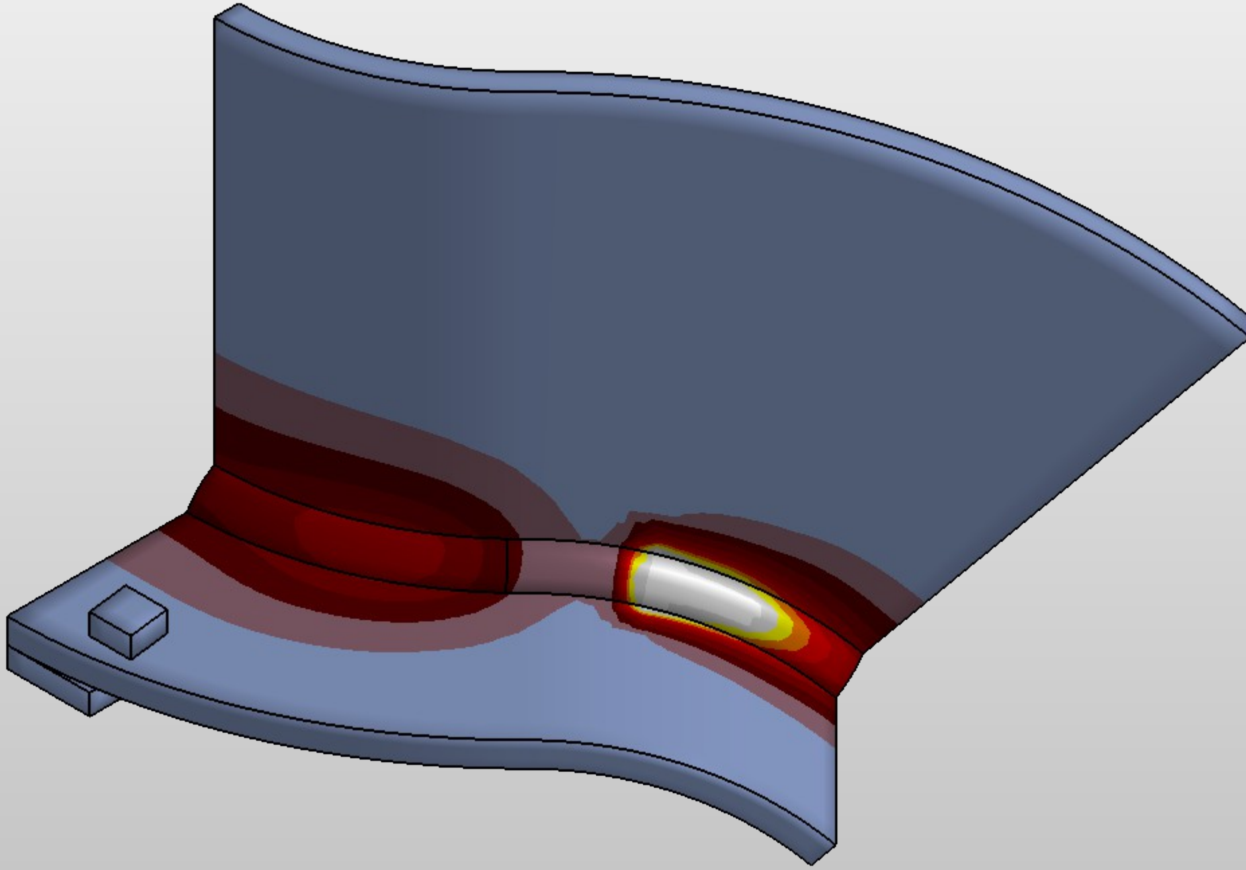
- Adjustment of Process Parameter
- Design of Geometrie
  - optimization of geometry concerning acceptable distortions
  - determination of invers distorted geometry for the design of forming
  - design of gap for laser welding
- Heat Management
  - preheating temperature, intermediate temperature
  - design of desired microstructure
- Design of Clamps
  - predeformation
  - clamp forces
- Design of the Order of the Welds
- Observation of the State of Stresses
  - prestressed zones / tension zones
  - delimitation of plastic strain
- Special Tasks ...

More Benefits of Welding and Heat Treatment Simulation

- Simulation is available in early stage of design.
- Simulation is available without any fabrication place.
- Simulation is helpful for the analysis of damages.
- Simulation helps to understand the process and its events.
- Simulation is helpful for education and training
- Welding and heat treatment simulation provides the state of the assembly for further simulation analyses.



Material



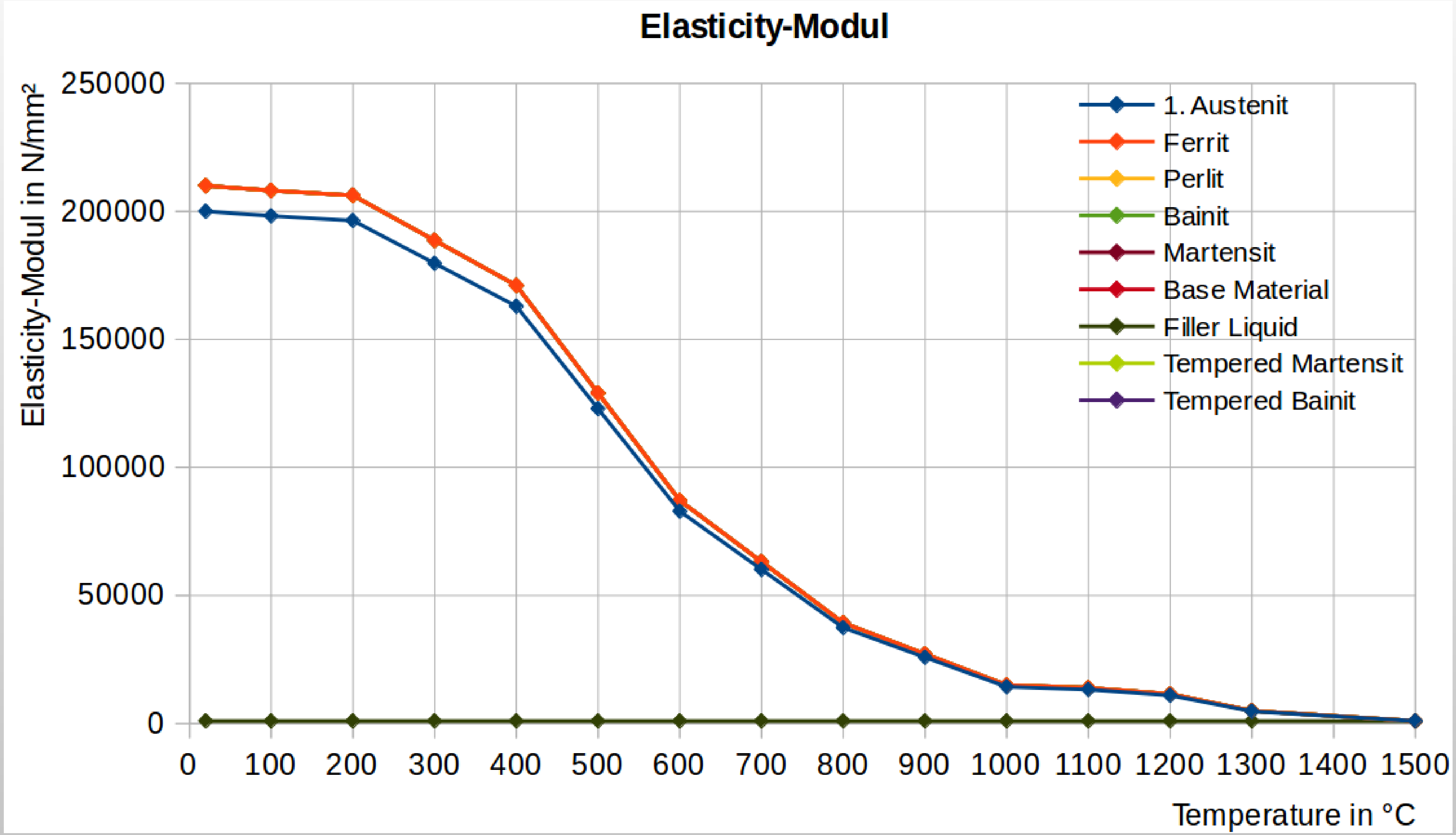
Sources of Material Data for Welding and Heat Treatment

- Experiment
  - Execution of tests

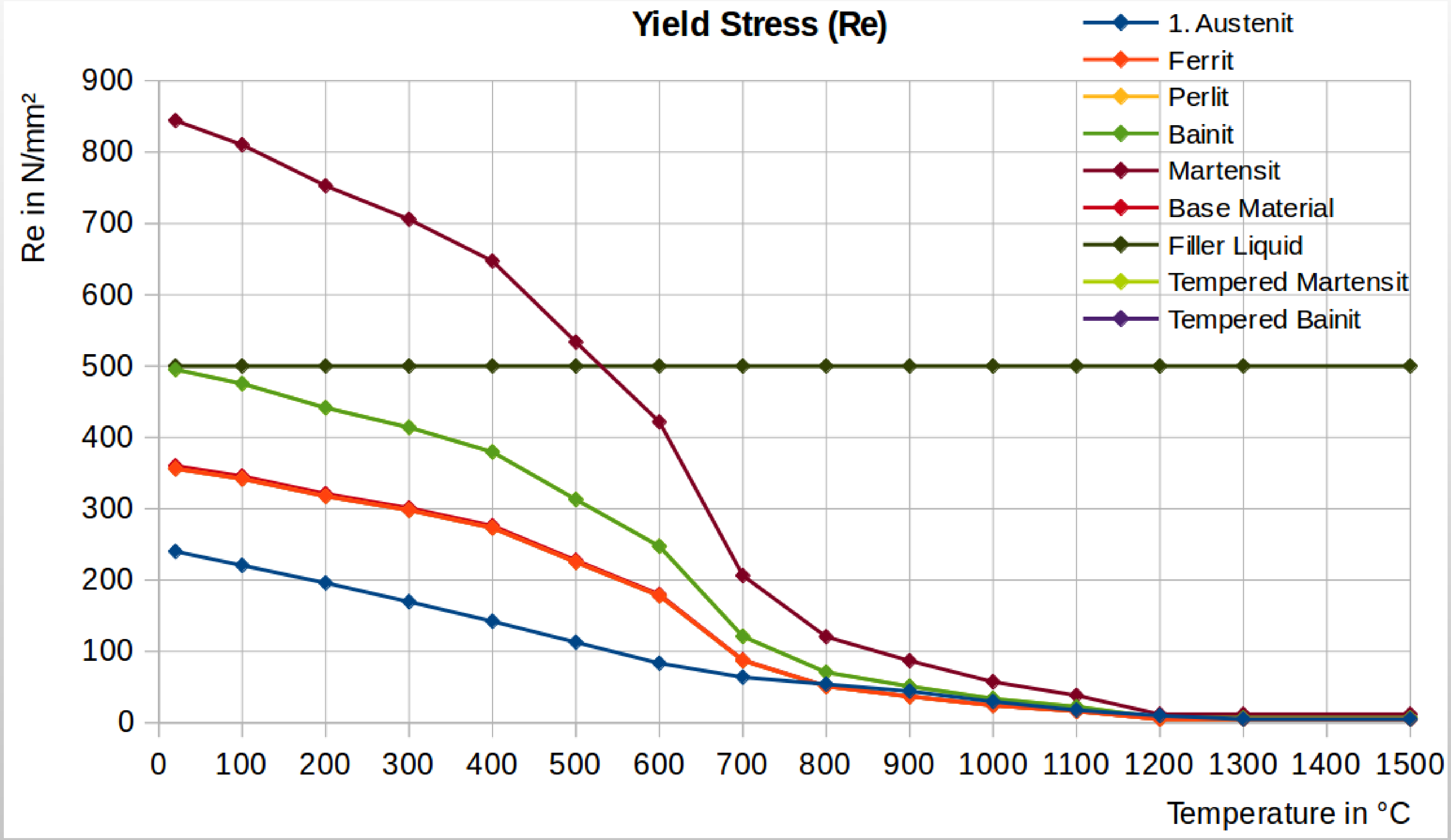
- References
  - Papers with test results for material data
  - Material data sheet

- Software / Material Simulation
  - WeldWare®
  - JMatPro
  - MatCalc

Depending on Temperature



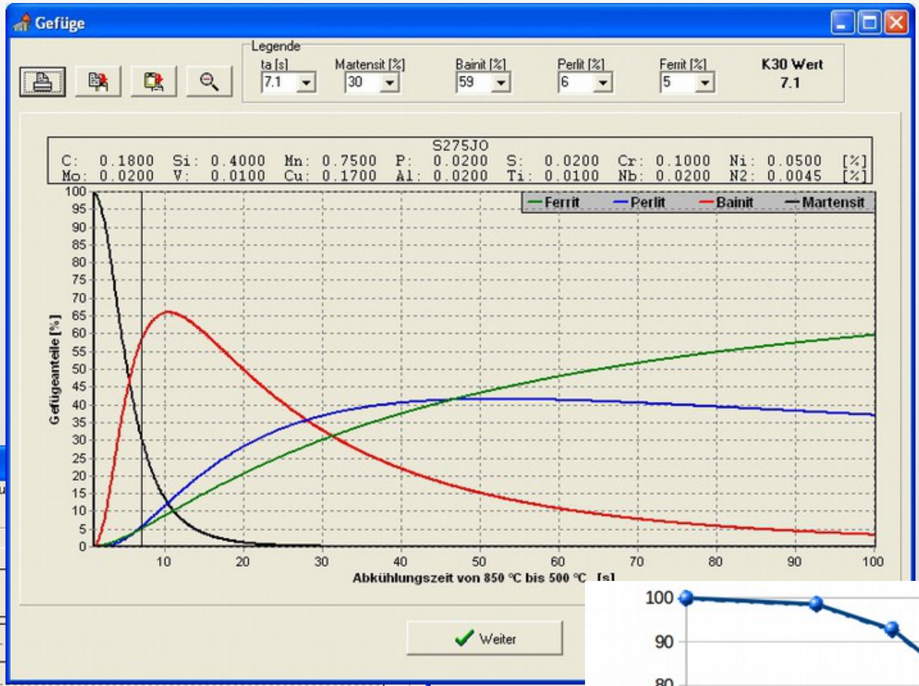
Depending on Microstructure

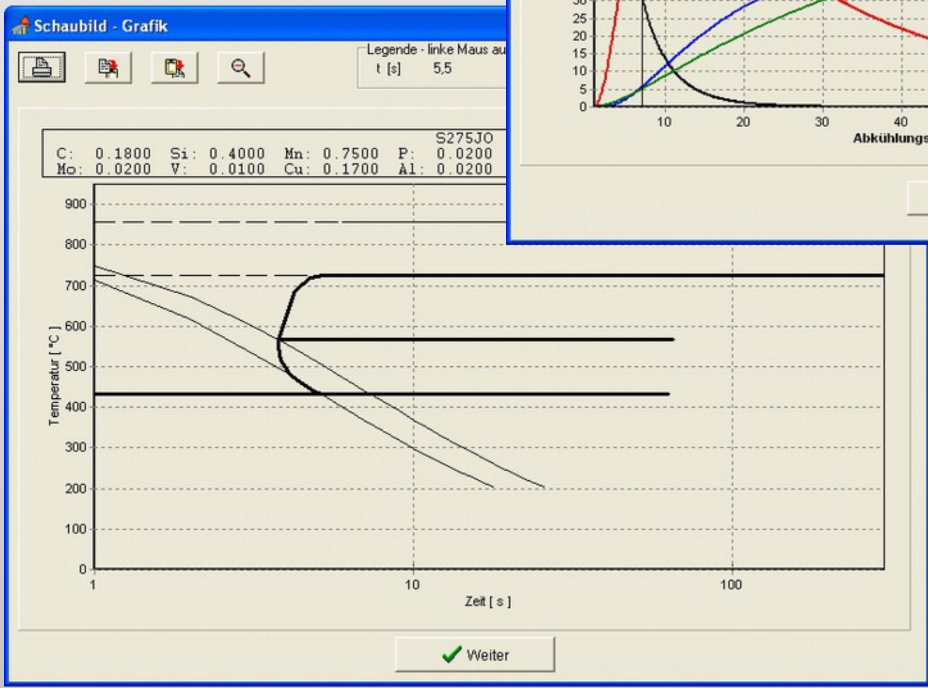


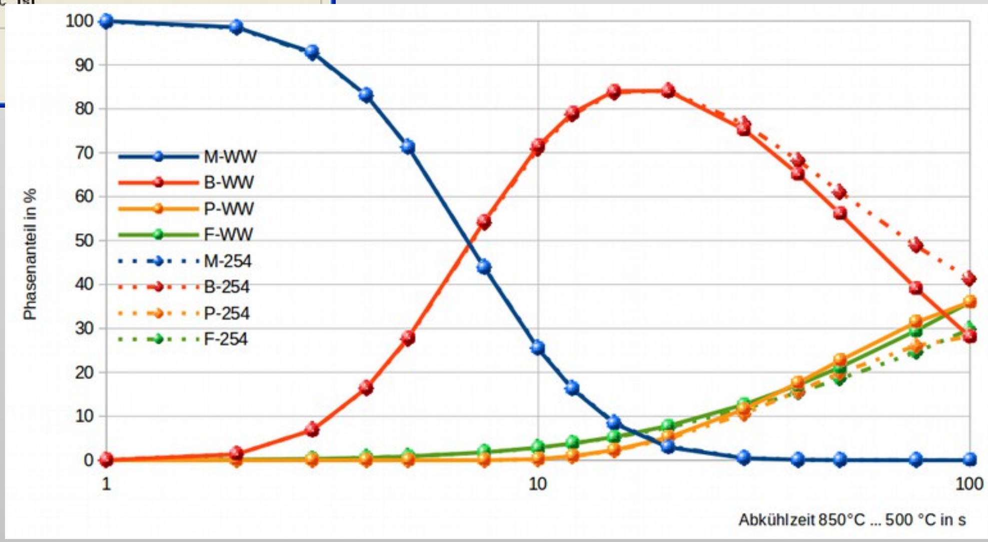
Description of phase transformation (ZTU, ZTA)

