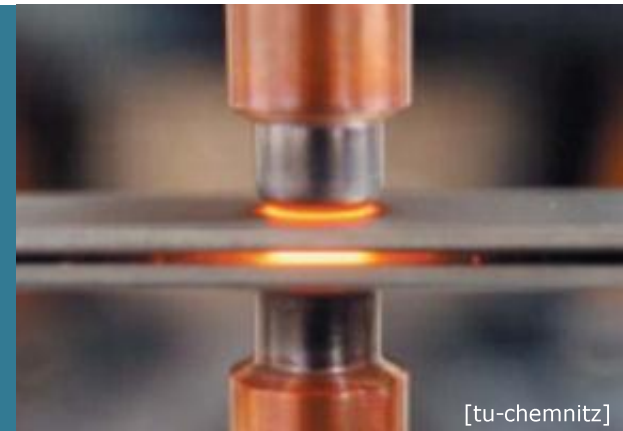


Process Simulation of Resistance Spot Welding



[tu-chemnitz]

Ingolf Lepenies*
Krassen Anakiev

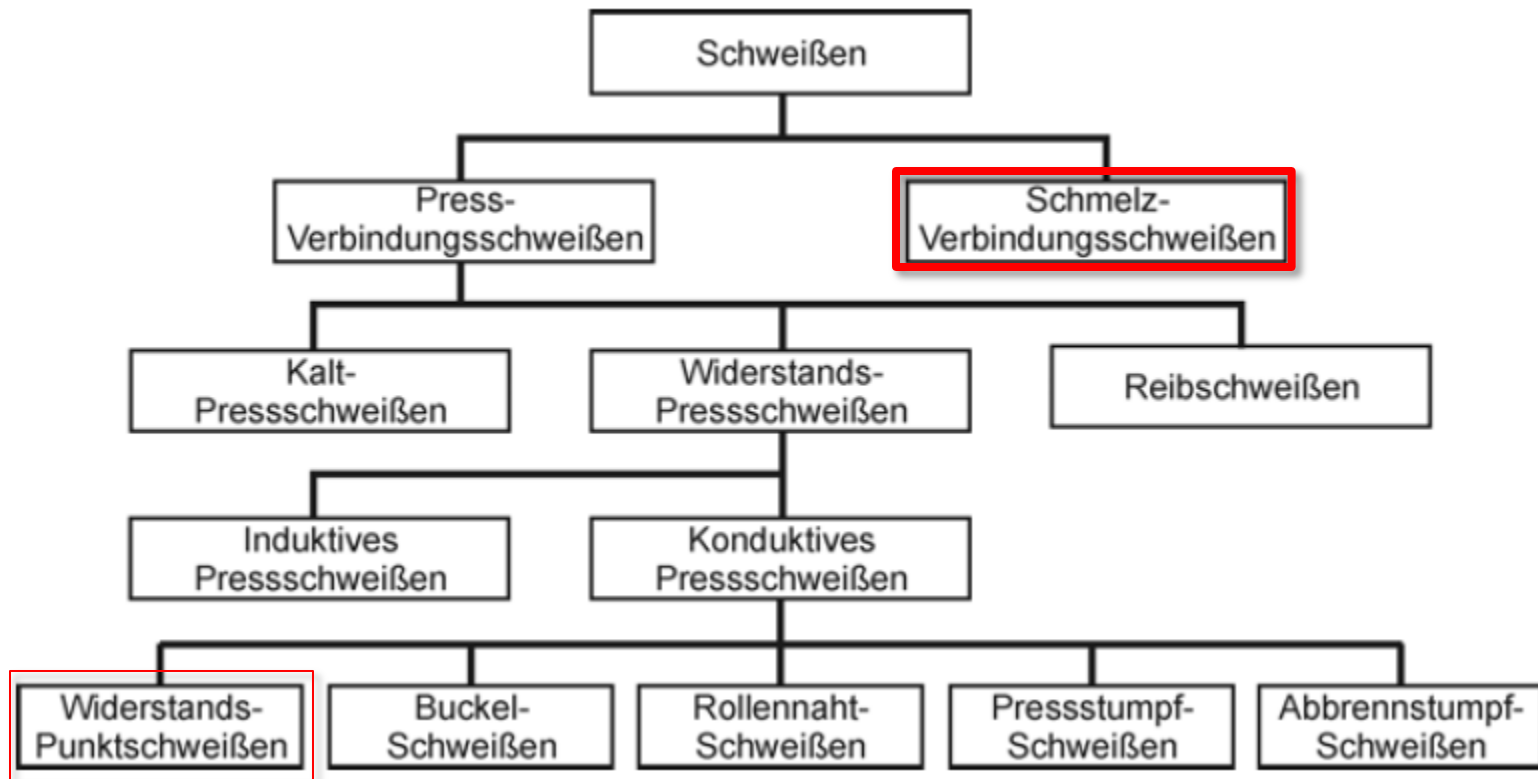
Multiphysics in LS-DYNA
17.03.2014

Contents

- **coupled mechanical and thermal solvers**
 - heat source models

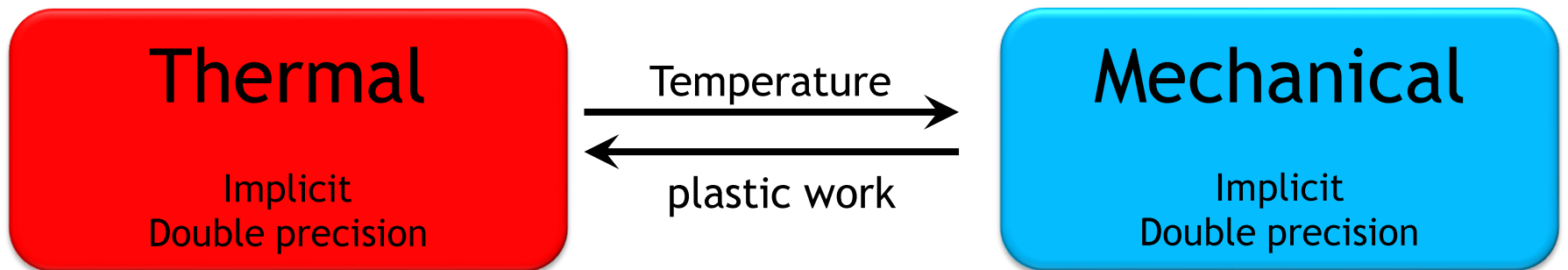
- **coupled mechanical, thermal and electro-magnetic solvers**
 - motivation, aim of the project
 - model setup, LS-DYNA v7.x - *EM cards
 - model parameter
 - example of a fully 3d process simulation of resistance spot welding
 - challenging problems

Types of welding



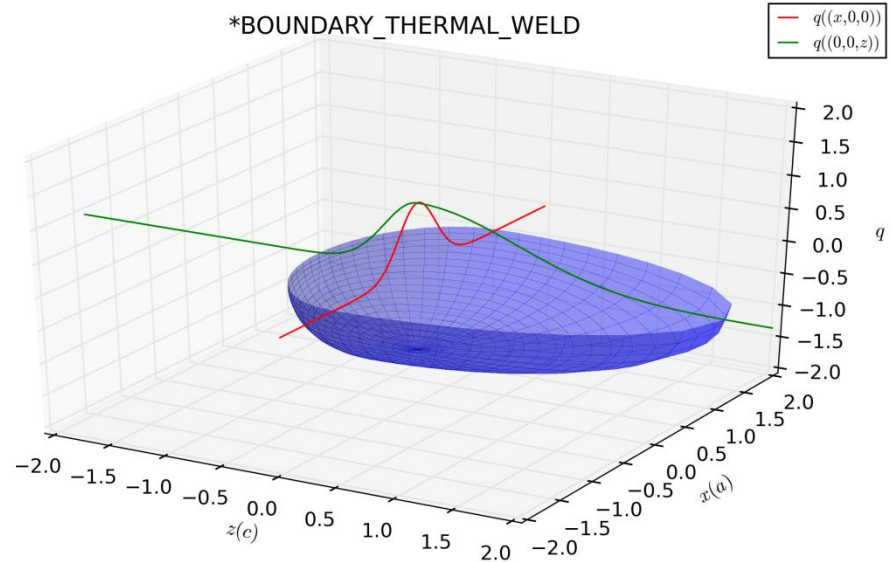
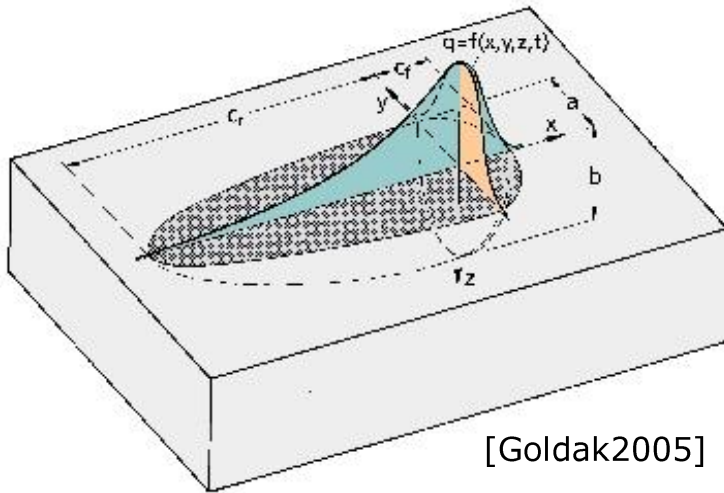
[diltthey2006]

