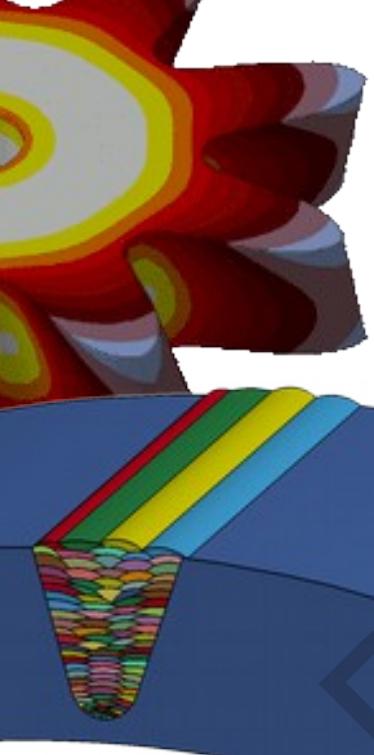


Foto: ISF



Efficient Setup and Documentation of Simulations for Welding and Heat Treatment with DynaWeld

LS-Dyna Forum Bamberg
10.10.16 till 12.10.16

Tobias Loose

Ingenieurbüro Tobias Loose, Herdweg 13, D- 75045 Wössingen,
loose@tl-ing.de www.tl-ing.eu



Heat treatment overview

Type
of heat treatment

Quenching

Case Hardening

Inductive hardening

Press hardening

Design of properties by local change of material properties and microstructure

Single
process steps

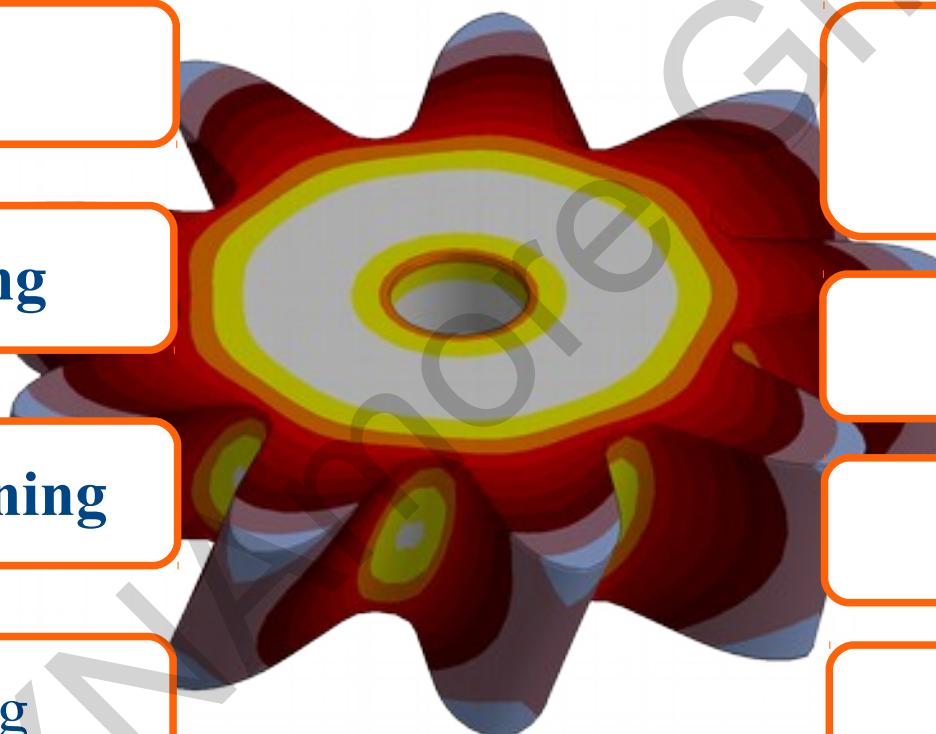
Heating

Thermal Heating
Inductive Heating

Carburisation

Quenching

Tempering





Welding overview

welding structure analysis

Type of Welding

Weld Process Type

- Arc Welding
- GMAW, SAW, TIG
- Laser
- Electron Beam
- GMAW-Laser-Hybrid
- Resistive Welding, RSW