CCT-Data
WeldWare®

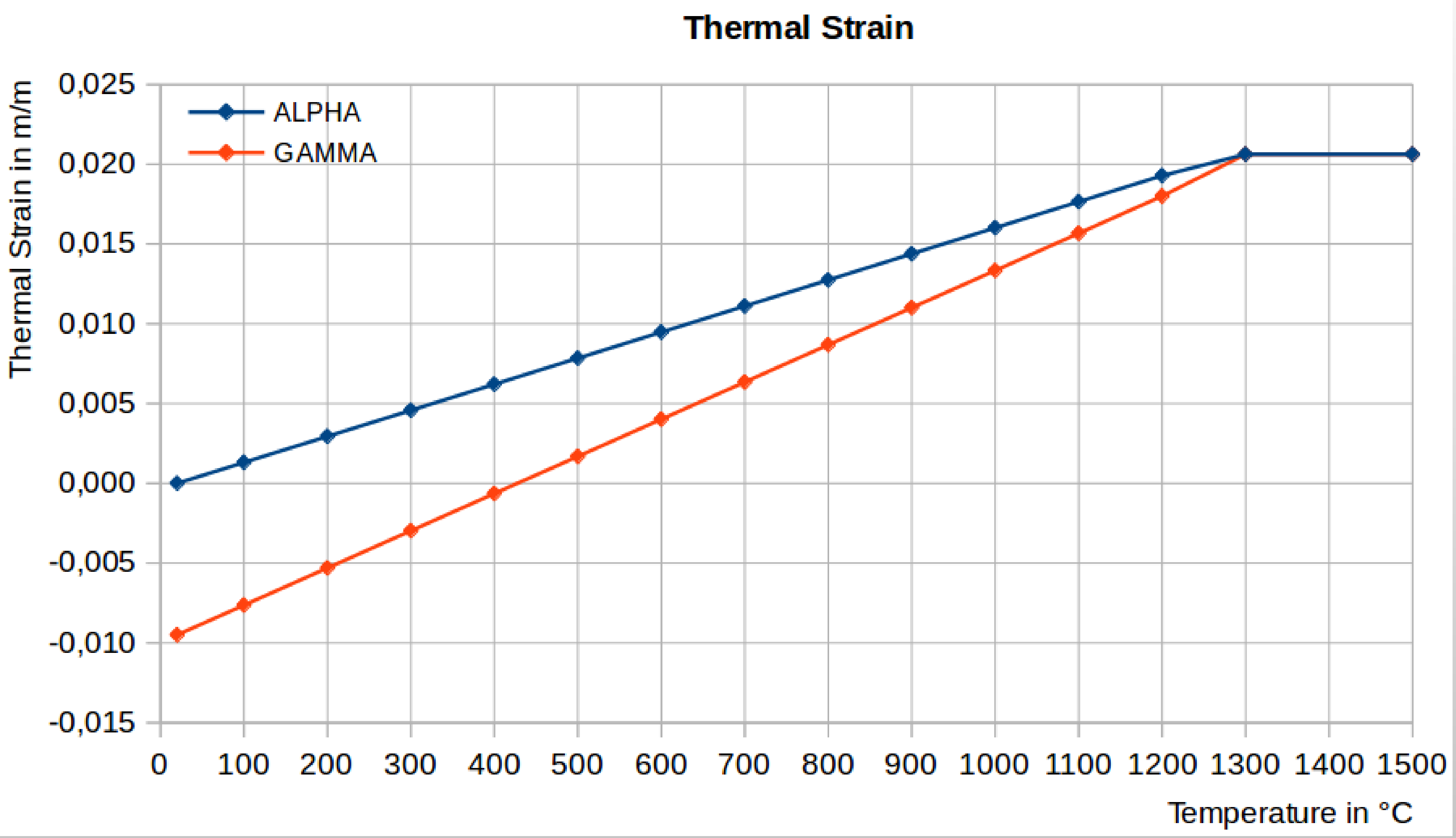
Microstructure Simulation with LS-DYNA *MAT_254