coupled mechanical and thermal solvers

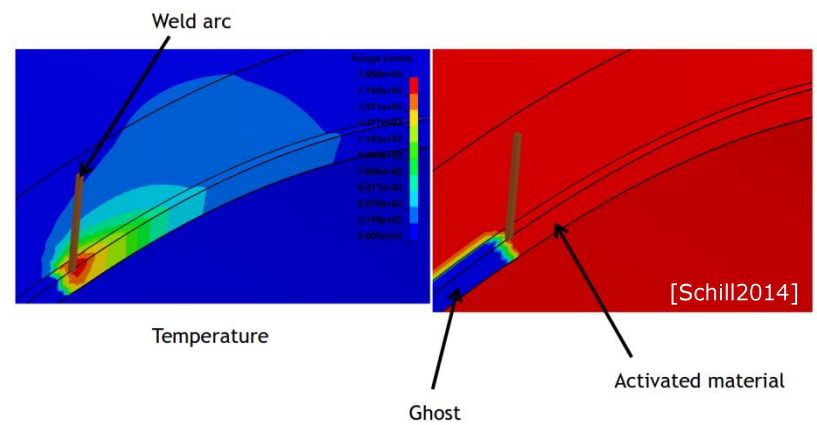


*BOUNDARY_THERMAL_WELD

■ GOLDAK's Double Ellipsoidal Power Density Distribution



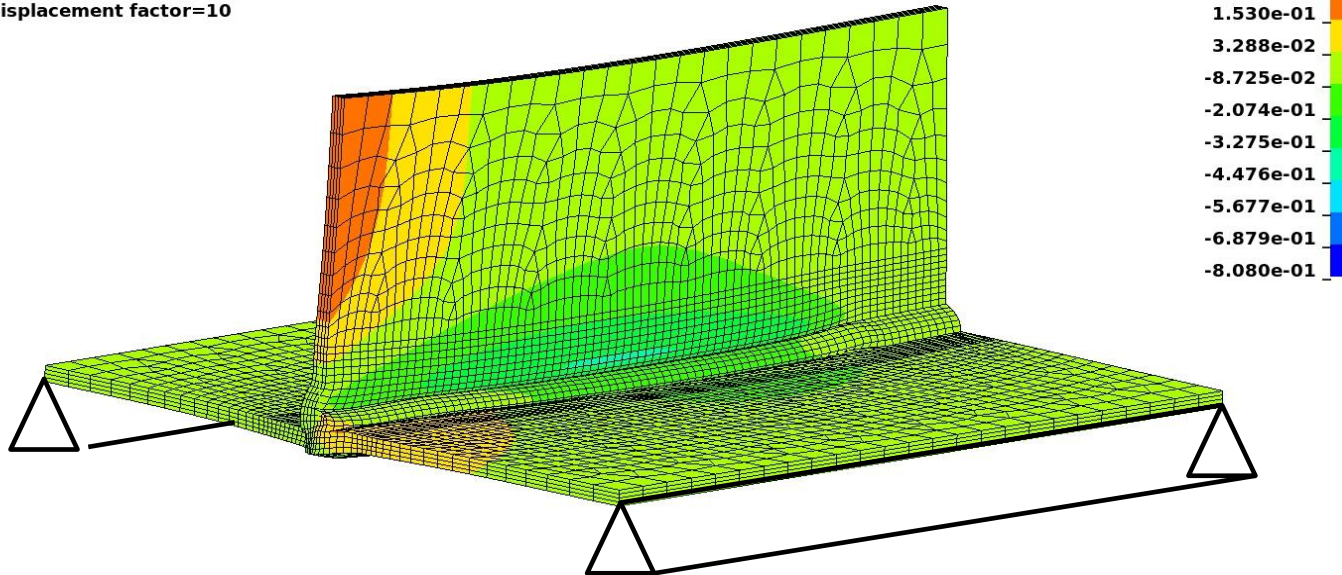
- definition of the heat source in LS-DYNA with *BOUNDARY_THERMAL_WELD
- relative movement of heat source and parts



LS-DYNA: Deformation (t=33.9 s)

Verschiebung u_z [mm] t=33.9 s, Darstellung 10-fach überhöht

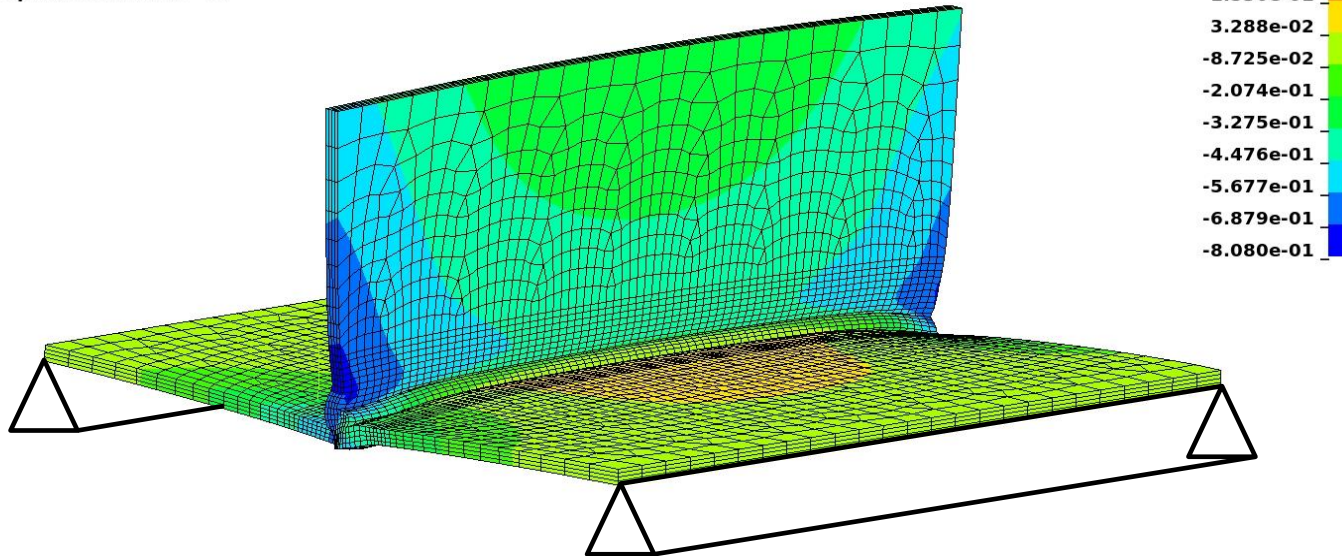
Time = 33.908
Contours of Z-displacement
min=-0.609782, at node# 7557
max=0.246563, at node# 23663
max displacement factor=10



LS-DYNA: Deformation (t=499.0 s)

Verschiebung u_z [mm] t=499 s, Darstellung 10-fach überhöht

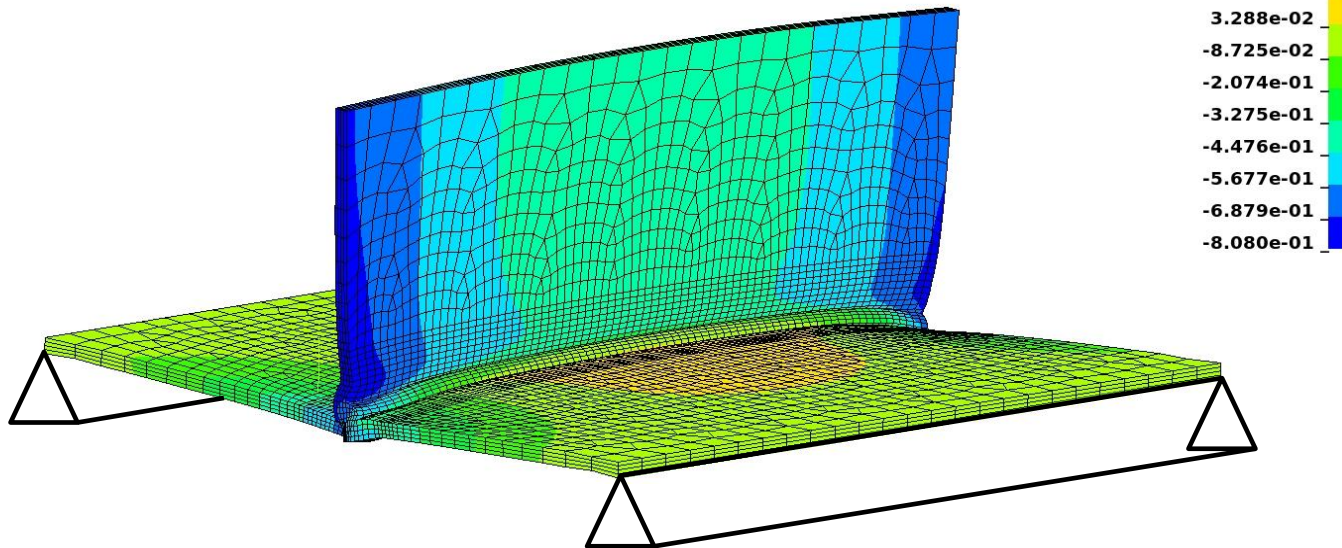
Time = 498.4
Contours of Z-displacement
min=-0.738878, at node# 14352
max=0.160208, at node# 6528
max displacement factor=10



