

Anwendungsbeispiele

der Schweißsimulation und Wärmebehandlungssimulation

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- Modellgröße
 - z.B. alle Schweißnähte eines ganzen Schiffes
 - Berechnungszeit
 - Rechnerkapazität
- Methoden
 - Vereinfachende Methoden ermöglichen die Berechnung größerer Bauteile
 - Vereinfachende Methoden liefern geringere Ergebnisqualität
- Kopplung physikalischer Vorgänge und Detaillierung der Modelle
 - Je komplexer das Modell desto eher ist die Anwendungsgrenze erreicht:
 - Thermisches Modell
 - Mechanisches Modell
 - elektrisches Modell
 - Werkstoffmodell
 - Strömungsmodell
 - Erstarrungskinetik
 - Optische Effekte
- Kosten
- Fachpersonal

- Verzugsberechnung
 - Optimierungsmaßnahmen, Verzugskompensation
- Prozess, Prozessparameter
 - Schmelzbadausbildung
 - Schweißlinse
 - Prozessfenster
- Mechanische und Metallurgische Eigenschaften
 - Gefüge
 - Spannungen, Dehnungen, plastische Verfestigung
- Wärmeführung
- Bauteilzustand als Ausgangszustand weiterer Berechnungen
 - Festigkeitsanalyse
 - Tragfähigkeitsberechnung
- Gekoppelte Simulation mehrerer Fertigungsschritte (Prozeßkette)
 - Wärmebehandlung, Schweißen, Umformen, Nachbehandlung

- Double sided T-Joint $a = 4 \text{ mm}$
- 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

Input-Parameter SimWeld

Workpiece parameters (Ctrl + 1)

Geometry
 EN ISO **EN ISO 9692-1: 2003 (D)**

Joint type **Square edges (3.1.1)**

width 40,00 [mm] height -1,00 [mm]
 t1 8,00 [mm] t2 8,00 [mm]
 b 0,00 [mm] c -1,00 [mm]
 radius -1,00 [mm] e -1,00 [mm]
 alpha 90,00 [°] beta -1,00 [°]

Left plate visible Right plate visible

Material
 Plates S355

Position
 Type Custom
 across 45,00 [°] along 0,00 [°]

Process parameters (Ctrl + 2)

Process parameters
 Welding speed 80,00 [cm/min]
 Initial temperature 20,00 [°C]

Simulation Options
 Consider gap

Calculation length User defined
 100,00 [mm]

Mesh density normal (1.0x)

Resources: medium
 Accuracy: medium

OK Cancel

Torch parameters (Ctrl + 3)

Wire
 Diameter 1.6 [mm]
 Material SG-Fe
 Wire initial heating
 Contact noz. t. 20 [°C]

Position
 X 0,00 [mm]
 Y 0,00 [mm]
 L 20,00 [mm]
 R 20,00 [mm]

Angle
 Along 0 [°]
 Across 0 [°]

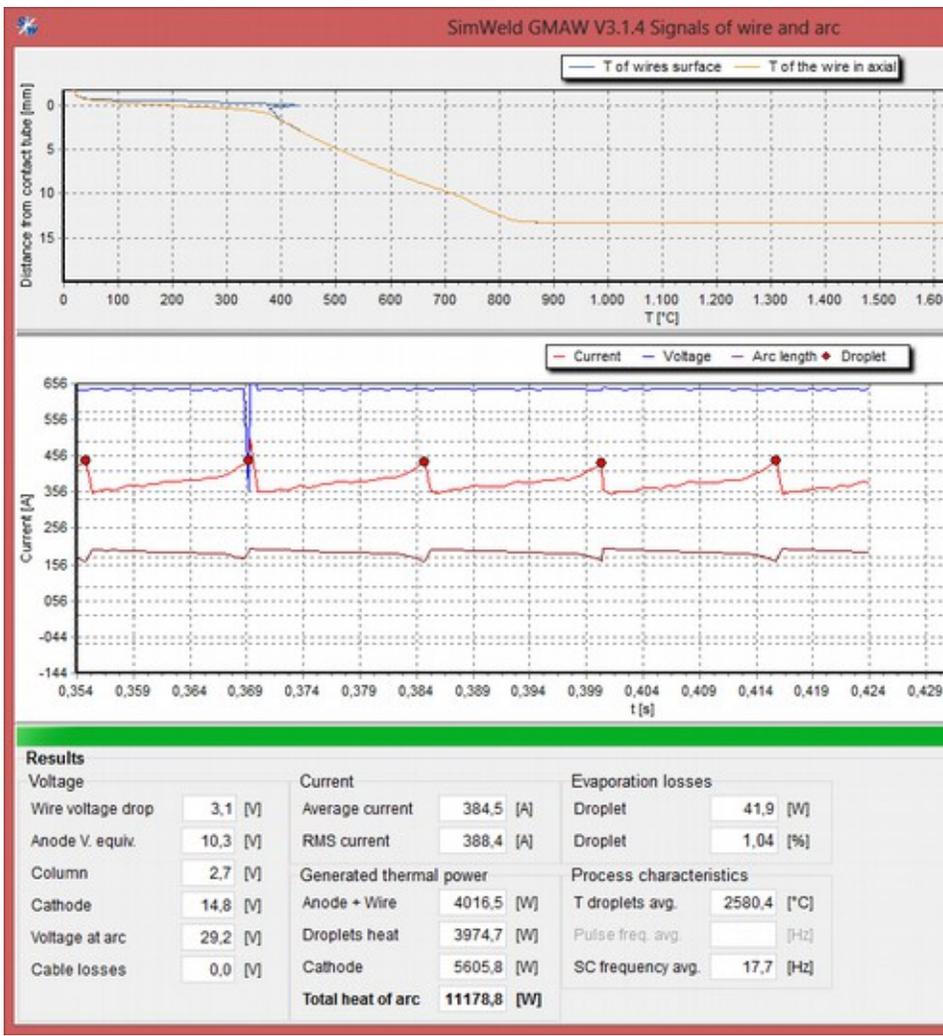
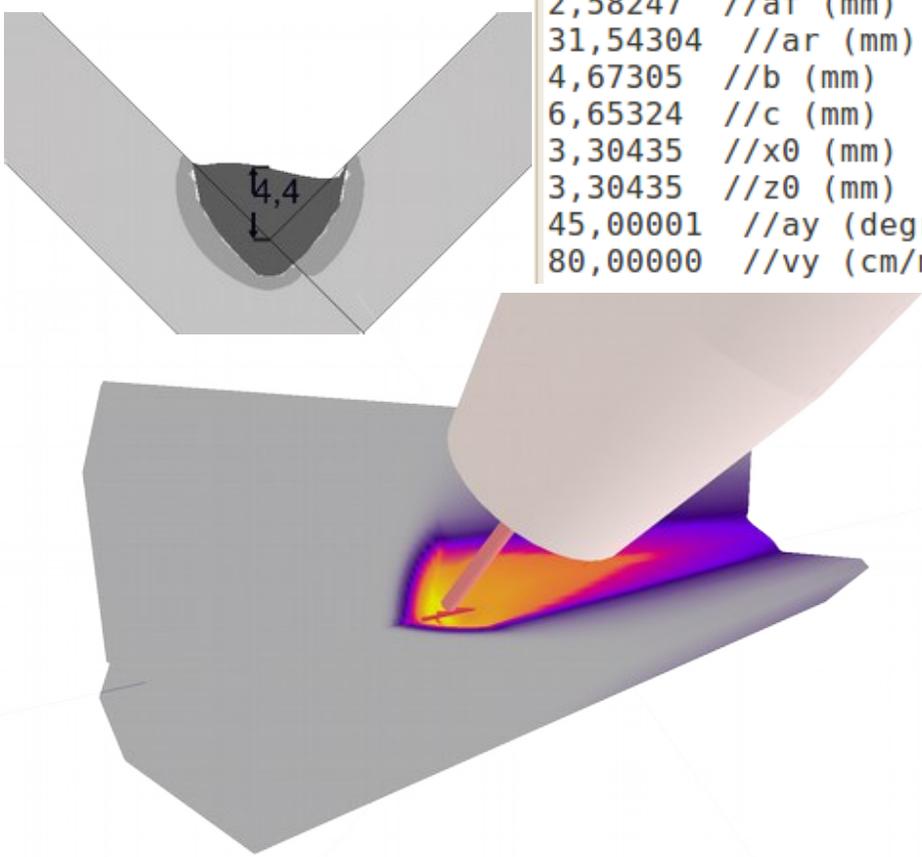
Equipment

Power source
 Select... Custom
 Process type Normal
 Wire feed 7,0 [m/min]
 Voltage 30,0 [V]
 Choke 30,0 [%]

- $a = 4,4 \text{ mm}$
- $I = 390 \text{ A}$
- $V = 29,2 \text{ V}$

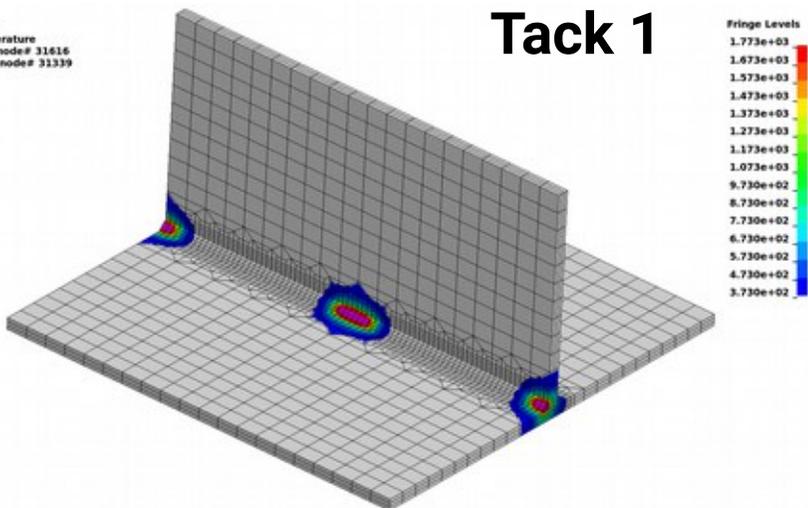
```

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)
    
```



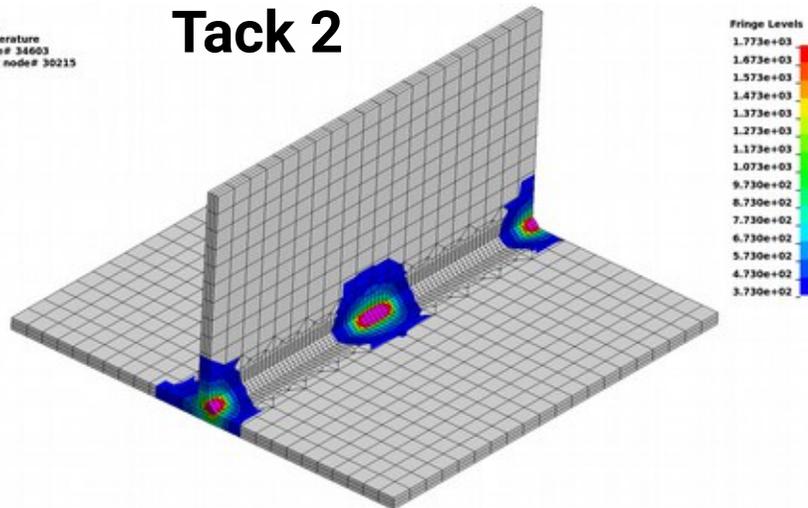
T-joint
Time = 7.1145
Contours of Temperature
min=292.704, at node# 31416
max=2772.31, at node# 31339

Tack 1



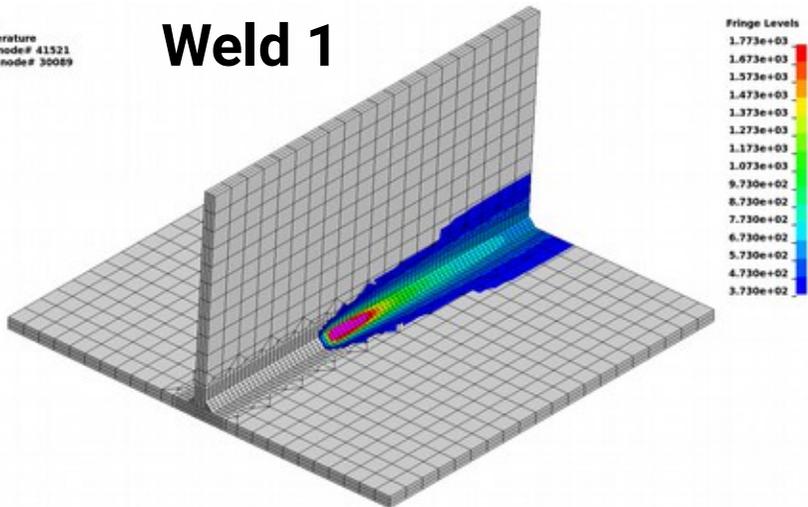
T-joint
Time = 27.114
Contours of Temperature
min=293, at node# 34603
max=3024.08, at node# 30215

Tack 2



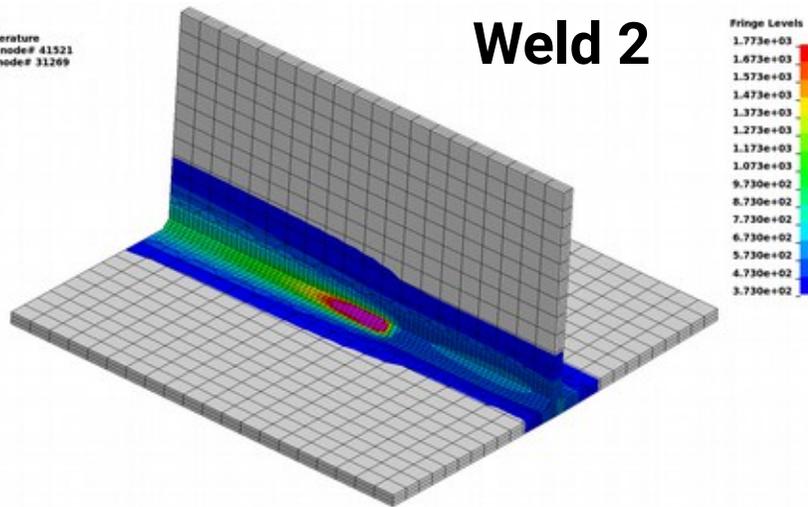
T-joint
Time = 1014.2
Contours of Temperature
min=309.221, at node# 41521
max=3706.89, at node# 30089

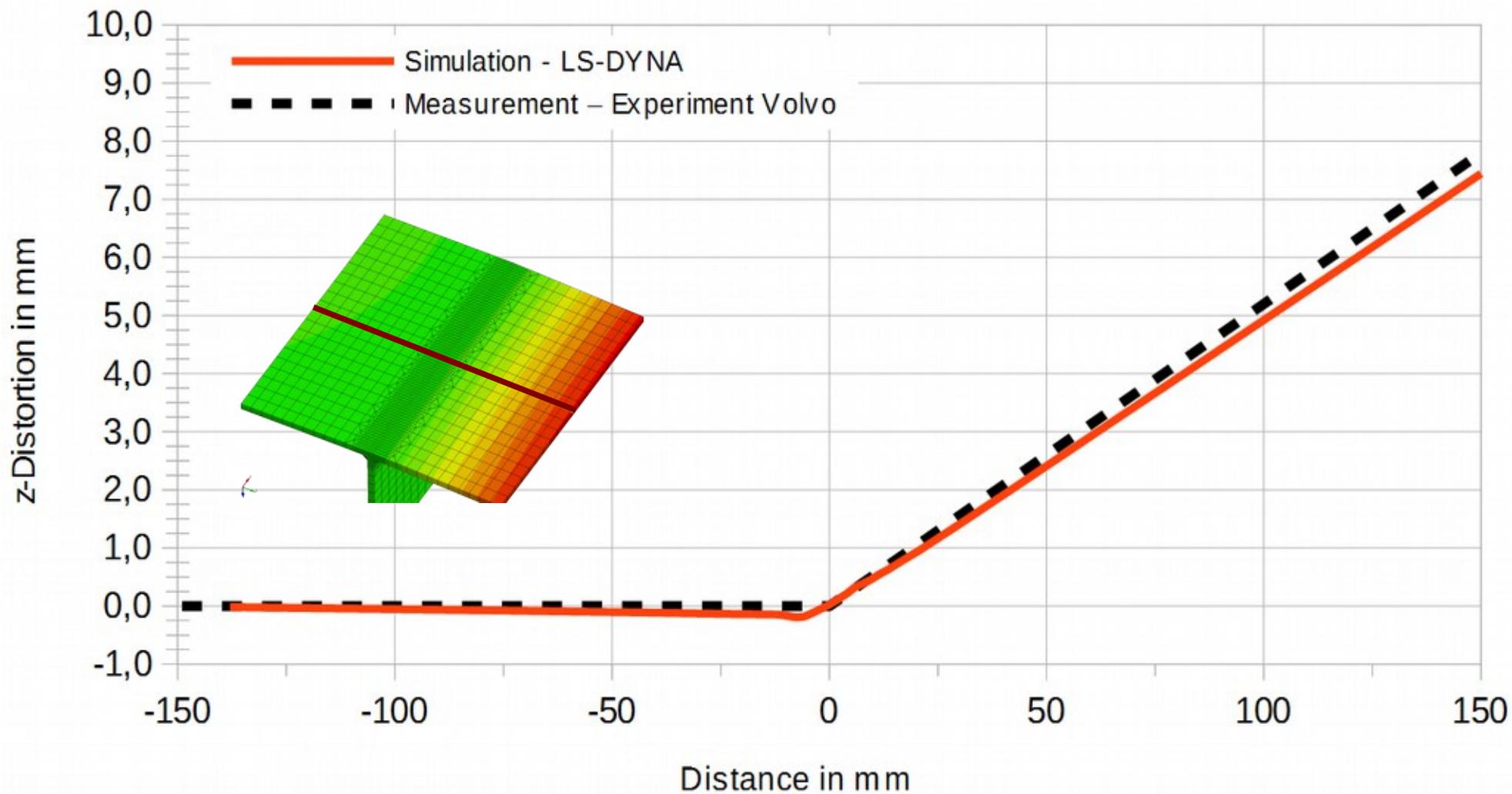
Weld 1



T-joint
Time = 1036
Contours of Temperature
min=309.069, at node# 41521
max=3706.2, at node# 31269