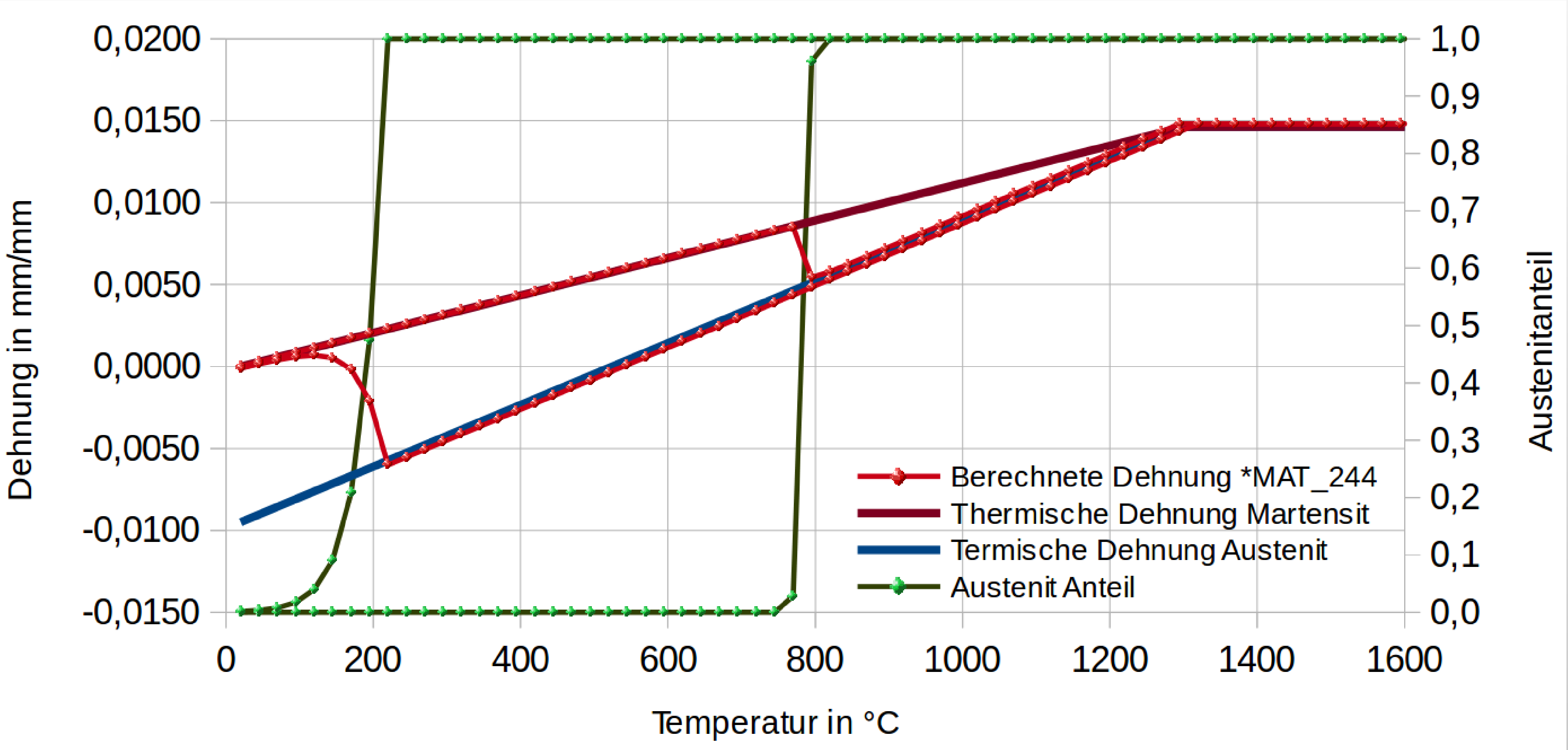




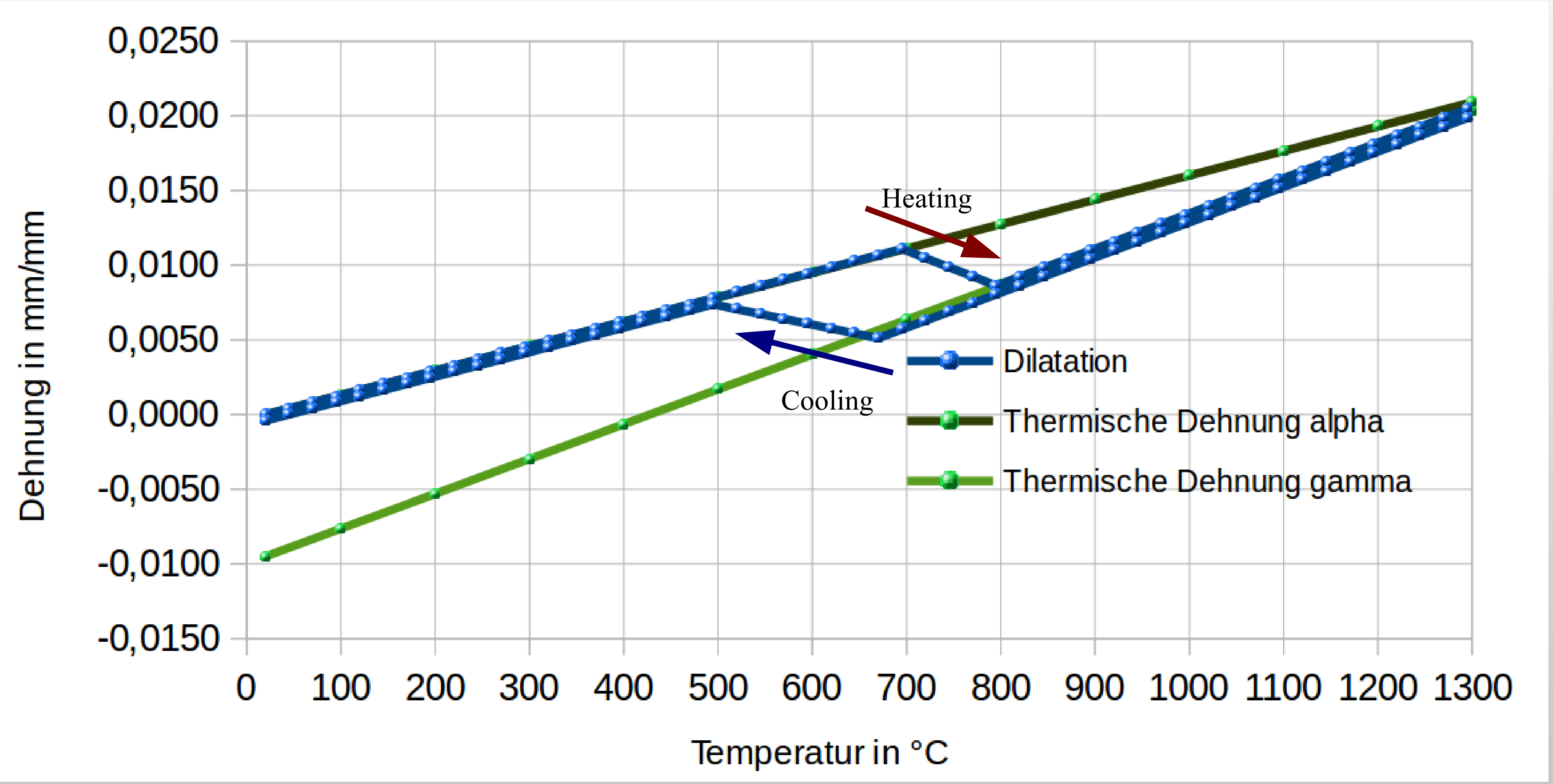
Thermal strain



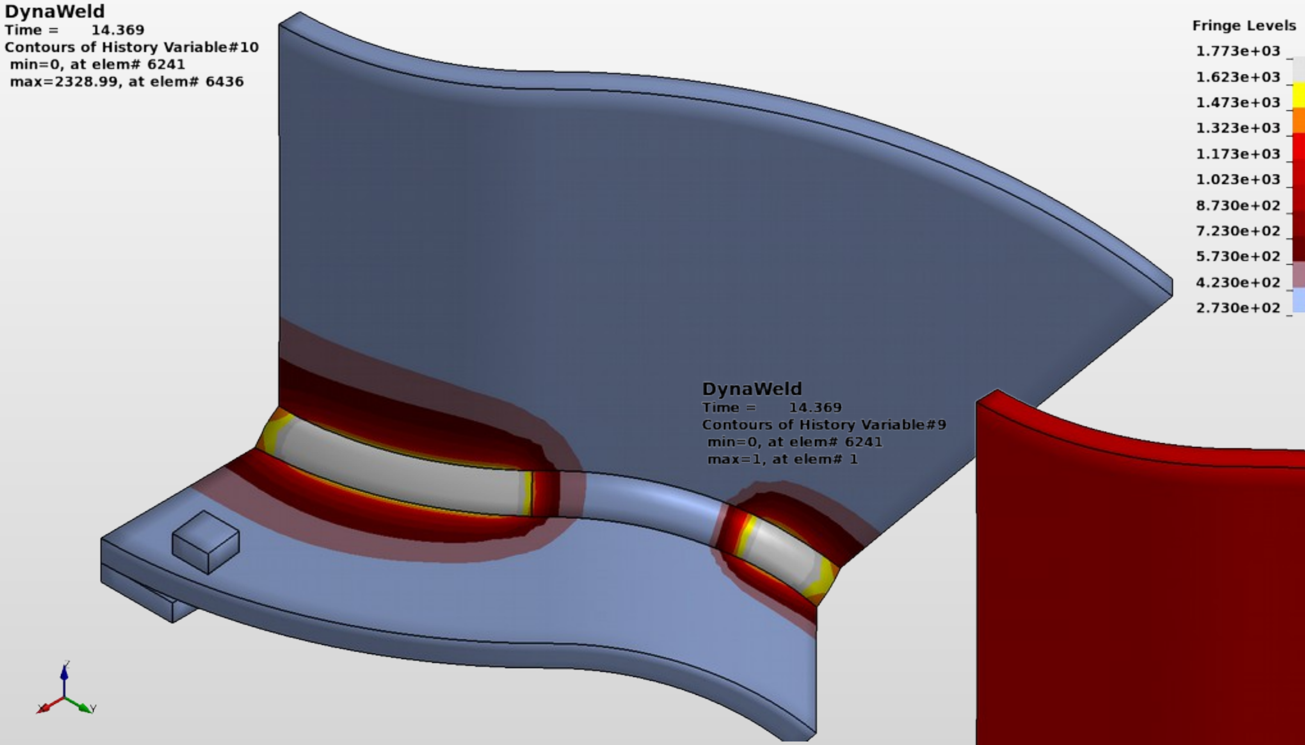
Transformation effects



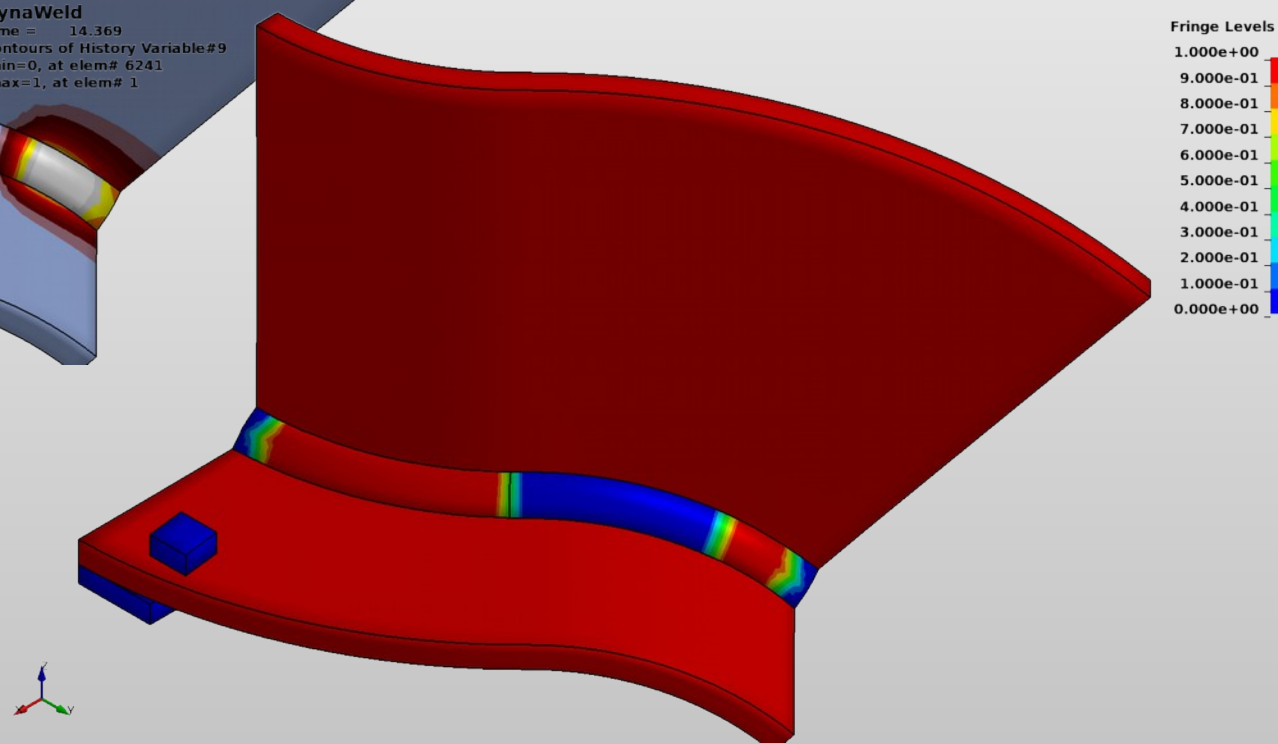
Simplified Approach



Deactivation of not yet deposited material



Deactivated material (blue)
Aktivation criterion:
Temperature

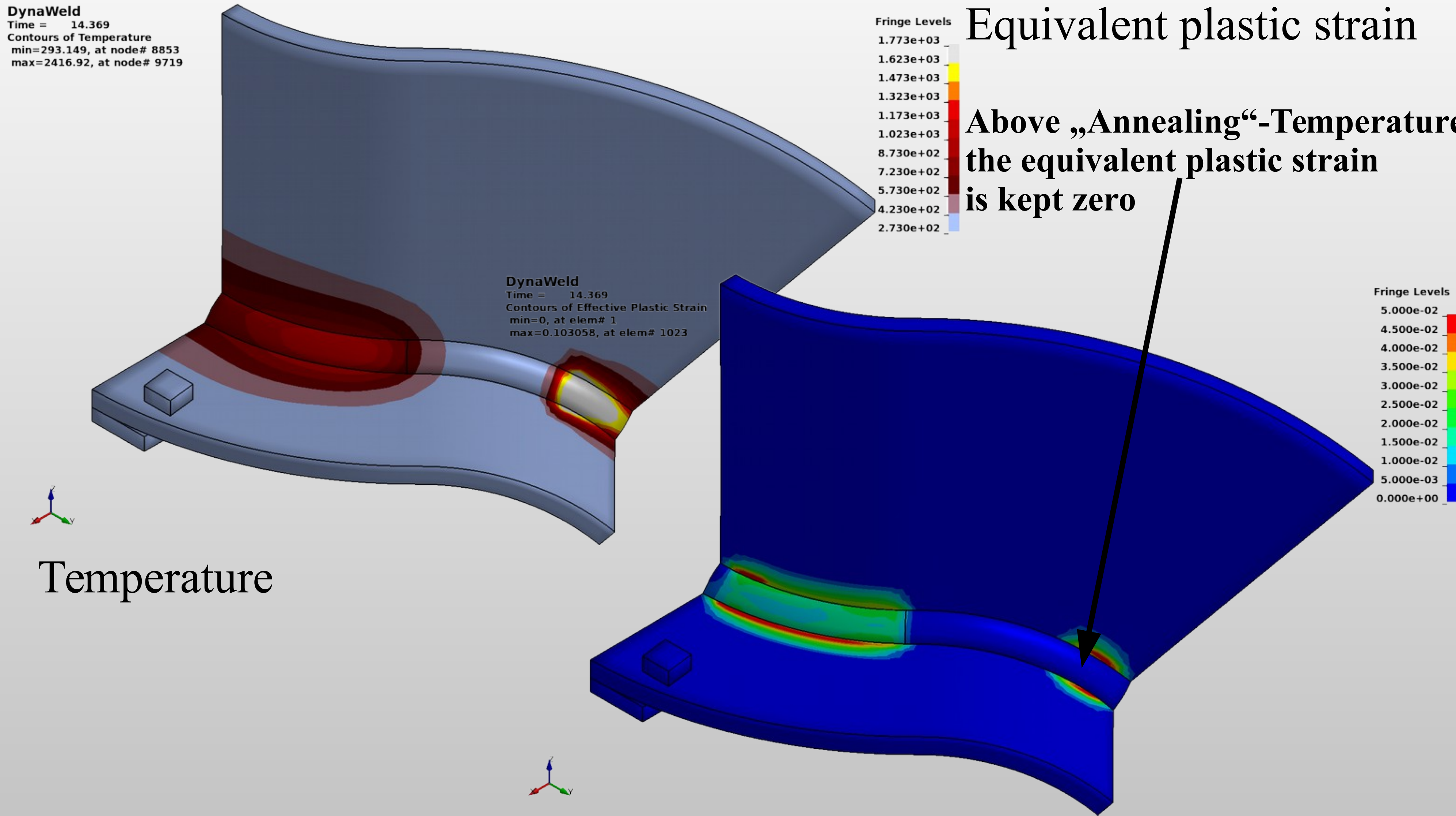


Peak Temperature

Reset of plastic strain

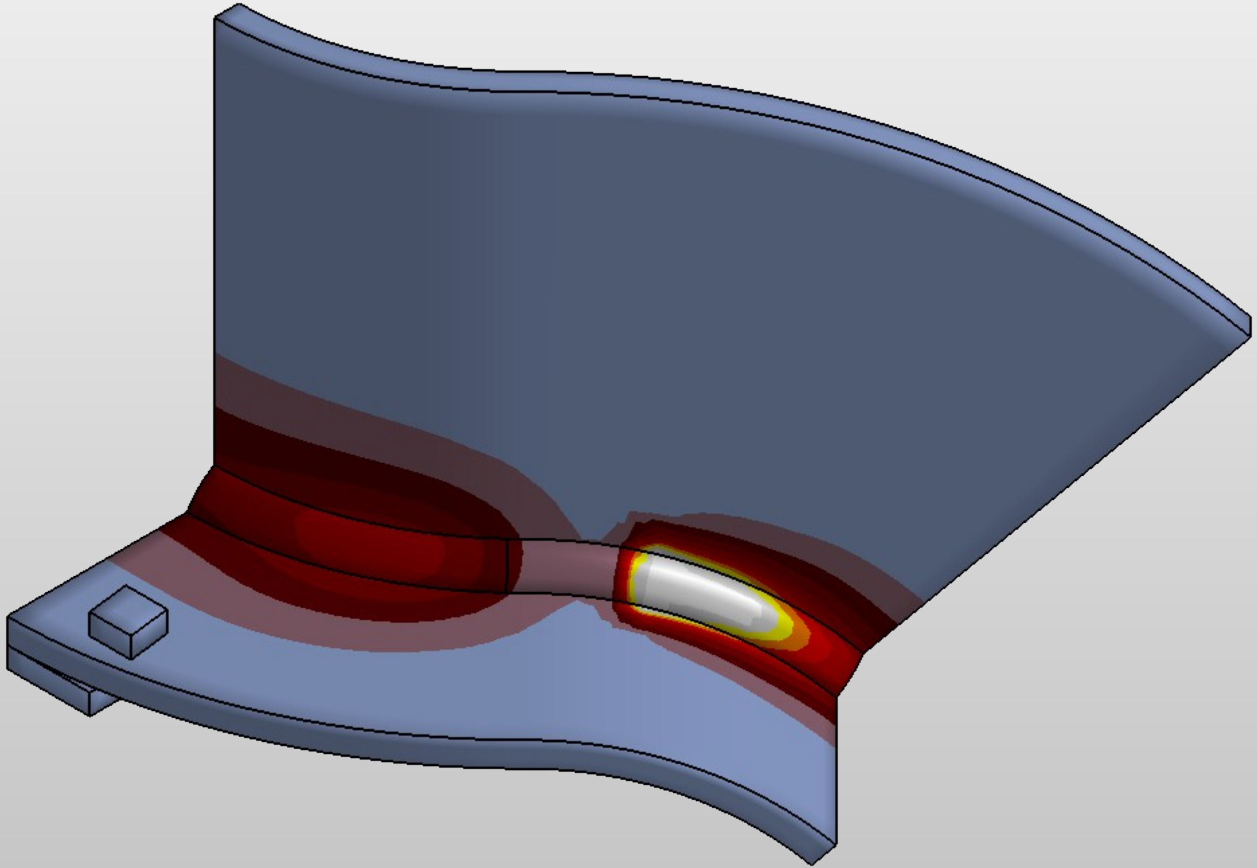
Equivalent plastic strain

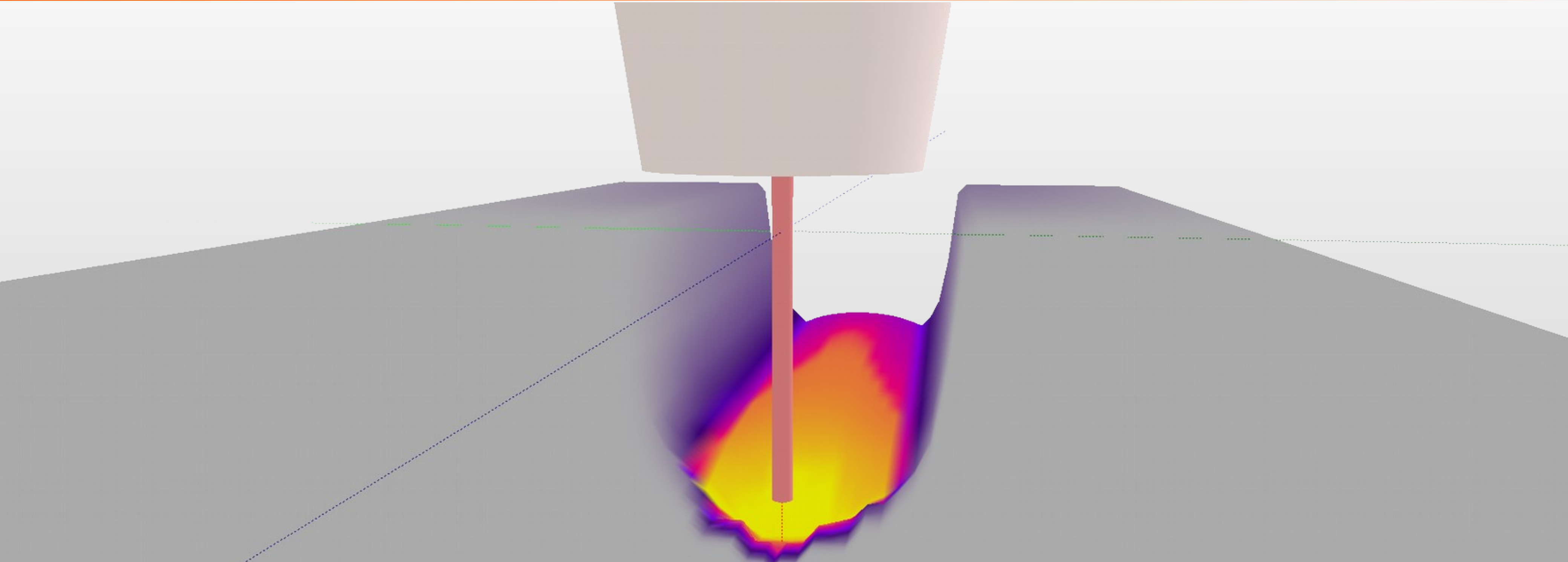
Above „Annealing"-Temperature the equivalent plastic strain is kept zero



Temperature

Heat Input





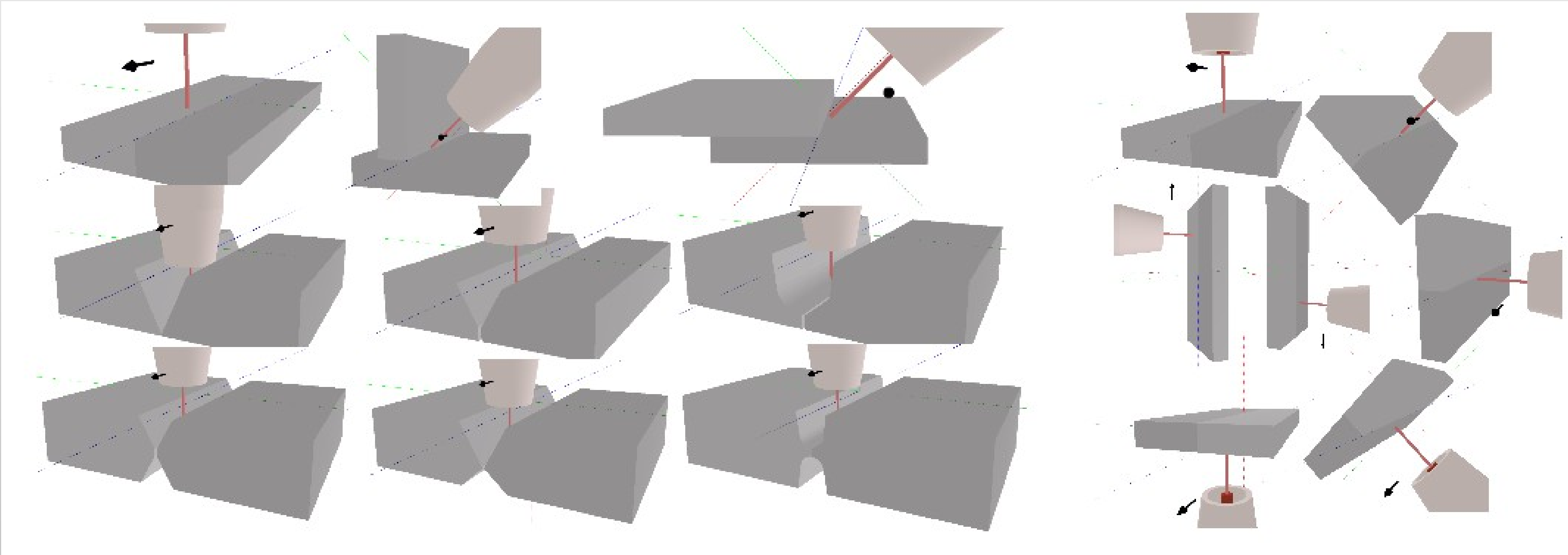
Simulation with SimWeld

Process Simulation GMAW

Numerical Prediction of Equivalent Heat Source

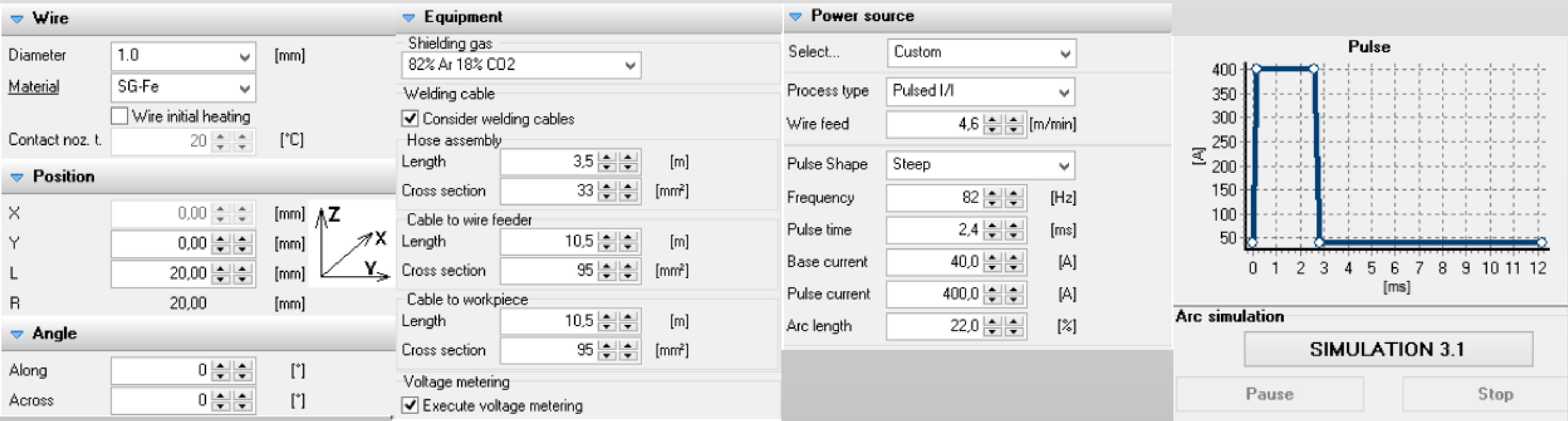
SimWeld Preprocessing

- Definition of:
  - weld preparation
  - geometry and geometric parameter
  - work position
  - material