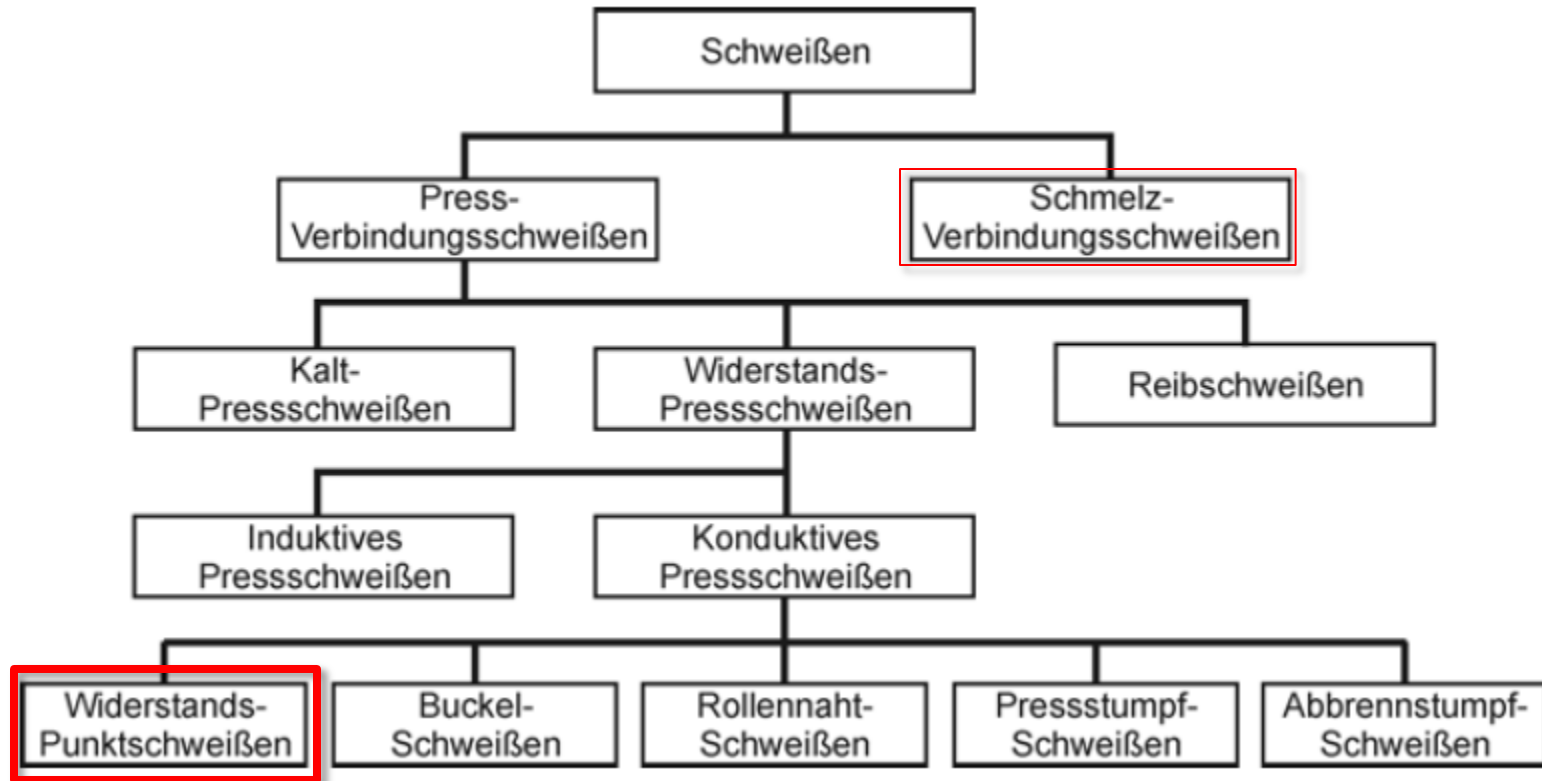
LS-DYNA: Deformation (t=5000. s)

Verschiebung u_z [mm] t=5000 s, Darstellung 10-fach überhöht

Time = 5000
Contours of Z-displacement
min=-0.807991, at node# 14362
max=0.189084, at node# 6528
max displacement factor=10

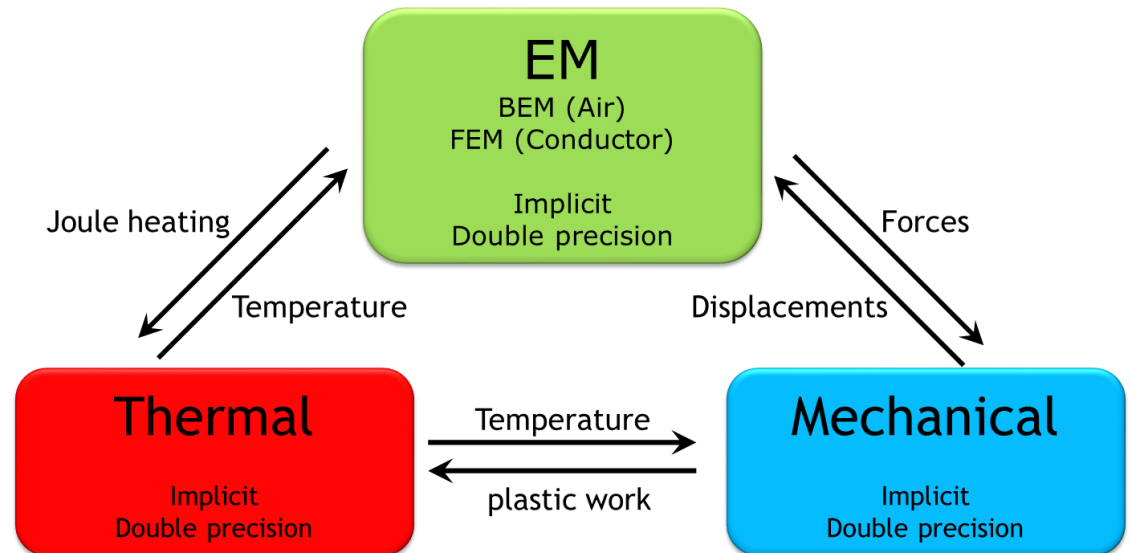
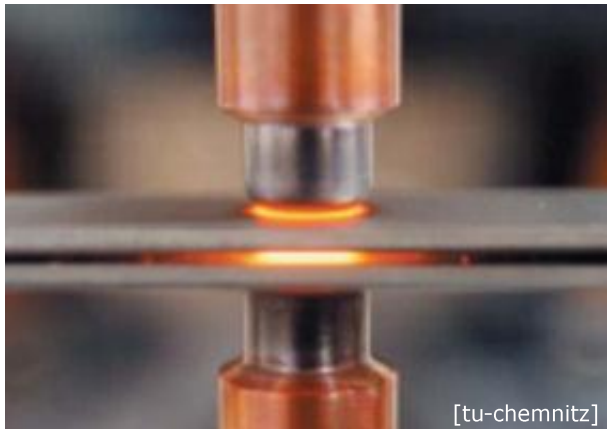


Types of welding

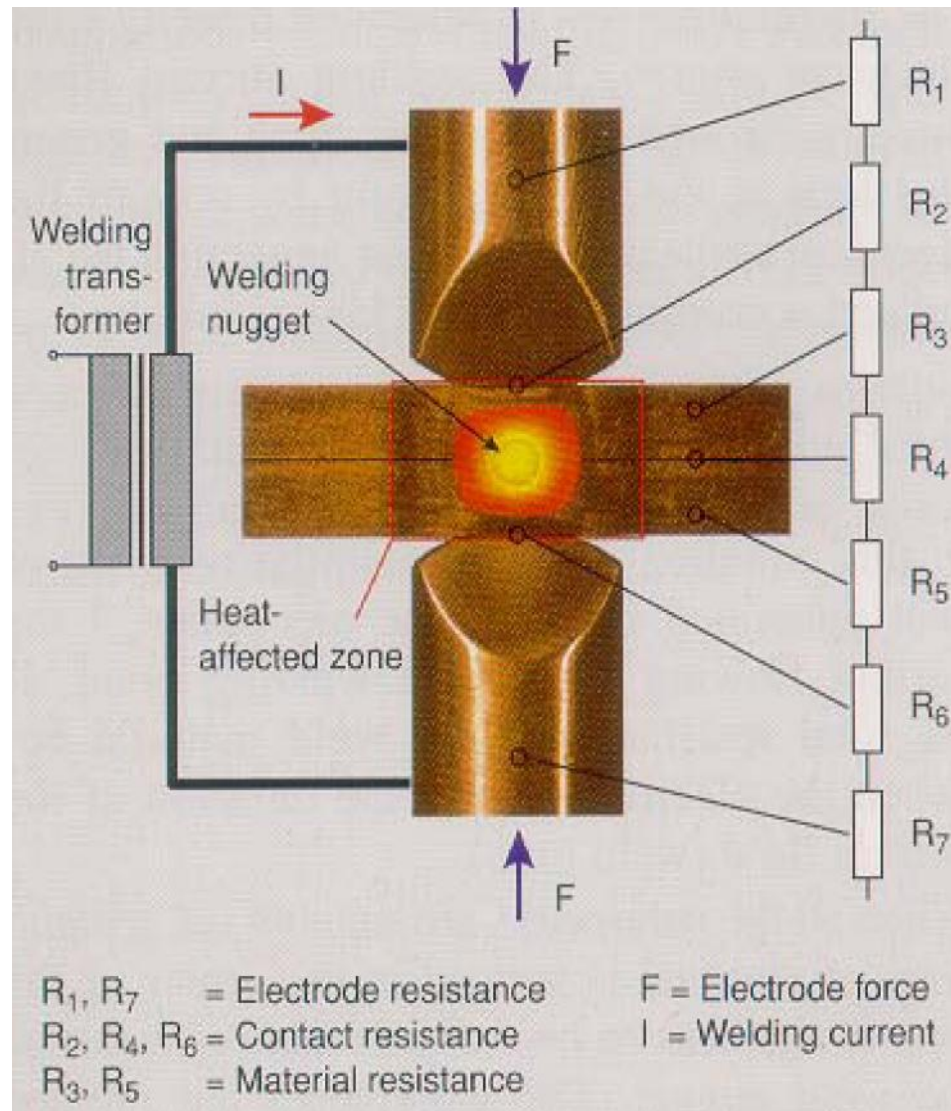


[diltthey2006]