Weld 2





www.dynaweld.eu

Time = 0

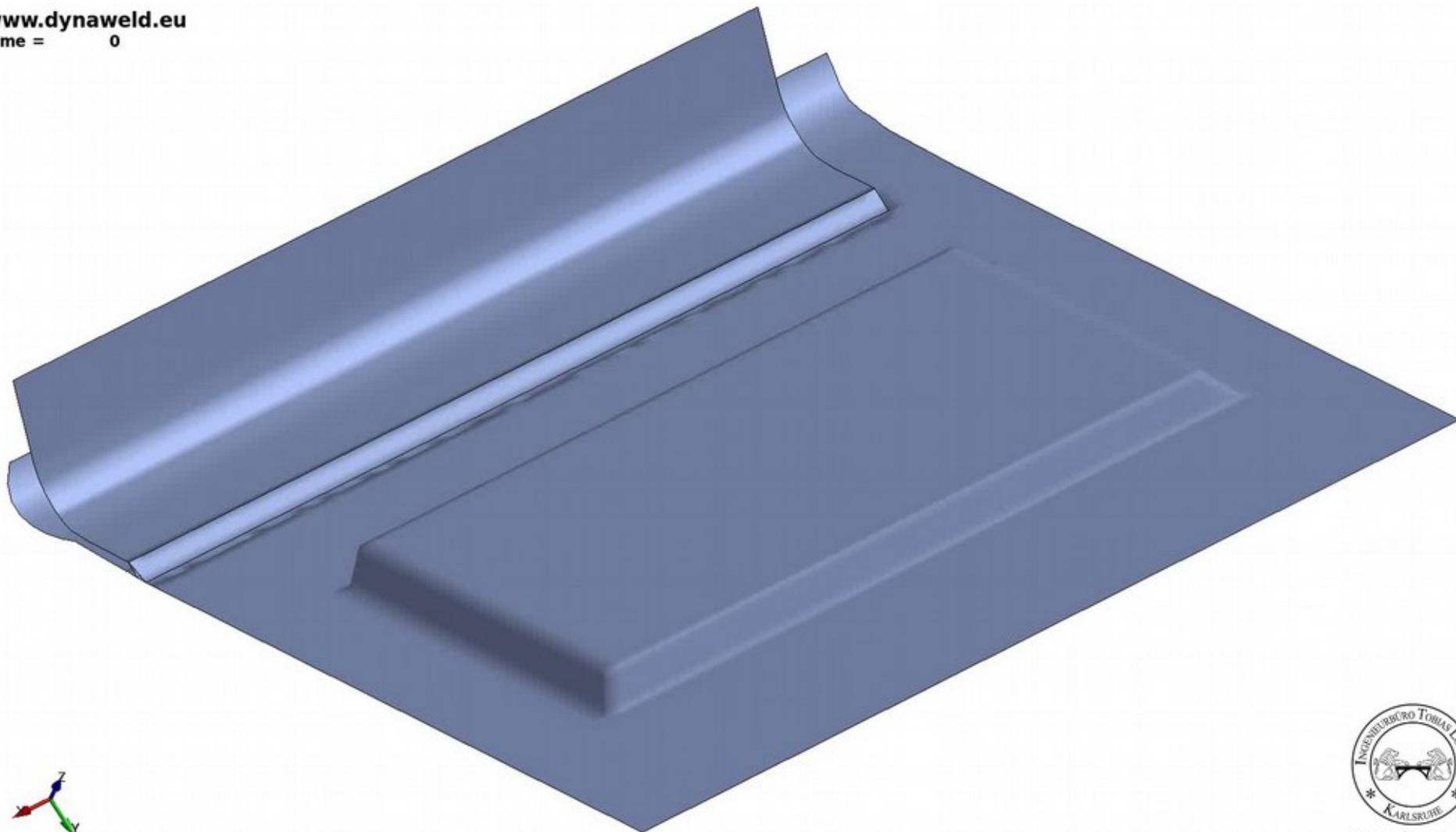
max displacement factor=10



www.loose.at

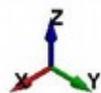
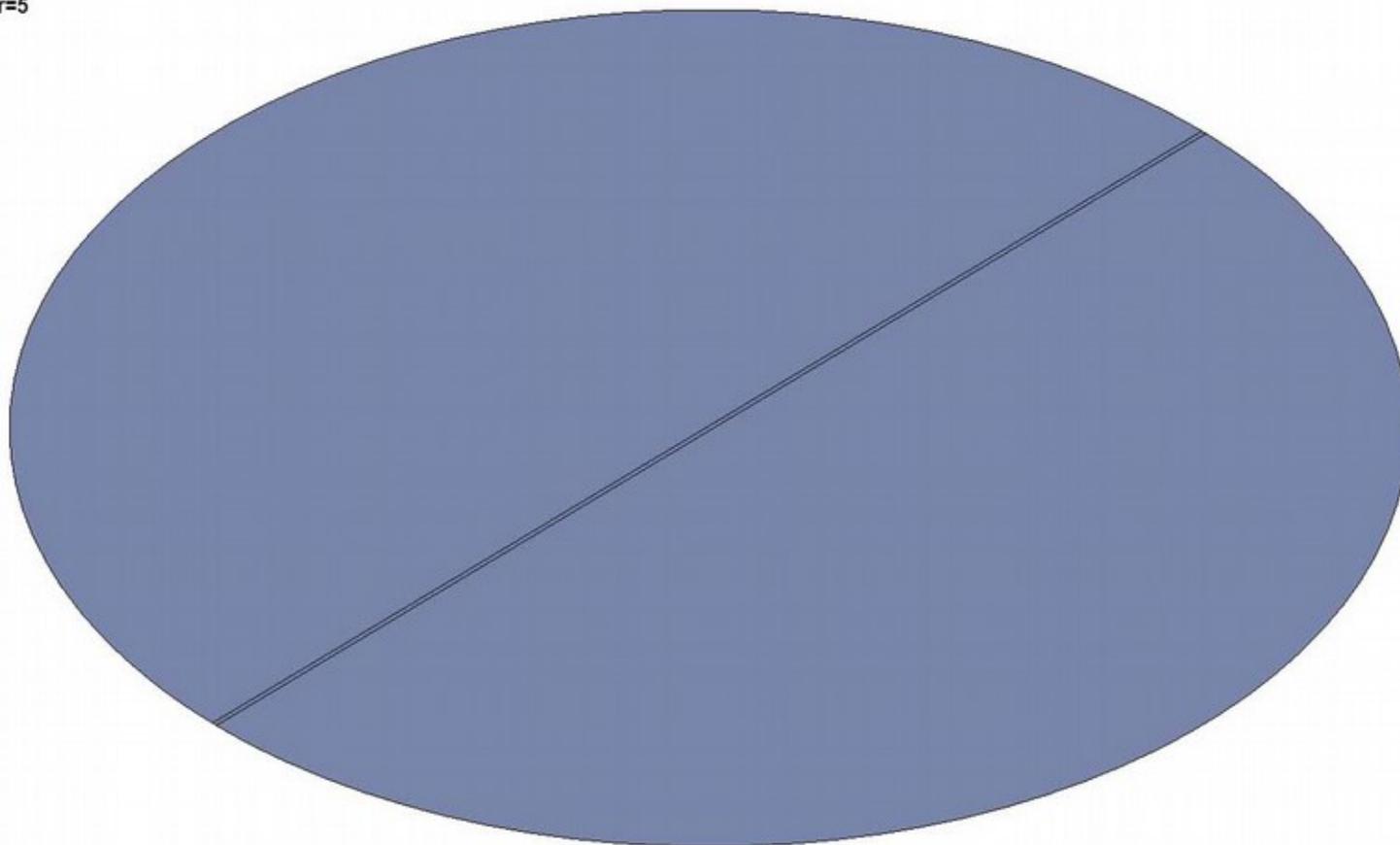
www.dynaweld.eu

Time = 0

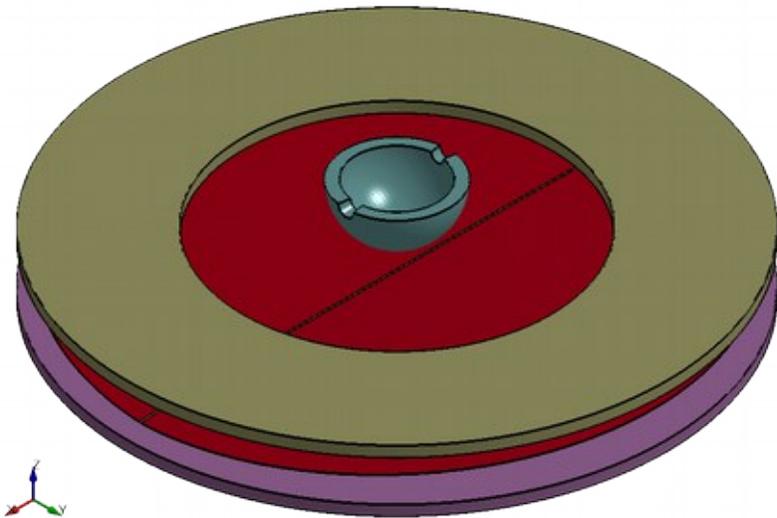


www.loose.at

Laser Welding
Time = 0
max displacement factor=5



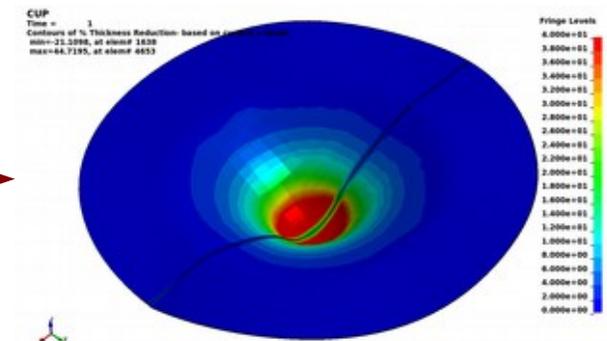
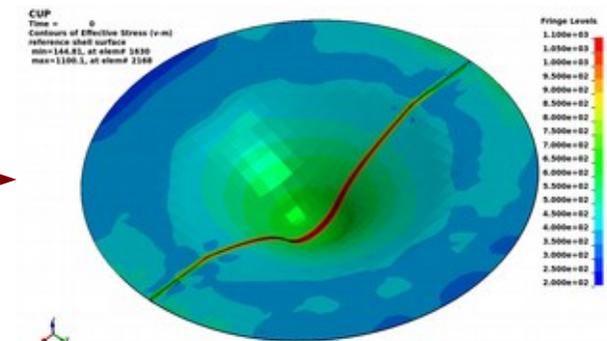
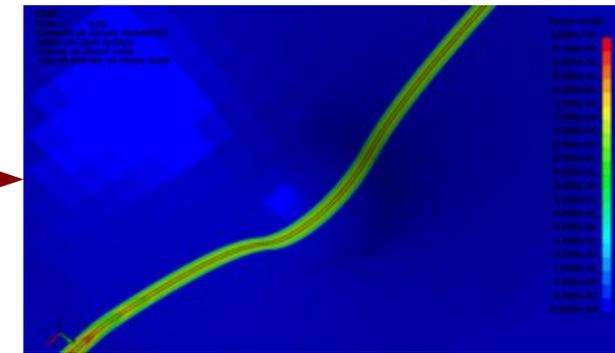
- Material change due to welding
- Material history kept in forming analysis
- Impact of different yield
 - high yield in weld seam due to martensite
 - low yield in base material



Microstructure
(Martensite proportion)

Residual stress
(v. Mises Stress)

Thickness
(Sheet thinning)



Quenching Gear # www.loose.at

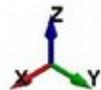
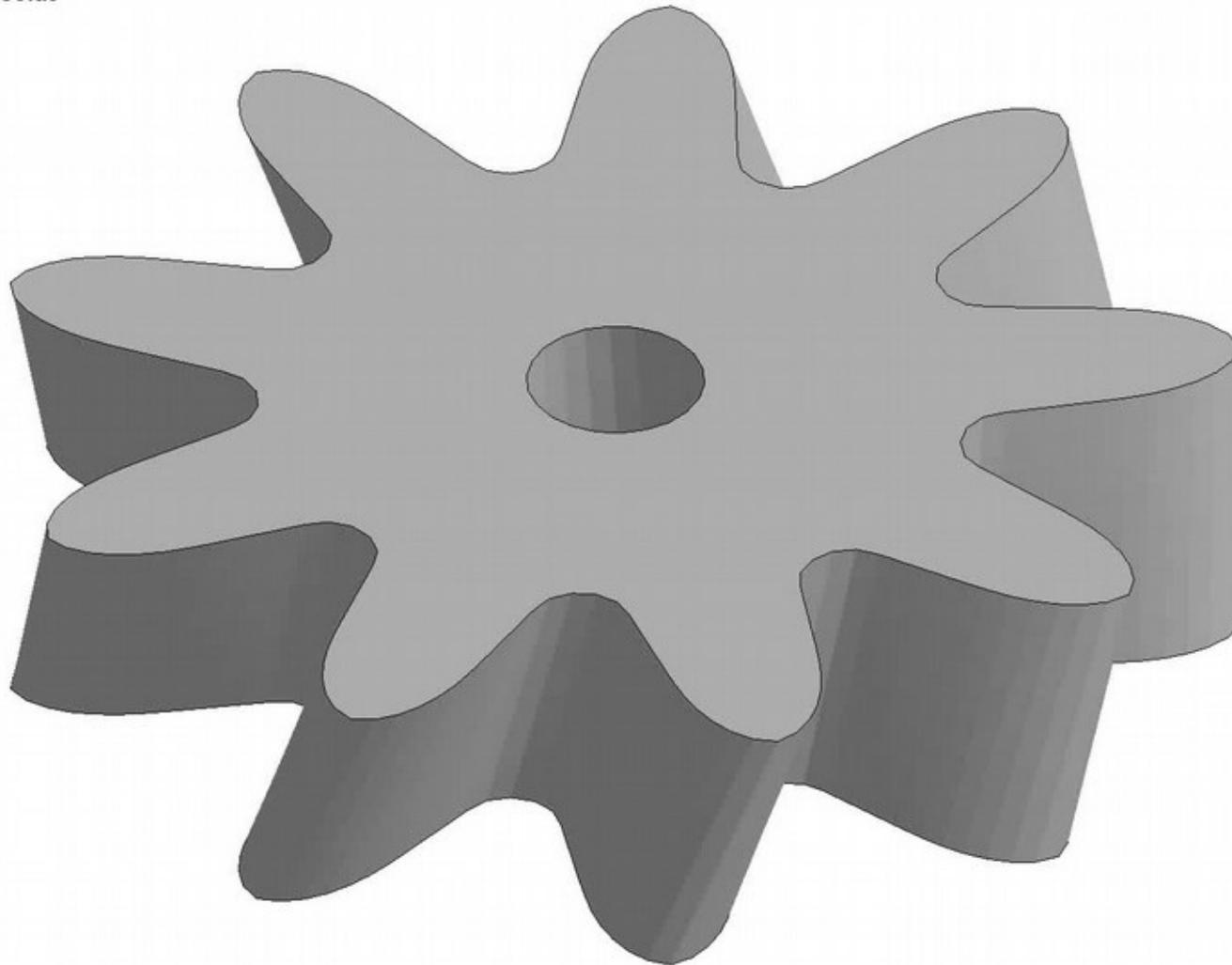
Time = 0

Contours of Temperature, outer

min=1173, at node# 5151

max=1173, at node# 5151

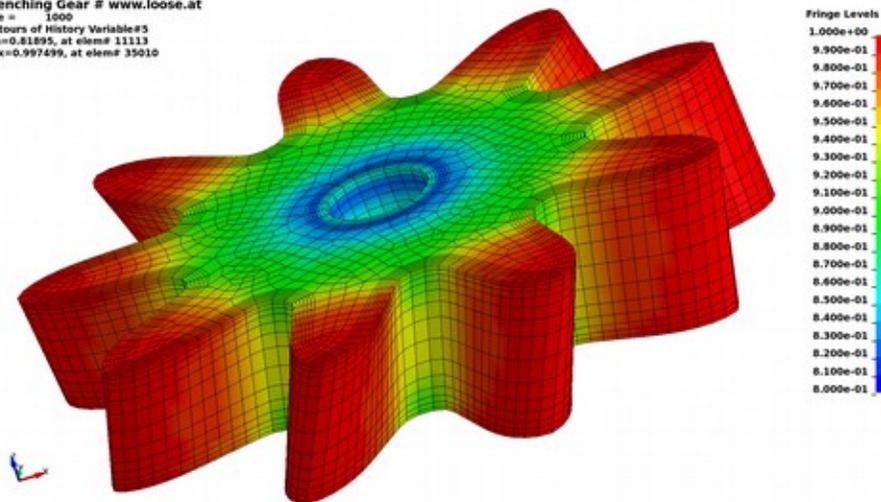
max displacement factor=20



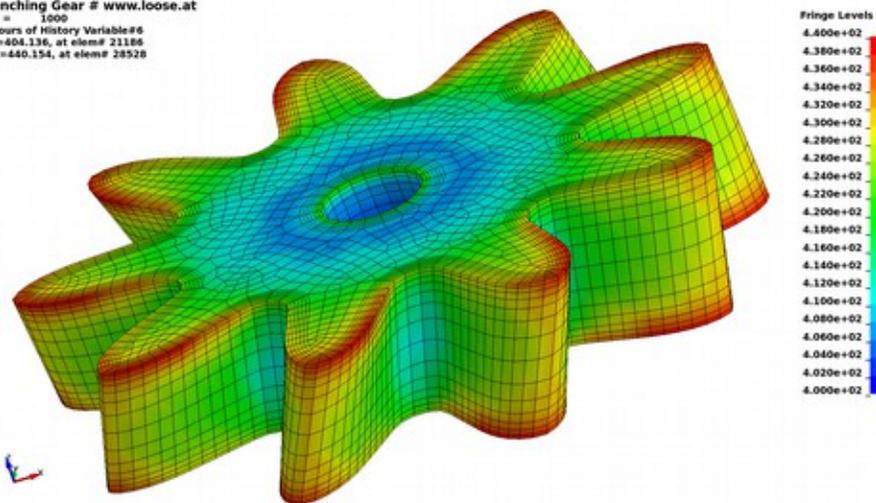
www.loose.at

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

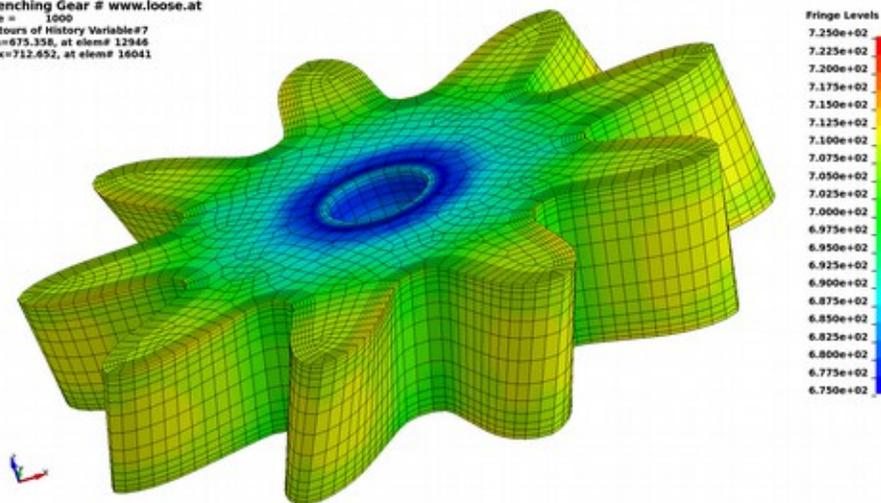
Quenching Gear # www.loose.at
 Time = 1000
 Contours of History Variable#5
 min=0.81895, at elem# 11113
 max=0.997499, at elem# 35010



Quenching Gear # www.loose.at
 Time = 1000
 Contours of History Variable#6
 min=404.136, at elem# 21186
 max=440.154, at elem# 28528

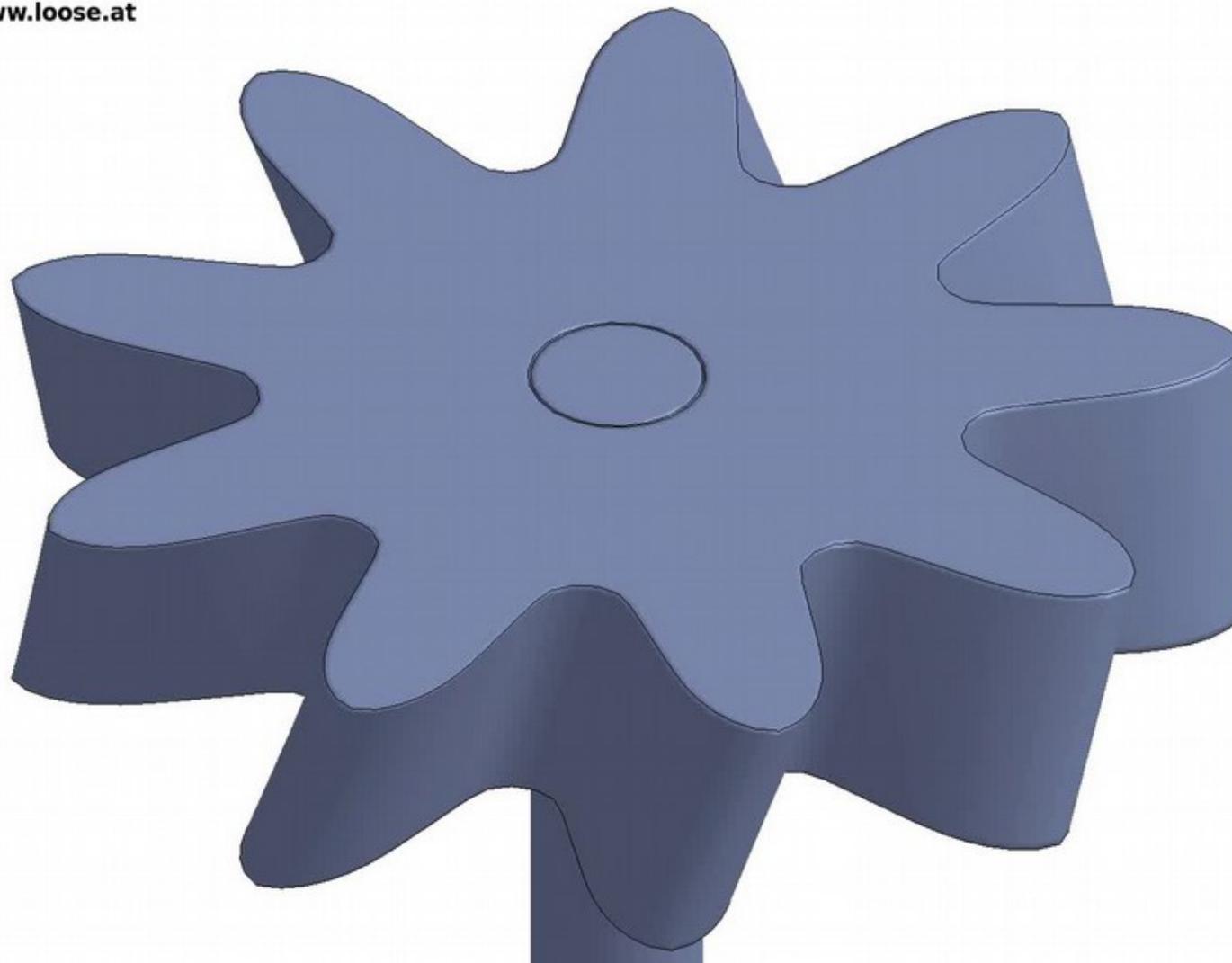


Quenching Gear # www.loose.at
 Time = 1000
 Contours of History Variable#7
 min=675.358, at elem# 12946
 max=712.652, at elem# 16041