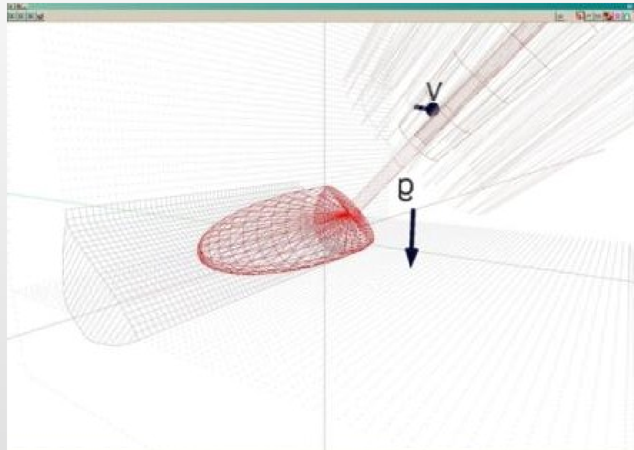
SimWeld Preprocessing

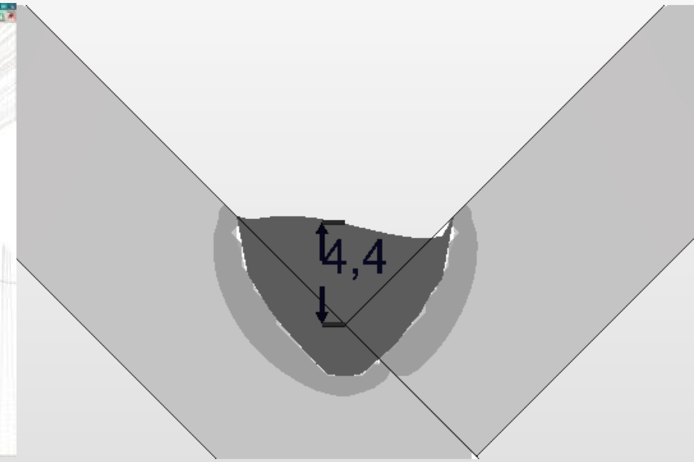
- Definition of:
  - wire: feed, diameter, material,
  - stick out
  - travel speed
  - angle of torch, stabbing, slabbing, skew
  - shielding gas
  - machine settings U, I
  - process type normal, pulsed U/I, pulsed I/I
  - pulse parameter

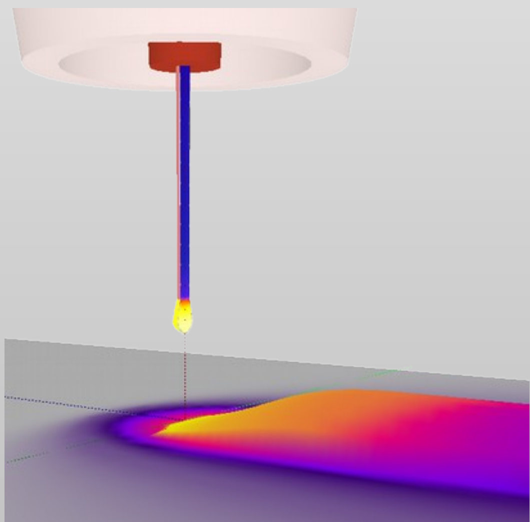


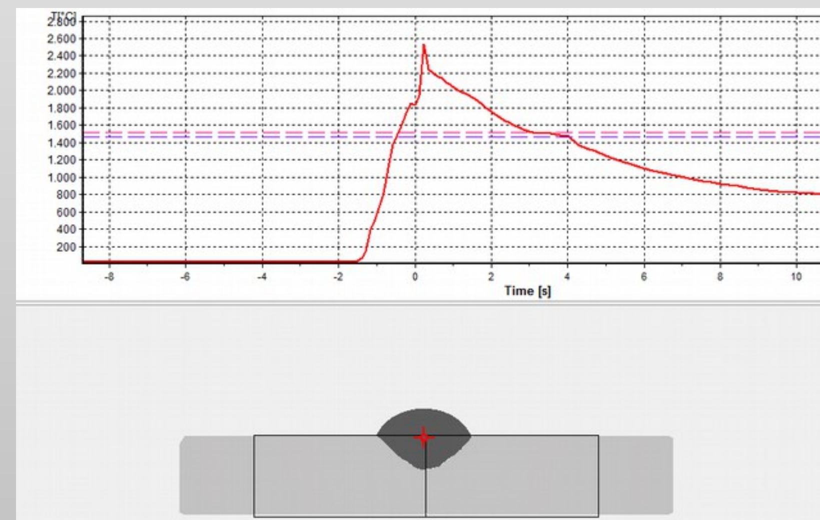
SimWeld Results

- **Equivalent Heat Source**
- Weld Pool Geometry
- Droplet
- Wire Temperature
- Energy, Voltage, Currency
- Temperature Curve



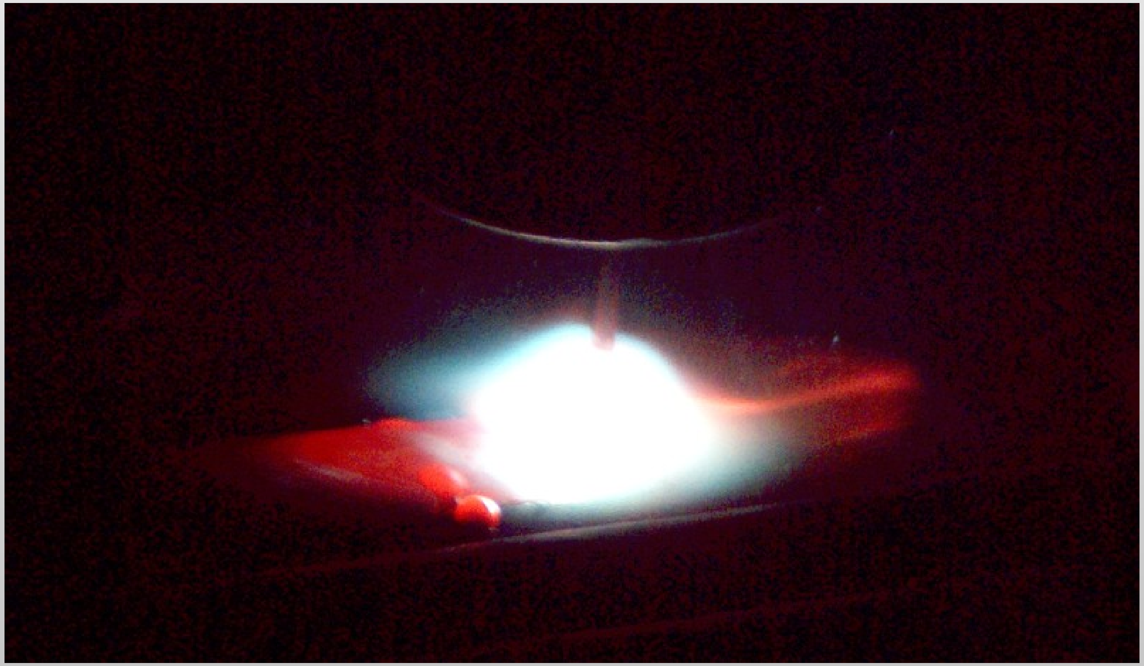






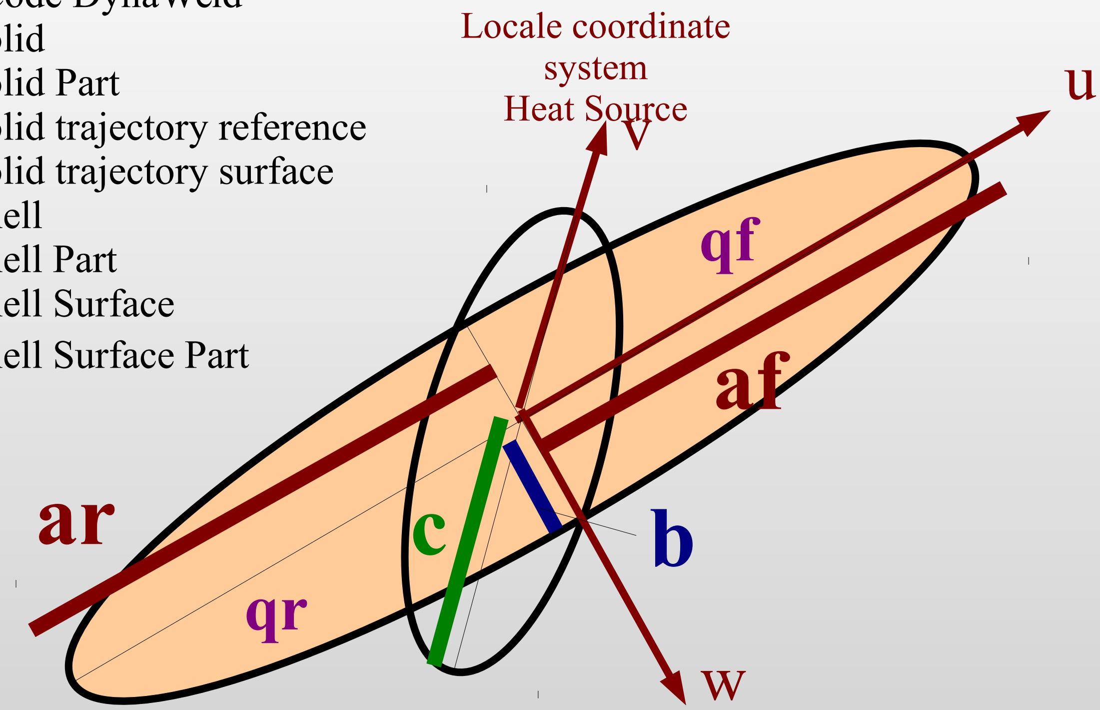
Estimation of Heat Source Parameter from
Welding Procedure Specification (WPS) for Arc Weld, TIG, GMAW, SAW

- Velocity
- Estimation of weld pool geometry
  - length = length of heat source
  - depth = depth of heat source
  - width = withd of heat source
- Energy input per time
  - Voltage
  - Currency
  - Energy per unit length
- Estimation of efficiency
  - TIG: 0,75
  - GMAW: 0,8
  - SAW: 1,0



Doppelt-Elipsoide Heat Source (Loose)
with constant heat source density

Heat Source Code DynaWeld	
LE	Solid
LEP	Solid Part
TRLE	Solid trajectory reference
TSLE	Solid trajectory surface
SLE	Shell
SLEP	Shell Part
SHLE	Shell Surface
SHLEP	Shell Surface Part



Geometry function (double-elipsoid)

Parameter:

Q: total energy per unit time

qf: source density front

qr: source denstiy rear

ff: ratio front

fr: ratio rear

af: radius front

ar: radius rear

b: radius width

c: radius depth

qf, qr: Wärmequelldichte konstant:

- Wärmeintrag qf für (u/af)^2 + (v/c)^2 + (w/b)^2 <= 1
- Wärmeintrag qr für (u/ar)^2 + (v/c)^2 + (w/b)^2 <= 1

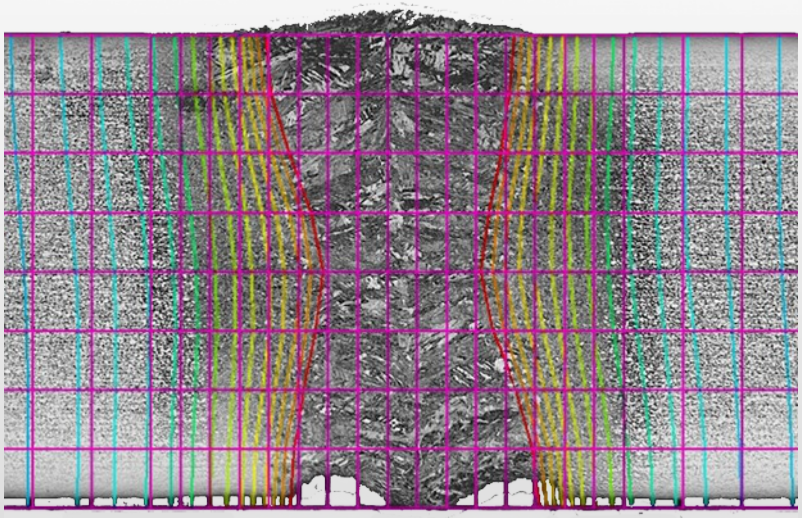
qf = 1,5 * Q * ff /(af^2 * b^2 * c^2)

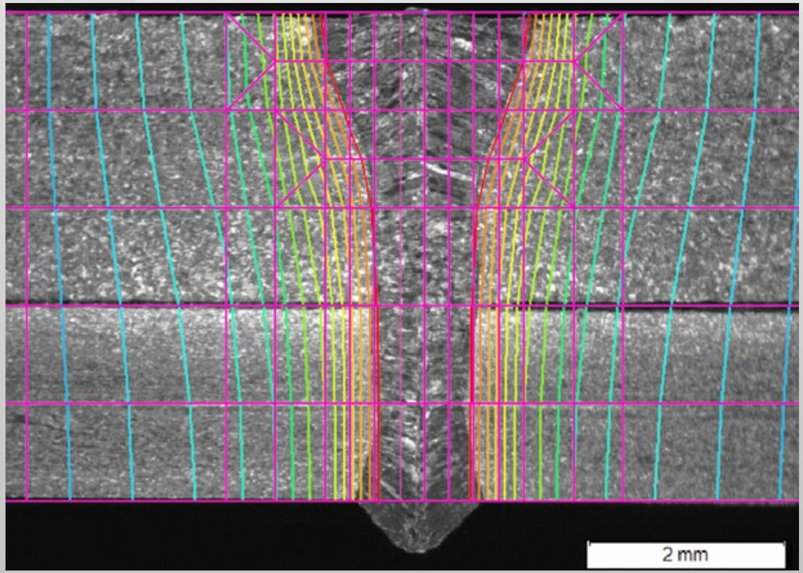
qr = 1,5 * Q * fr /(ar^2 * b^2 * c^2)

ff + fr := 2

Adjustment due to Microsection

- Velocity
- Estimation of the geometry of weld pool from microsection
- Geometry of weld pool = geometry of equivalent heat source
- Adjustment of heat input until calculated liquidus line fits liquidus line of microsection

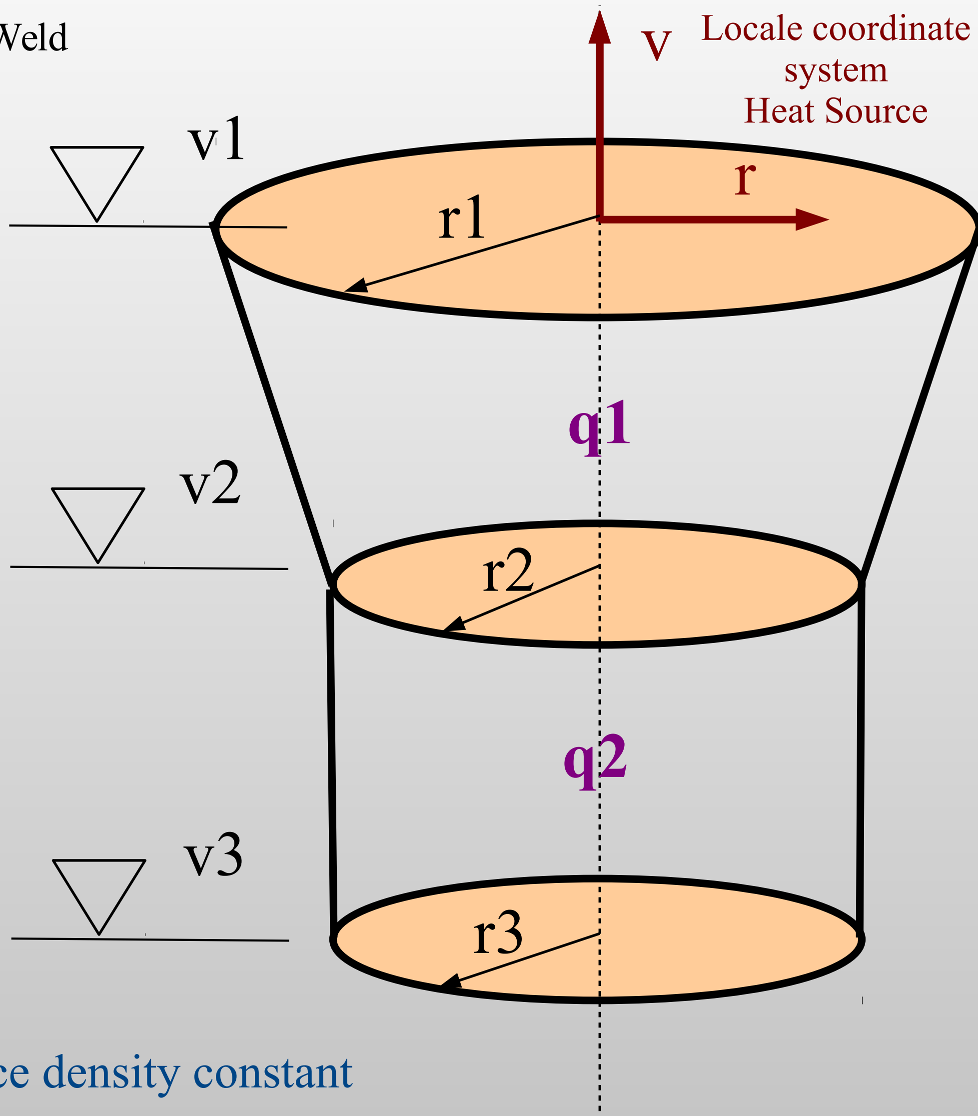




Double Conical Heat Source (Loose)
with constant heat source density

Heat Source Code DynaWeld

TRLK	Solid
LK	Solid
LKP	Solid Part



Geometry function
(double-elipsoid)

Parameter:
q1: source density top
q2: source denstiy bottom
r1: radius top
r2: radius middle
r3: radius bottom
v1: v-coordinate top
v2: v-coordinate middle
v3: v-coordinate bottom