coupled mechanical, thermal and electro-magnetic solvers

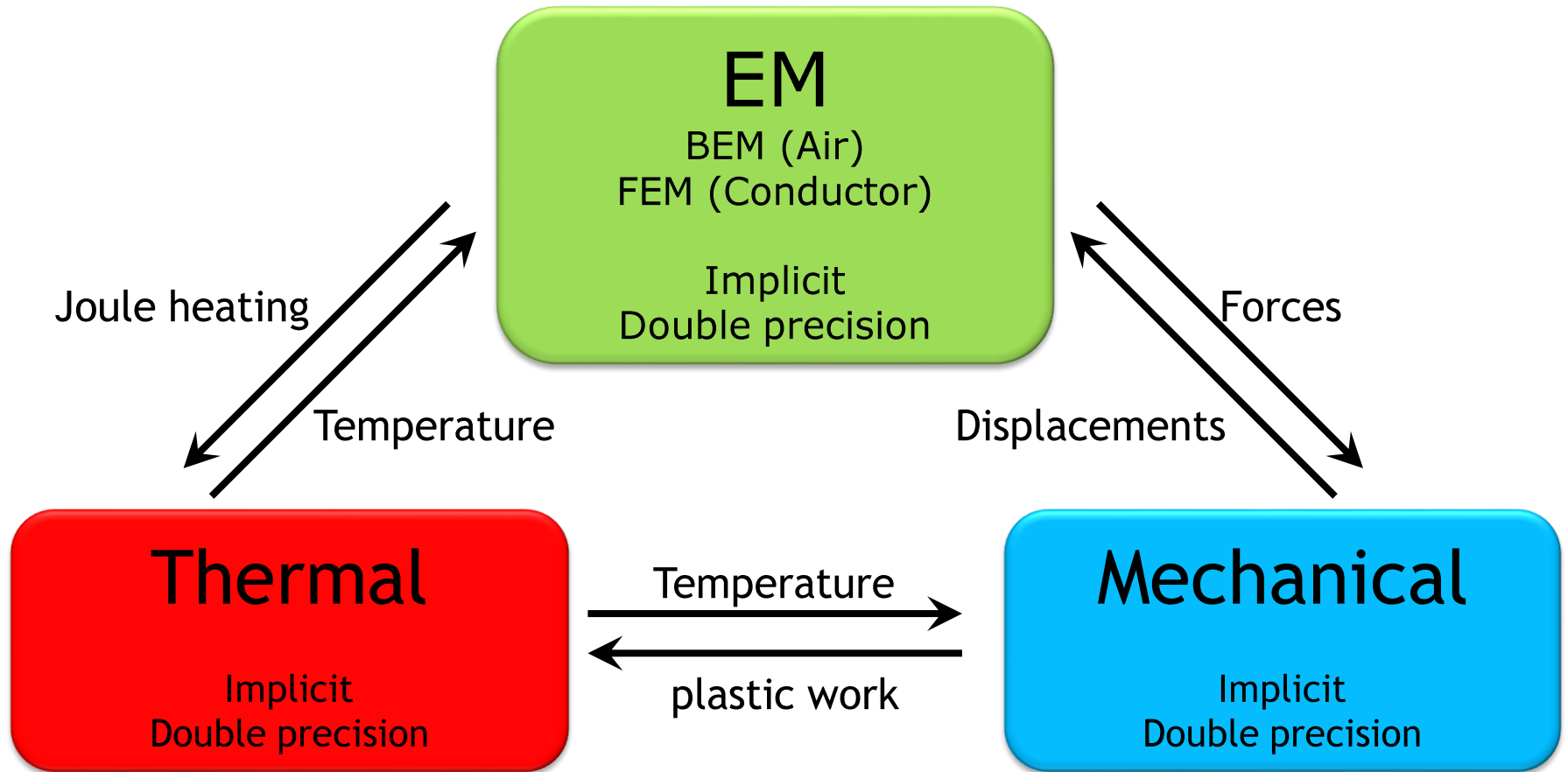


Analysis of the welding process



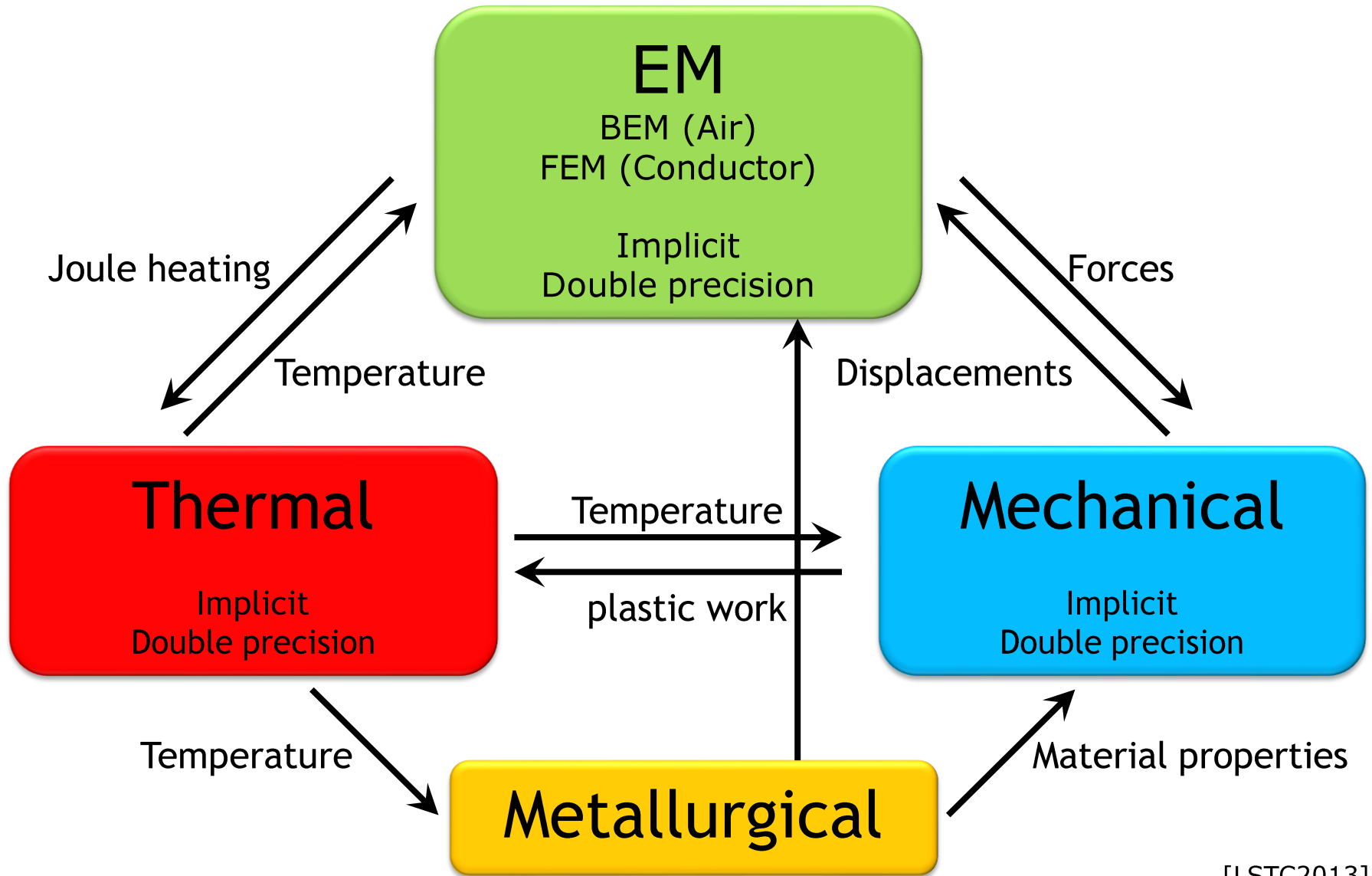
[greitmann2013]

coupled mechanical, thermal and electro-magnetic solvers



[LSTC2013]

coupled mechanical, thermal and electro-magnetic solvers



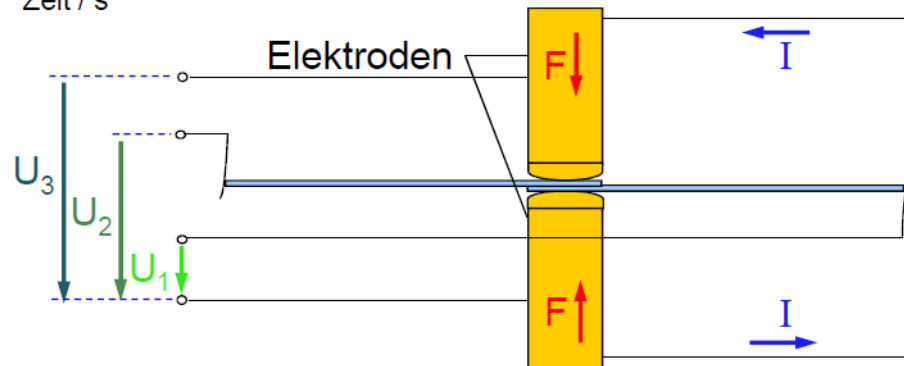
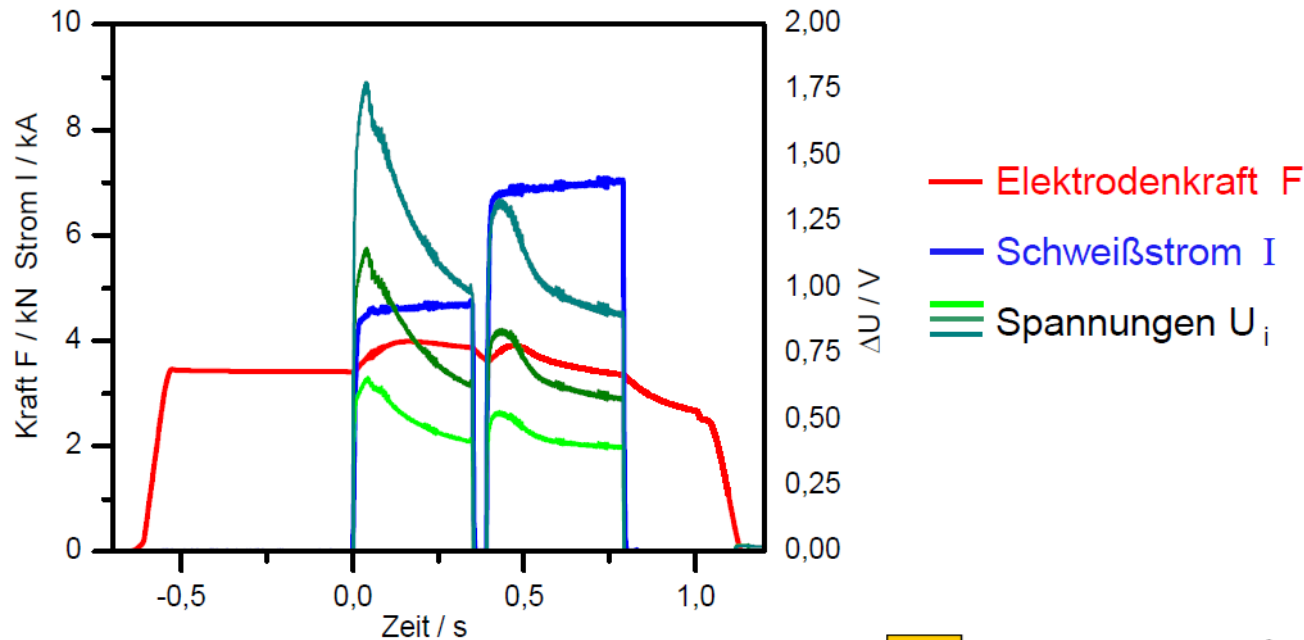
[LSTC2013]