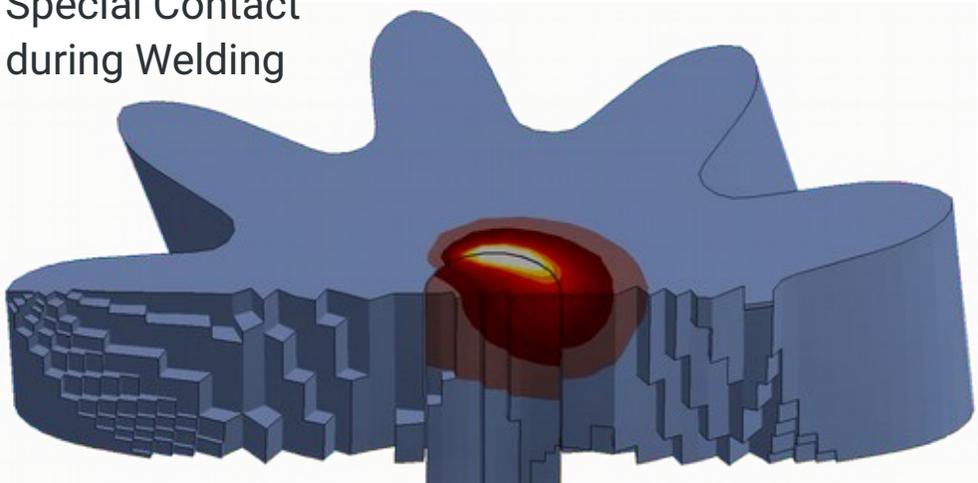
Welding Gear # www.loose.at

Time = 0

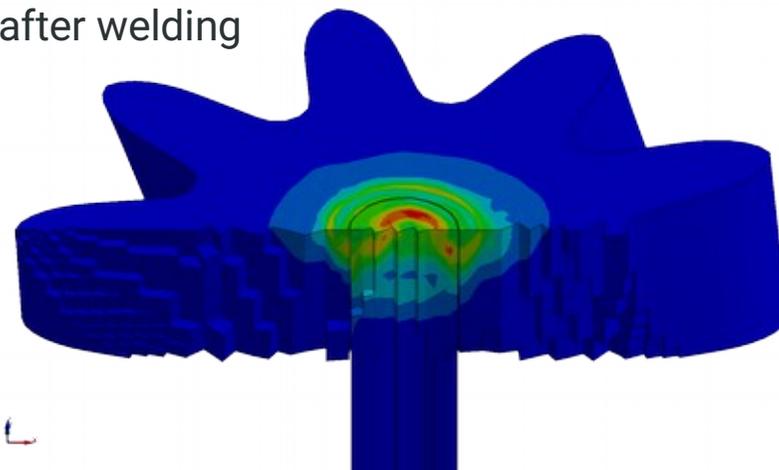


www.loose.at

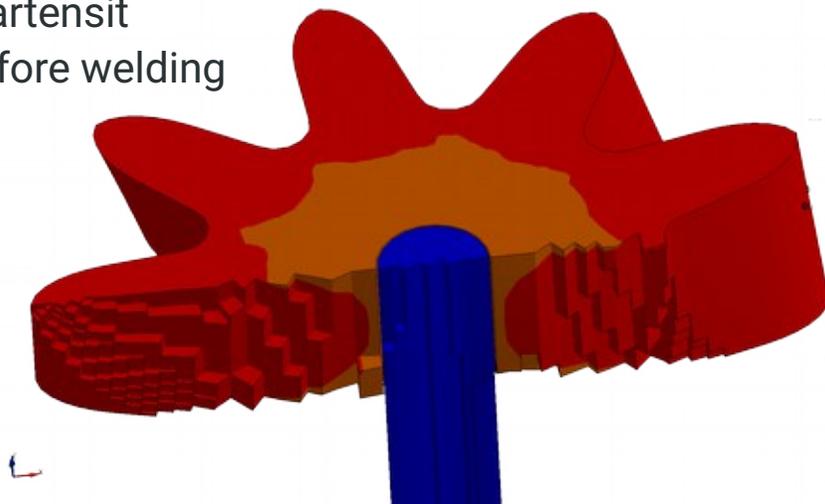
Special Contact
during Welding



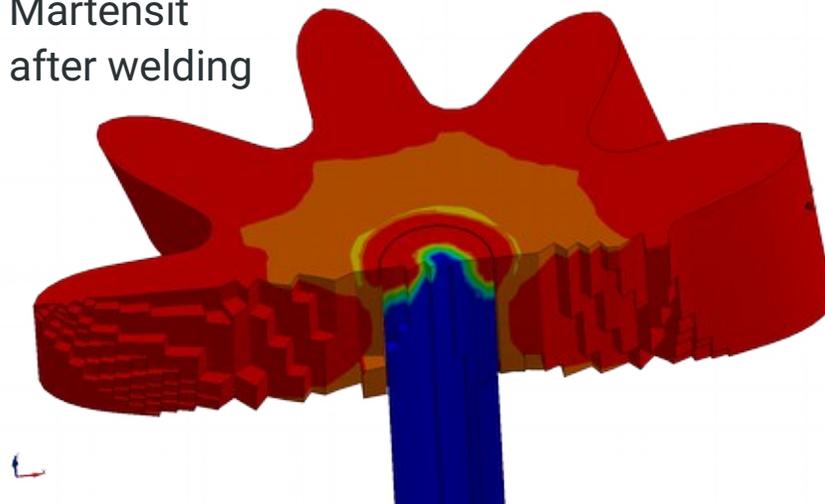
Equivalent Stress
after welding



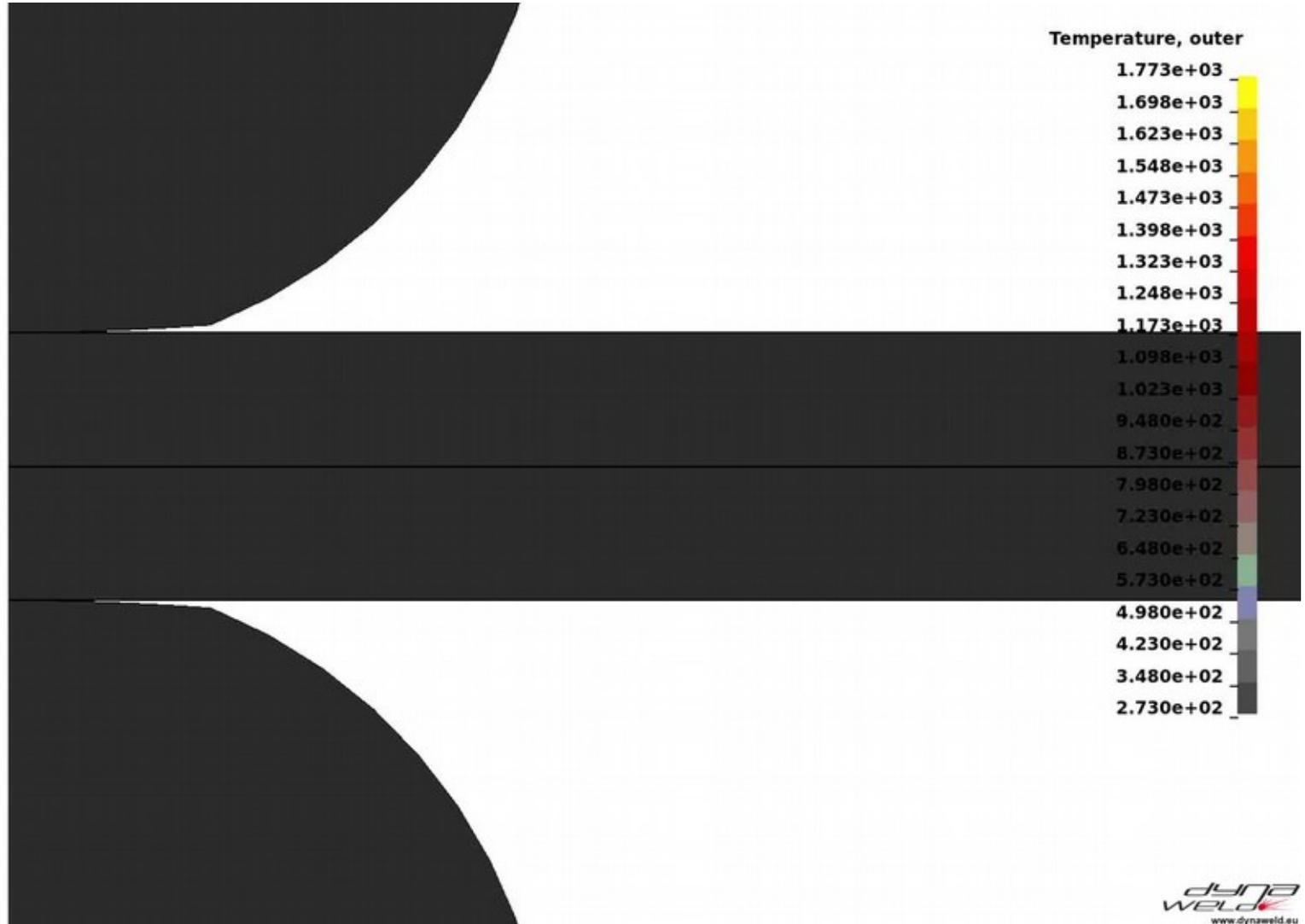
Martensit
before welding

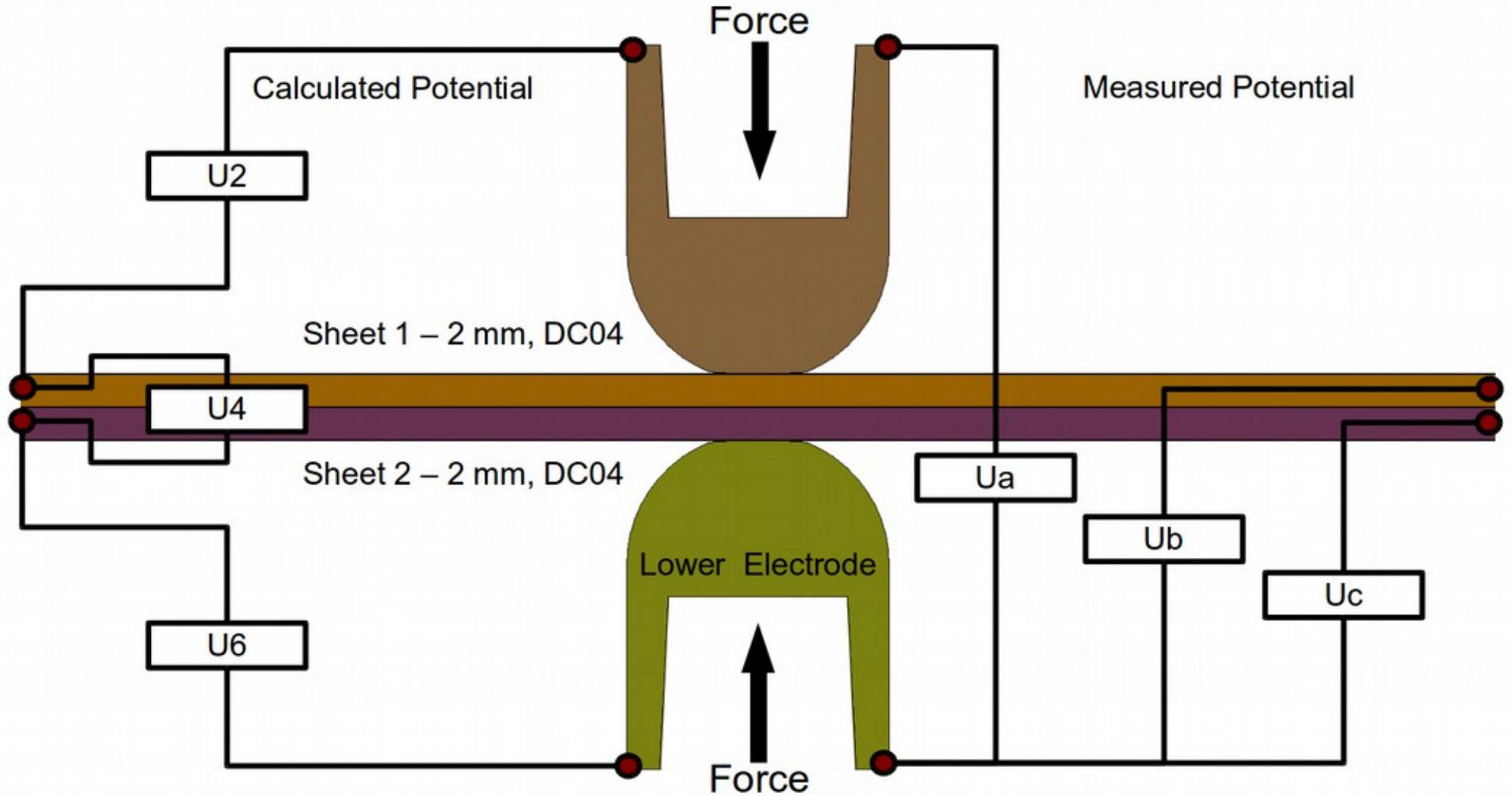


Martensit
after welding



Time = 0
Contours of Temperature, outer
min=293.15, at node# 757
max=293.15, at node# 757

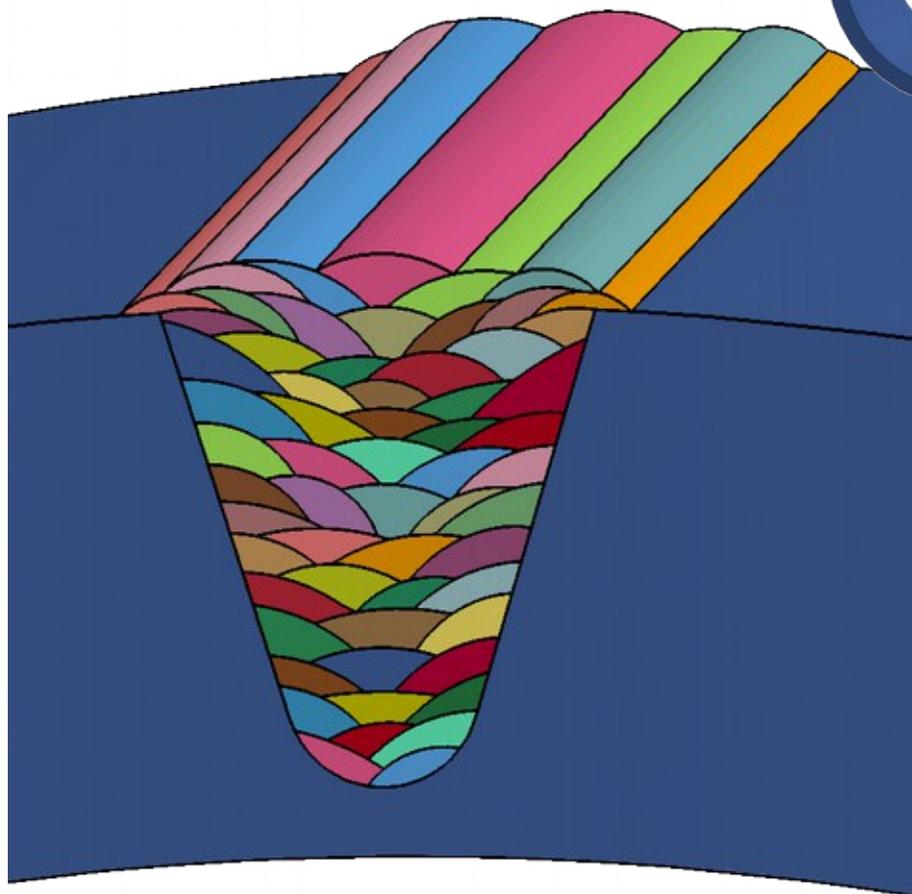




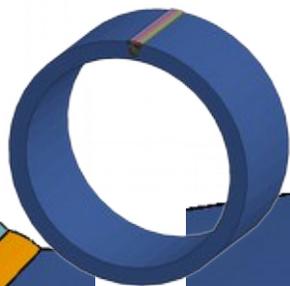
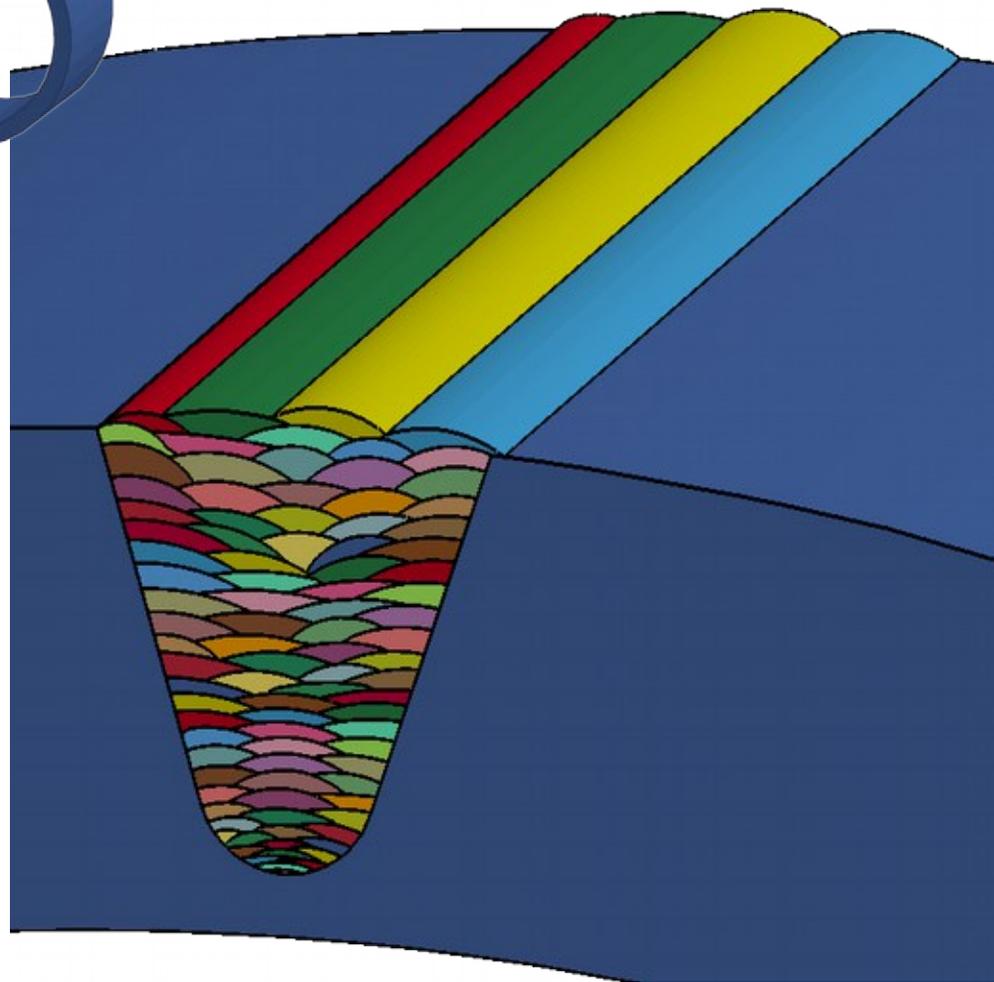
- impuls of constant current
- hot test – no nugget
- calibration of „temperature“-parameter