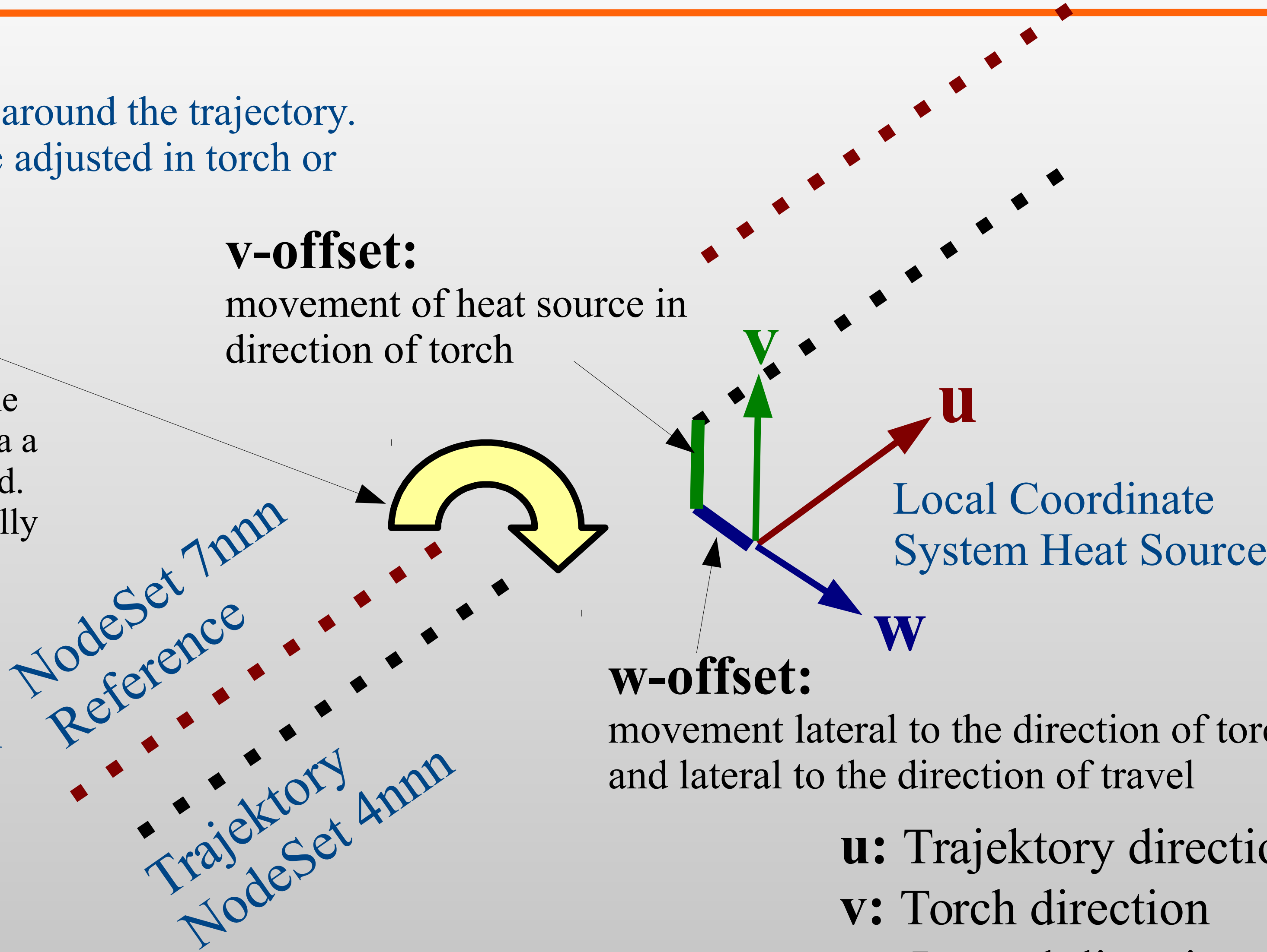
q1, q2: heat source density constant

Local Coordinate System Heat Source
Moving along Trajectory

ay:
Rotation of the reference around the trajectory.
The reference needs to be adjusted in torch or beam direction.

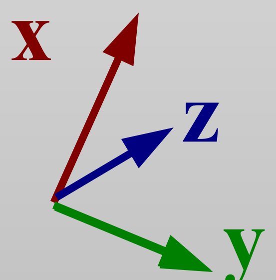
For the Heat Sources with the DynaWeld Code TSxx only a a trajectory needs to be defined. The Reference is automatically set normal to the surface.

v-offset:
movement of heat source in direction of torch



w-offset:
movement lateral to the direction of torch and lateral to the direction of travel

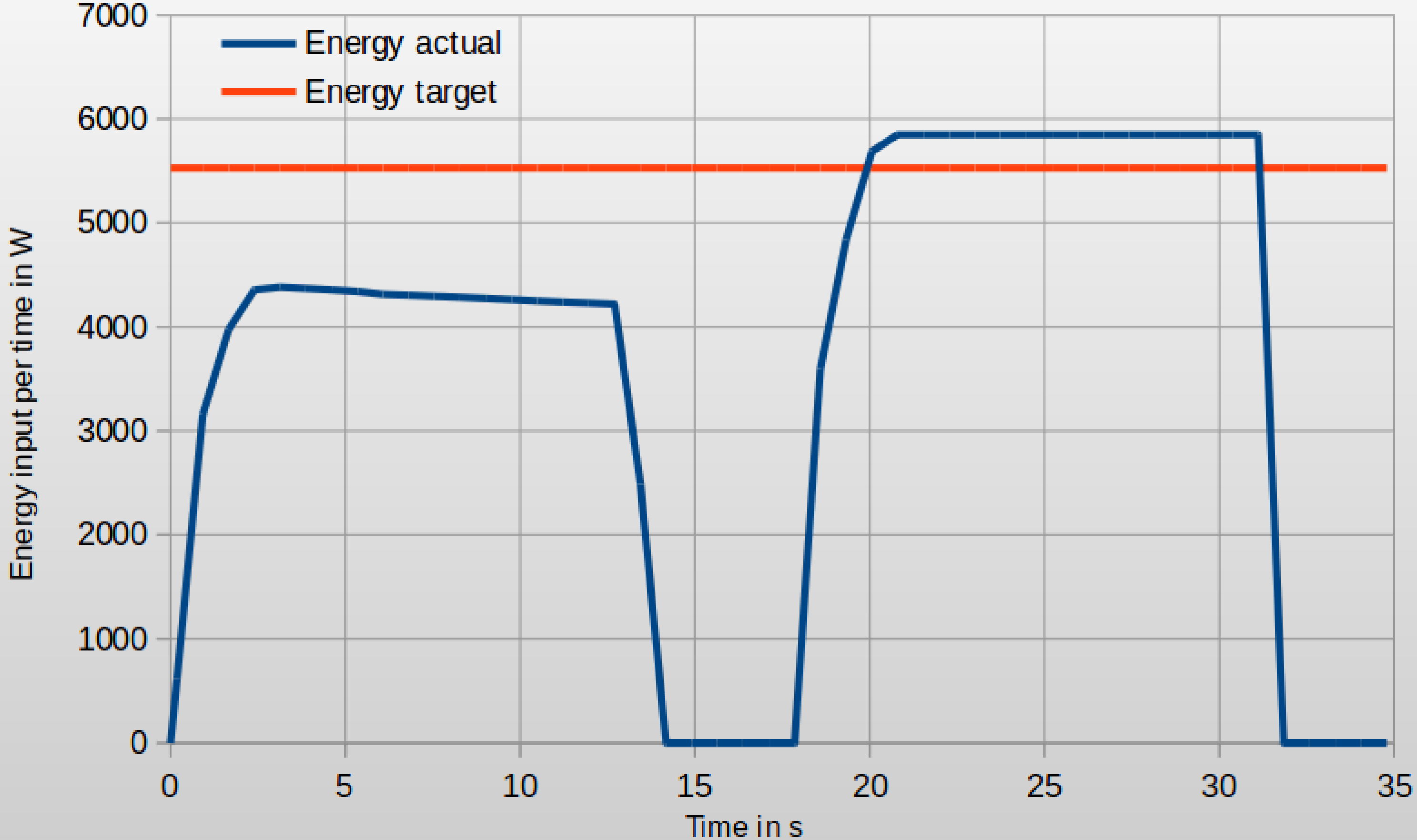
Global Coordinate System



u: Trajektory direction
v: Torch direction
w: Lateral direction

Final Adjustment of Heat Input

Determination of calibration factor kf to achieve the target heat input



Heat Input Adjustment:					
Weld	**actual**	**target**	**Faktor**	**kf old**	**kf new**
1001	4212,63	5525,82	1,31	1,00	1,31
1002	5838,02	5525,82	0,95	1,00	0,95

Metatransient Heat Source

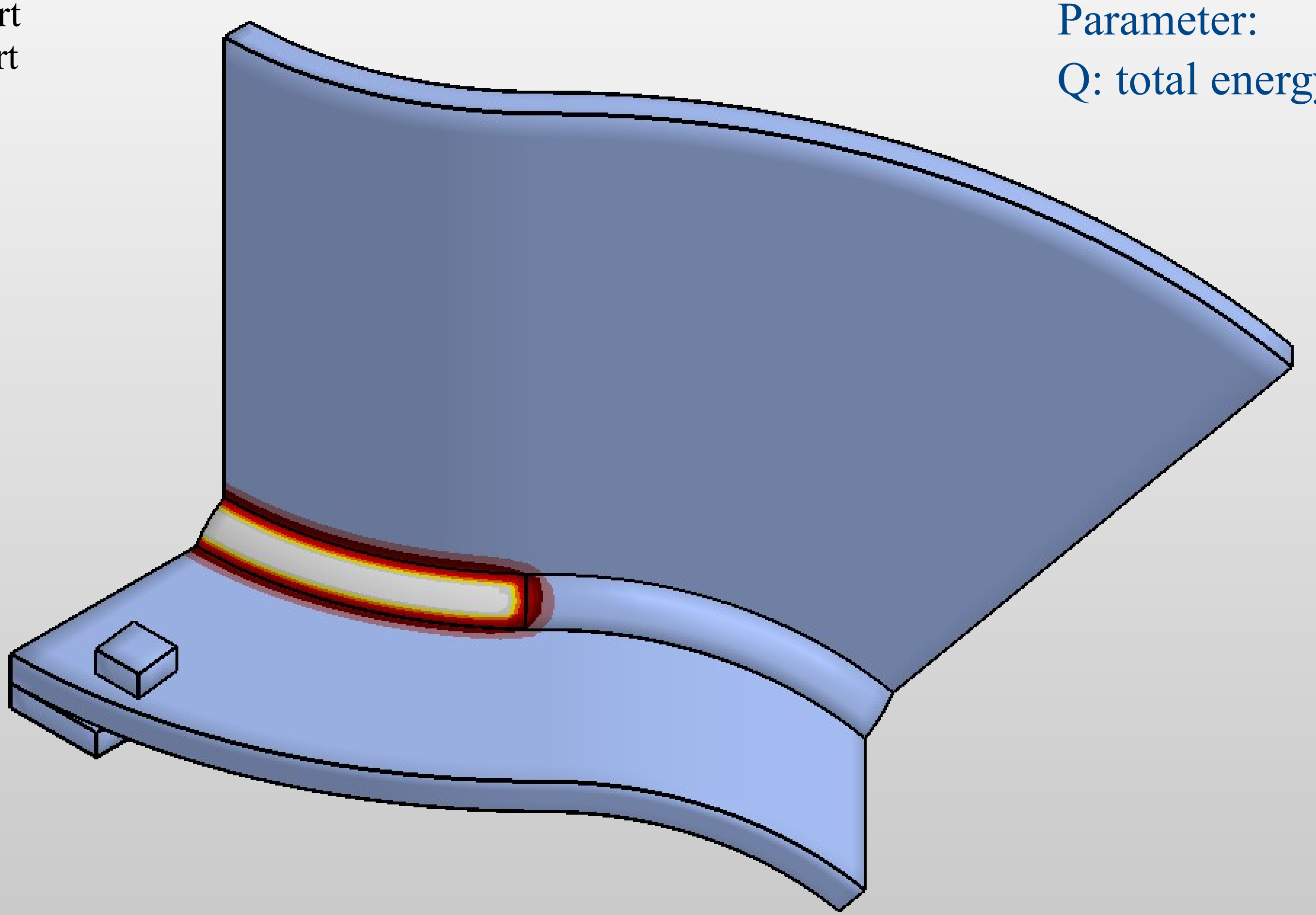
with constant heat source densiy in the whole part

Heat Source code DynaWeld

PH	Solid Part
PHS	Shell Part

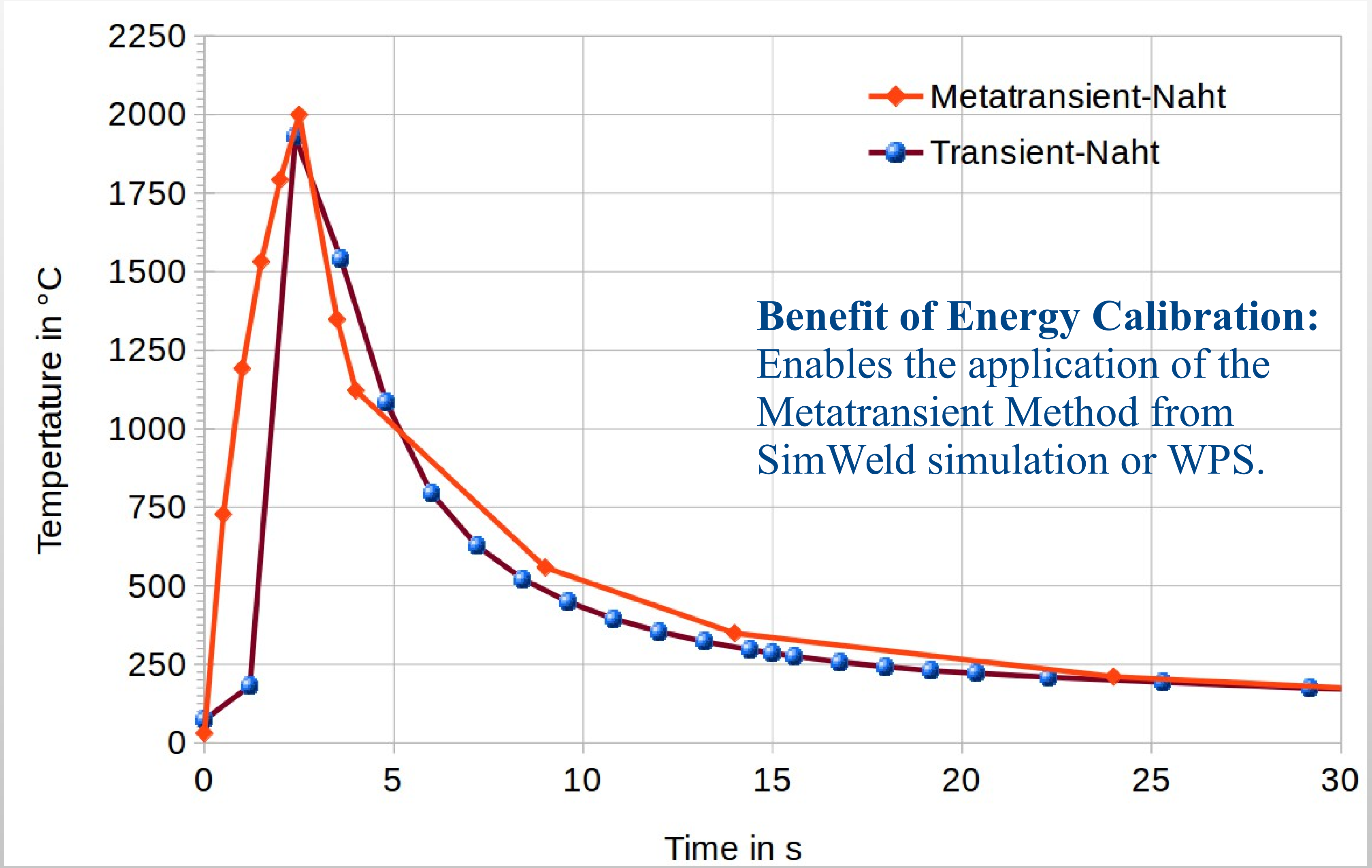
Parameter:

Q: total energy per unit time

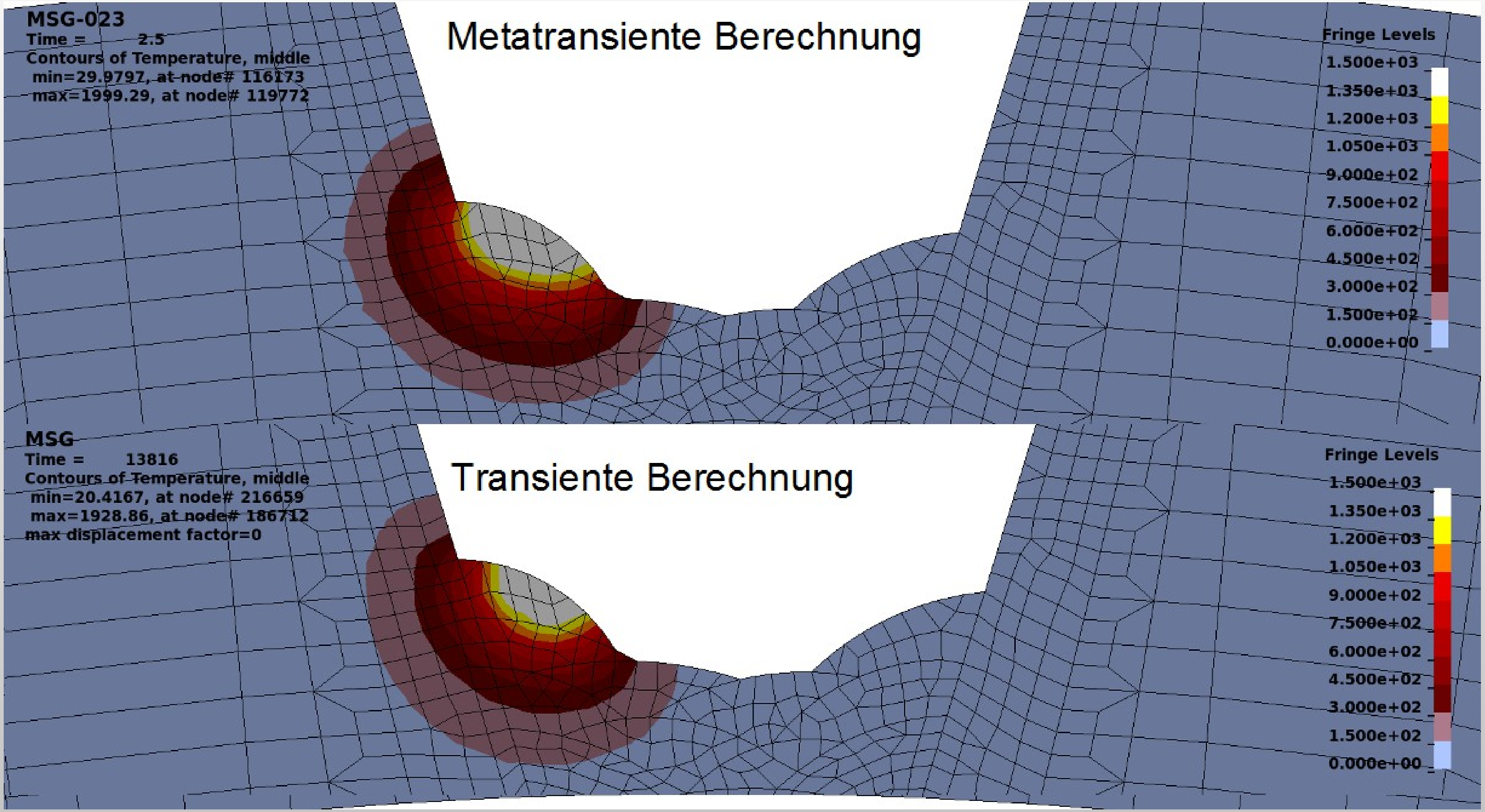


q: heat source density constant over all elements of considered part.