single or multi
layered welds,
tack welds

Dimension

10 µm .. 500 mm

Distortion - Residual Stress - Material Properties after Welding

Single process steps

Clamping

Predeformations

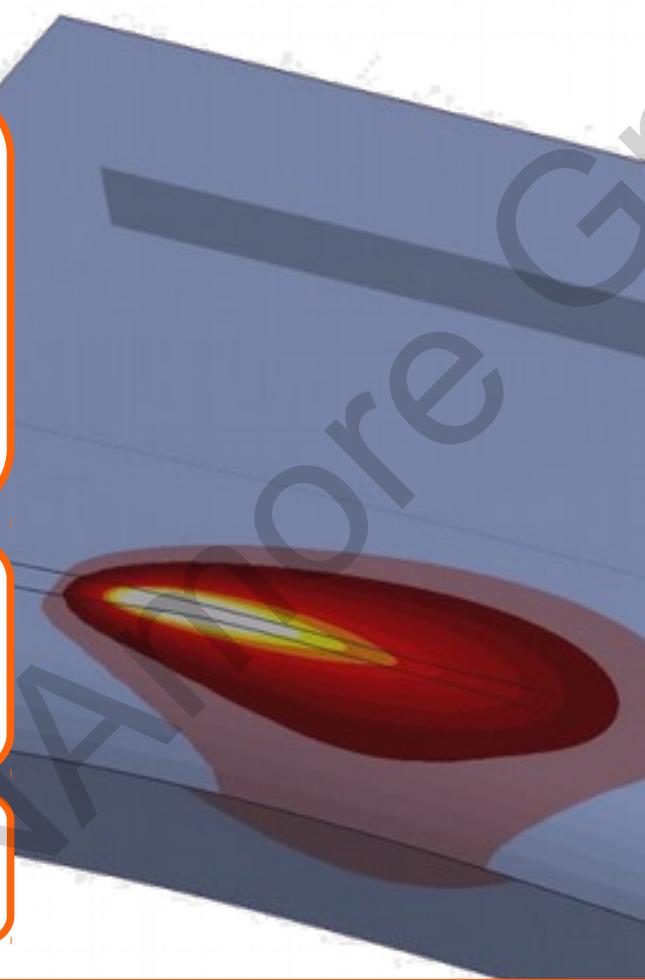
Heating

Cooling

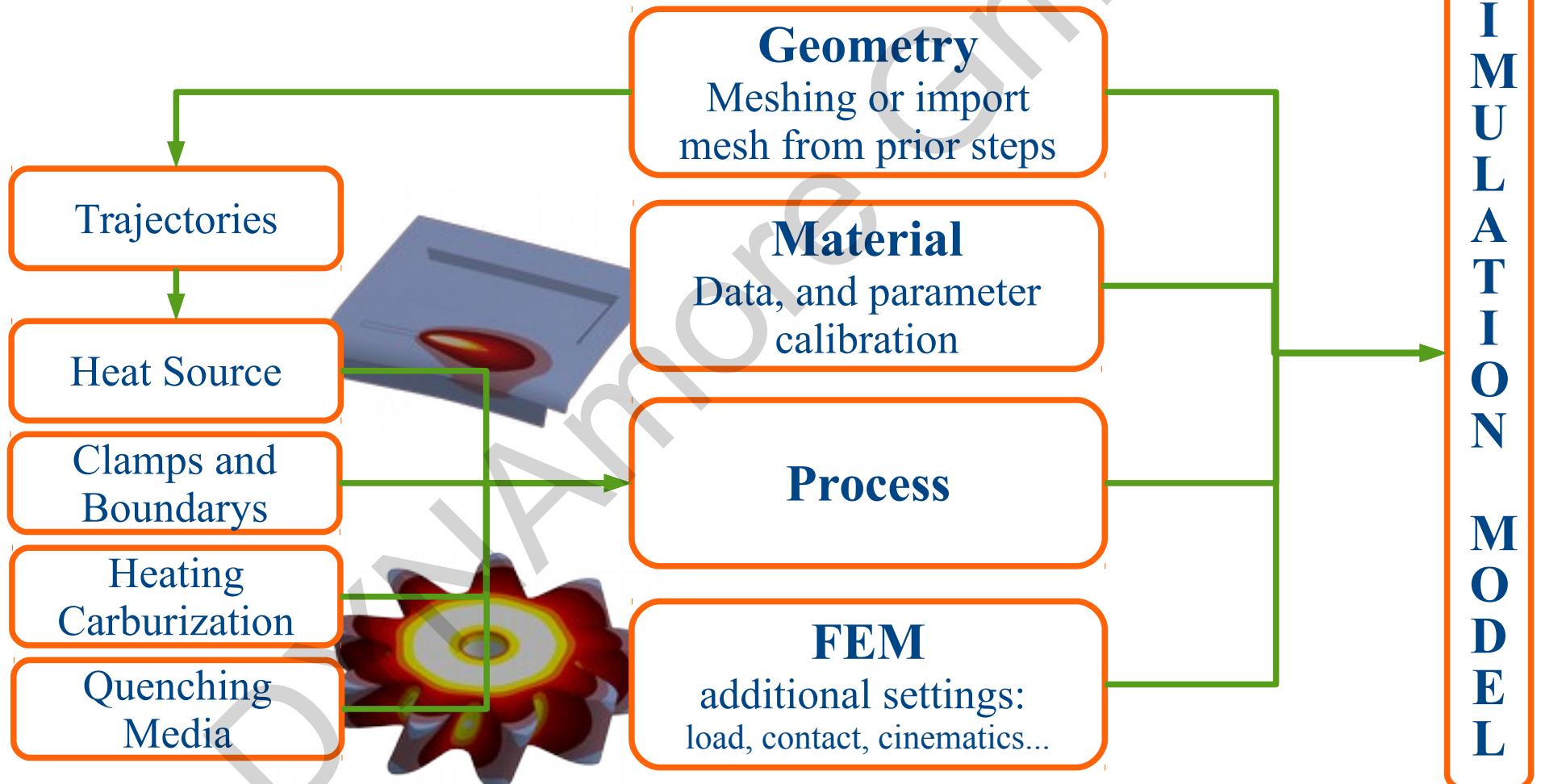
Reheating

Tempering

Grinding and Rewelding



Substructuring of models for welding and heat treatment



Benefit of sub structuring

Complex simulation task with many disciplines

easy to mange by task sharing

outsourcing single tasks

Material specialist

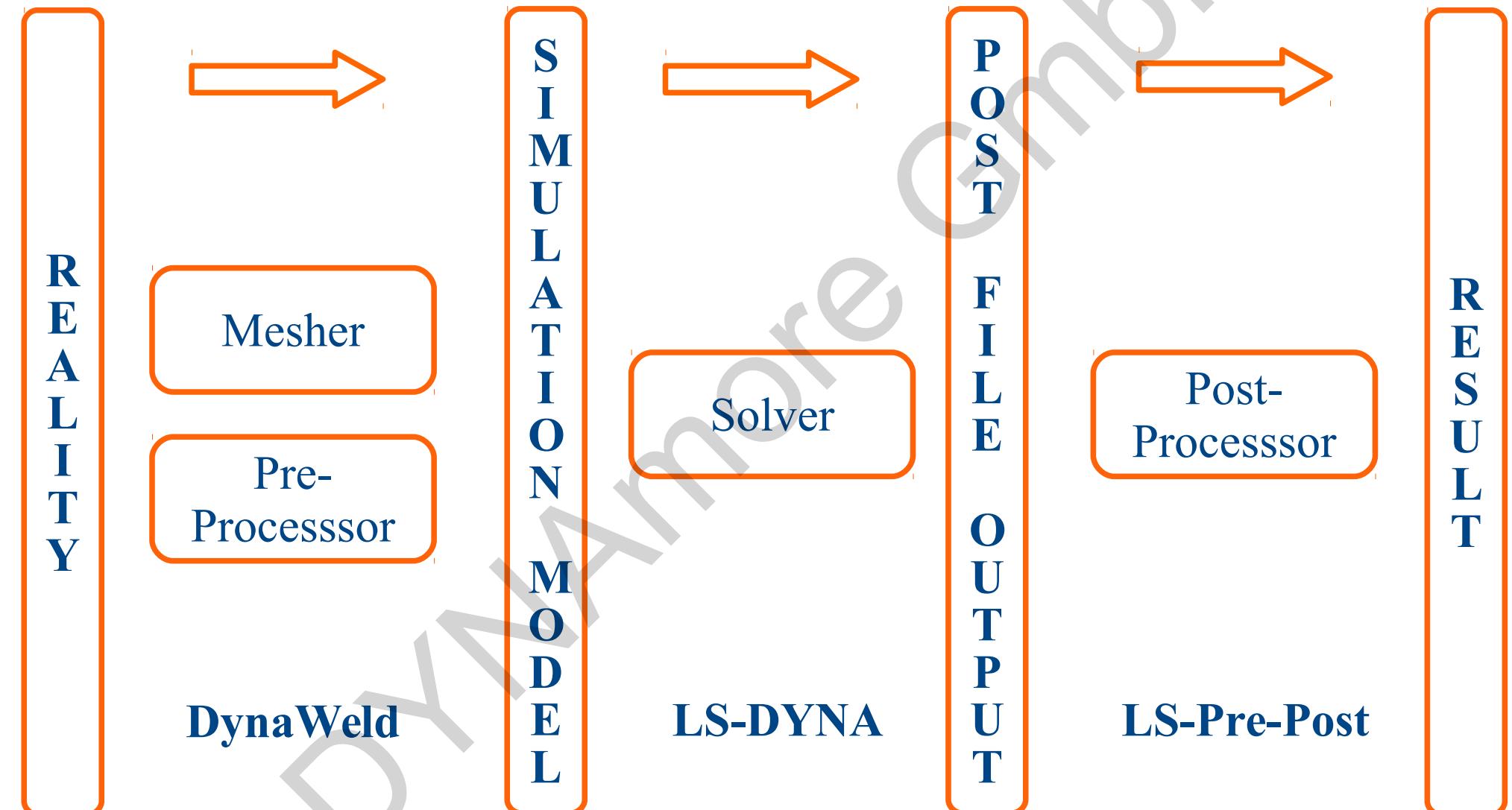
Mesh specialist

FEM specialist

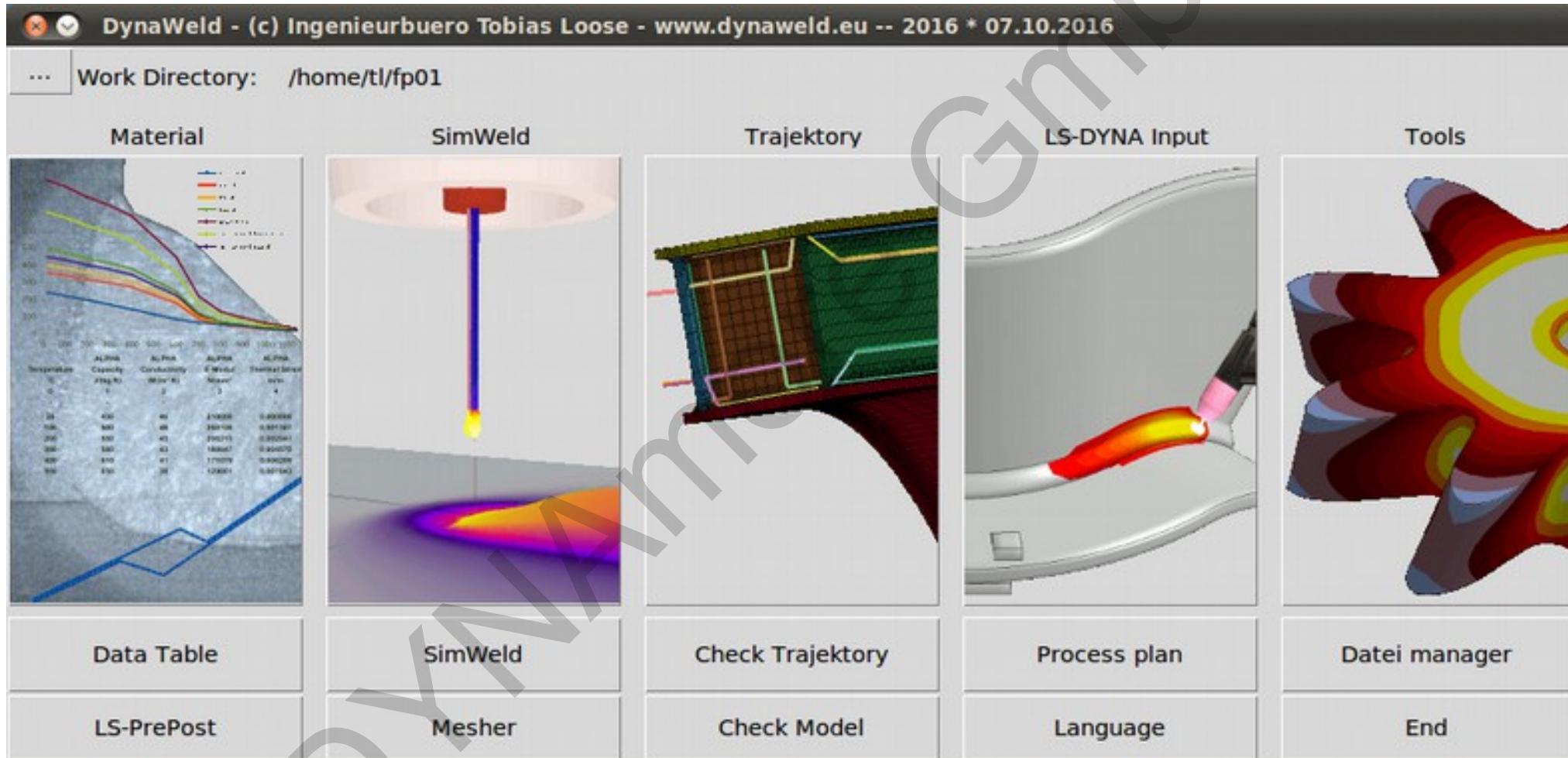
Welding specialist

Heat Treatment specialist

Definition of simulation steps



DynaWeld environment and preprocessor





DynaWeld environment and preprocessor

DynaWeld is not an Island-Solution!

Material

Customer defined Environment:

- Mesher
- PreProcessor
- PostProcessor
- Auxilary Software

SimWeld

Traiektry

LS-DYNA Input

Tools

Process Chain

Interface

- Material Simulation
- Welding Process Simulation

Heat Treatment and Welding related auxilary Tools

Linux and Windows
Excel and Libre Calc

User defined Keyword
→ no limitation in modeling

Plug In for existing Software environment as well as stand alone

Check Trajektry

Process plan

Datei manager

Supports LS-DYNA FE-Code
one Code - many Solvers - one License Fee

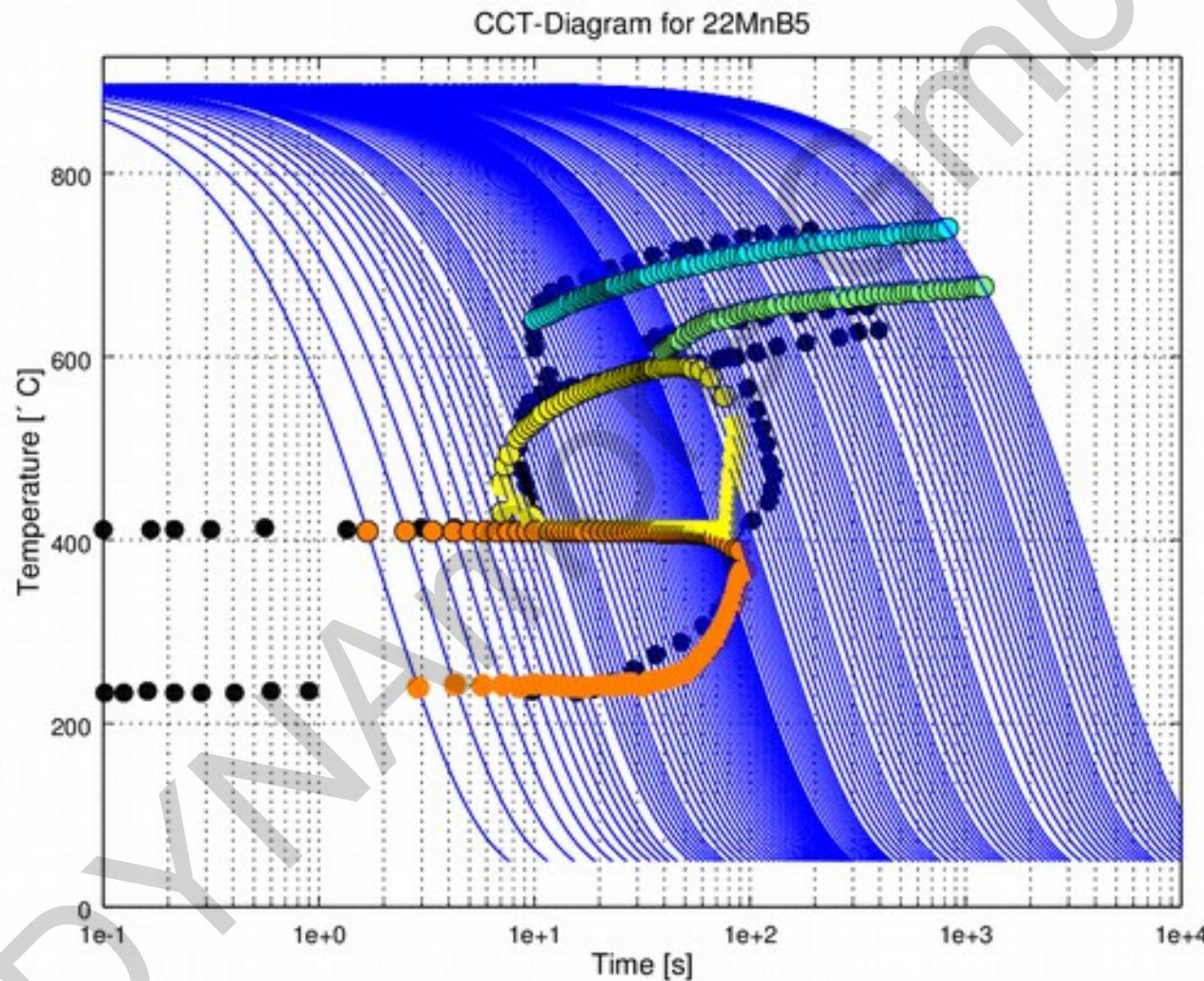


Material

Foto: Edyta Łopatecka

Phase transformation during cooling

CCT-diagram





Phase kinetic models

Law:
Koistinen-Marburger

Parameter:

T_{start}: Start Temperature
 α : kinetic faktor

MS
KM

Use:
f(temperature)
diffusionless transformation

Austenit → Martensit

$$x_b = x_a (1.0 - e^{-\alpha(T_{start} - T)})$$



Phase kinetic models

Law:
generalized JMAK
Jonhson-Mehl-Avrami-Kolmogorov

Parameter:

x_{eq} :	Proportion at equilibrium (T)	PEQ
n :	form parameter (T)	N
τ :	kinetic faktor (T)	TAU
f, f' :	Leblond factor (dT/dt)	F, F'

$$\frac{dx_b}{dt} = n(T)(k_{ab}x_a - k'_{ab}x_b) \left(\ln \left(\frac{k_{ab}(x_a + x_b)}{k_{ab}x_a - k'_{ab}x_b} \right) \right)^{\frac{n(T)-1.0}{n(T)}},$$

Advantage:

no limitation on material type nor chemical composition. Fitting according:
temperatur(T) and temperature rate(dT/dt)

based on Avrami equitation
extended by Leblond

Use:

f (temperature, temperture gradient, time)
diffusion-driven transformation
Austinitisation, Tempering
Austenite \rightarrow Ferrite, Pearlite, Bainite
phase transformation Aluminium

$$k_{ab} = \frac{x_{eq}(T)}{\tau(T)} f(\dot{T}), k'_{ab} = \frac{1.0 - x_{eq}(T)}{\tau(T)} f'(\dot{T})$$

Disadvantage:

needs calibration
on existing CCT or TT



Materials with phase kinetic models in LS-DYNA

*MAT_254 / *MAT_GENERALIZED_PHASE_CHANGE

Heat treatment
Welding

all materials

Laws:
Koistinen Marburger
Oddy
Kirkaldy
generalized JMAK
Time criterium
list might be extended

userdefined
assignment of laws

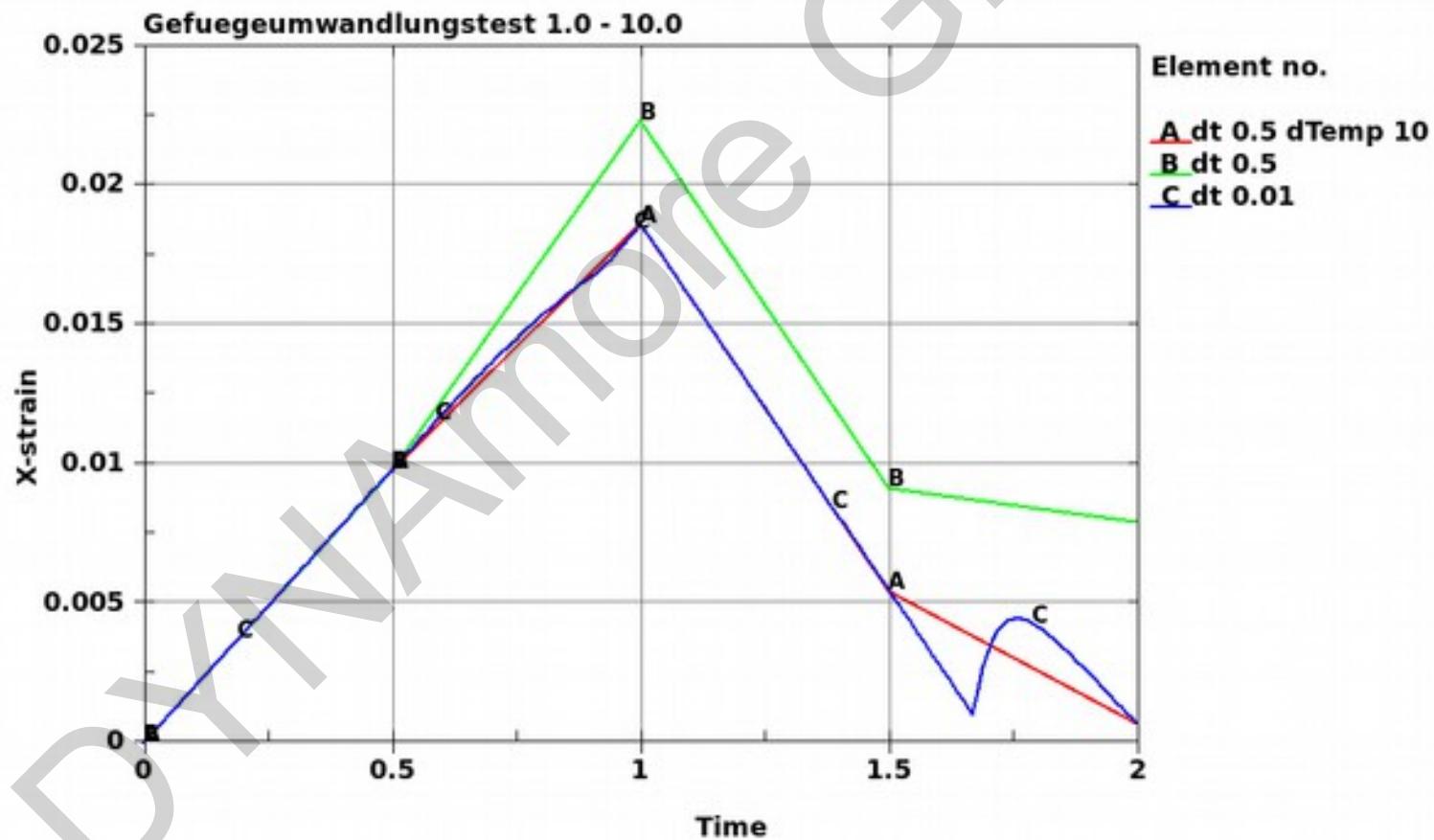
Features:
24 Phases
Shells, Solids, 2D-shells
Welding features
Phase transformation strain
Transformation induced plasticity (TRIP)
Subcycling for phase transformation
Tempering
Hardeness computation