60 Layer - GMAW



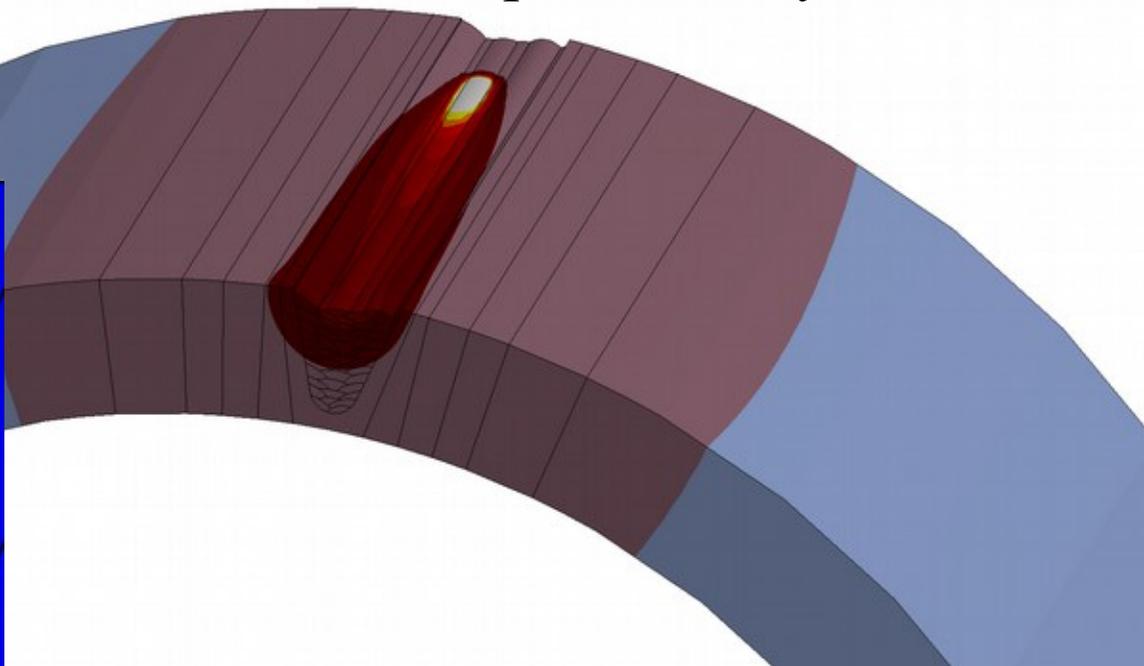
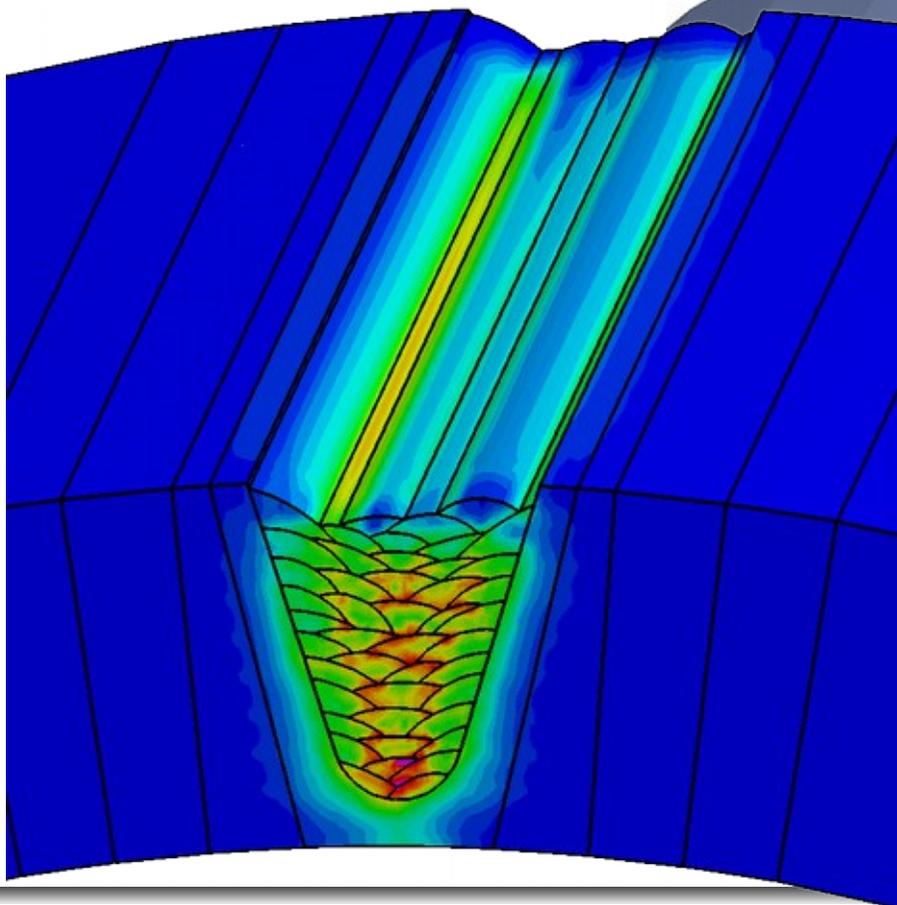
93 Layer - TIG



MSG
Time = 26425

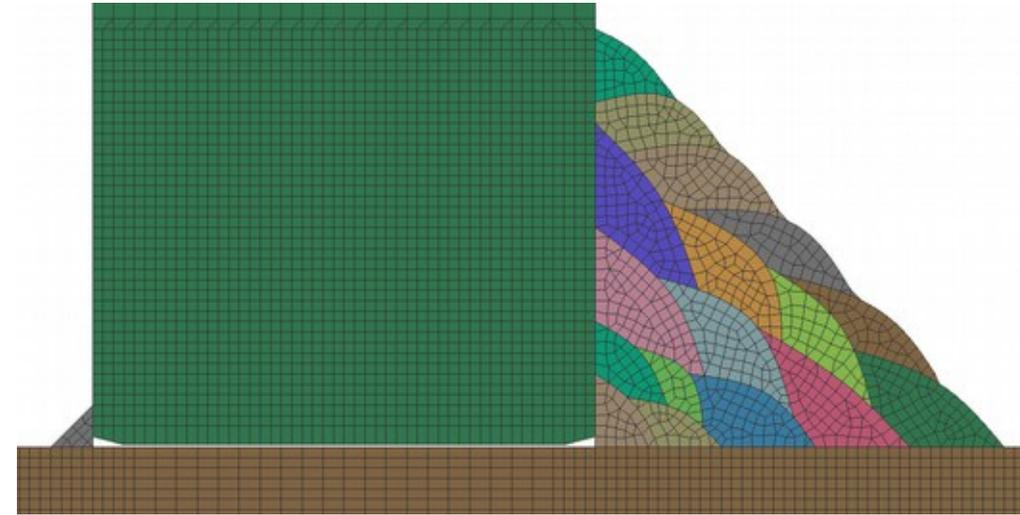
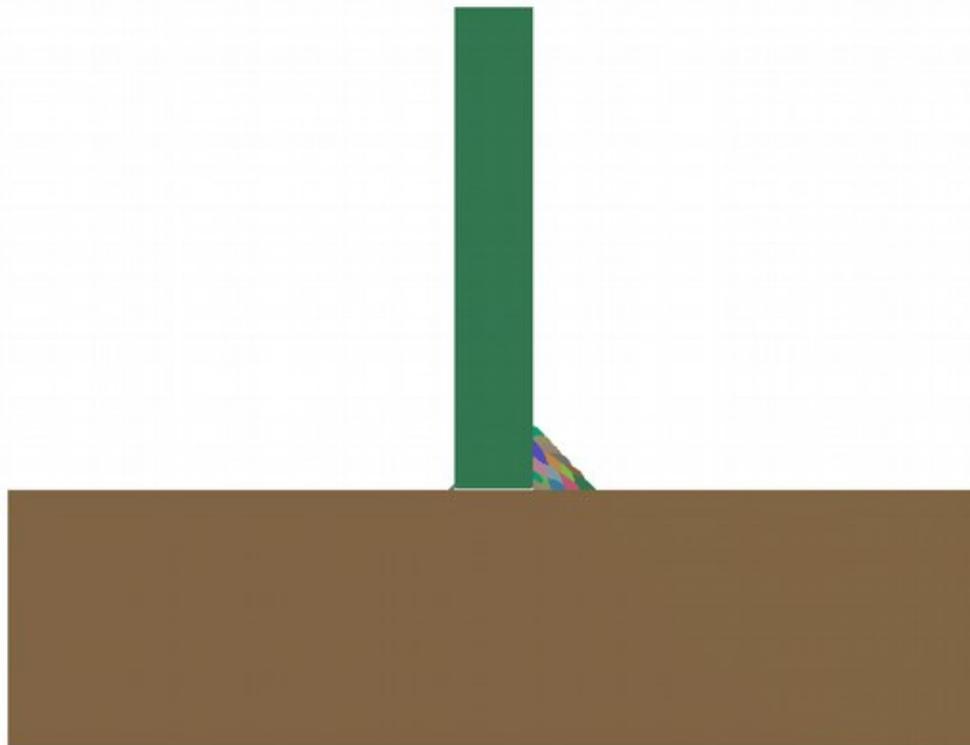
Temperature Layer 44

Equivalent Plastic Strain



Multilayered weld T-Joint with large plate thickness

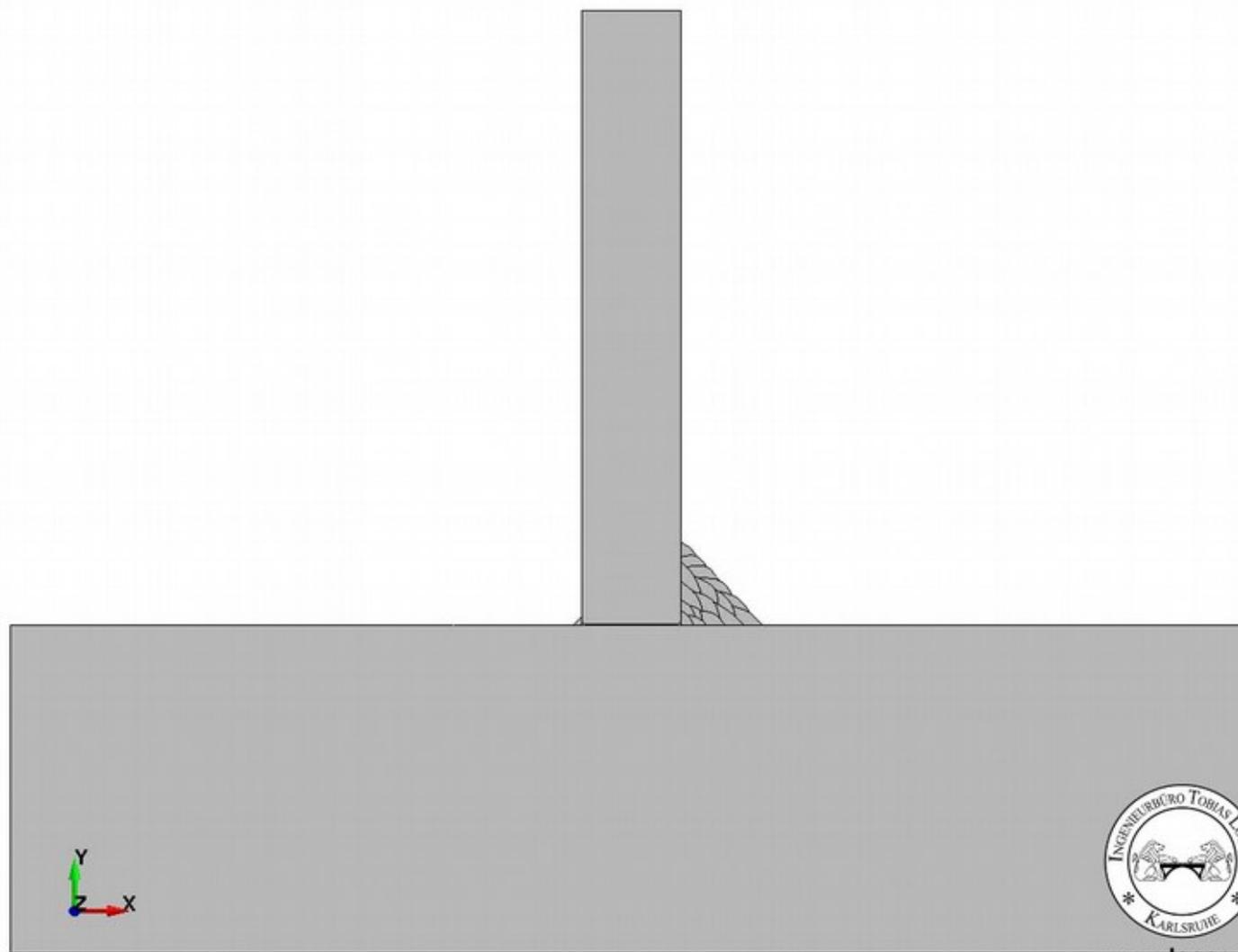
2D plain strain
Plate: 300 x 80 mm
Stiffener: 150 x 24 mm
Fillet Weld: $a = 13$ mm
Material: 1.4301



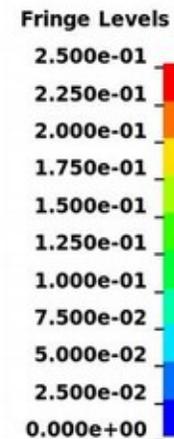
Tack $a = 1,4$ mm
with failure on strain $K_{FAIL} = 0,25$ m/m

Initial gap between stiffener and plate:
0,1 mm

Symmetry boundary conditions on left and right side.



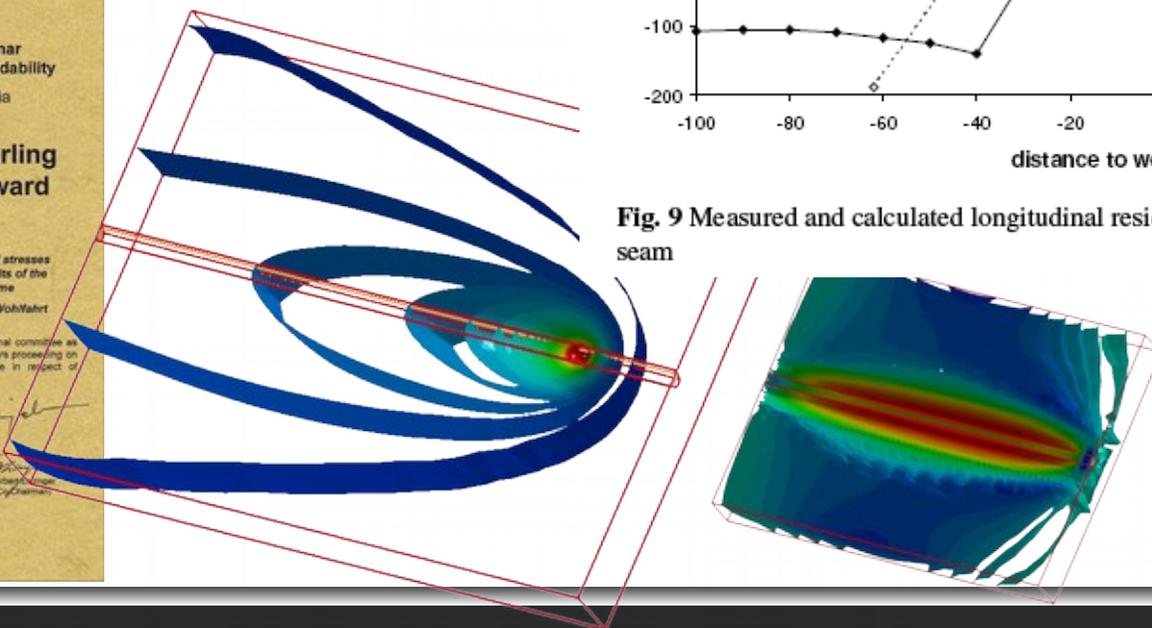
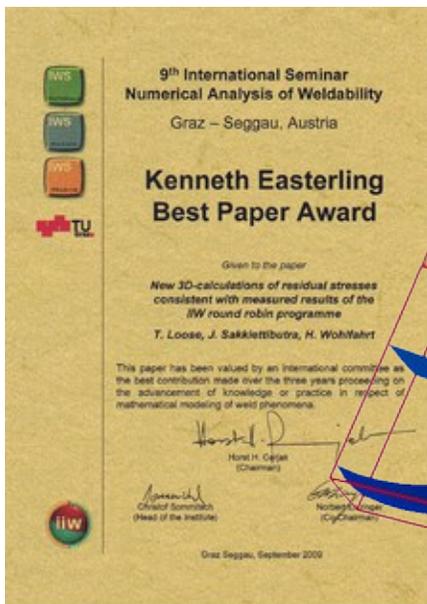
T2D
Time = 0
Contours of Effective Plastic Strain
min=0, at elem# 11222
max=0, at elem# 11222



www.loose.at



- Plate with the dimensions 270 x 200 x 30 mm³ with V/U-shaped notch
- Austenitic stainless steel (316LNSPH, Re = 275 MPa)
- 2 Layer weldings of the notch with same material: 316L
- TIG Welding with U = 9 V, I = 155 A, v = 0,67 mm/s



Longitudinal residual stresses

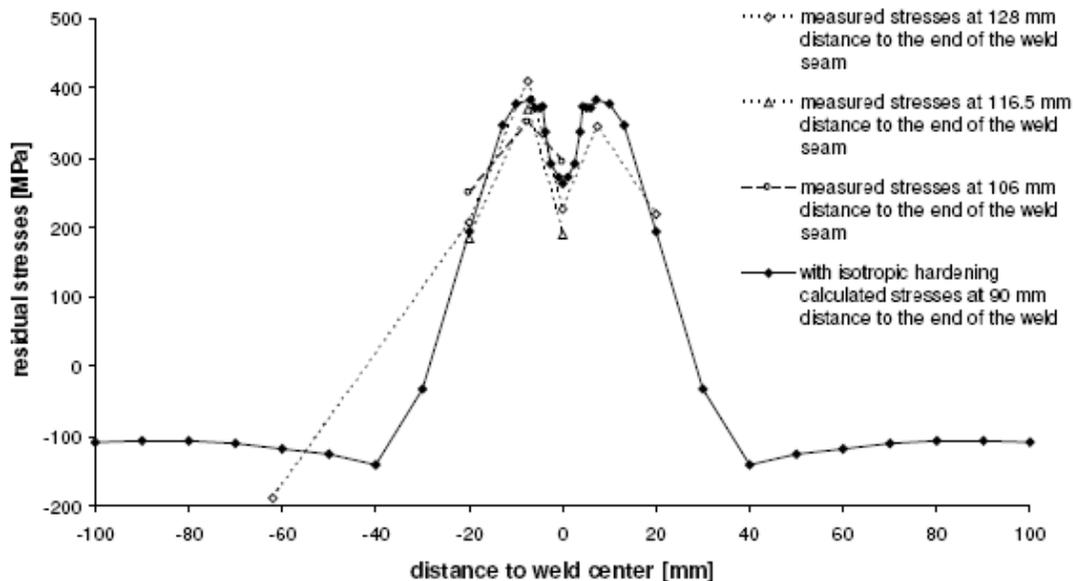
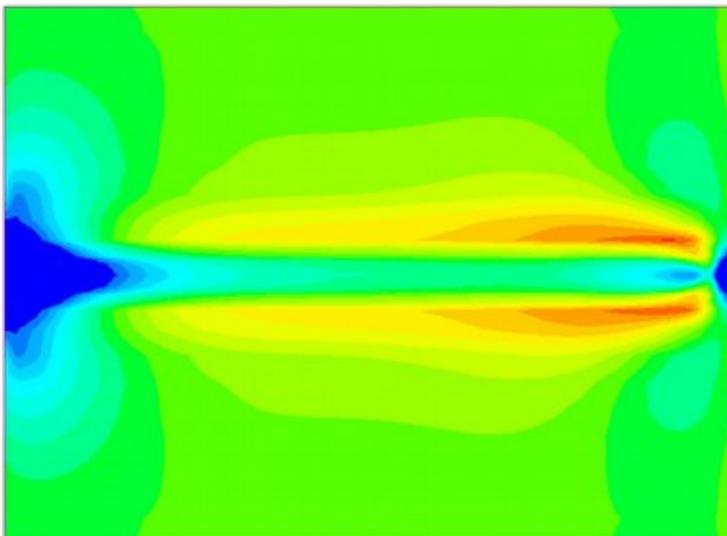


Fig. 9 Measured and calculated longitudinal residual stresses along a line transverse to the weld seam

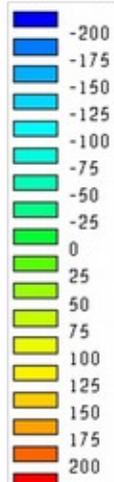
Loose, T. ; Sakkietitbutra, J. ; Wohlfahrt, H. :
New 3D-Calculations of residual stresses
consistent with measured results of the
IIW Round Robin Programme.
In: Cherjak, H. (Ed.) ; Enzinger, N. (Ed.) :
Mathematical Modelling of Weld Phenomena Bd. 9,
Verlag der Technischen Universität Graz, 2010

Transversal Stress

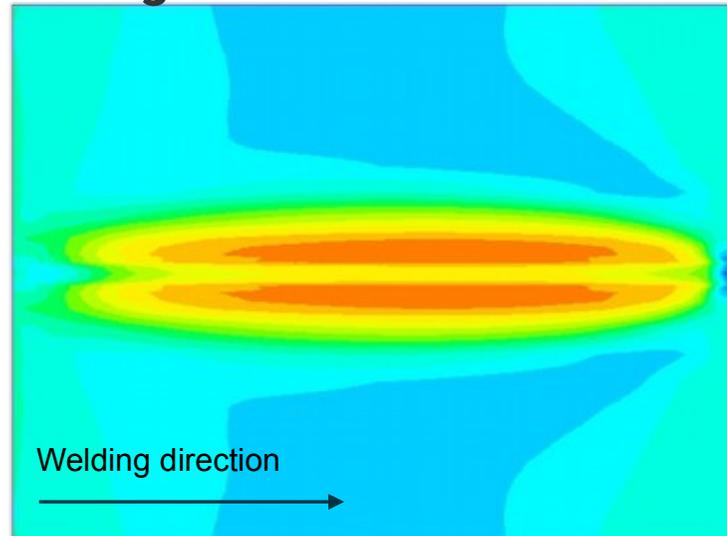
SYSWELD



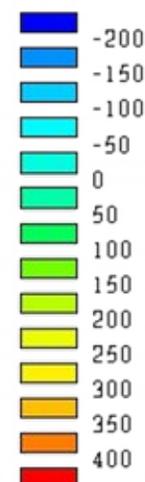
[MPa]



Longitudinal Stress

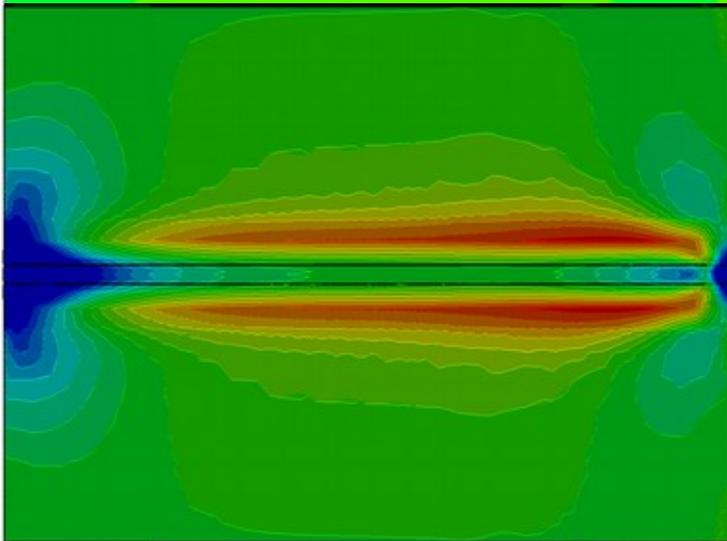


[MPa]