LS-DYNA - Resistance Welding Simulation

- Double precision
- Fully implicit
- 2D axisymmetric solver / 3D solver
- **strongly coupled mechanical-thermal-EM solver**
- Solid elements for conductors. Shells can be isolators.
- SMP and MPP versions available
- Dynamic memory handling
- Automatically coupled with LS-DYNA solid and thermal solvers.
- New set of keywords starting with *EM for the solver
- FEM for conducting pieces only, **no air mesh needed** (FEM-**BEM** method)

Typical welding process

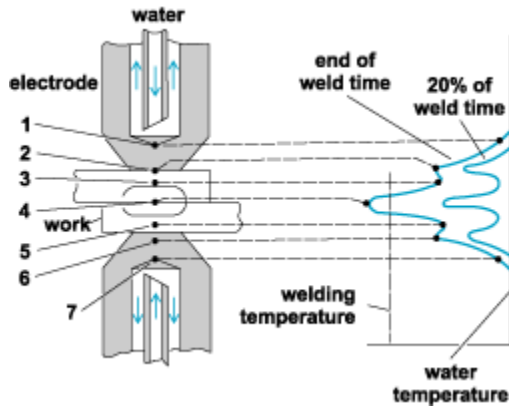
- Typical force, current and voltage curves during the resistance spot welding (from [wick2012])



[wick2012]

Aim of the process simulation

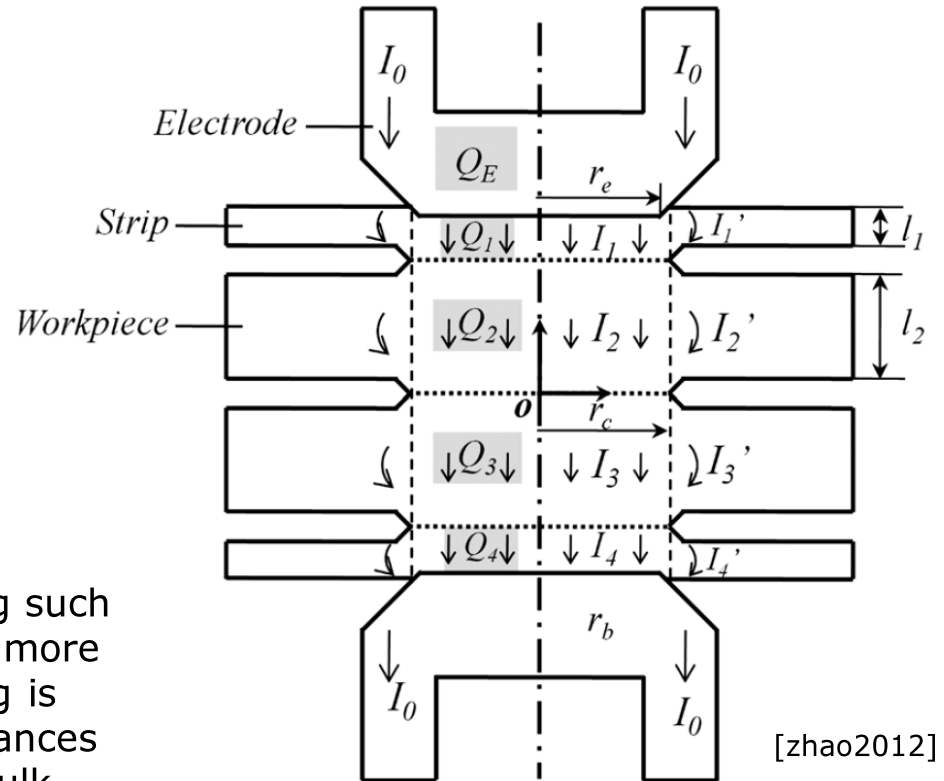
- Heat generation, temperature history, material structure in dependence of the (contact) resistance



[<http://www.answers.com/topic/spot-welding>]

“Furthermore, with aluminium metal being such a good electrical conductor (~three times more than steel), heat generated during welding is primarily obtained from the contact resistances at the faying surfaces, and not from the bulk material resistance.

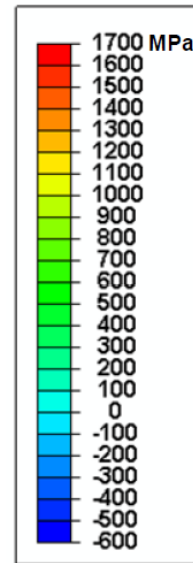
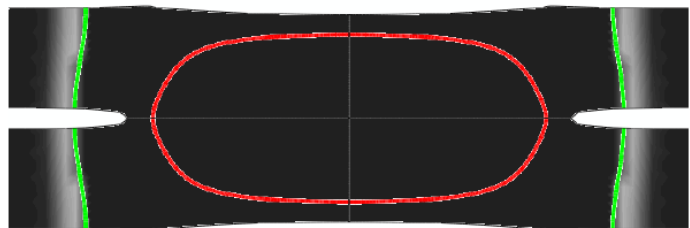
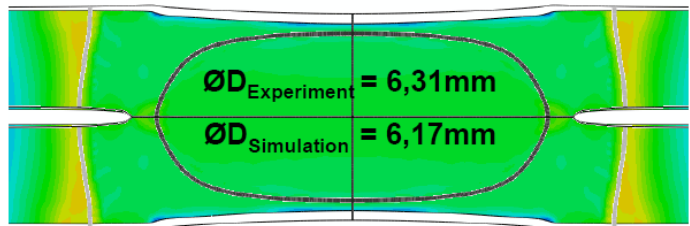
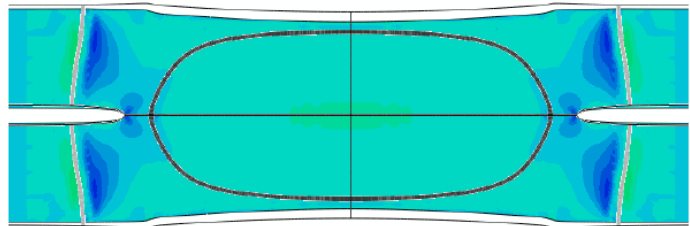
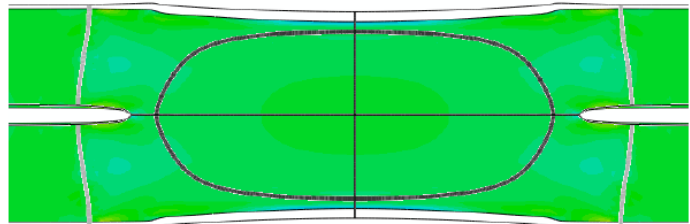
Resistance spot welding of aluminium is therefore a **surface-critical process**”
[alueurope.eu]



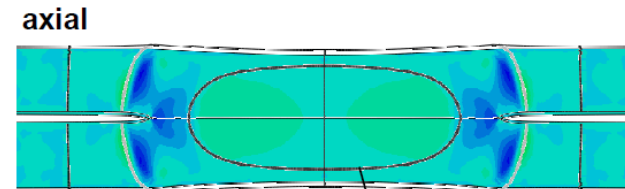
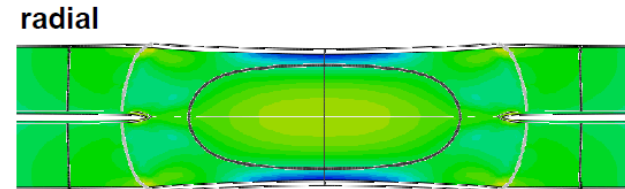
$$Q = \int_{t=t_0}^{t=t_s} I^2(t) R_{ges}(t) dt$$

Aim of the process simulation

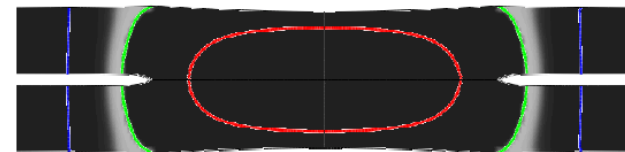
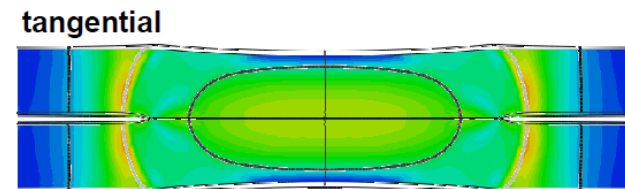
■ Residual stresses, nugget size [MPA Stuttgart - wick2012]