Selected features: DTEMP

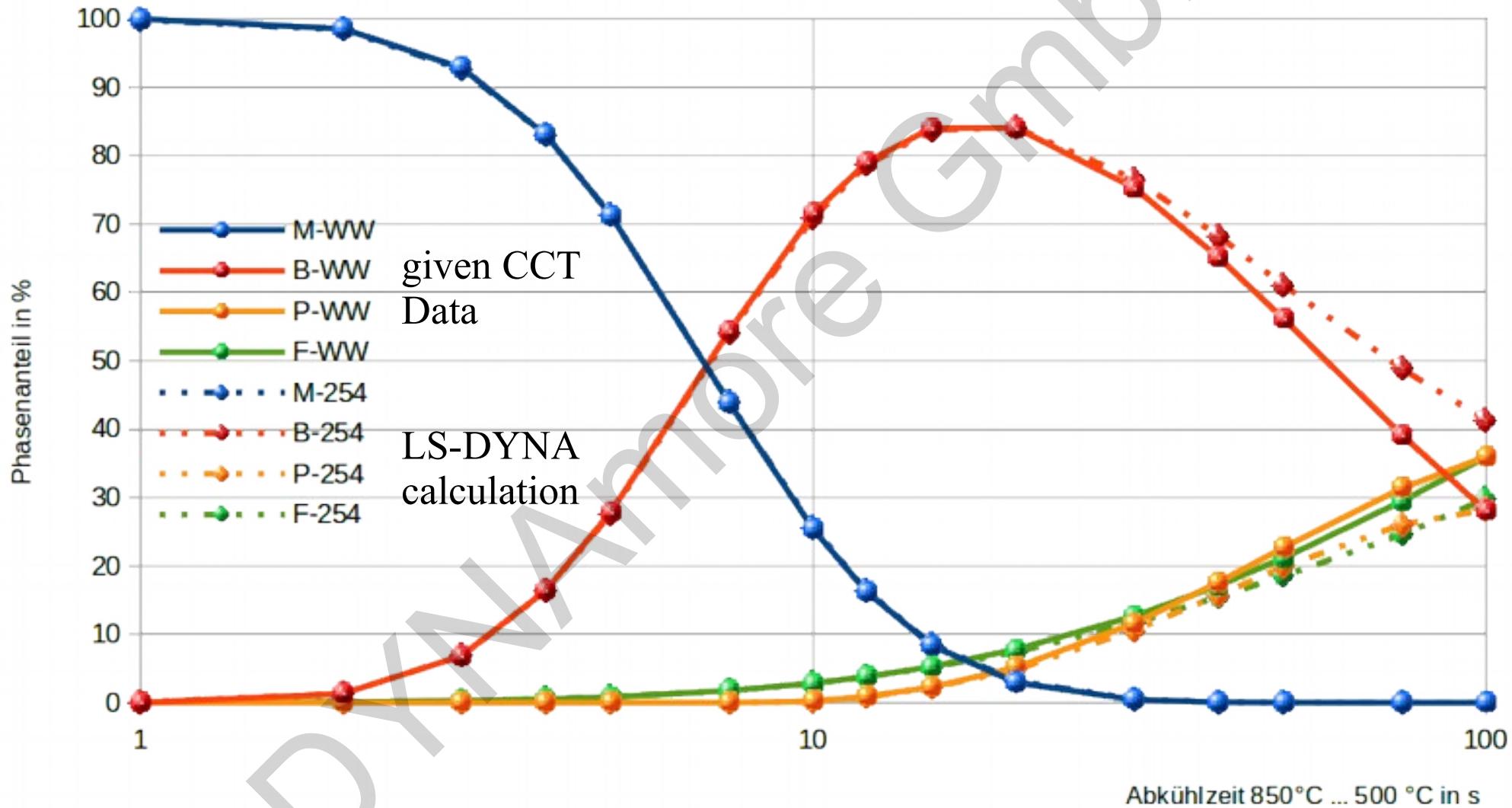
Phase transformation calculation temperature requires limit on temperature step

Phase transformation shall not reduce time step of mechanical solver

DTEMP = maximum allowed temperature step drives subcycle for phase transformation:

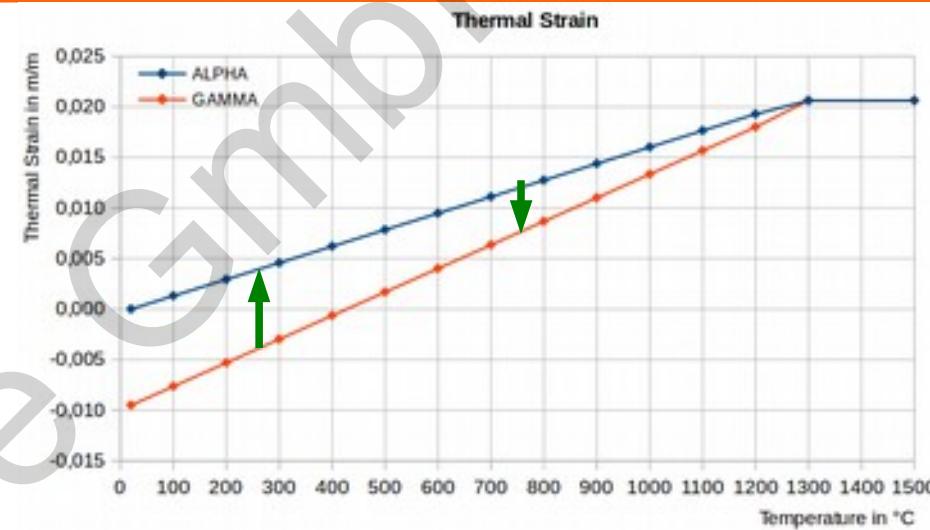


*MAT_254 calibration of phase transformation law

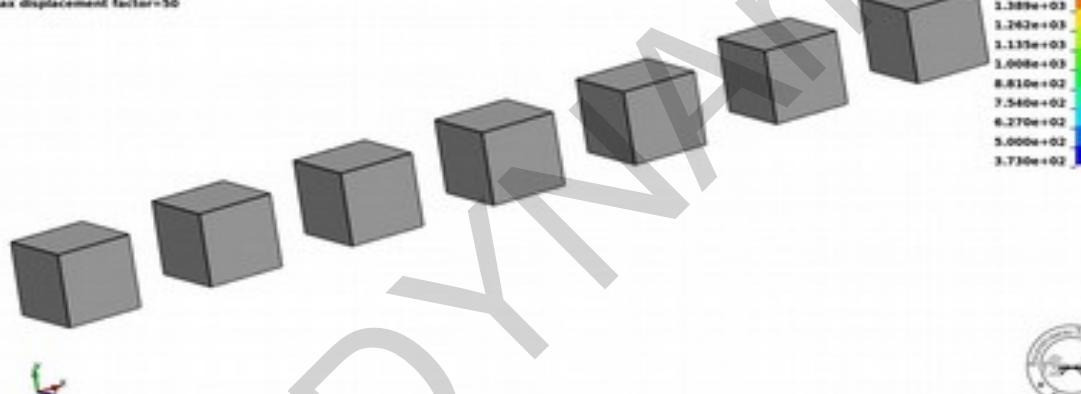


Selected features: phase transformation strain

If Phase A and B have different density
in case of phase transformation
additional strain arises due to volume change:
Phase Transformation Strain.

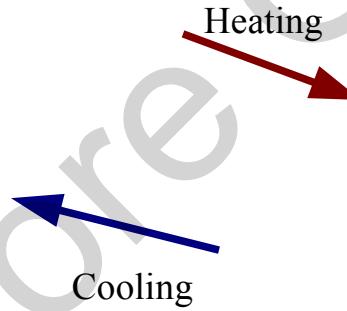


Gefügeumwandlungstest 1.0 - 10.0
Time = 0
Contours of Temperature
min=293, at node# 5
max=293, at node# 5
max displacement factor=50

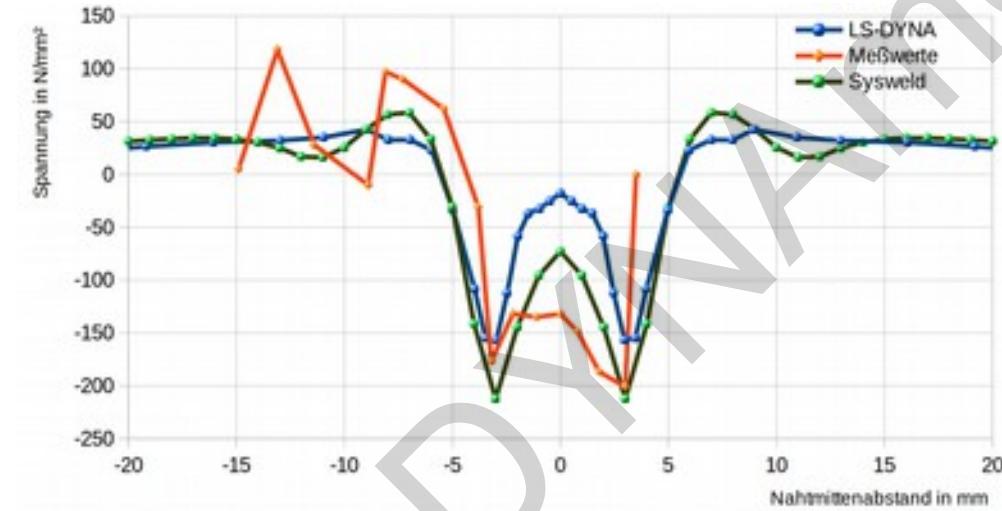
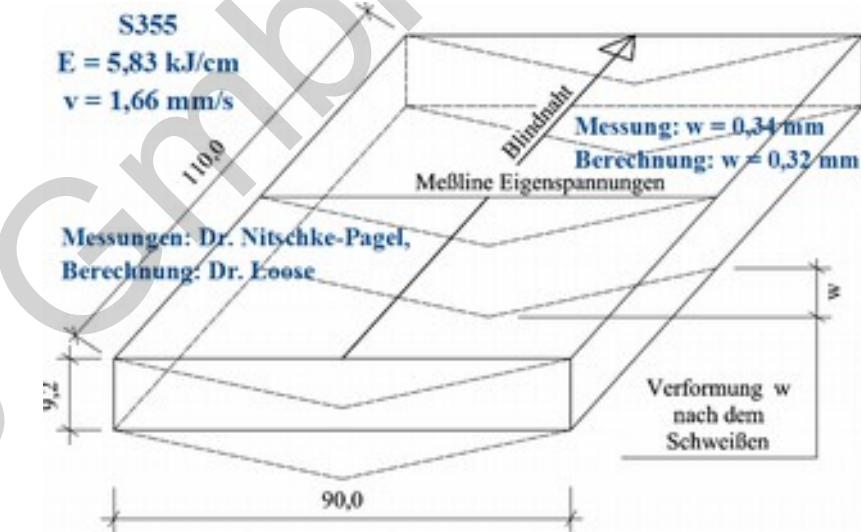
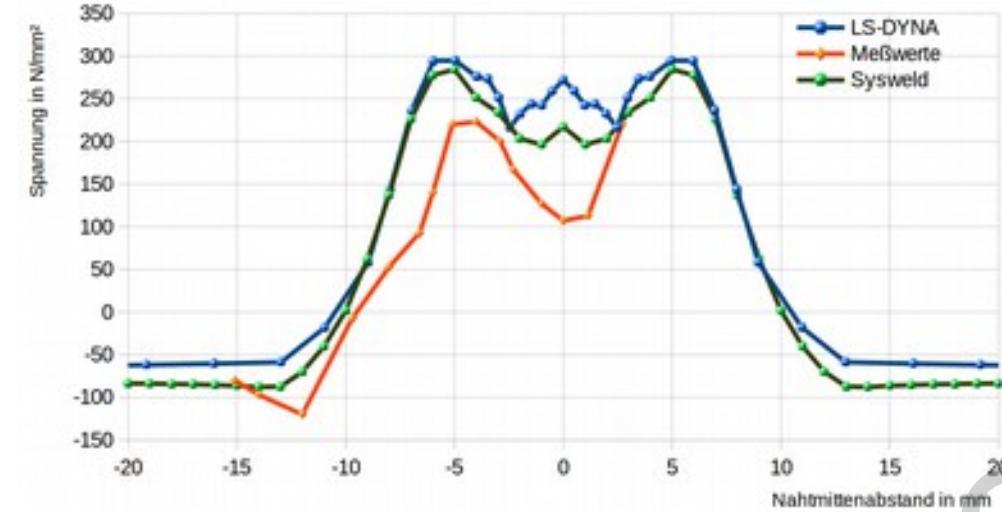