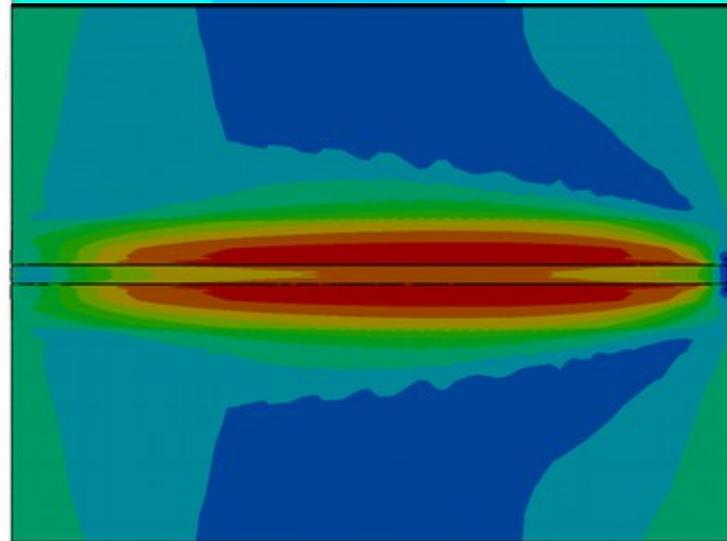
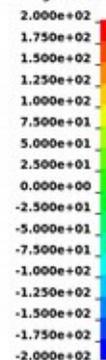


Round Robin
Time = 15000
Contours of Z-stress
min=-445.209, at elem# 286
max=352.951, at elem# 36458

LS-DYNA



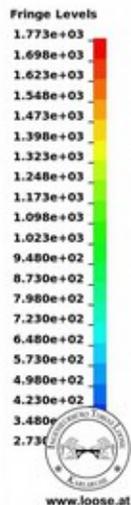
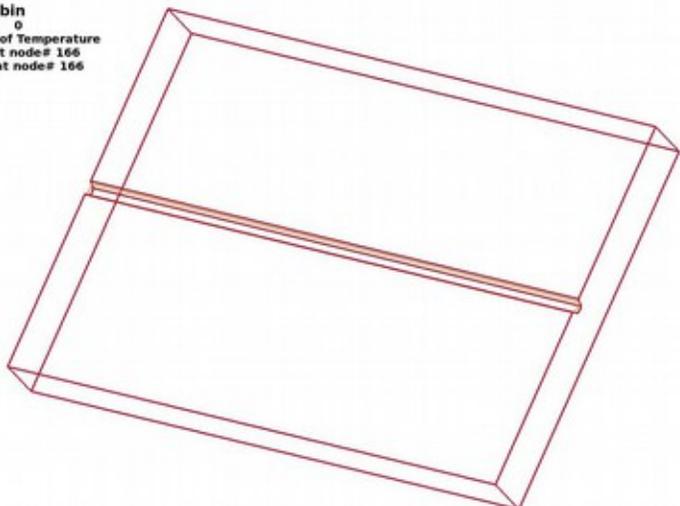
Fringe Levels



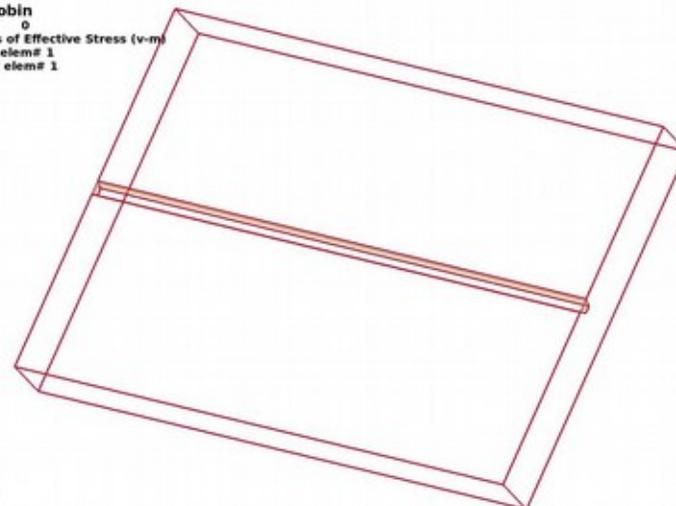
Fringe Levels



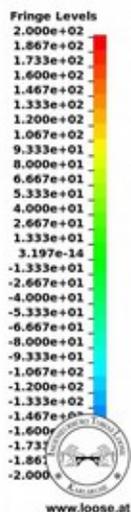
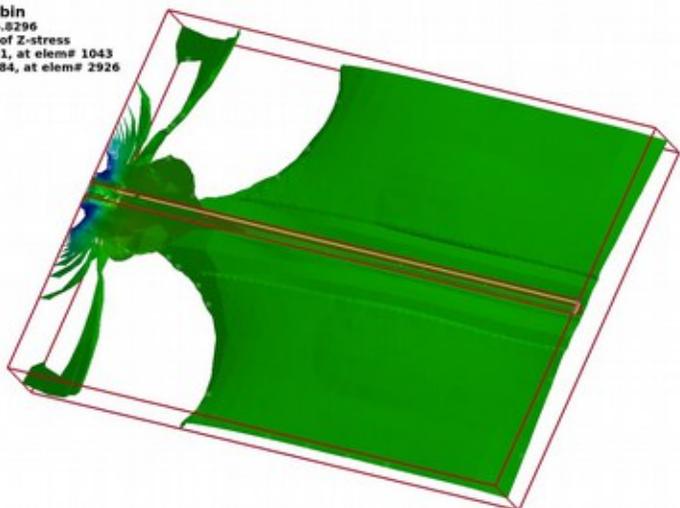
Round Robin
Time = 0
Isosurfaces of Temperature
min=293, at node# 166
max=293, at node# 166



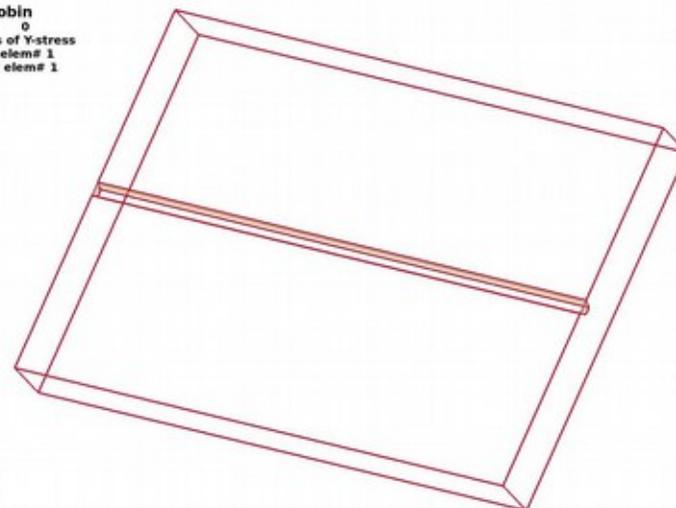
Round Robin
Time = 0
Isosurfaces of Effective Stress (v-m)
min=0, at elem# 1
max=0, at elem# 1

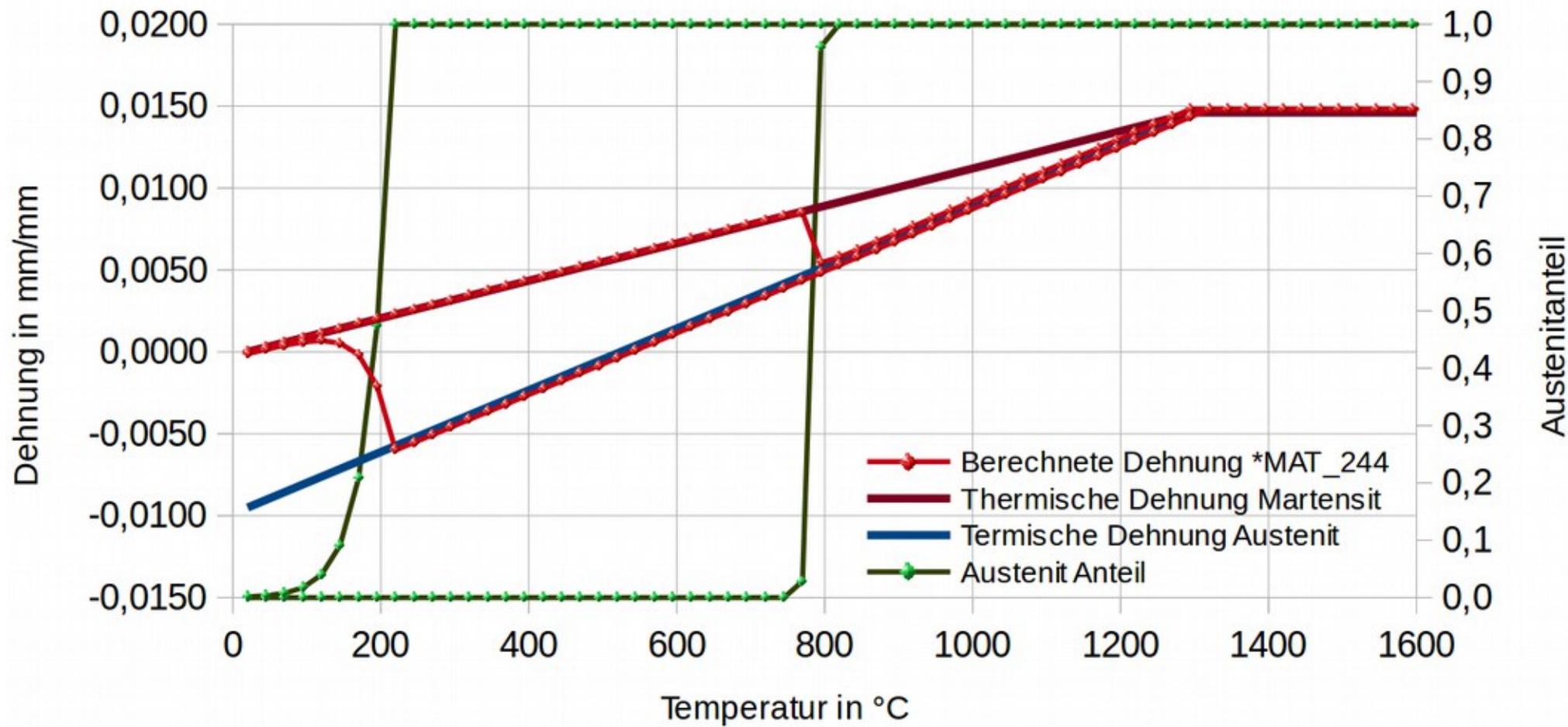


Round Robin
Time = 5.8296
Isosurfaces of Z-stress
min=-429.51, at elem# 1043
max=171.084, at elem# 2926



Round Robin
Time = 0
Isosurfaces of Y-stress
min=0, at elem# 1
max=0, at elem# 1





Gefuegeumwandlungstest 1.0 - 10.0

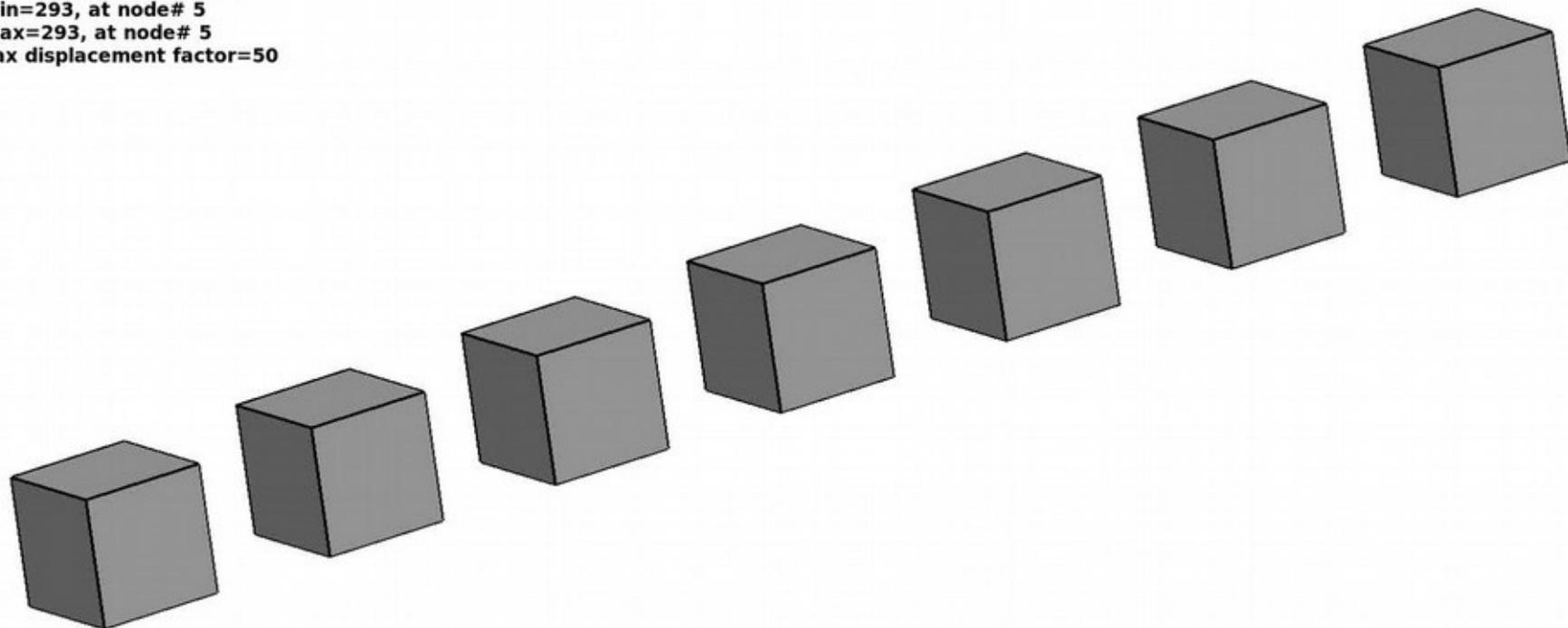
Time = 0

Contours of Temperature

min=293, at node# 5

max=293, at node# 5

max displacement factor=50



Fringe Levels

1.643e+03

1.516e+03

1.389e+03

1.262e+03

1.135e+03

1.008e+03

8.810e+02

7.540e+02

6.270e+02

5.000e+02

3.730e+02



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SmartScan

Simulation of temperature field and heating due to laser load of optic elements.

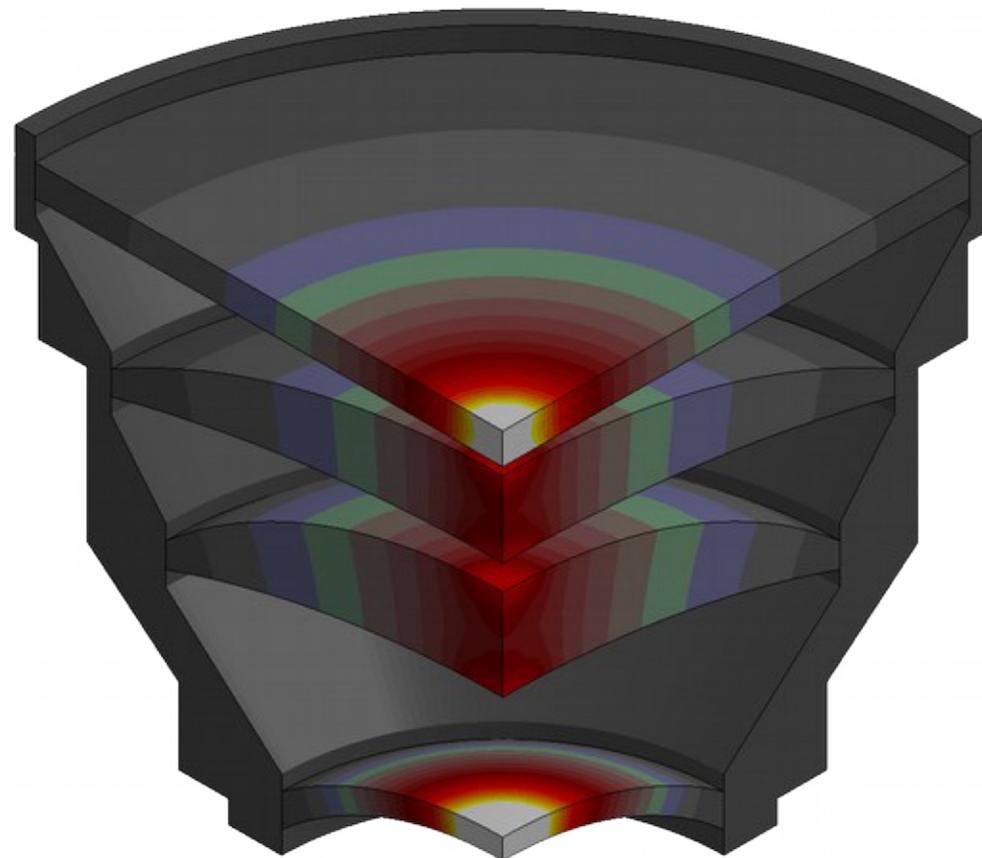


Gefördert durch:

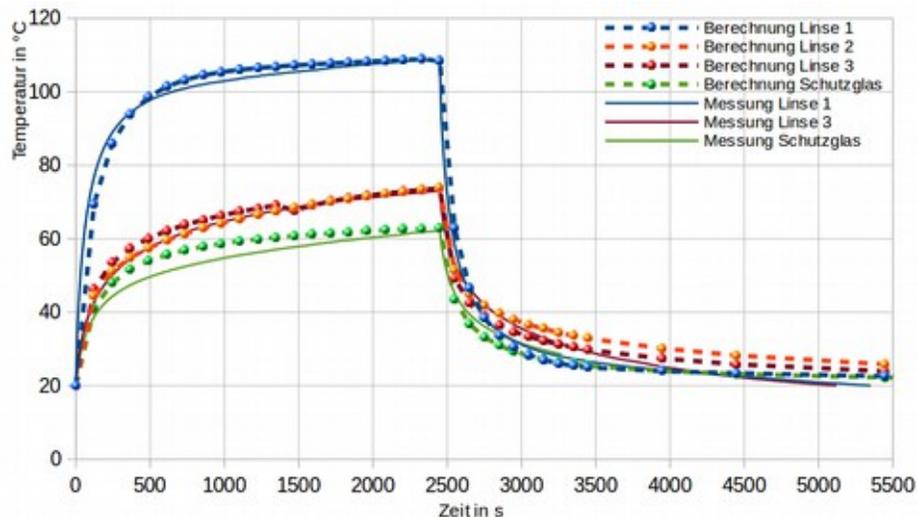


aufgrund eines Beschlusses
des Deutschen Bundestages

Das Projekt wird gefördert von der AIF Projekt GmbH, ZIM - Kooperationsprojekte, Tschalkowskistrabe 49, D-13156 Berlin im Rahmen des Förderprogramms „Zentrales Innovationsprogramm Mittelstand“ des Bundesministeriums für Wirtschaft und Energie (BMWi) - Fördermodul FuE-Kooperationsprojekte Förderkennzeichen VP3018202NT4



Experimental measurement validated by simulation:



Welding of a car door

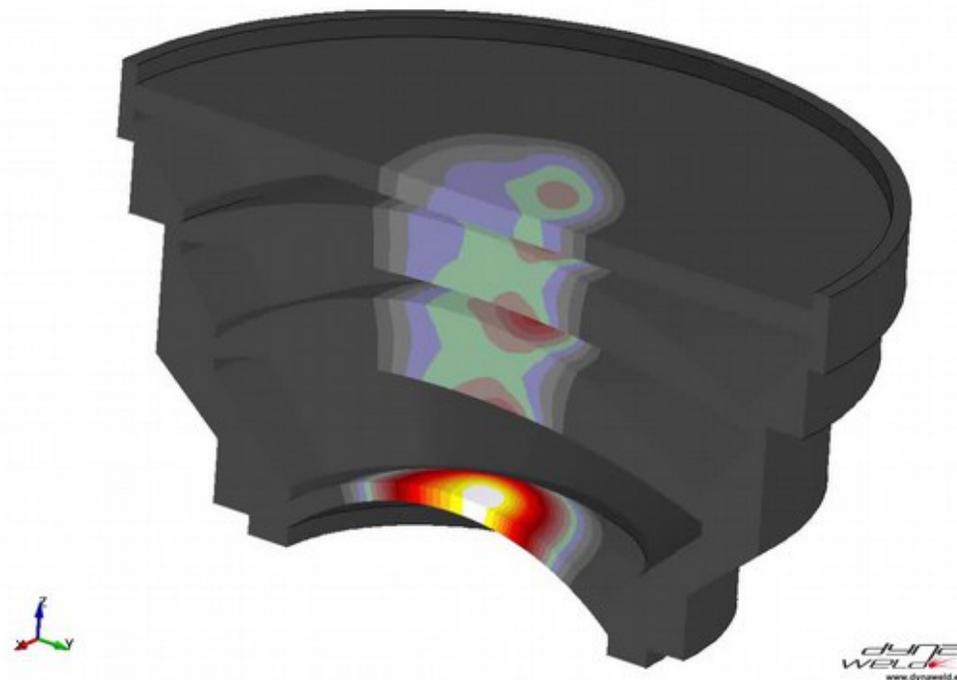
1st weld sequence

2500 W Tuer
Time = 0

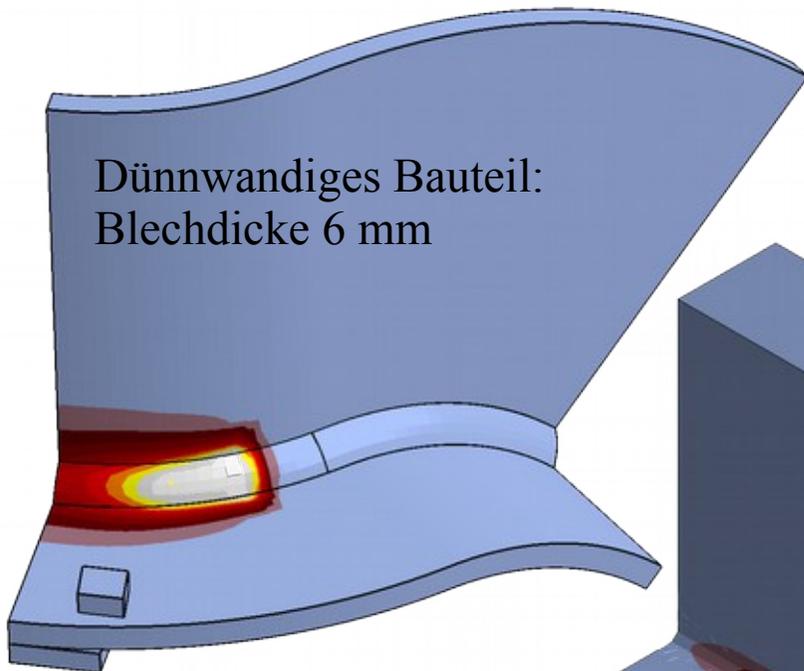


10th weld sequence

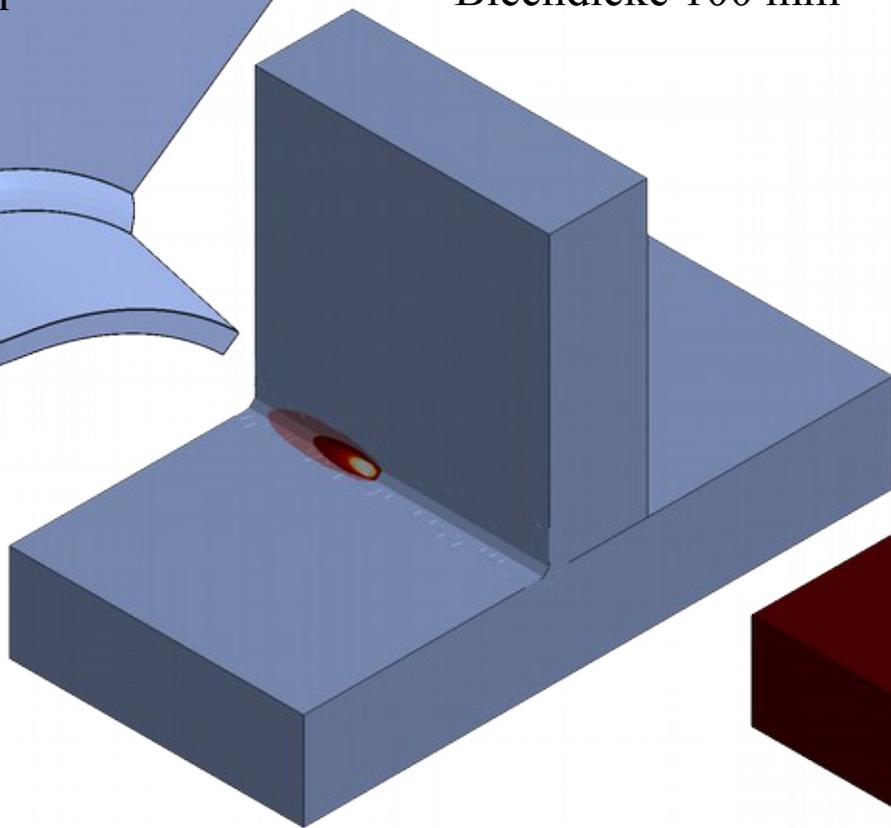
2500 W Tuer
Time = 0



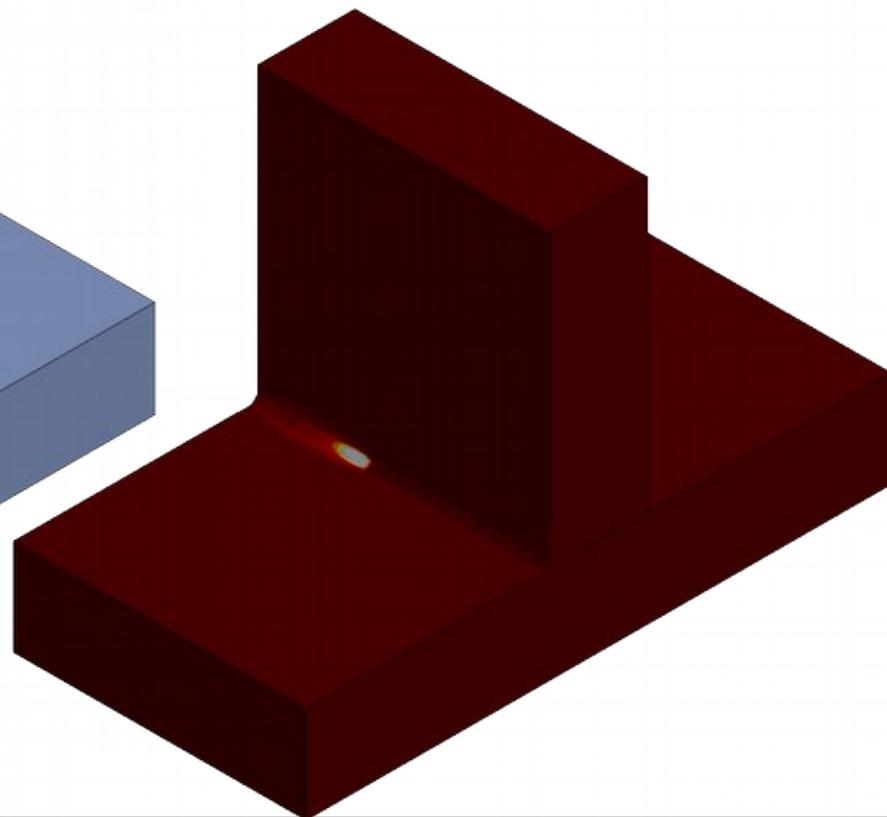
Dünnwandiges Bauteil:
Blechdicke 6 mm

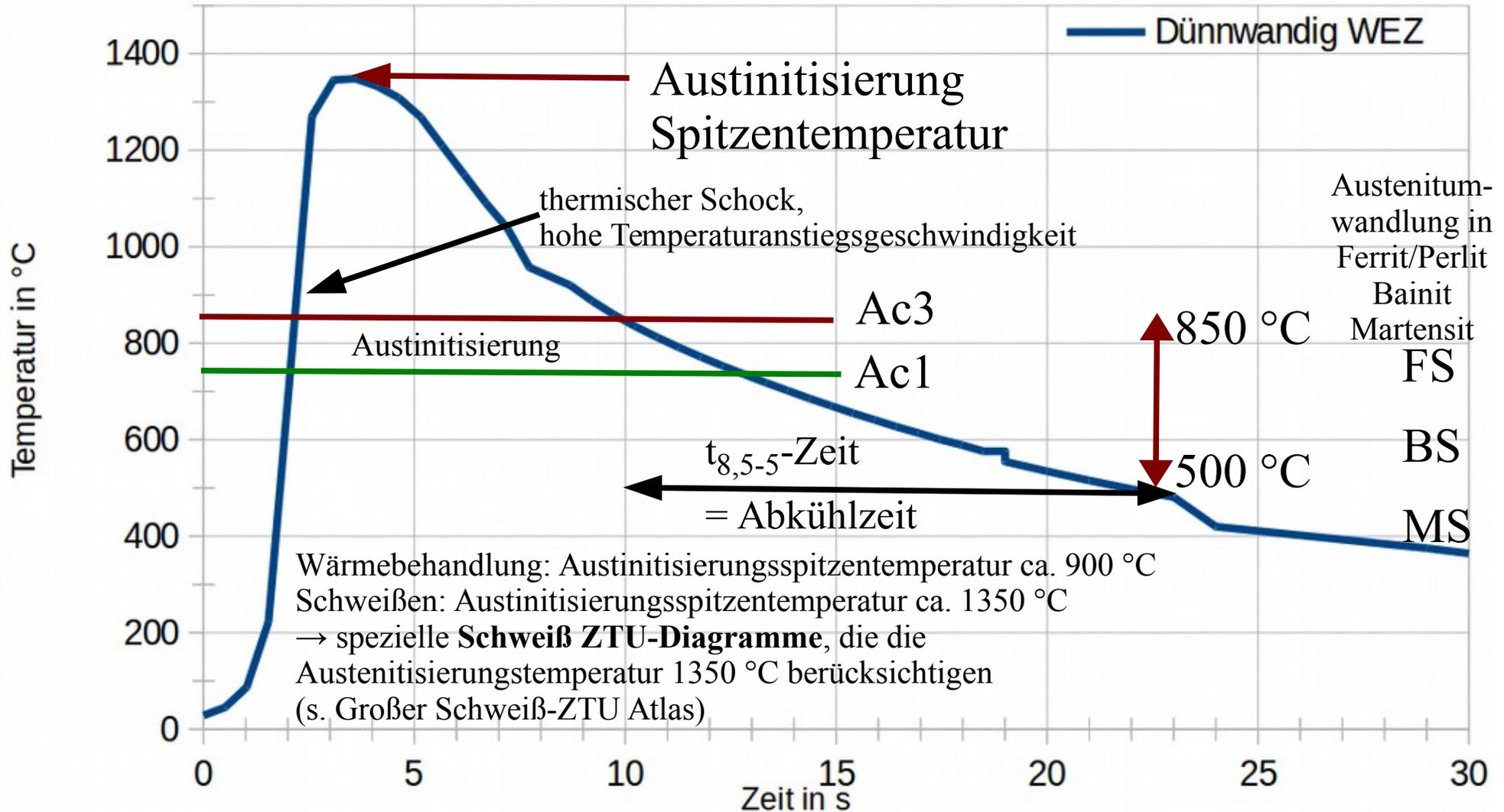


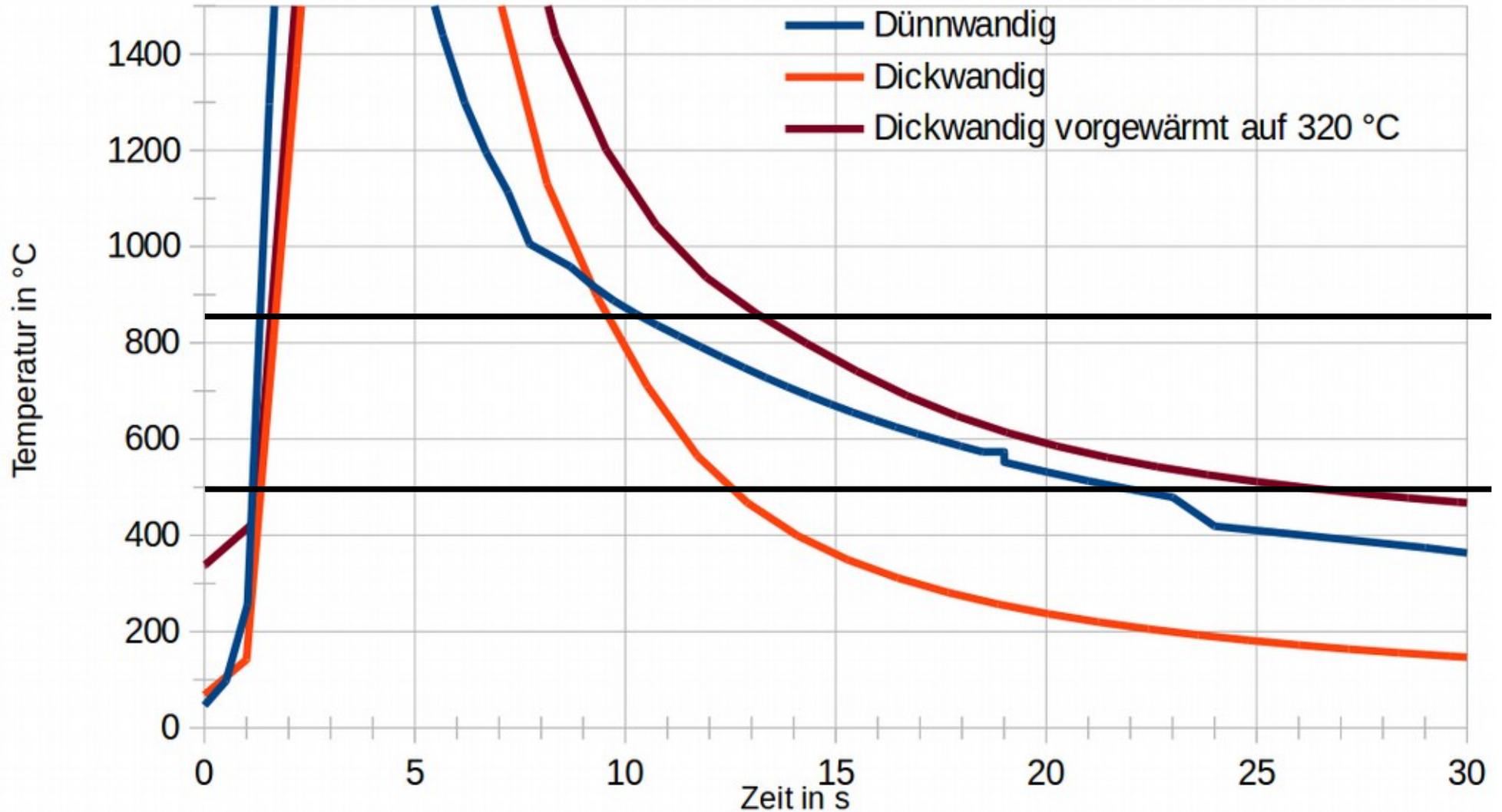
Dickwandiges Bauteil:
Blechdicke 100 mm

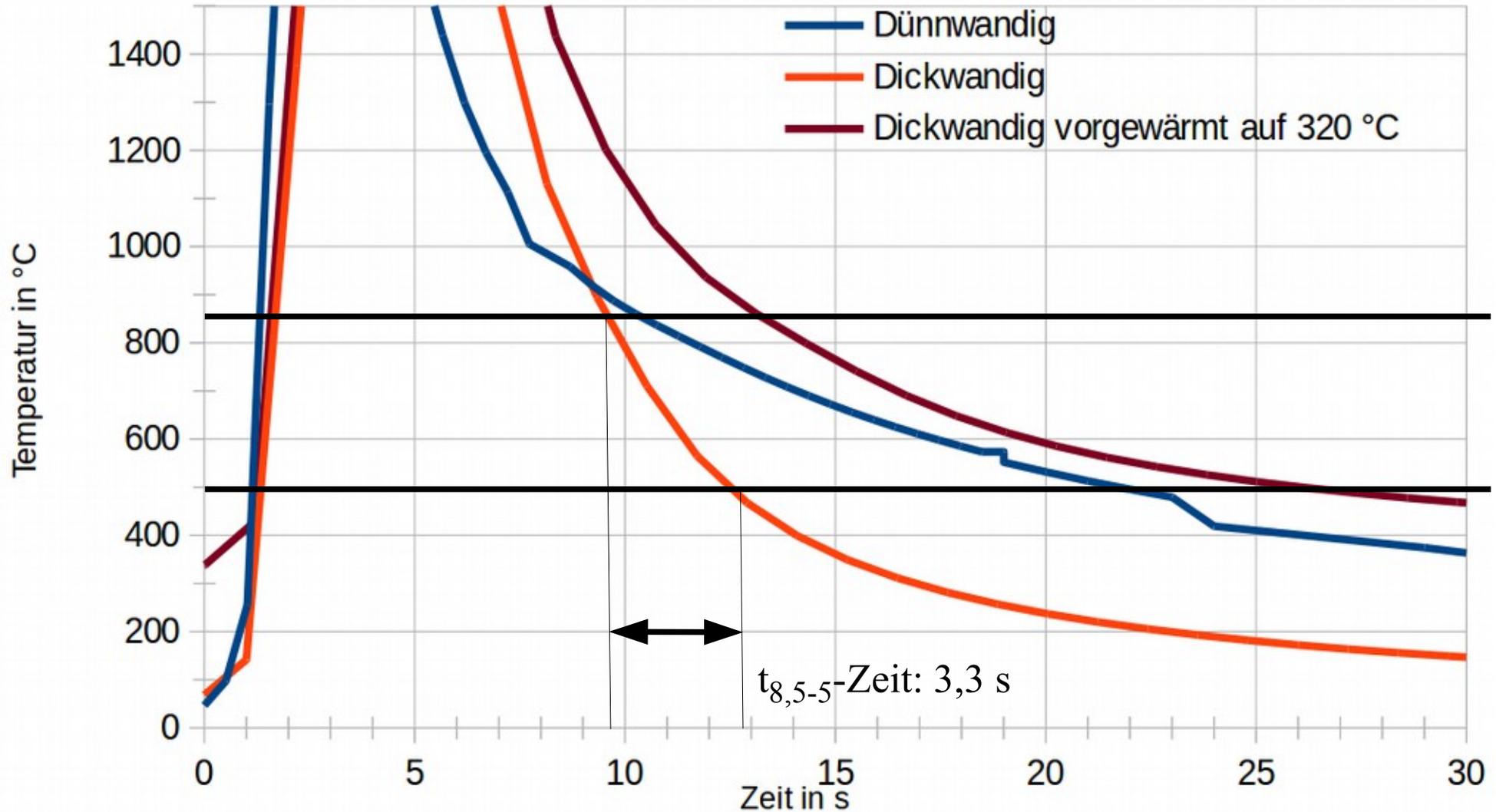


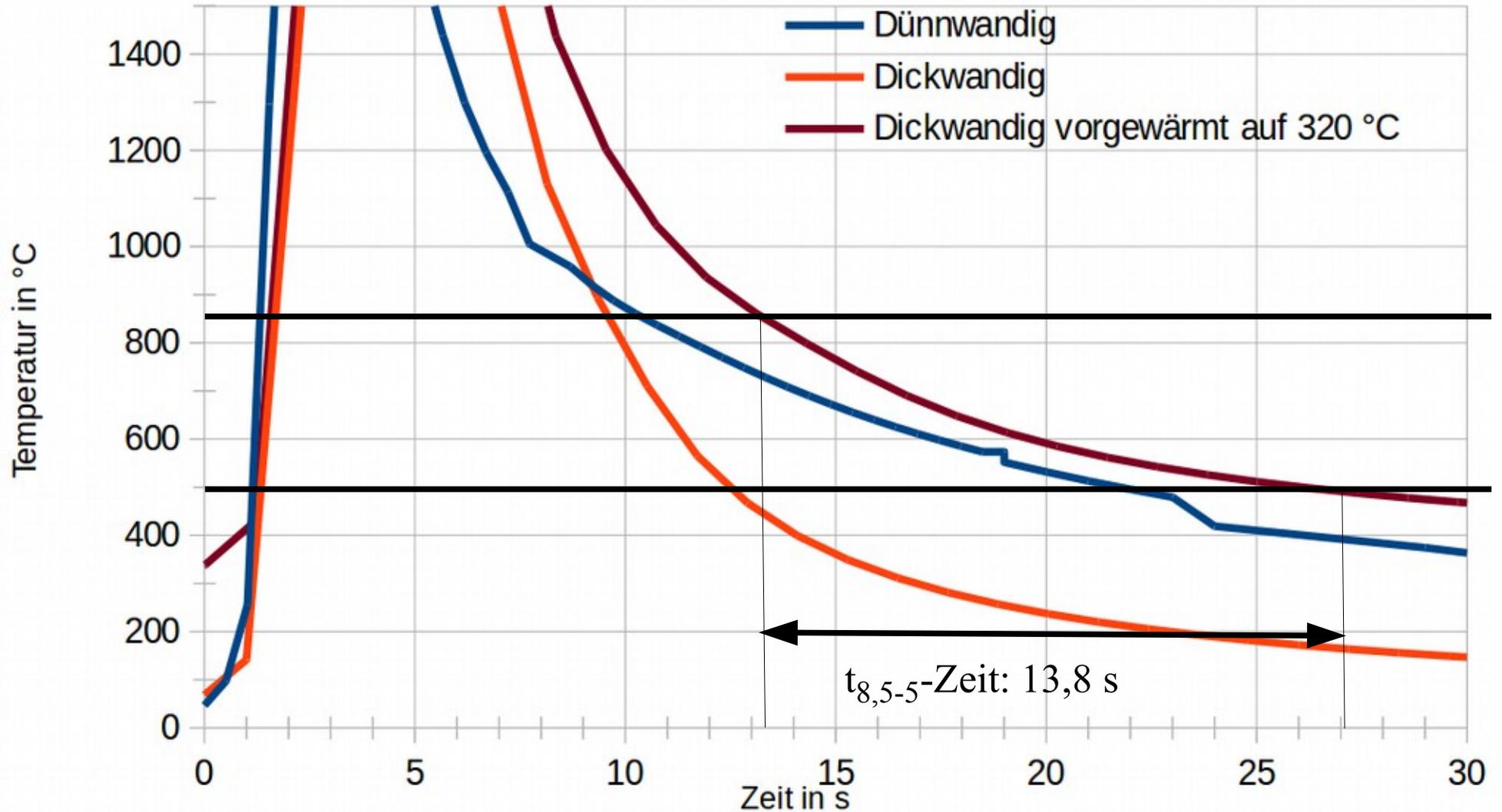
Dickwandiges Bauteil:
Blechdicke 100 mm
Vorwärmtemperatur 320 °C