22MnB5+AS / 22MnB5+AS, **Blechdicke 1,5 mm**



$\varnothing D_{\text{Experiment}} = 4,26\text{mm}$ $\varnothing D_{\text{Simulation}} = 4,18\text{mm}$

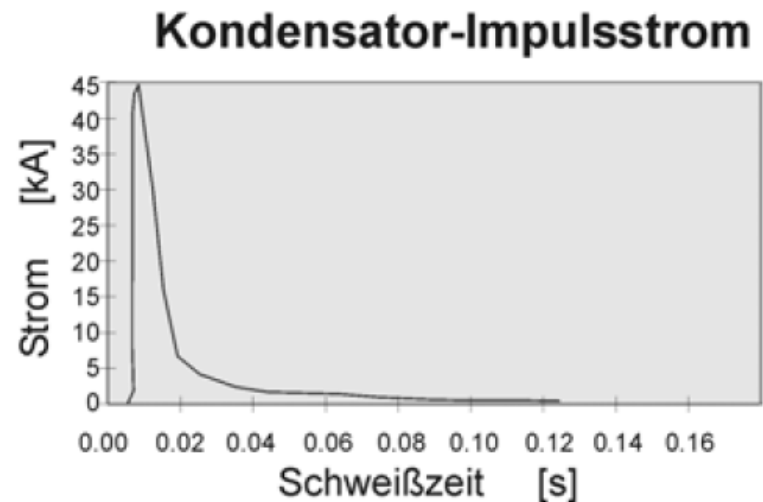
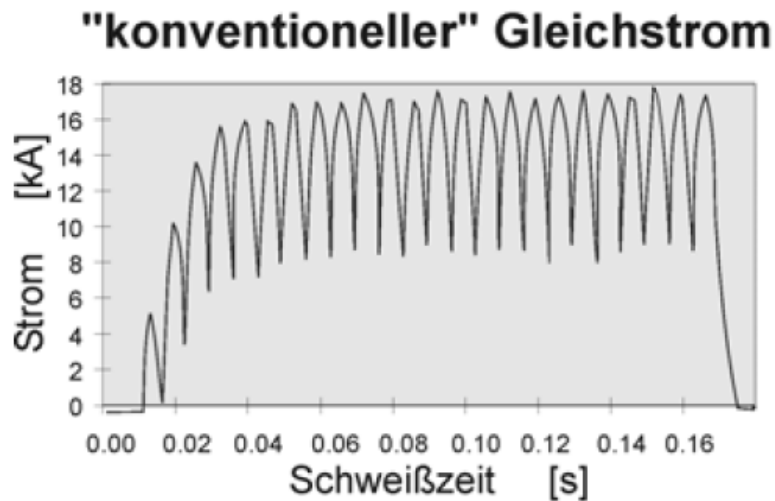
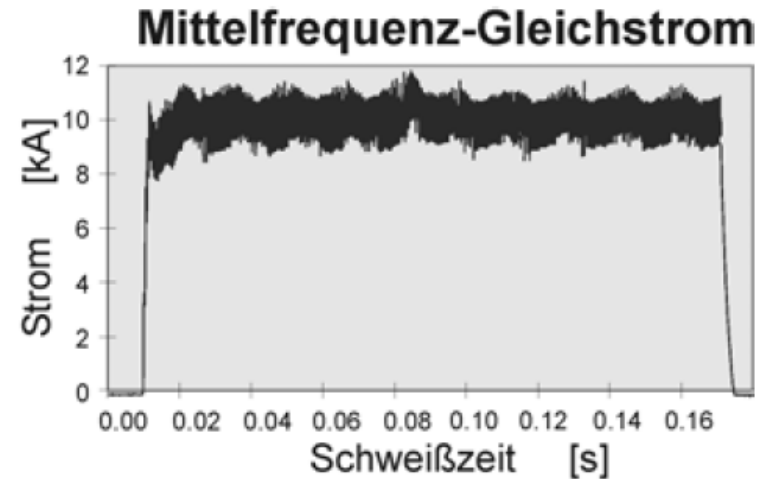
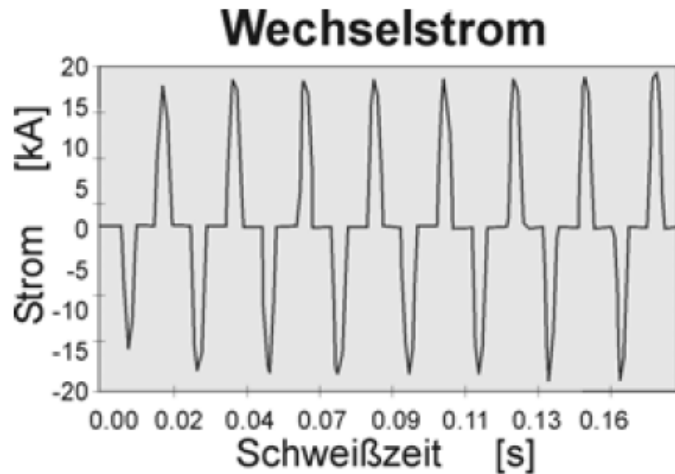


Erweichungszone

22MnB5+AS / 22MnB5+AS, **Blechdicke 1,0** [wick2012]

Aim of the process simulation

■ Influence of the current type



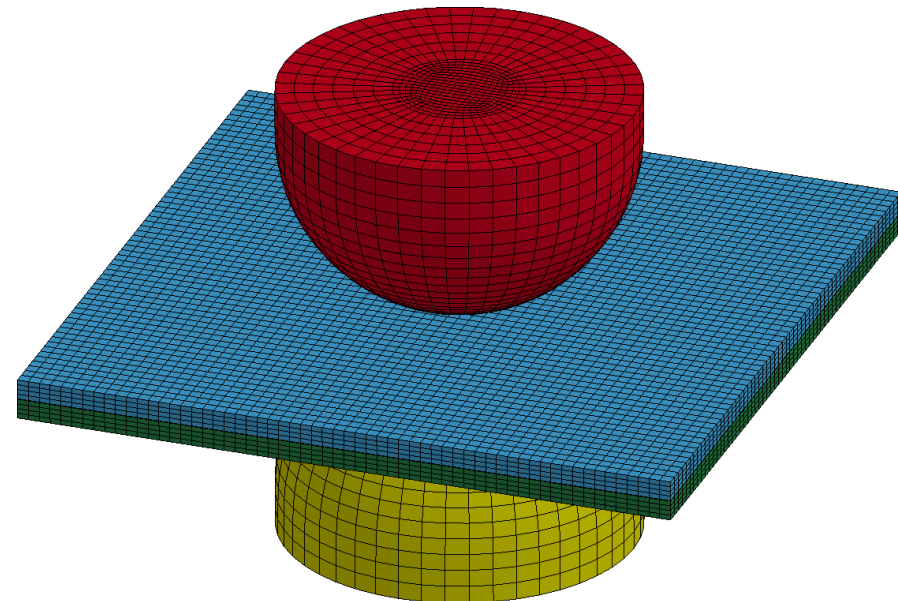
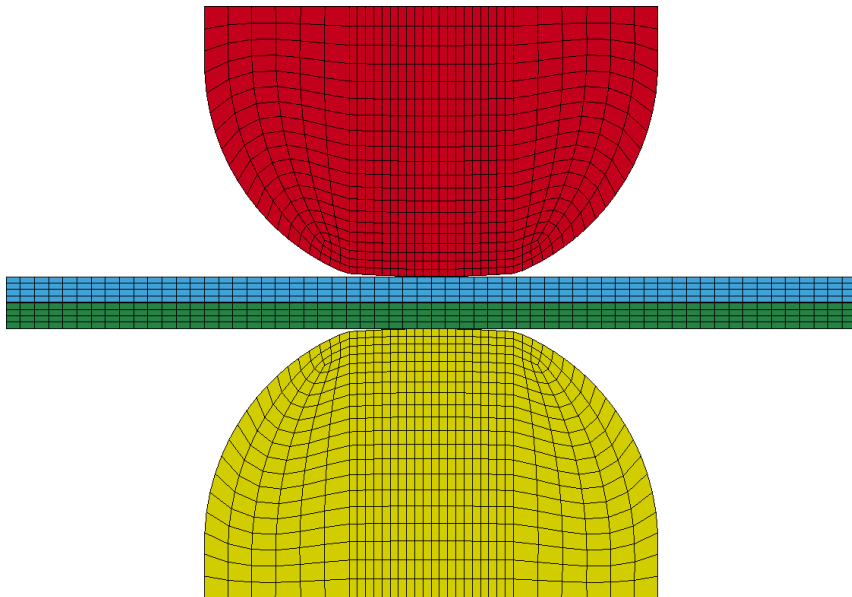
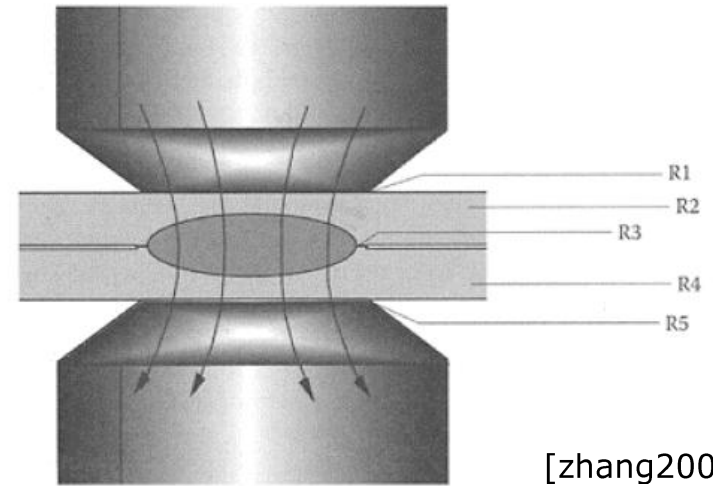
[dilthey2006]