Simplified approach for single phase model *MAT_270



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 Stabilitätsverhalten axial gedrückter Kreiszylinderschalen aus Stahl, Diss, Karlsruhe, 2008



DynaWeld – Management for high sofisticated welding and heat treatment materials

Material

DynaWeld Material

Import and extensions:
Base material phase
Liquid material phase
Tempering phase
Flowcurve adjustment
Welding settings

User defined

JMatPro

WeldWare

other material
simulation software

LS-DYNA
Material keyword-file
multi phase *MAT_254

LS-DYNA
Material keyword-file
singel phase *MAT_270



DynaWeld Material - Import

Interfaces

DynaWeld - Material Data Preparation -- 28.10.10.2016
Work Directory: /home/tl

Import:

- without Data Import
- User defined CCT (13-ZTU.csv)
- WeldWare Import (*.wwd)
- JMatPro Import single phase (*.jmt)
- JMatPro / SysWeld Import (*.mat)

Material Class:

- Steel
- Steel - without phase transformation
- Aluminium
- Other

Export:

- *MAT_254 Multi Phase Model
- *MAT_270 Single Phase Model Nonlinear
- *MAT_270 Single Phase Model Bilinear

Decimal Separator csv-file--> ,

STATUS:

single phase

DynaWeld-Material - Material Parameter

Material Name: NICROFER-Probe Draht 002-13 Scharma:
Material ID (1 ... 999):
1
Solidus Temperature (Aktivierung Start):
1400
Liquidus Temperatur (Aktivierung End):
1500
History Reset Start Temperature (TASTART):
1250
History Reset End Temperature (TAEND):
1300
Minimum E-Modul (MPa):
10000
Plastic Strain at Ultimate Stress:
0.13
Strain Rate:

- 0.0010
- 0.01
- 0.1
- 1.0
- 10.0
- 100.0
- 1000.0

Settings for Filler / Liquid / Deactivated

E-Modul (MPa):
1000
 Melting

single phase

DynaWeld-Material - Material Parameter

Material Name: from_JMatPro
Material ID (1 ... 999):
1
Solidus Temperature (Aktivierung Start):
1400
Liquidus Temperatur (Aktivierung End):
1500
Latent Heat of Melting (kJ/kg):
270
History Reset Start Temperature (TASTART):
1445.6904
History Reset End Temperature (TAEND):
1495.6904
Minimum E-Modul (MPa):
10000
Plastic Strain at Ultimate Stress:
0.13
 Import electric resistivity from 11-MATERIAL.csv

Settings for Filler / Liquid / Deactivated

- Flow Curve as imported
- Flow Curve according Austenit
- Constant Yield Stress

E-Modul (MPa):
1000
 Melting

Basmaterial: Composition of Phase

Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
0.0	0.25	0.75	0.0	0.0

multi phase

Phase Relation

Target	Source	Yield MPa	Ultimate MPa	Add
DynaWeld	JMatPro / Sysweld P-1 P-2 P-3 P-4 P-5			
Austenit	<input type="checkbox"/>	182.0	555.48	
Ferrit	<input type="checkbox"/>	316.8	586.76	
Perlit	<input type="checkbox"/>	554.3	922.939999999	
Bainit	<input type="checkbox"/>	768.1	1191.35	
Martensit	<input checked="" type="checkbox"/>	842.0	1278.93	
Base Material		494.924999999	838.895	
Filler Liquid		1000	1100	
Tempered Martensit		768.1	1191.35	
Tempered Bainit		554.3	922.939999999	

Material Class:

- Steel
- Steel - without phase transformation
- Aluminium
- Other

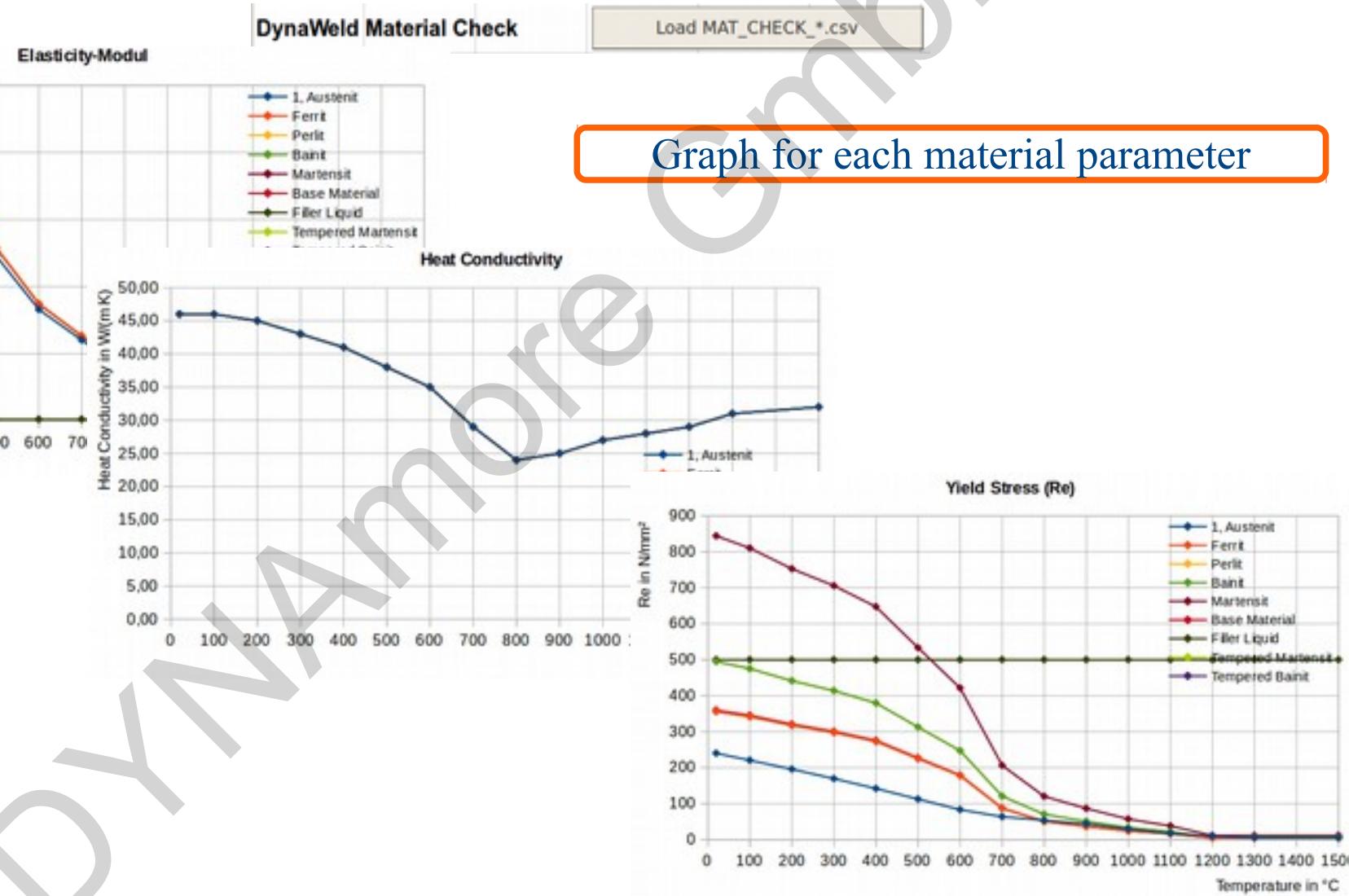
Skip Update Re and Rm according Source Phase Check and End