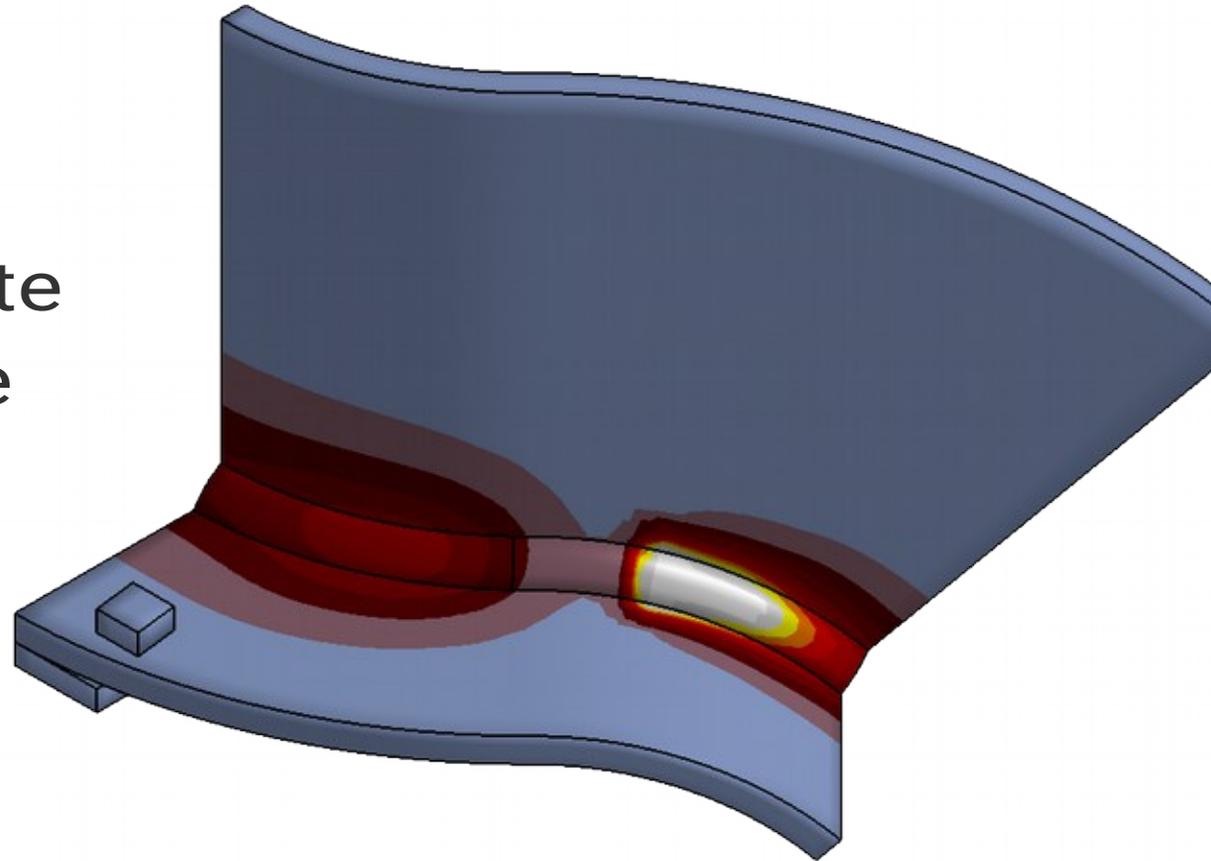








Auswirkung des
Schweißtemperaturzyklus
auf die
Mikrostruktur
und die mechanisch
technologischen Werte
umwandelnder Stähle



Auswirkung des
Schweißtemperatur-
zyklus auf die
Mikrostruktur
und die mechanisch
technologischen Werte
umwandelnder Stähle



WeldWare

Charge – Chemische Analyse

Microstruktur – Mechanische Eigenschaften

- **Datenbank:**
 - Vielzahl gemessener Schweiß-ZTU Diagramme durchgeführt von der SLV Mecklenburg Vorpommern
 - Regressions-Analyse zur Berechnung von Zwischenwerten
 - Mikrostruktur / Gefügezusammensetzung in Abhängigkeit der Abkühlzeit $T_{8,5-5}$
 - Mechanische Eigenschaften bei Raumtemperatur in Abhängigkeit der Abkühlzeit $T_{8,5-5}$
- **Wärmeführung:**
 - einfache Berechnung der Abkühlzeit
 - Bestimmung der Vorwärmtemperatur



Werkstoffprüfbericht Nr. **2016-550-3058/000.1** Entwurf Seite 1 von 17
Material test report no. Page of

| | | | |
|--|--|----------------------------------|--|
| Auftraggeber: Client: | Sonderlehrgang "Das Messen der Streckenenergie ist doch so einfach!...?" | | |
| Bestell Nr.: Order no.: | -- | Eingangsdatum: Date of order: | |
| Werkstoff: Material: | S690QL (Kundenangabe) (Client information) | Bemerkung: Remark: | -- |
| Prüfer: Operator: | Herr Thiel / Herr Gube Mr. Thiel / Mr. Gube | Prüfdatum: Date of testing: | 01.03.2016 / 31.03.2016 2016-03-01 / 2016-03-31 |
| Weitere Prüfungen Seite Additional tests see page | 2-3 Härteprüfung Hardness test | | |

| Probe Nr. Specimen no. | Prüfgegenstand Test object | Anzahl Number | Abmessungen Dimensions [mm] | Prozess Process | Position | WPS-Nr. WPS-no. |
|---------------------------|---|------------------|-----------------------------------|--------------------|----------|--------------------|
| 1N | Schweißprobe "niedrige Streckenenergie" | 1 | t = 12 mm | 138 | PA | |
| 2H | Schweißprobe "hohe Streckenenergie" | 1 | t = 12 mm | 138 | PA | |

Querzugversuch gemäß DIN EN ISO 4136

Transverse tensile test acc. to EN ISO 4136

DIN EN ISO 6892-1 B

Prüftemperatur: RT
Test temperature:

Maschine Nr.:
Machine-No.:

| Pos. | t _S [mm] | b / D ₀ [mm] | S ₀ [mm ²] | F _m [kN] | R _m [N/mm ²] | Bruchlage Pos. of fracture) | Bemerkung Remark | Bewertung Evaluation **) |
|------------------------------|------------------------|----------------------------|--------------------------------------|------------------------|--|------------------------------------|---------------------|--------------------------------|
| Anforderung: Requirement: | | DIN EN 10025-6 | | | ≥ 770 | | | |
| 1N | 11,9 | 25,2 | 299,9 | 247,7 | 826 | G | -- | e |
| 2H | 11,9 | 25,3 | 301,1 | 218,9 | 727 | S | -- | ne |

) G = Grundwerkstoff, U = Übergang, S = Schweißgut; **) e = erfüllt, ne = nicht erfüllt

) G = Parent metal, U = Heat affected zone, S = Weld metal; **) e = acceptable, ne = not acceptable

| Chemische Zusammensetzung [%] ¹⁾ | | | | | | | | | | | | | | <input type="checkbox"/> Schmelzanalyse Ladle analysis | <input checked="" type="checkbox"/> Stückanalyse Product analysis | | |
|---|-------|------|------|-------|---------|--------|--------|------|------|------|------|-------|-------|---|--|-------------------|--|
| Pos. | C | Si | Mn | P | S | Al | N | Cr | Mo | Ni | Cu | V | Nb | Ti | -- | CEV ²⁾ | |
| min. ³⁾ | | | | | | | | | | | | | | | | | |
| max. ³⁾ | 0,220 | 0,86 | 1,80 | 0,025 | 0,012 | 0,0150 | 0,0160 | 1,60 | 0,74 | 2,10 | 0,55 | 0,140 | 0,070 | 0,070 | | 0,65 | |
| 1N/2H | 0,158 | 0,21 | 0,83 | 0,009 | < 0,001 | 0,091 | 0,0023 | 0,30 | 0,20 | 0,03 | 0,02 | 0,003 | 0,032 | 0,003 | -- | 0,40 | |

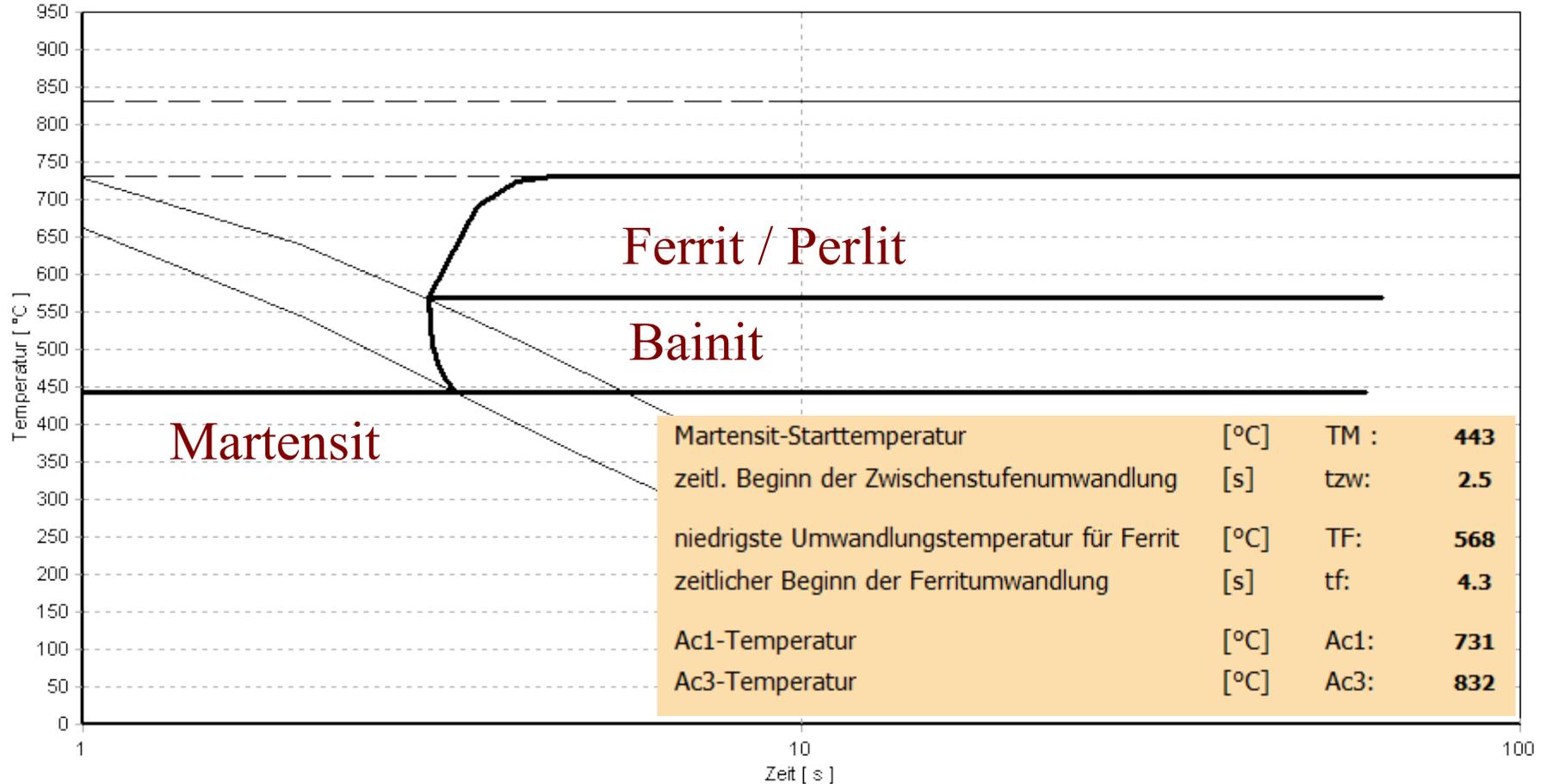
1) gemäß QM-VA 2.4.5 der GSI mbH, Niederlassung SLV Duisburg 2) CEV = C+(Mn/6)+(Cr+Mo+V)/5+(Ni+Cu)/15

3) Anforderung für die Stückanalyse gem. DIN EN 10025-6

Requirements of the ladle product analysis acc. to DIN EN 10025-6

S690QL SLV-DU

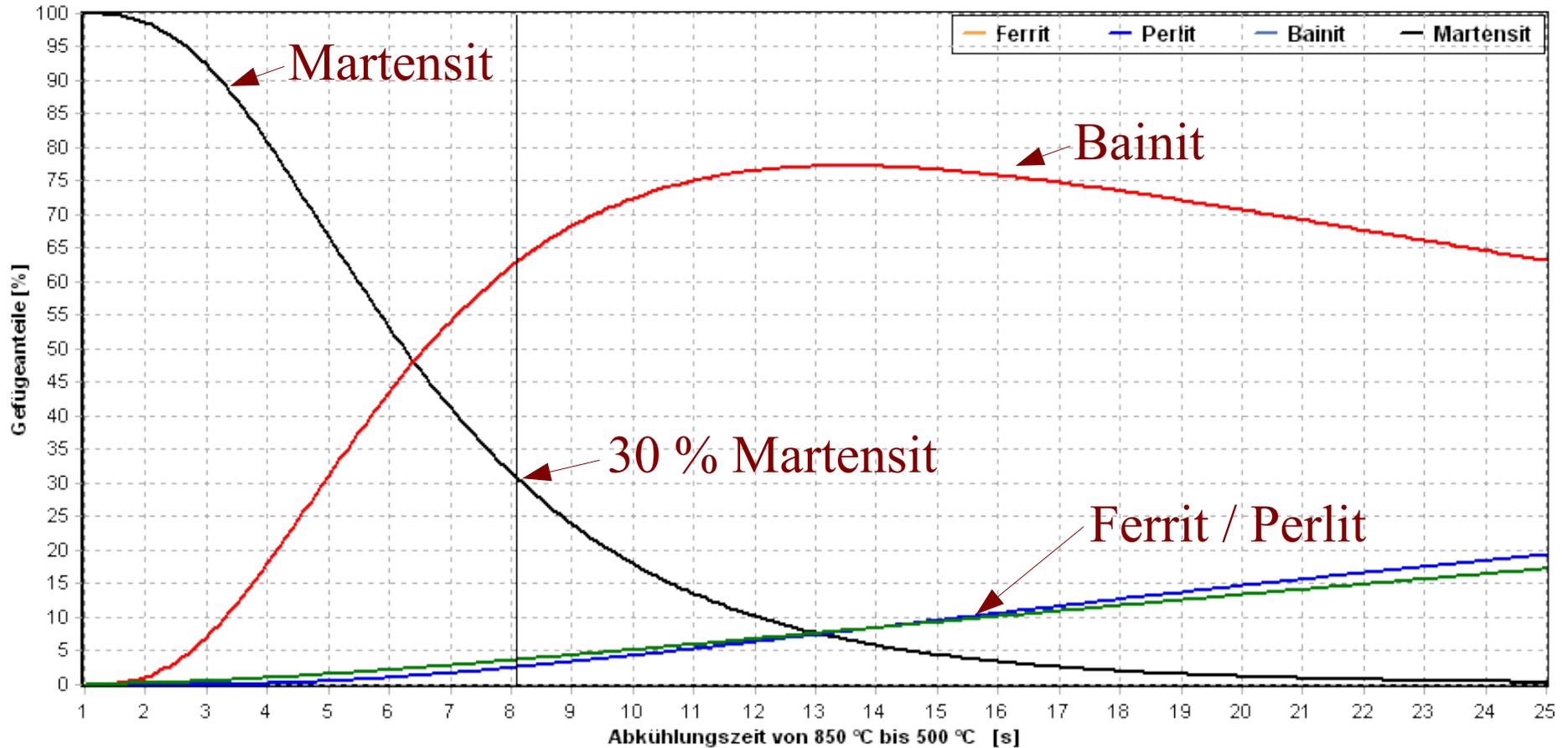
C: 0.158 Si: 0.29 Mn: 0.83 P: 0.009 S: 0.0013 Cr: 0.3 Ni: 0.03 [%]
 Mo: 0.2 V: 0.003 Cu: 0.02 Al: 0.091 Ti: 0.003 Nb: 0.032 N2: 0.0023 [%]



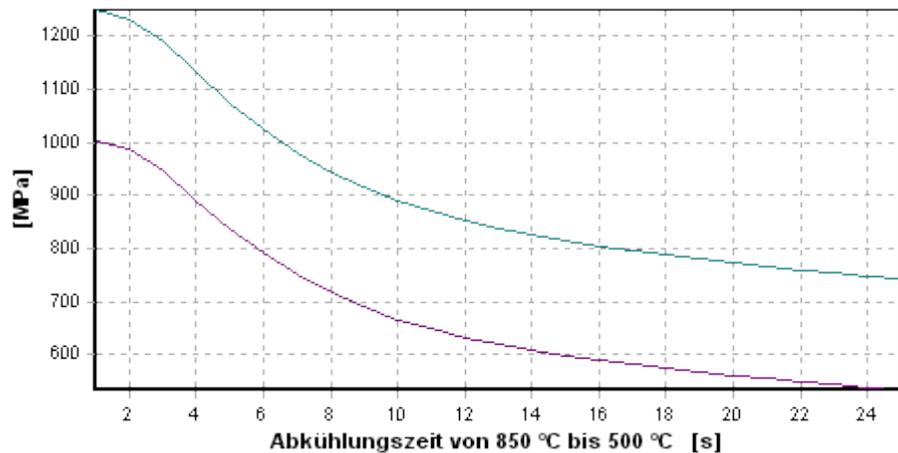
| Legende | | | | | |
|---------|---------------|------------|------------|------------|----------|
| ta [s] | Martensit [%] | Bainit [%] | Perlit [%] | Ferrit [%] | K30 Wert |
| 8.1 | 31 | 63 | 3 | 4 | 8.1 |

S690QL SLV-DU

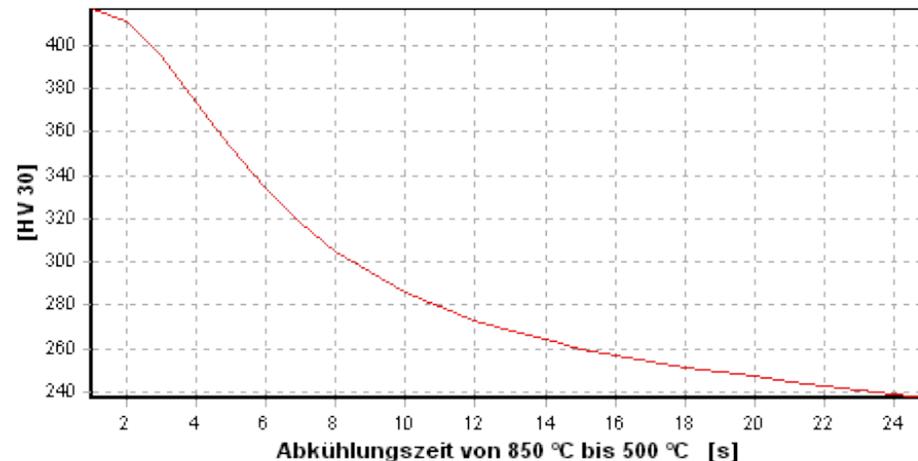
| | | | | | | | |
|----------|----------|----------|-----------|-----------|-----------|------------|-----|
| C: 0.158 | Si: 0.29 | Mn: 0.83 | P: 0.009 | S: 0.0013 | Cr: 0.3 | Ni: 0.03 | [%] |
| Mo: 0.2 | V: 0.003 | Cu: 0.02 | Al: 0.091 | Ti: 0.003 | Nb: 0.032 | N2: 0.0023 | [%] |