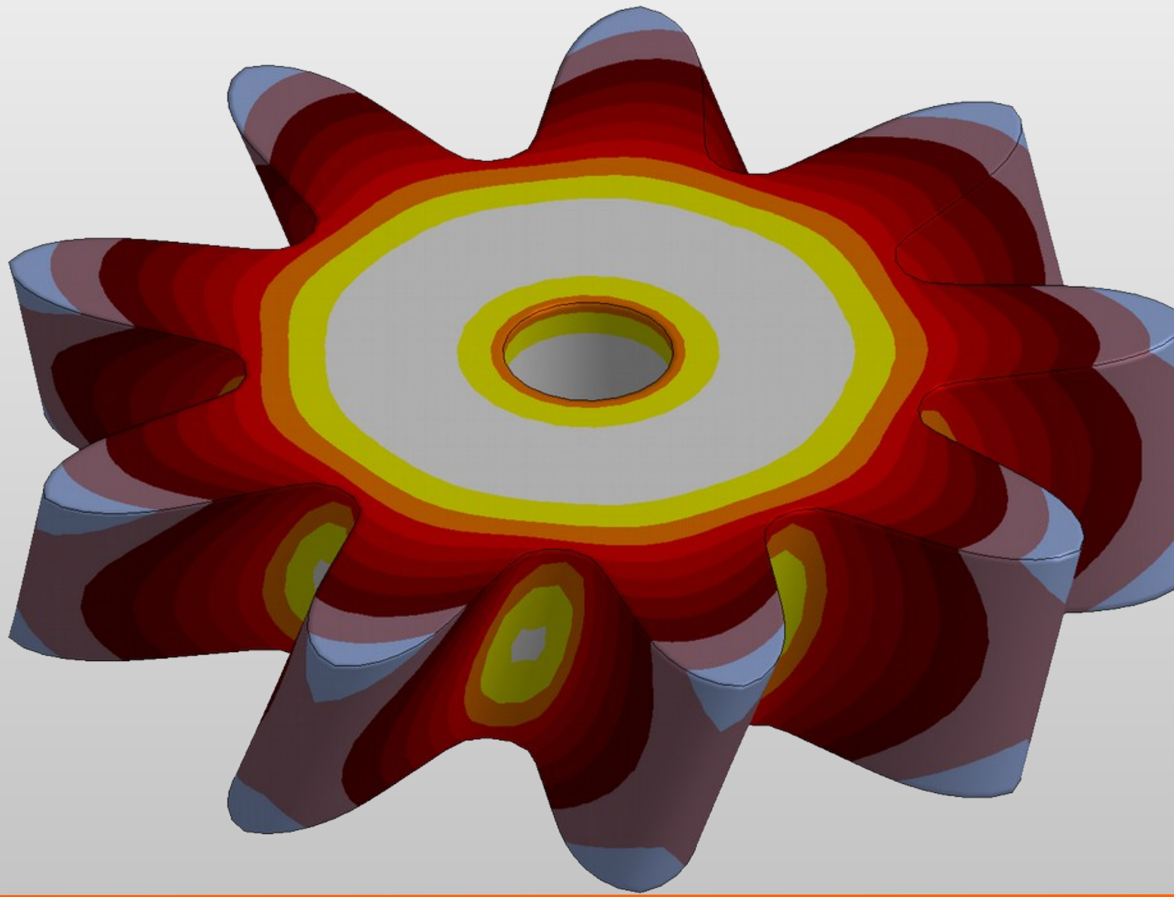
Metatransient Method with Engergy calibration



Metatransient Method with Engergy calibration



Process



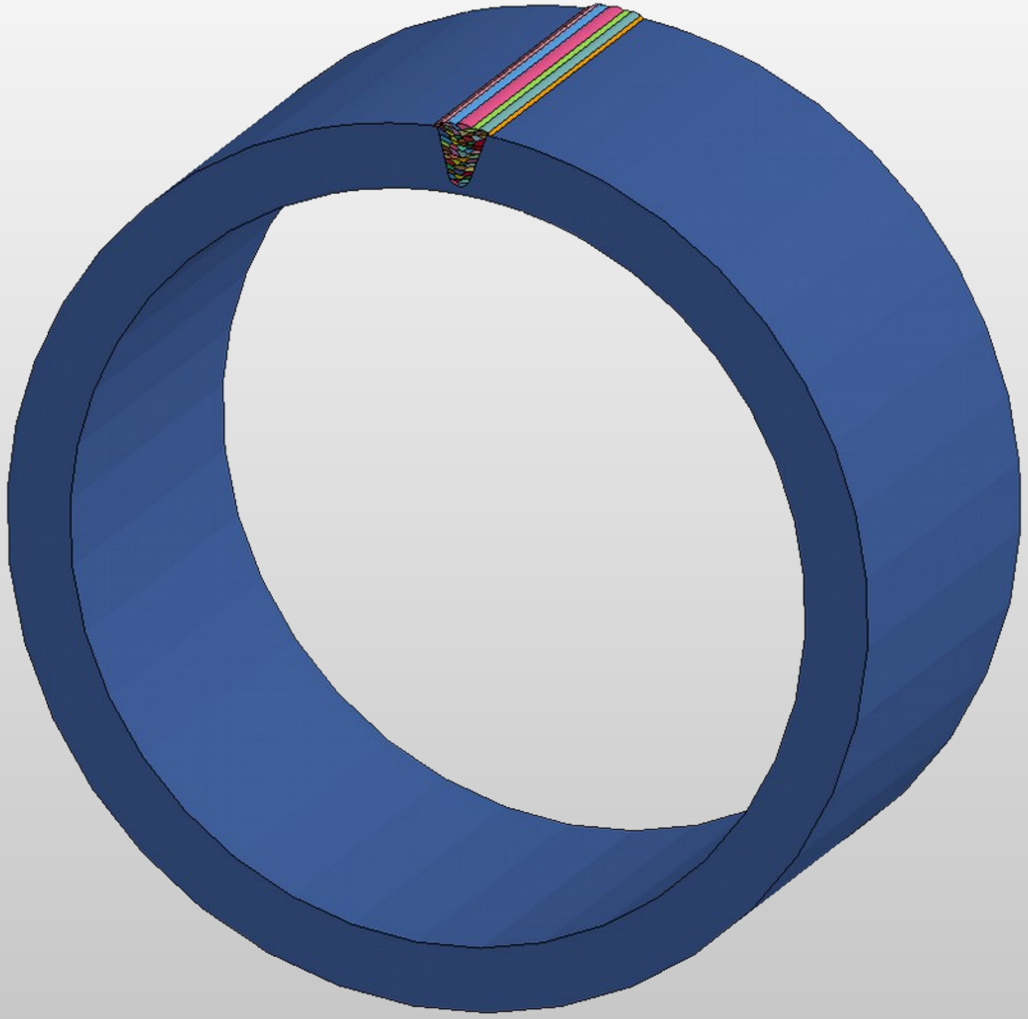
Welding

Heating

Cooling

Reheating
Tempering Effects

Grinding and Rewelding



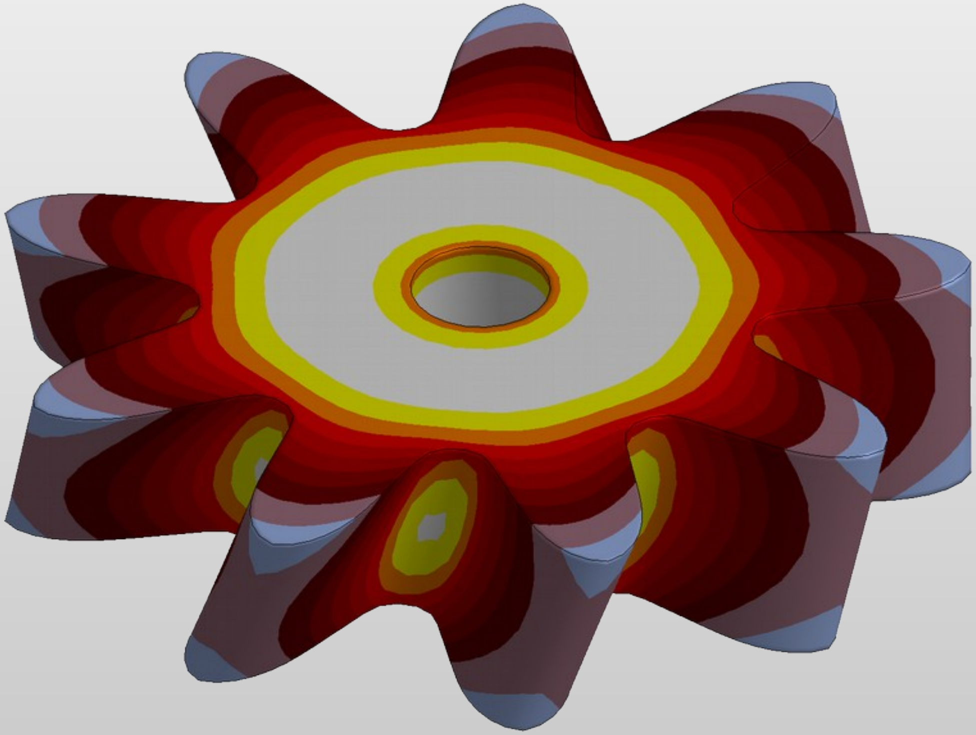
Heat Treatment

Heating
Thermal Heating
Inductive Heating

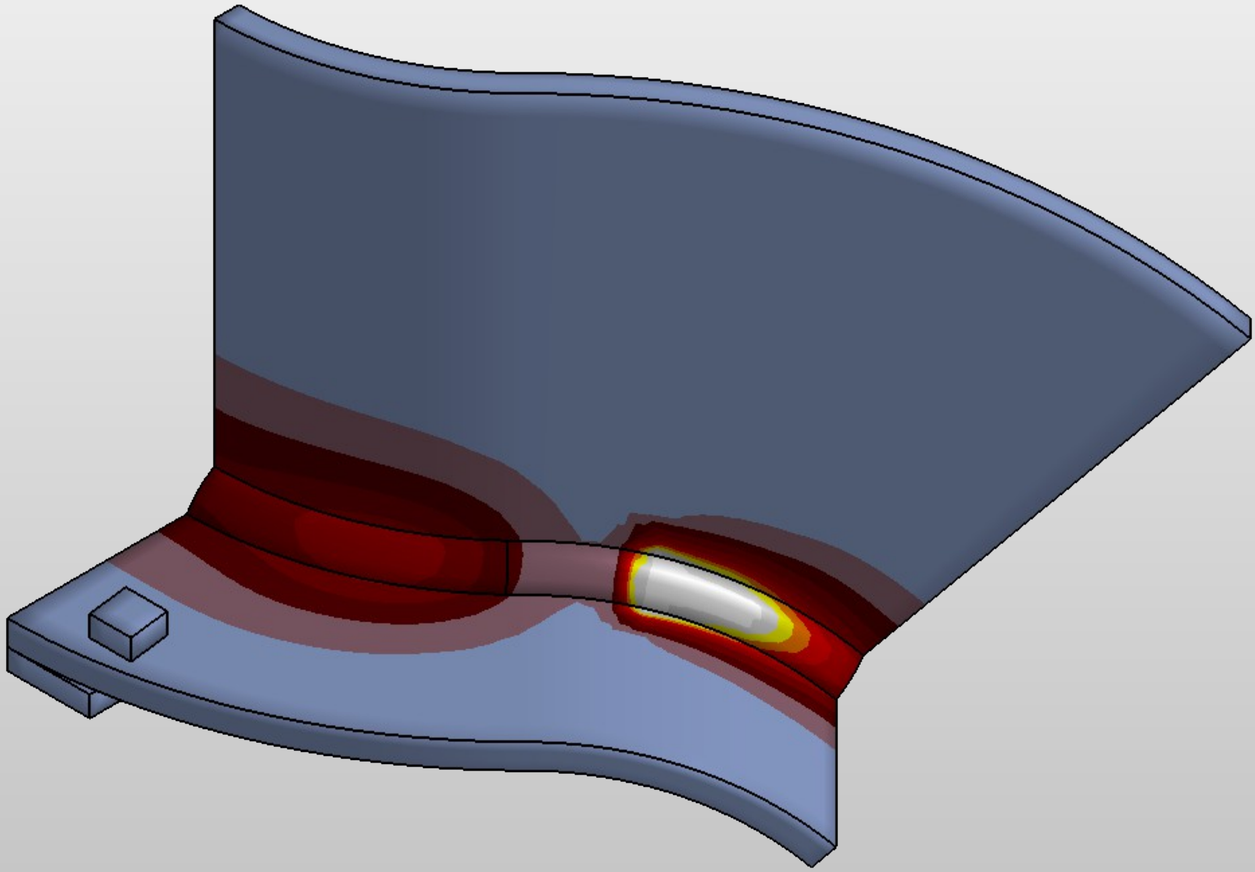
Carburisation

Quenching

Tempering



Process Chain



Manufacturing of a Box
Task and Model

Forming:
- The roof geometry is made by forming a 3 mm thick sheet (1.4301)

Assembly:
- Add the sidewall

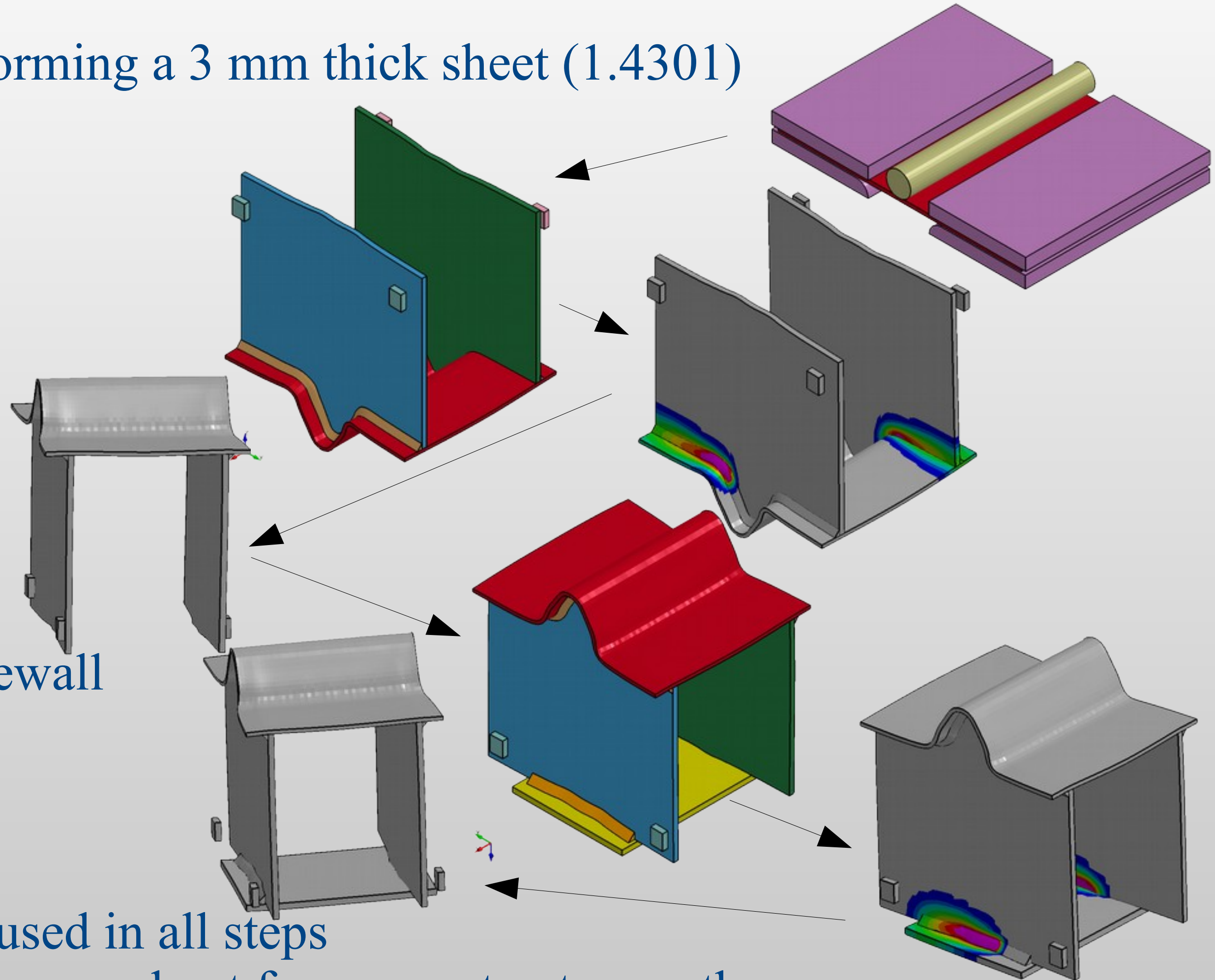
Welding:
- Weld the sidewall to the roof