Settings and Extensions



DynaWeld Material – Documentation

Spreadsheet DynaWeld-Material-Check

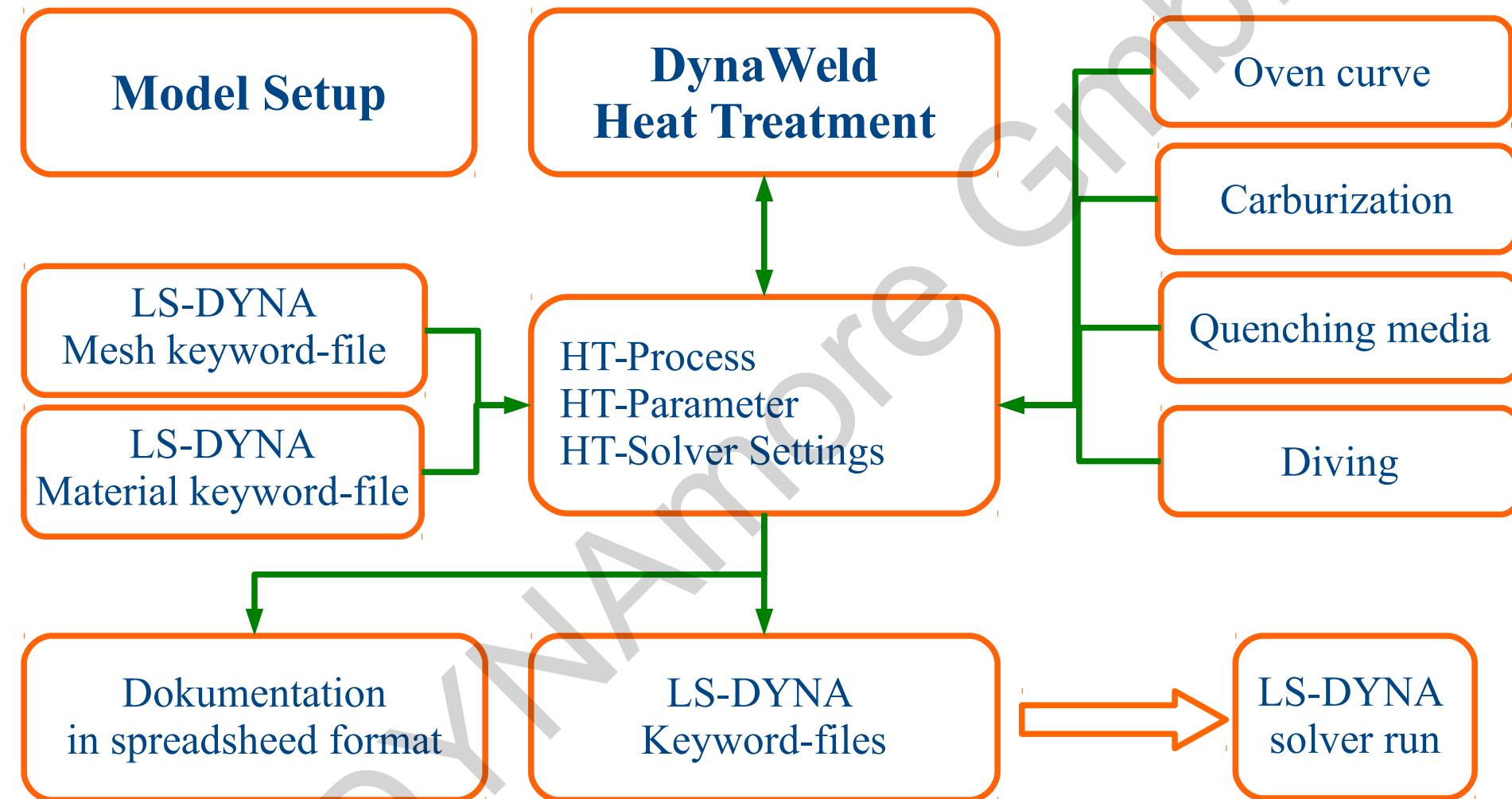




DynaWeld Heat Treatment

Foto: Edyta Łopatecka

DynaWeld – Management for high sofisticated heat treatment simulation setup





DynaWeld Heat Treatment - Process

DYNAmore GmbH



DynaWeld Heat Treatment - Parameter

DYNAmore GmbH



DynaWeld
Welding



Laser welded sheet with tensile test

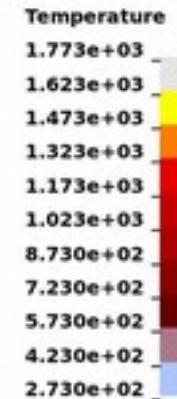
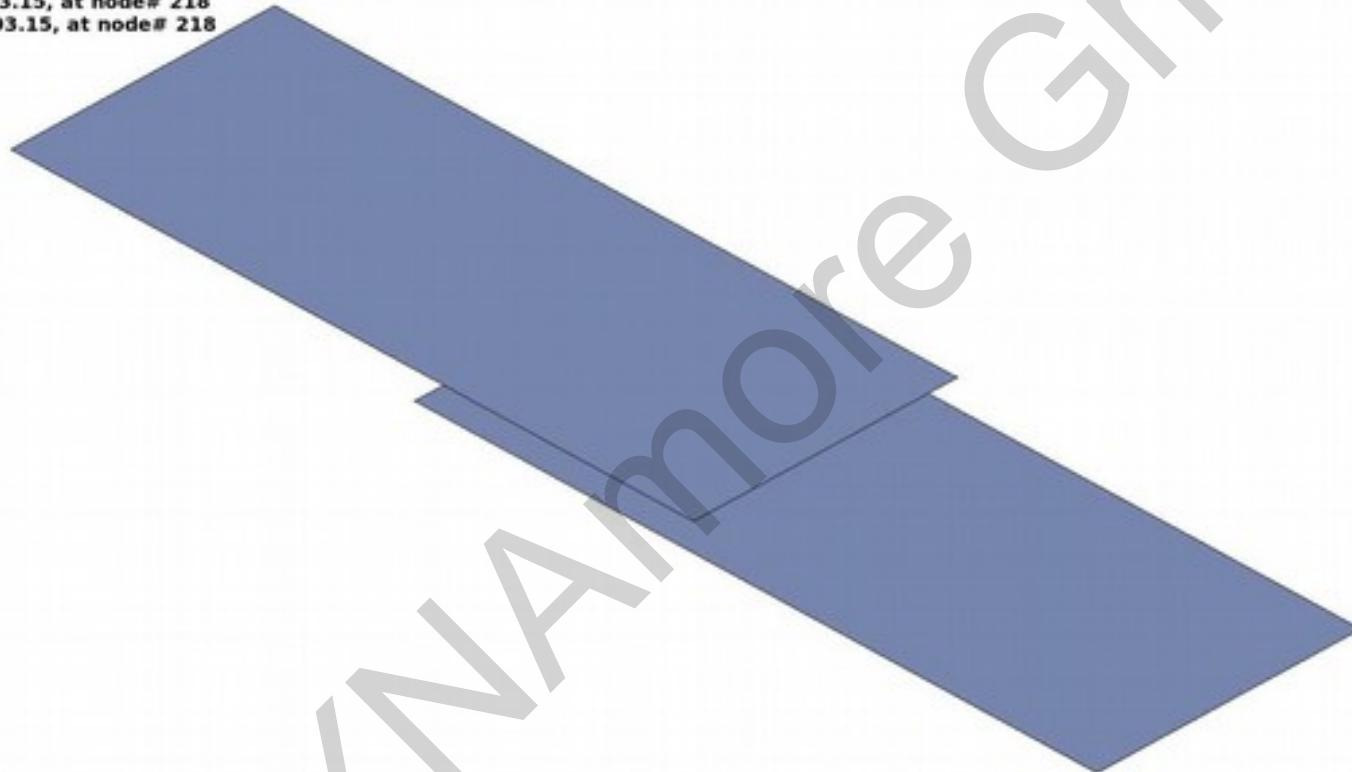
DynaWeld # Weld Contact Shell