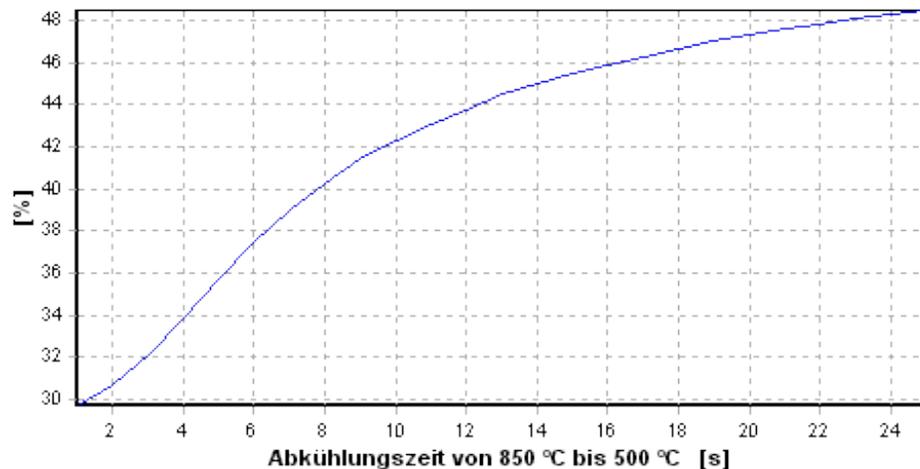
Festigkeit S690QL SLV-DU



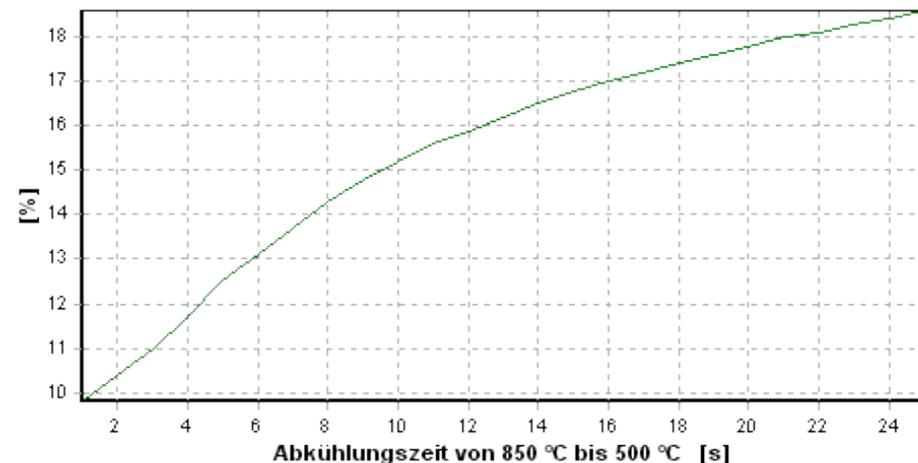
Härte S690QL SLV-DU



Brucheinschnürung S690QL SLV-DU



Bruchdehnung S690QL SLV-DU

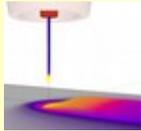


WeldWare[®]



- Einfache Blechgeometrie
- Analytische Ansätze

SimWeld[®]



- Prozesssimulation
- Numerische Simulation des Wärmeeintrages
- Berechnung des Schmelzbades

DynaWeld



- Berechnung der Wärmeableitung für komplexe Geometrien
- Wärmeeintrag muss als Eingangsgröße vorgegeben werden

Abkühlzeit ✕

Berechnung

Drucken

Protokoll

Übernehmen

Verwerfen

Auswahllisten

| Prozeß | Draht |
|---------------|-------|
| 111 (E) | 1.0 |
| 121 (UP) | 1.2 |
| 131 (MIG) | 1.4 |
| 135 (MAG) | 1.6 |
| 136 (MAG, FD) | 1.8 |
| 137 (MIG, FD) | 2.0 |
| 141 (WIG) | |
| 751 (Laser) | |

Naht

Blech

 Rohr

Nahtart 1100 Stumpfstoß

Nahtform 1104 V-Naht

Wurzellage

 Fülllage

 Decklage

Wärmephysikalische Kennwerte

| | | | |
|-----------------------|----------------|------------|---|
| Wärmeleitfähigkeit | [W/(cm K)]: | 0.4 | |
| Volumenwärmekapazität | [J/(cm³ K)]: | 4.3 | Kennwerte ändern |

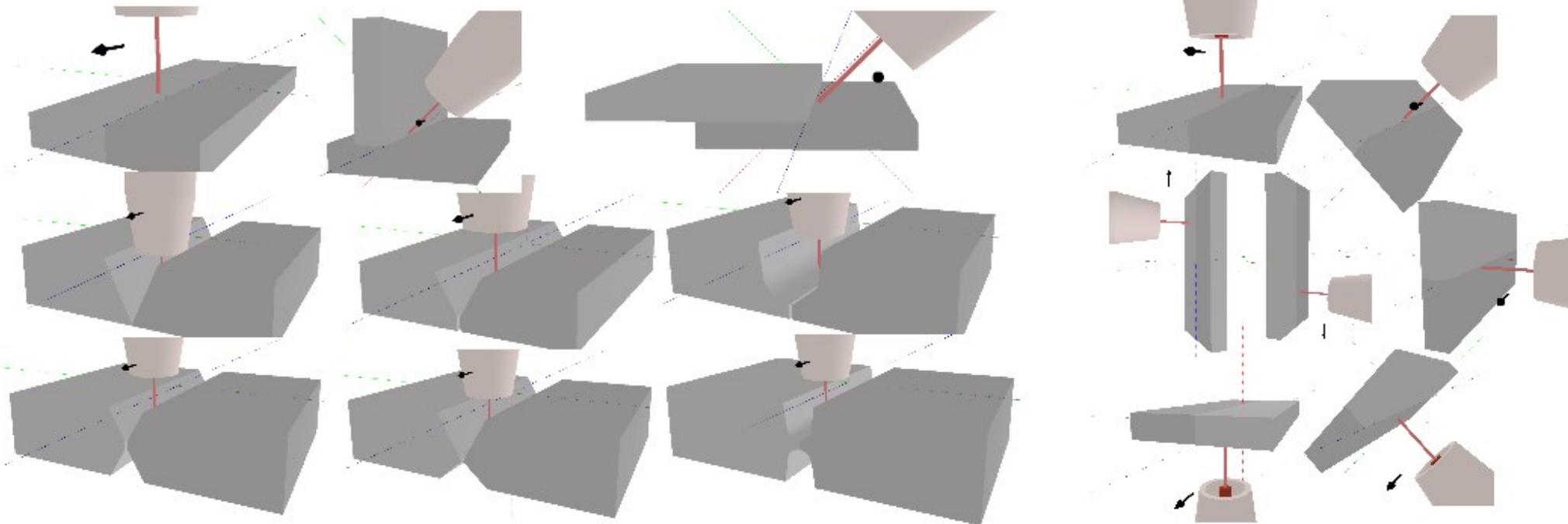
Parameter

| | | | | | |
|------------------------|---------------------|--|-------------------------------------|--------------|---|
| Stromstärke | 60... 200 [A] | 240 | Blechdicke 1 | [mm] | 12 |
| Spannung | 18... 25 [V] | 26 | Blechdicke 2 | [mm] | 12 |
| Schweißgeschwindigkeit | 16... 40 [cm/min] | 36 | Effektiver thermischer Wirkungsgrad | 0.58... 0.72 | 0.67 |
| Vorwärmtemperatur | 20... 450 [°C] | 100 | Relativer thermischer Wirkungsgrad | 0.8... 0.9 | 0.85 |

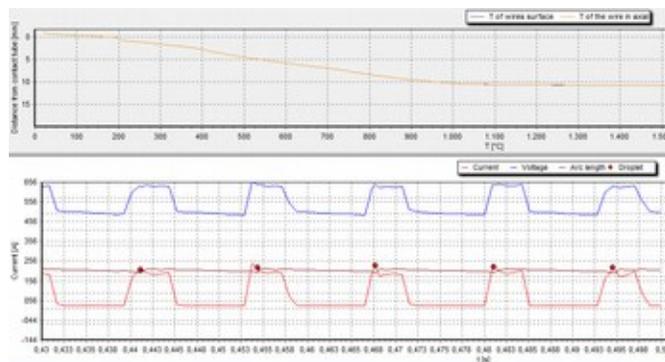
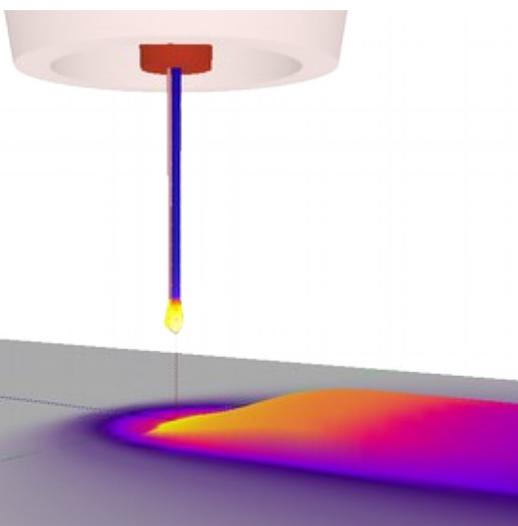
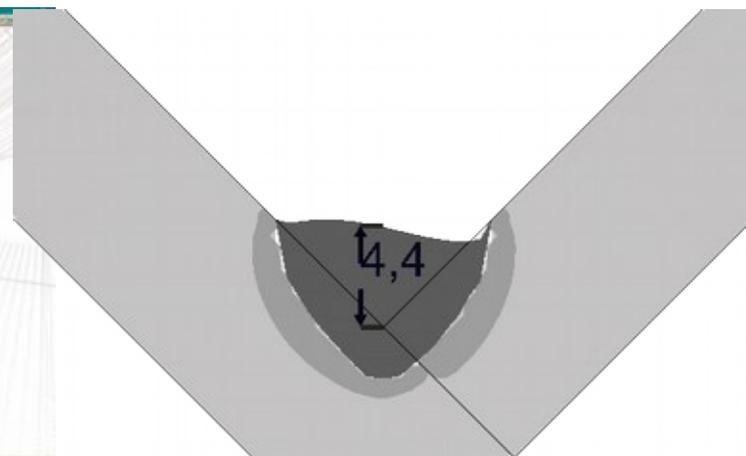
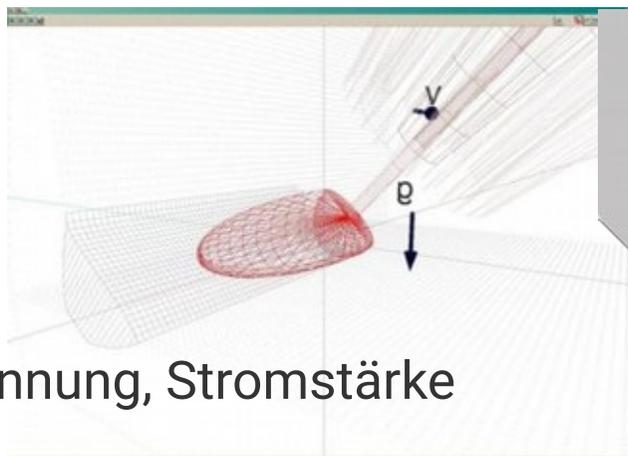
Ergebnisse

| | | | |
|----------------------------------|-----------|--------------|---------------------------------|
| Abkühlzeit | [s] | 9.70 | Uwer-Degenkolbe (2-dim.) |
| Streckenenergie U*I*60/vs | [kJ/cm] | 10.40 | |

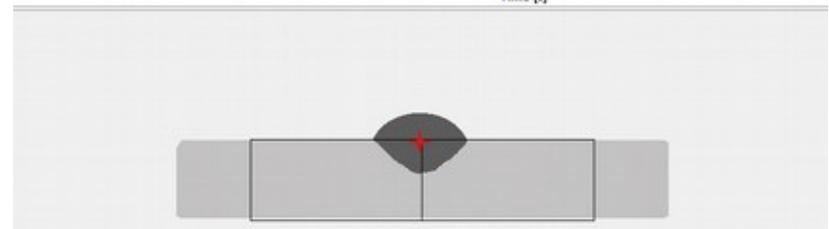
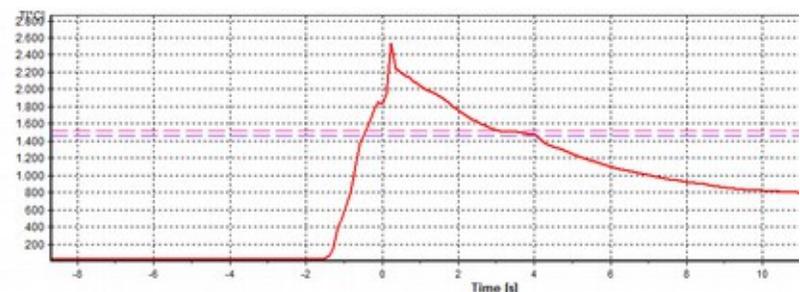
- Definition von:
 - Nahtvorbereitung
 - Geometrie und Bauteilabmessung
 - Arbeitsposition
 - Werkstoff

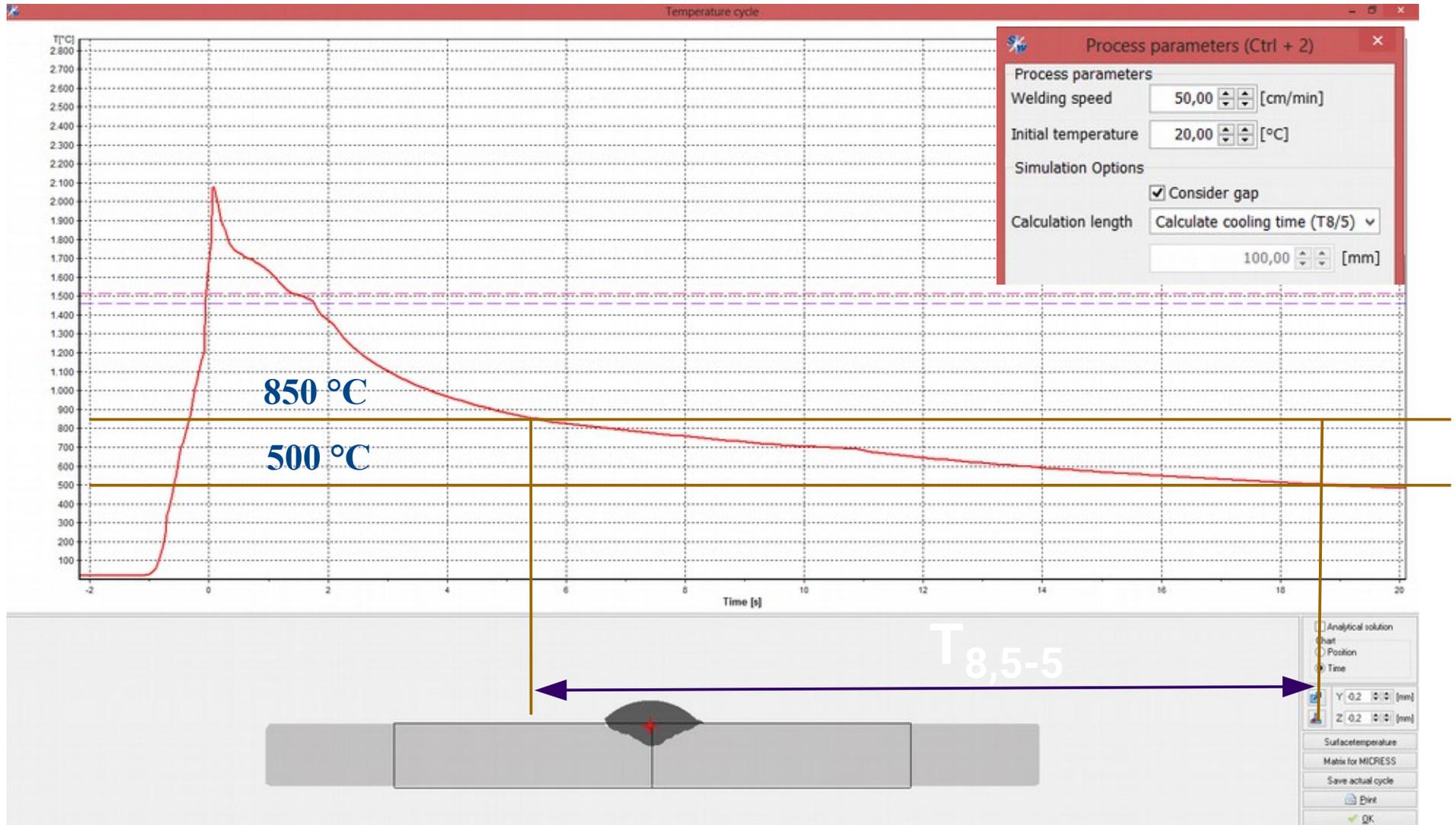


- Äquivalente Wärmequelle
 - Wärmeeintrag für DynaWeld
- Schmelzbadgeometrie
- Tropfenablösung
- Drahttemperatur
- Energie, Wärmeeintrag, Spannung, Stromstärke
- **Temperaturverlauf**

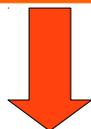


| Results | | Current | | Evaporation losses | |
|-------------------|----------|-------------------------|------------|-------------------------|-------------|
| Voltage | | Average current | 85.2 [A] | Droplet | 15.2 [W] |
| Wire voltage drop | 2.4 [V] | RMS current | 118.1 [A] | Droplet | 1.66 [W] |
| Anode V. equiv | 8.0 [V] | Generated thermal power | | Process characteristics | |
| Column | 4.8 [V] | Anode + wire | 919.0 [W] | T droplets avg | 2673.0 [°C] |
| Cathode | 10.4 [V] | Droplets heat | 803.7 [W] | Pulse freq. avg | 0.0 [Hz] |
| Voltage at arc | 23.5 [V] | Cathode | 976.4 [W] | IG frequency avg | 0.0 [Hz] |
| Cable losses | 0.5 [W] | Total heat of arc | 2281.2 [W] | | |





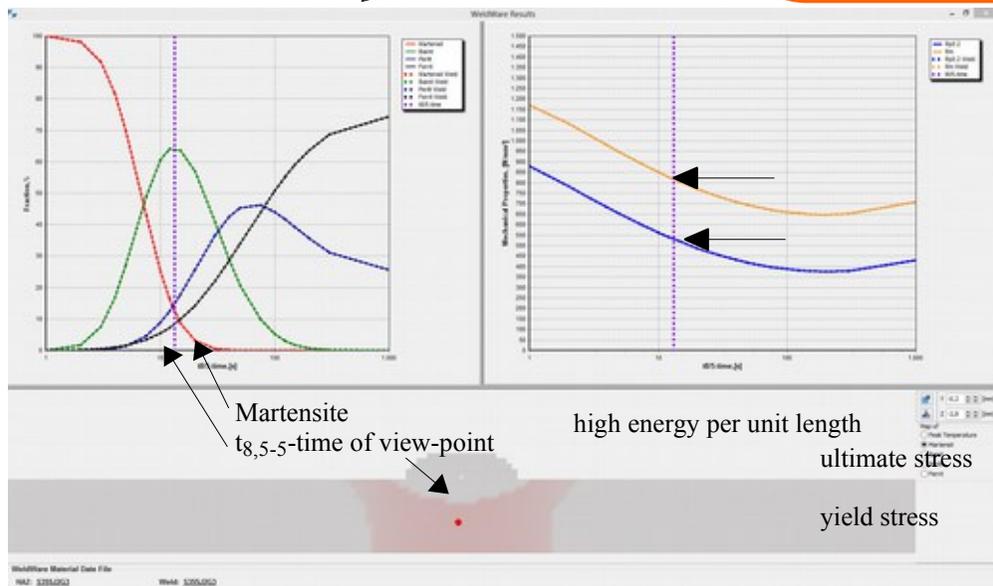
**Material Specification
Chemical Composition**



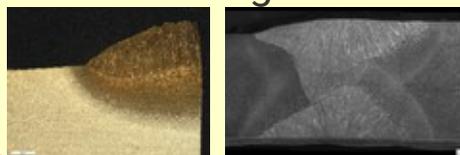
WeldWare®



S355



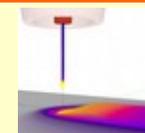
- Weld-Pool
- HAZ
- Microstructure
- Yield Strength
- Ultimate Strength
- Hardness
- Ultimate Elongation



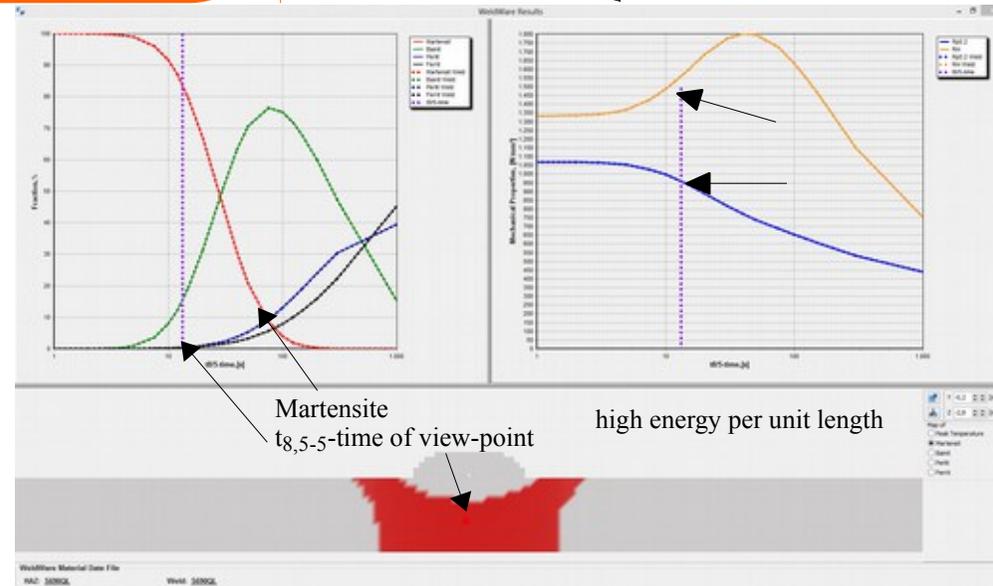
**WPS
Welding Procedure Specification**



SimWeld®



S690



Merci vielmals!