Geometry

■ 2 Electrodes

- only foot of the electrode meshed
- electrode shape according DIN 5821

■ 2 metal sheets



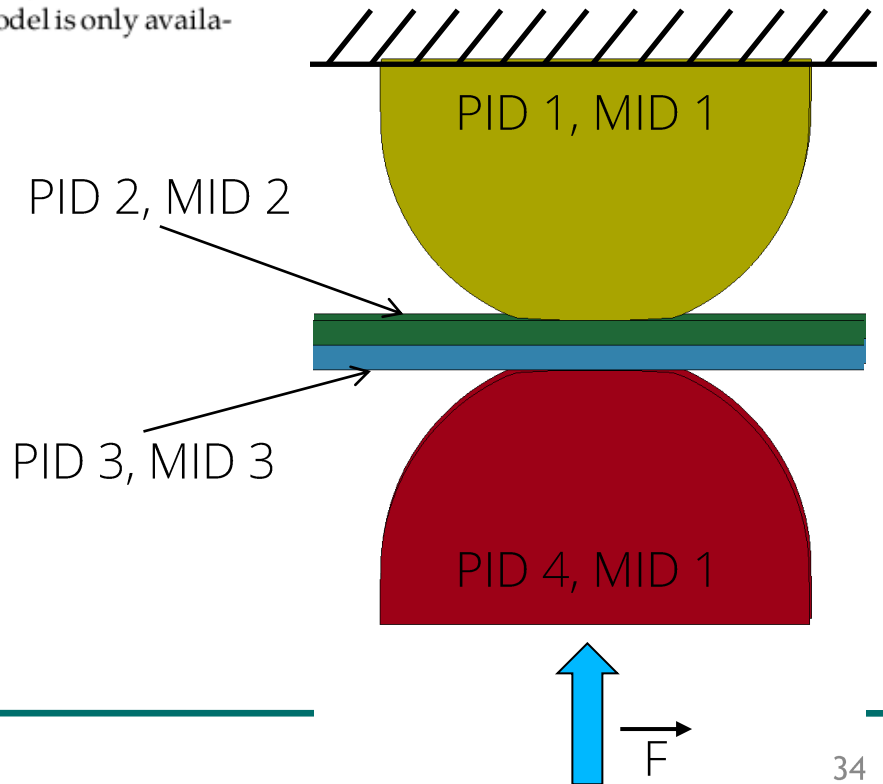
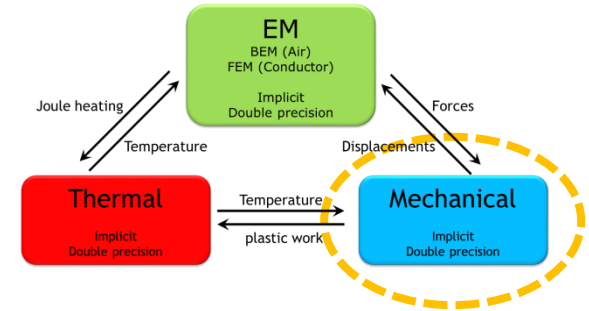
Mechanical Input

- Part definition
- Material definition (mechanical properties)

*MAT_CWM

This is material type 270. This is a thermo-elastic-plastic model with kinematic hardening that allows for material creation as well as annealing triggered by temperature. The acronym CWM stands for Computational Welding Mechanics, Lindström (2013), and the model is intended to be used for simulating multistage weld processes. This model is only available for solid elements.

- Boundary conditions
- Load conditions - Force



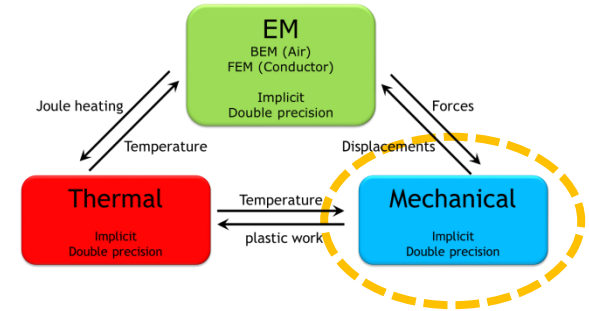
Mechanical Input

■ e.g. *MAT_CWM

Card 1	1	2	3	4	5	6	7	8
Variable	MID	RO	LCEM	LCPR	LCSY	LCHR	LCAT	BETA

Card 2	1	2	3	4	5	6	7	8
Variable	TASTART	TAEND	TLSTART	TLEND	EGHOST	PGHOST	AGHOST	

RO	Material density	TASTART	Annealing temperature start
LCEM	Load curve for Young's modulus as function of temperature	TAEND	Annealing temperature end
LCPR	Load curve for Poisson's ratio as function of temperature	TLSTART	Birth temperature start
LCSY	Load curve for yield stress as function of temperature	TLEND	Birth temperature end
LCHR	Load curve for hardening modulus as function of temperature	EGHOST	Young's modulus for ghost (quiet) material
LCAT	Load curve (or table) for thermal expansion coefficient as function of temperature (and maximum temperature up to current time)	PGHOST	Poisson's ratio for ghost (quiet) material
BETA	Fraction isotropic hardening between 0 and 1	AGHOST	Thermal expansion coefficient for ghost (quiet) material
	EQ.0: Kinematic hardening	T2PHASE	Temperature at which phase change commences
	EQ.1: Isotropic hardening	T1PHASE	Temperature at which phase change ends



Thermal Input

- Initial temperature
- Material definition (thermal properties)

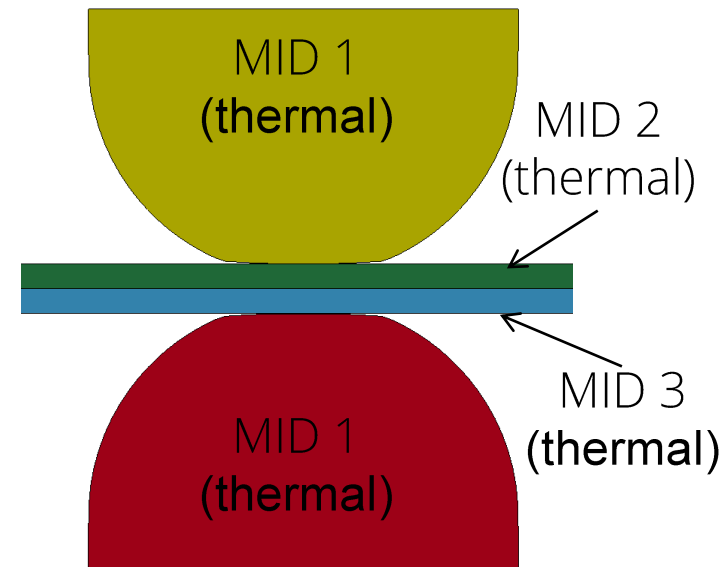
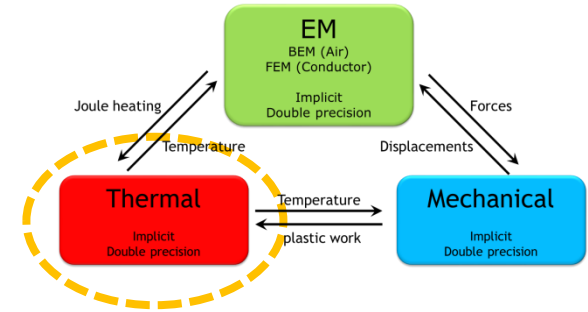
*MAT_THERMAL_CWM

This is thermal material type 7. It is a thermal material with temperature dependent properties that allows for material creation triggered by temperature. The acronym CWM stands for Computational Welding Mechanics and the model is intended to be used for simulating multistage weld processes in combination with the mechanical counterpart, *MAT_CWM.

Card 1	1	2	3	4	5	6	7	8
Variable	TMID	TRO	TGRLC	TGMULT				

Card 2	1	2	3	4	5	6	7	8
Variable	LCHC	LCTC	TLSTART	TLEND	TISTART	TIEND	HGHOST	TGHOST

LCHC Load curve for specific heat as function of temperature
 LCTC Load curve for thermal conductivity as function of temperature
 TLSTART Birth temperature of material start
 TLEND Birth temperature of material end
 TISTART Birth time start
 TIEND Birth time end
 HGHOST Specific heat for ghost (quiet) material
 TGHOST Thermal conductivity for ghost (quiet) material



Electro-Magnetical Input

■ Material definitions (incl. electromagnetical properties)

***EM_MAT_001**

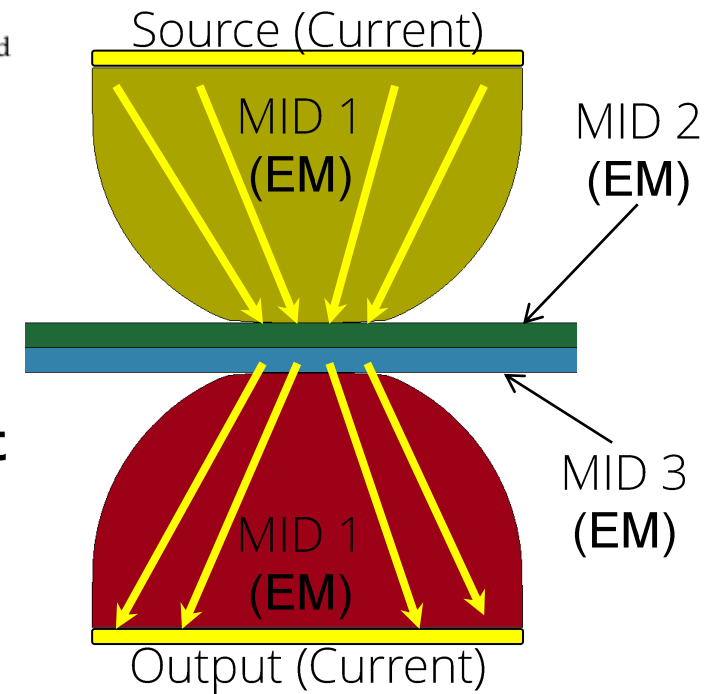
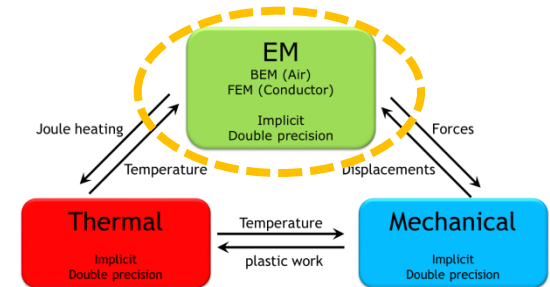
Purpose: Define the electromagnetic material type and properties for a material whose permeability equals the free space permeability.