Clamp and predeformation:
- press the sidewall on measure

Assembly:
- Add the bottom plate

Welding:
- Weld the bottom plate to the sidewall

Unclamping



Model:
- Solid-element model
- Material model (*MAT_270) is used in all steps
- History variables and deformations are kept from one step to an other
- Implicit analysis in all steps

Deep-Drawing of a Cup from a Laser Welded Sheet

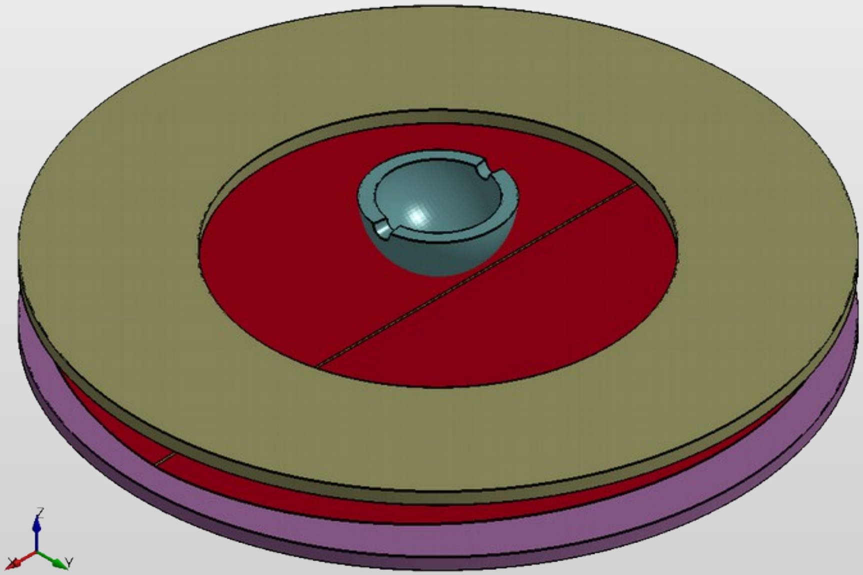
Task and Model

Welding:

- Two sheets (S355) with 1 mm wall thickness are laser welded

Forming:

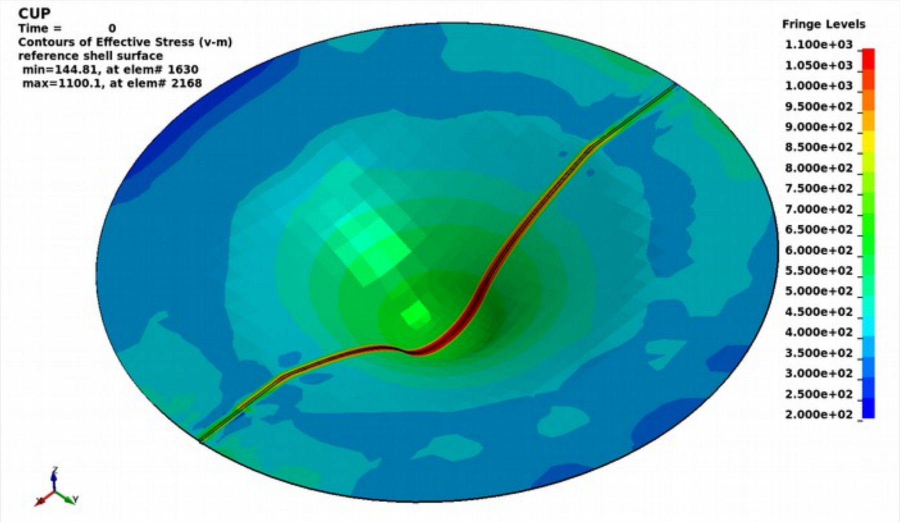
- The welded and distorted sheet is clamped
- a globular die is pressed slow in the sheet.



Model:

- Shell-elements are used for the sheet, solid elements are used for the clamps and the die
- Same material model (*MAT_244) is used in all steps
- History variables, phase proportions and deformations are kept from one step to an other
- Welding: implicit analysis, Forming: explicit analysis

Stresses and Strains in Midsurface of Shell after welding and deep drawing



top left:

effectiv stress bevor unclamping

200 .. 1100 N/mm²

bottom left:

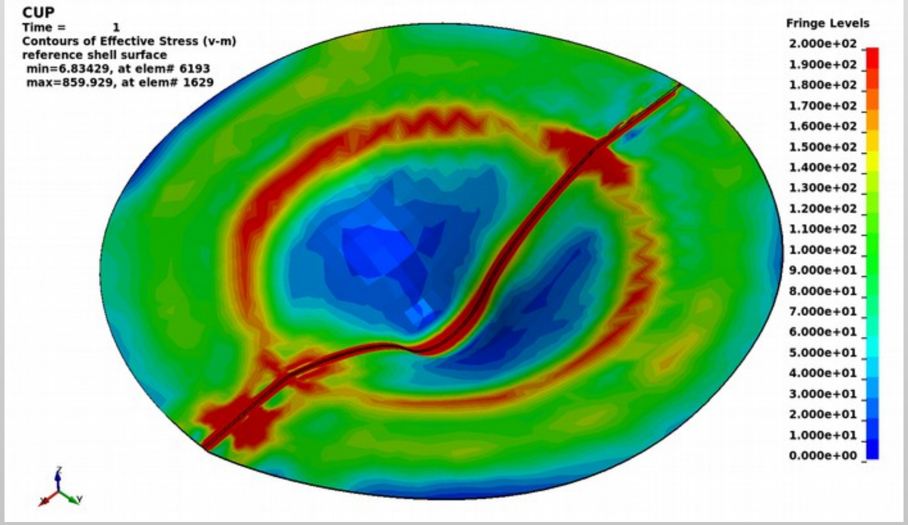
effectiv stess after unclamping

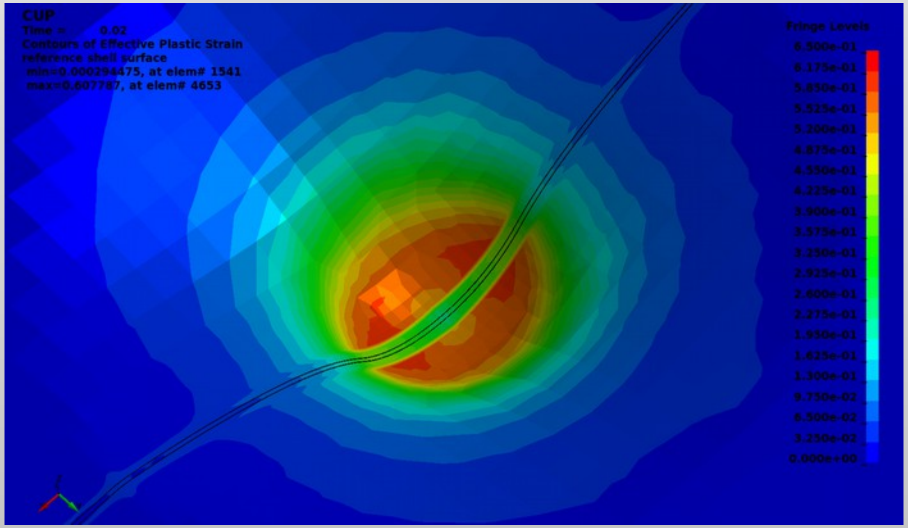
0 .. 200 N/mm²

bottom right:

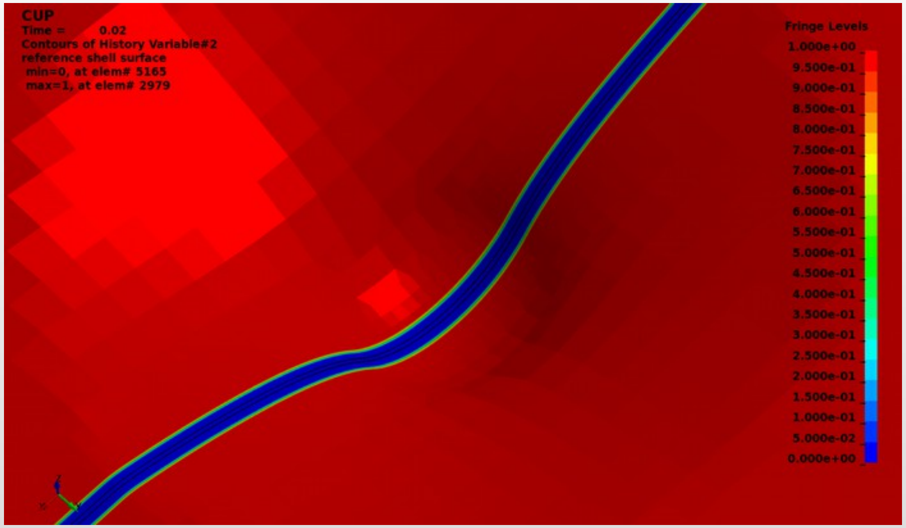
plastic strain after unclamping

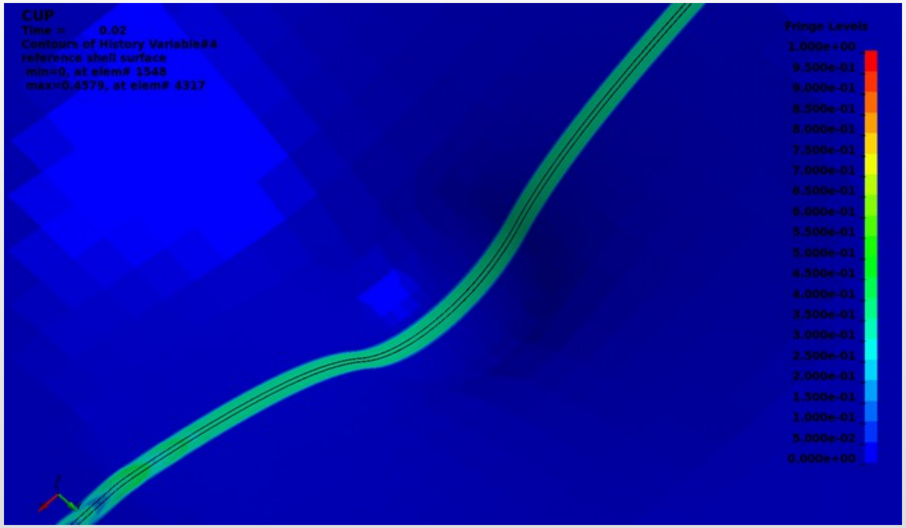
0 .. 0.65 m/m

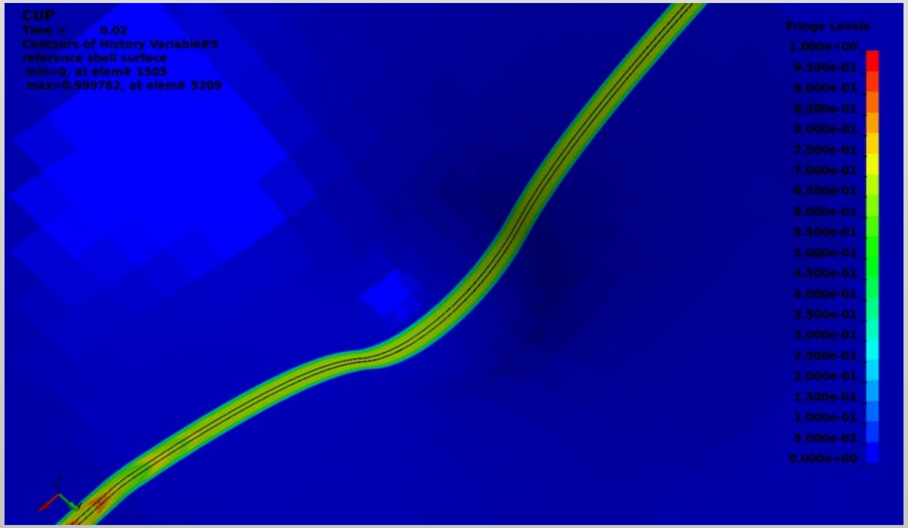




Microstructure during Deep-Drawing







top left:

Ferrit proportion

top right:

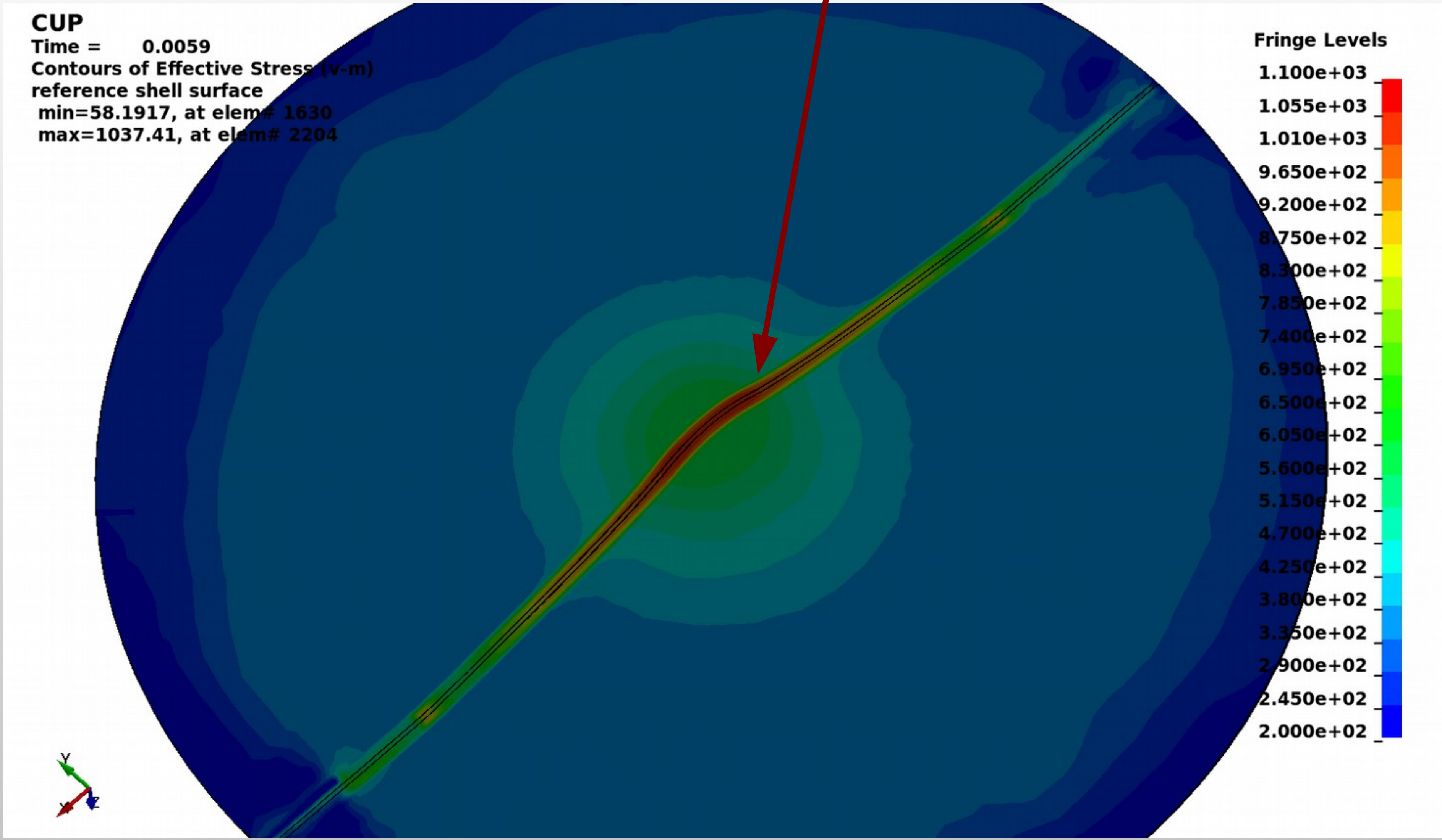
Bainit proportion

bottom right:

Martensit proportion

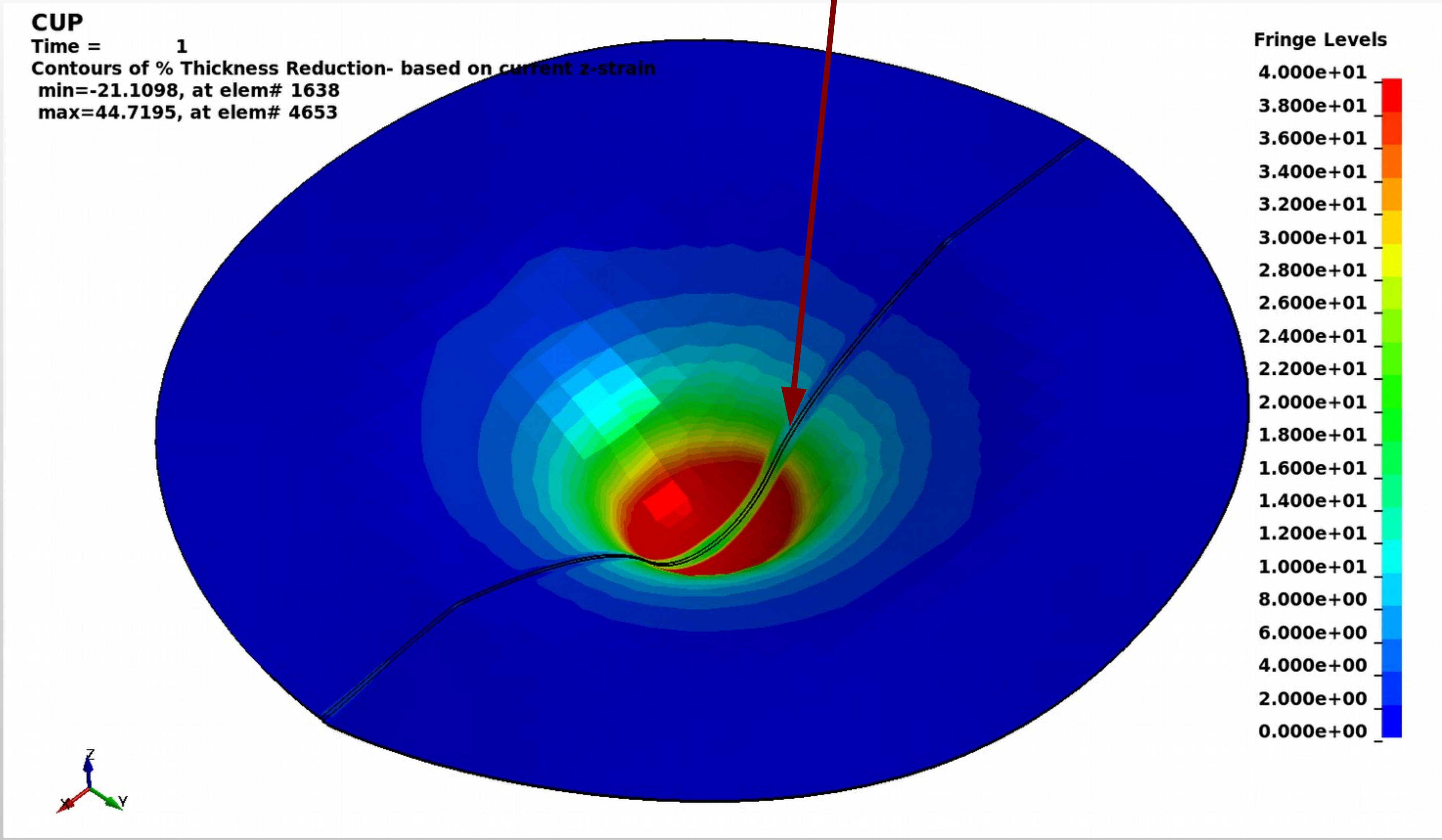
Effective Stress during Forming

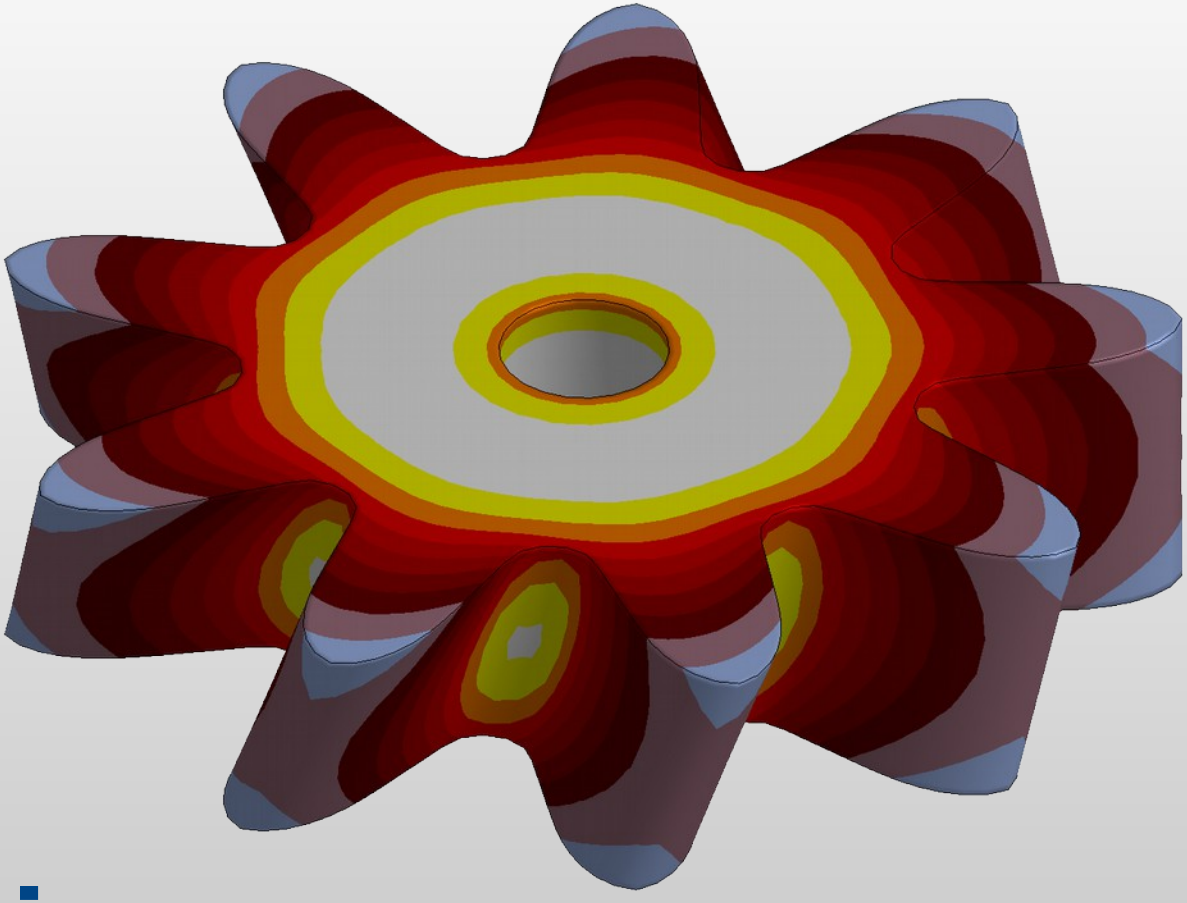
Influence of Material Property Change from Welding



Thinning of the Sheet

Influence of Material Property Change from Welding

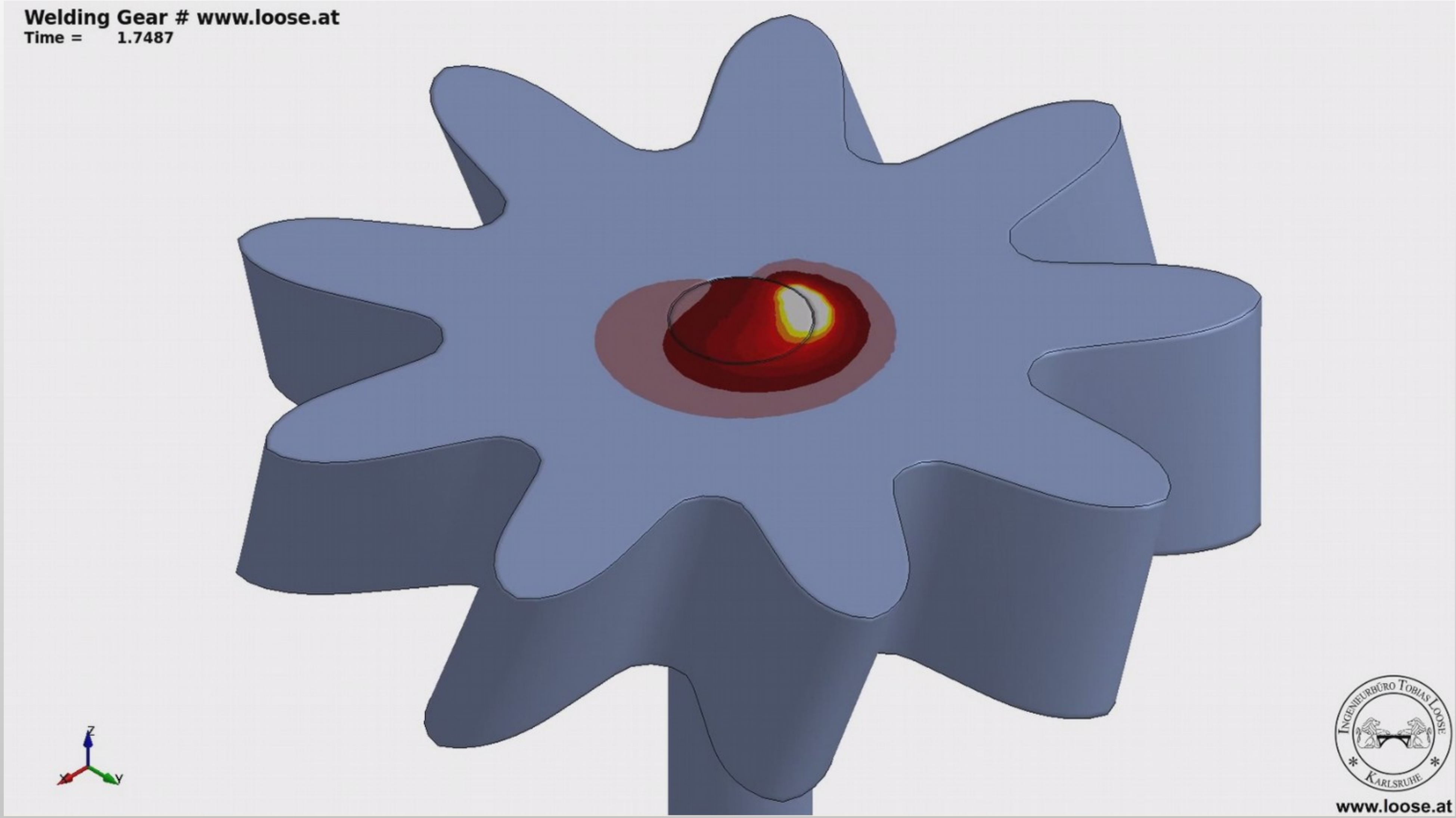




Process chain

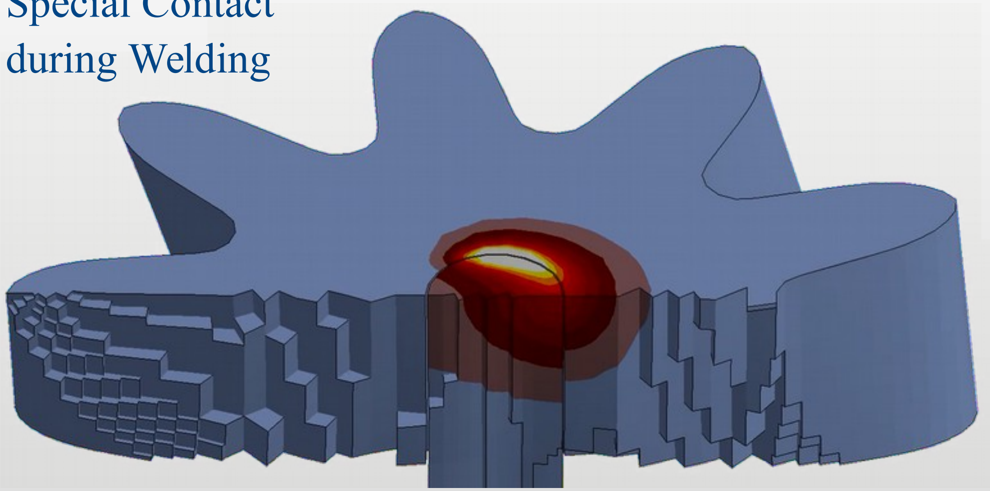
Heat Treatment - Welding

Welding after Heat Treatment

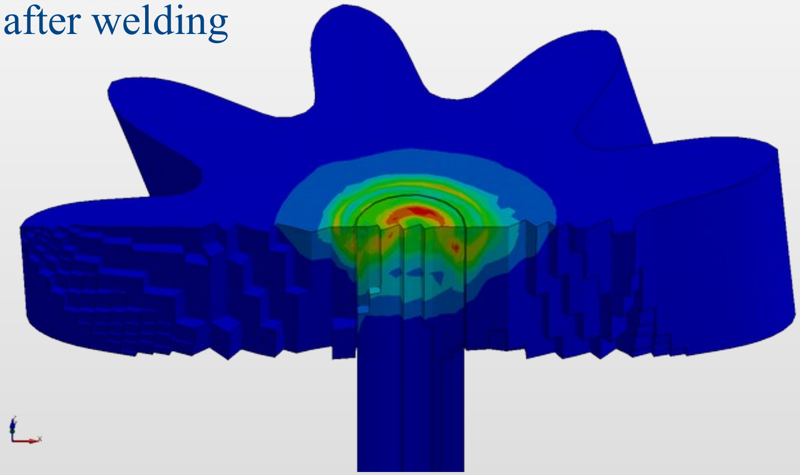


Results of Process Chain Simulation
Heat Treatment - Welding

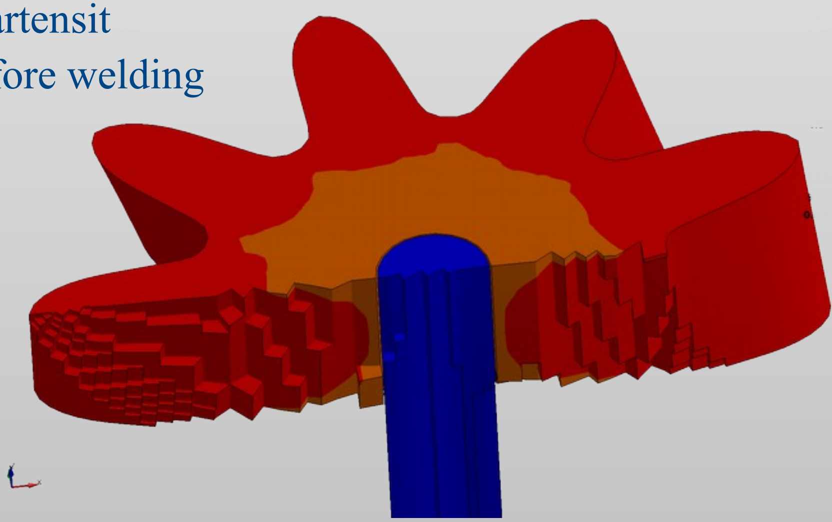
Special Contact
during Welding



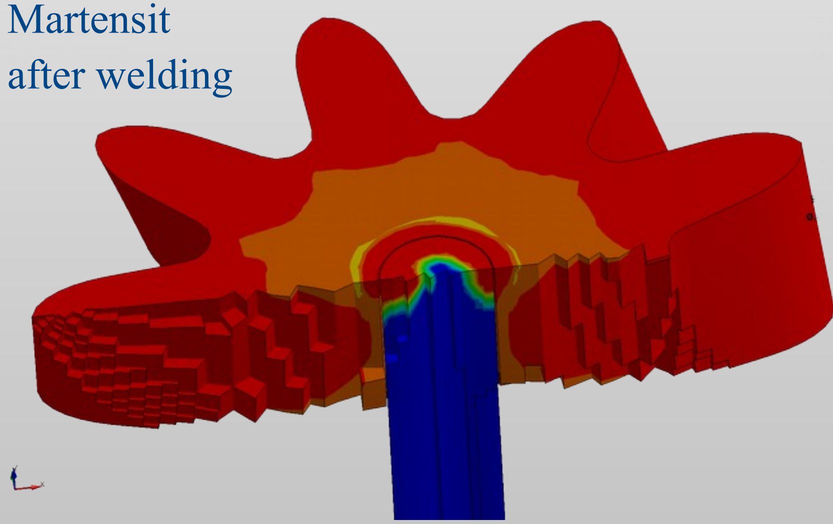
Equivalent Stress
after welding



Martensit
before welding



Martensit
after welding

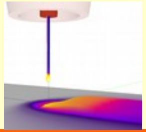


Thanks for your Attention!

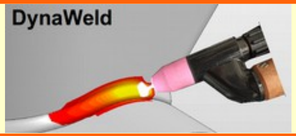
Forming

Heat Treatment

SimWeld



DynaWeld



Forming

Structure Analysis

Post Weld Heat Treatment

Crash

Assembly