Time = 0

Contours of Temperature

min=293.15, at node# 218

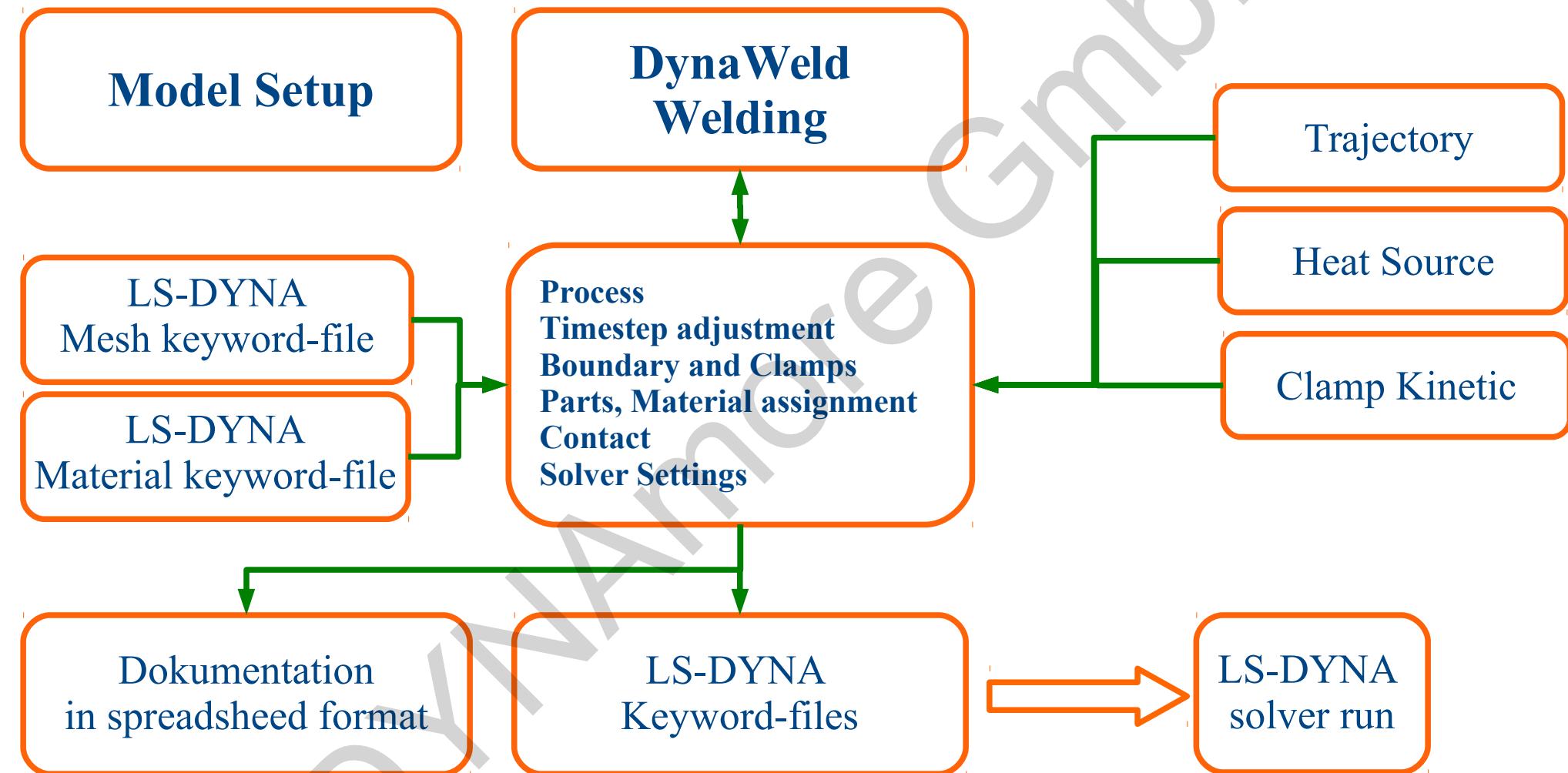
max=293.15, at node# 218



www.loose.at



DynaWeld – Management for high sofisticated welding simulation setup





DynaWeld Process

DynaWeld – Process plan										Save Table		Save All		29.04.16									
Process nr.	Weld ID	Length mm	v mm/s	Duration s	Start s	End s	PAUSE s	Q W	TRLK MOP	TRLZ MOP	r1 af	r2 ar	r3 bR3	b1 cf	b2 br	b3 cr	v1 br / v2	v3 cr / v3	kf	ay			
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	*	*	*	*	*	*	
*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
1	1001	58,75208426	7,5	7,8336	0,0000	7,8336	0,0000	7838,4482	3	10,72505	5,07272	4,91363	1,33183878	90									
2	1002	64,93651425	7,5	8,6582	7,8336	16,4918	5,0000	7838,4482	3	10,72505	5,07272	4,91363	1,26103721	-90									

Types of heat source

surface heat source
volumetric heat source
part heating

Geometric shapes

elipsoid – double elipsoid
cylinder
conus – double conus

Heat input on

shell, shell 2D
solid
segment

Start, end, intermediate time

Multi robots simultaneous

Multiple heat source

auto fill or copy option

Reverse option

Reorder of sequence

Multi layered welds

auto deactivation of
not yet deposit material

SimWeld interface

supports the new LS-DYNA heat source

- on shells and solids
- shell thickness distribution
- energy input control
- sub cycling
- mesh independent
- time step independent



Weldpath definition - trajectory and reference

**Definition with one Nodeset
auto detection of reference**

normal on surface

*BOUNDARY_THERMAL_WELD_TRAJECTORY

Local adjustment:

- rotation
- v-offset reference direction
- w-offset lateral

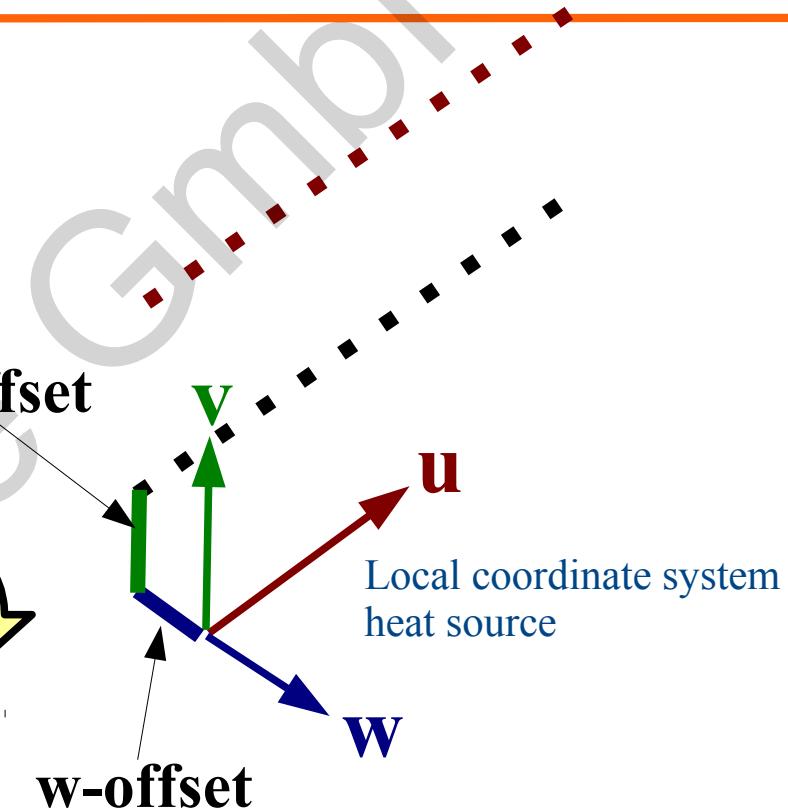
automatic calculation of the
length of trajectory

**Display of trajectory,
reference, startpoint**



Reference NodeSet
Trajectory NodeSet

**Rotation of
reference**



u: Trajectory direction
v: Torch direction
w: Lateral direction

DynaWeld Boundary

Single point constraints (SPC)

Symetry surfaces

Force on Nodes or Node Sets

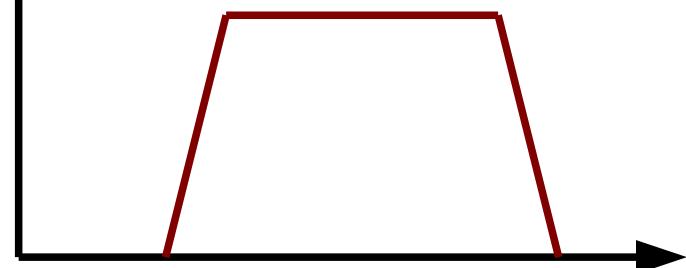
Displacement on Nodes or Node Sets

Force or Displacement:

- user defined ramp at start and end
- local coordinate system
- Predeformation
- Prestress

Force or displacement driven clamps

force
disp



Clamped
force driven or
displacement driven

Clamping

Unclamping



DynaWeld Contact

Standard Contact

R: * _SURFACE_TO_SURFACE_THERMAL
 RSH: * _SURFACE_TO_SURFACE_THERMAL in Area of Heat Sources. BC_FLG = 0
 RG: * _SURFACE_TO_SURFACE_THERMAL IGAP = 1
 RGSH: * _SURFACE_TO_SURFACE_THERMAL IGAP = 1 in Area of Heat Sources. BC_FLG = 0
 RO: * ONE_WAY_SURFACE_TO_SURFACE_THERMAL
 ROX: * ONE_WAY_SURFACE_TO_SURFACE (without Thermal Contact)
 RM: * SURFACE_TO_SURFACE_MORTAR_THERMAL
 RS: * SURFACE_TO_SURFACE_SMOOTH_THERMAL (SOFT = 0)
 F: * TIED_SURFACE_TO_SURFACE
 FSH: * TIED_SURFACE_TO_SURFACE in Area of Heat Sources. BC_FLG = 0
 FO: * TIED_SURFACE_TO_SURFACE_OFFSET
 FOSH: * TIED_SURFACE_TO_SURFACE_OFFSET in Area of Heat Sources. BC_FLG = 0
 FCO: * TIED_SURFACE_TO_SURFACE_CONSTRAINED_OFFSET
 FCOSH: * TIED_SURFACE_TO_SURFACE_CONSTRAINED_OFFSET in Area of Heat Sources. BC_FLG = 0
 N: * NODES_TO_SURFACE (without Thermal contact)
 NI: * NODES_TO_SURFACE_INTERFERENCE (without Thermal contact)
 SO: SLIDING_ONLY
 R2D: * 2D_AUTOMATIC_SURFACE_TO_SURFACE_THERMAL (SSID, MSID := ID of Part Sets)
 F2D: * 2D_AUTOMATIC_TIED_THERMAL (SSID, MSID := ID of Part Sets)

Additional Options for Standard Contact to drive MST and SST:

*M0: MST = 0 (M0 0 := zero)

*S0: SST = 0

*MOS0: MST = 0 and SST = 0

Syntax: append after Standard contact R, RSH, RG, RGSH, RO, ROX, RM, F, FSH, FO FOS

Example: ROM0, ROS0, ROM0S0

Additional Options for Standard Contact to drive Smooth Option:

S*: SOFT = 0 SBOPT = 3

Syntax: prefix bevor Standard contact R, RSH, RG, RGSH, RO, ROX, RM

Example: SR SRM SROMO

Welding Contact:

WRnnn: Welding Contact Friction
 nnn := Fusion Temperature

mechanical and thermal

Welding contact

change friction → tied by temperature

Friction contact

Tied contact

Shell edge to surface or solid

friction or tied contact

mechanical

Node to surface

auto-correct of large penetration

mechanical only

Special features

smooth option for curved sheets

mortar option for implicit analysis

shell thickness considered automatically



DynaWeld-Welding Input file generator

Analysis Options

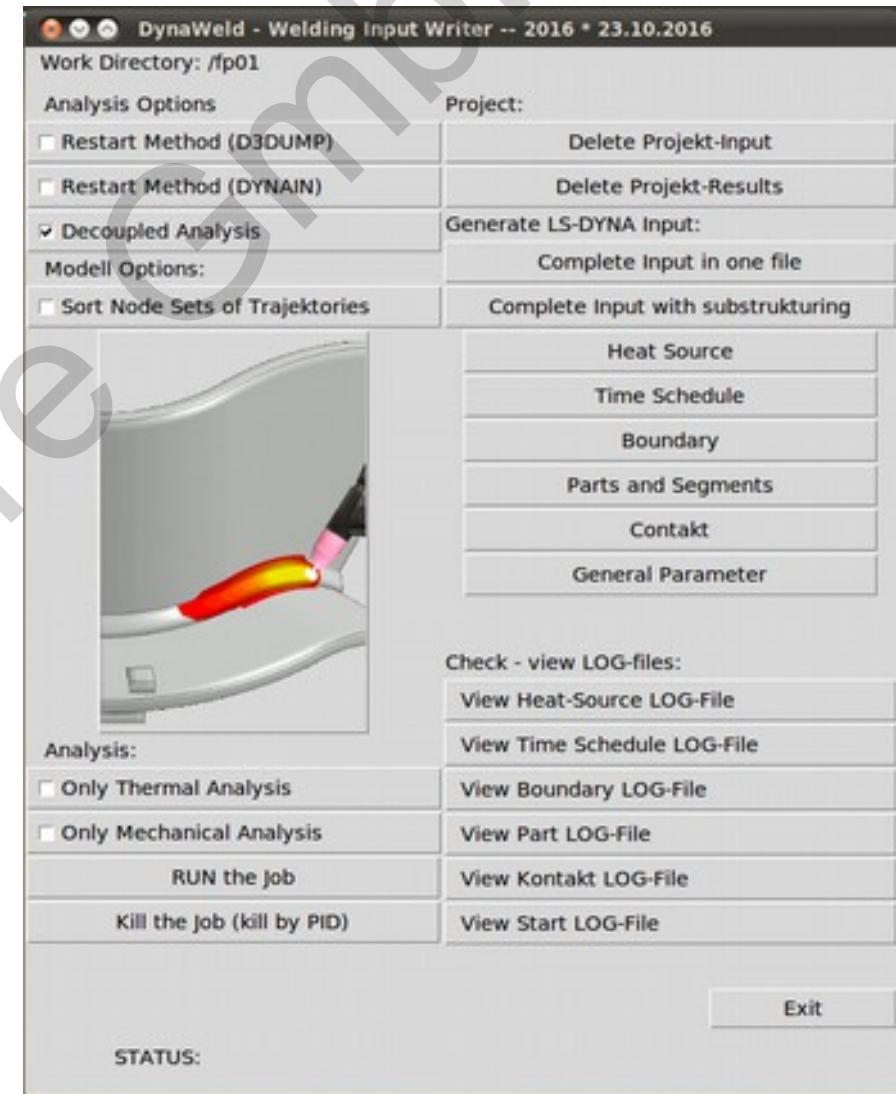
Clean Work Directory

Generate Input

- one file
- structured input
- single task creation

Check options

**Run
and
Kill**





DynaWeld Tools

Create Variants

Heat input check

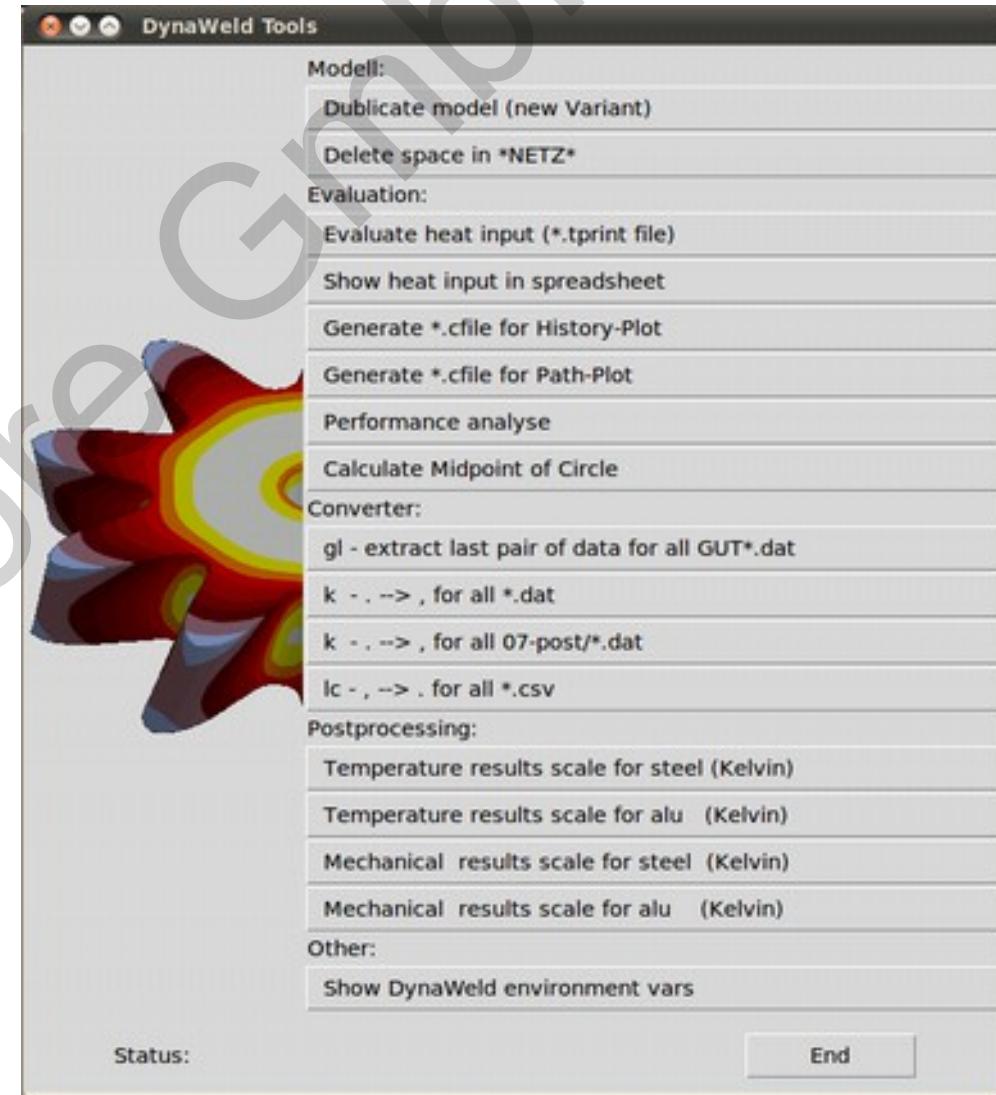
Automatisation
for results along path
or time history at nodes

Performance analyse

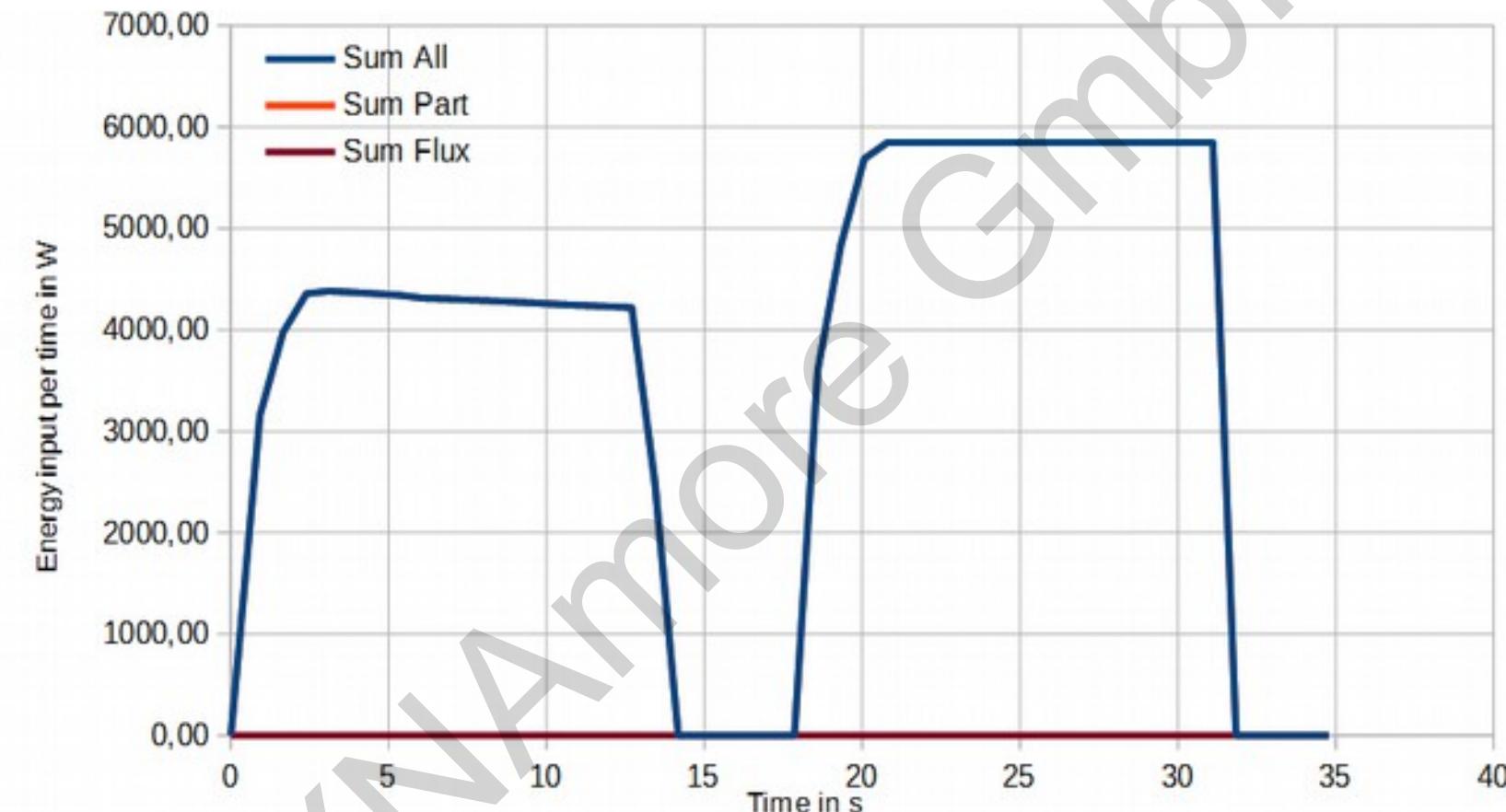
Midpoint by 3 Points

Conversion utilities

Launch postprocessing file
with
DynaWeld temperature scale



Check of heat input and final adjustment



Heat Input Adjustment:

WID	input	target	factor	kf old	kf new
1001	3678	4000	1,09	1,00	1,09
1002	5658	5528	0,98	1,00	0,98

right energy input
right results

Conclusion

LS-DYNA

Material Models
representing physics
within phase kinetics

from Process
parameter to solver
keyword input

DynaWeld

Succes
in industrial applied
simulation for
manufacturing
processes with high
sophisticated
physical phenomena
like
Heat Treatment
and Welding

DYNAJET
WELDING

DYN



Foto: Martin Loose