***EM_EOS_TABULATED1**

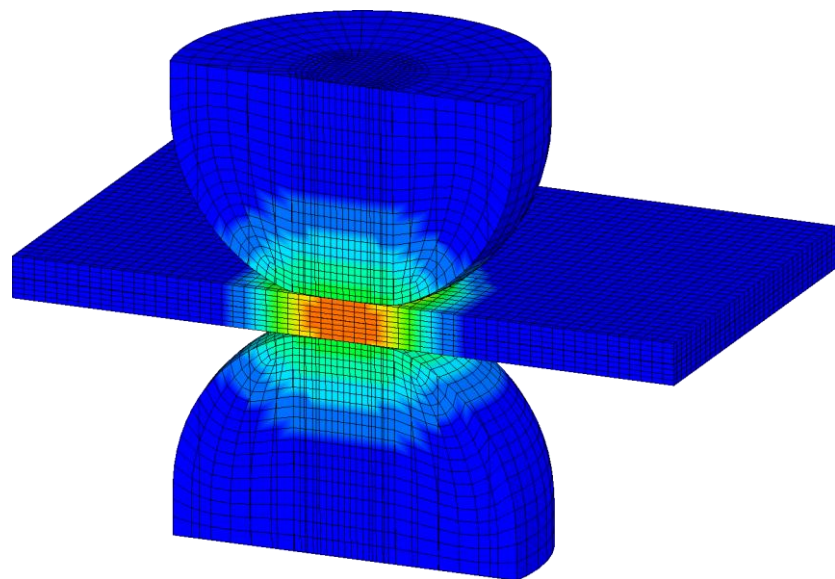
Purpose: Define the electrical conductivity as a function of temperature by using a load curve.

■ Definition of an electrical circuit

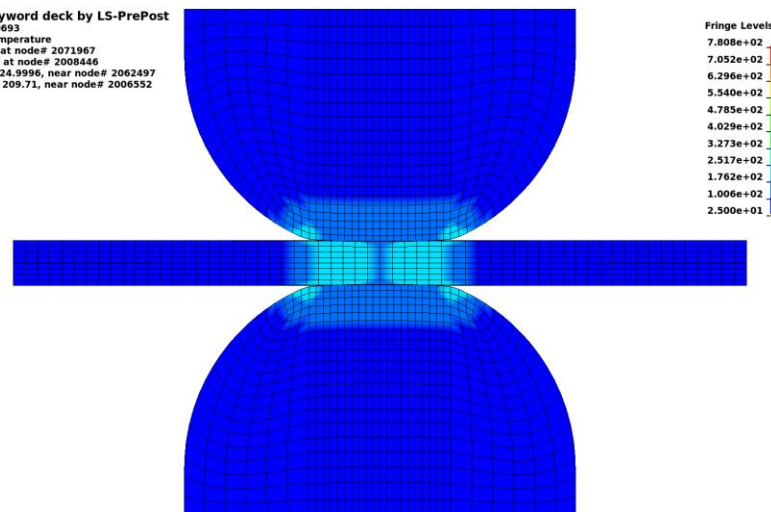
■ Definition of an electro-magnetic contact



History of the 3d temperature field

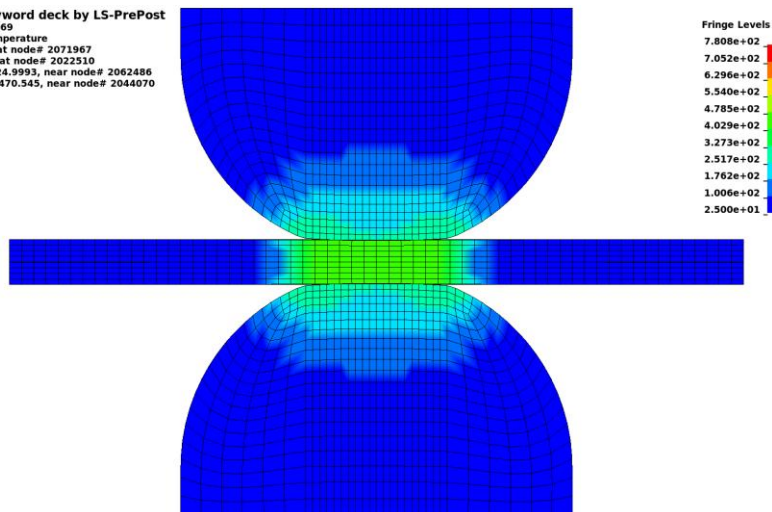


LS-DYNA keyword deck by LS-PrePost
Time = 0.070693
Contours of Temperature
min=24.9996, at node# 2071967
max=211.577, at node# 2008446
section min = 24.9996, near node# 2062497
section max = 209.71, near node# 2006552



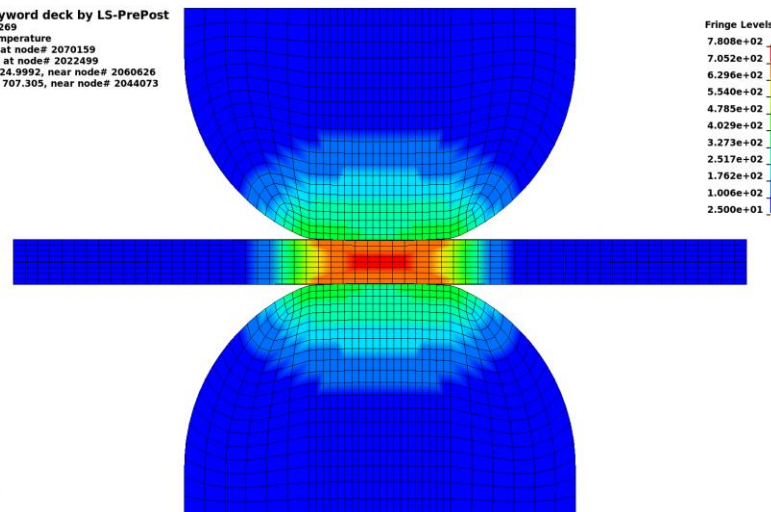
Fringe Levels
7.808e+02
7.052e+02
6.296e+02
5.540e+02
4.785e+02
4.029e+02
3.273e+02
2.517e+02
1.762e+02
1.006e+02
2.500e+01

LS-DYNA keyword deck by LS-PrePost
Time = 0.12669
Contours of Temperature
min=24.9993, at node# 2071967
max=470.825, at node# 2022510
section min = 24.9993, near node# 2062486
section max = 470.545, near node# 2044070



Fringe Levels
7.808e+02
7.052e+02
6.296e+02
5.540e+02
4.785e+02
4.029e+02
3.273e+02
2.517e+02
1.762e+02
1.006e+02
2.500e+01

LS-DYNA keyword deck by LS-PrePost
Time = 0.16269
Contours of Temperature
min=24.9991, at node# 2070159
max=707.959, at node# 2022499
section min = 24.9992, near node# 2060626
section max = 707.305, near node# 2044073



Fringe Levels
7.808e+02
7.052e+02
6.296e+02
5.540e+02
4.785e+02
4.029e+02
3.273e+02
2.517e+02
1.762e+02
1.006e+02
2.500e+01

Contours and Vector Plot of the Current Density

■ Contours and vector plot of the current density

LS-DYNA keyword deck by LS-PrePost

Time = 0.11069

Contours of Current density (magnitude)

min=0.411121, at node# 44343

max=5.27665e+08, at node# 13166

Vector of Current density:EM solid integ. pts

min=0.411121, at node# 2064396

max=3.59291e+08, at node# 1000087

Fringe Vector Frir

3.593e+08

3.234e+08

2.874e+08

2.515e+08

2.156e+08

1.796e+08

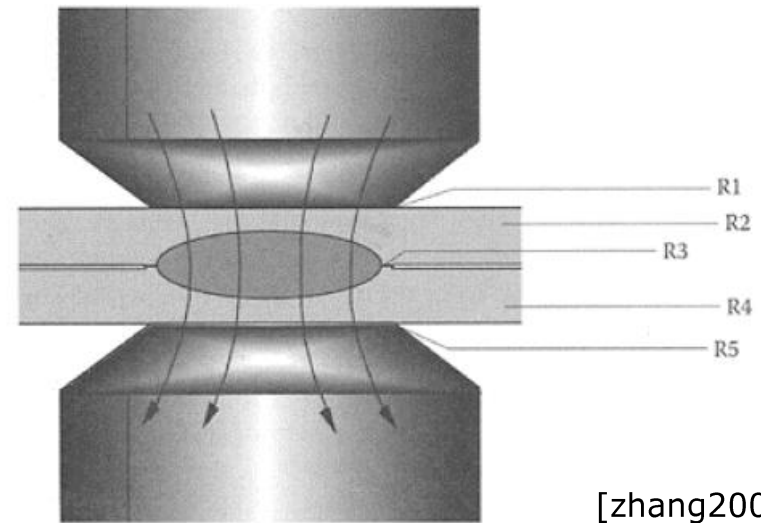
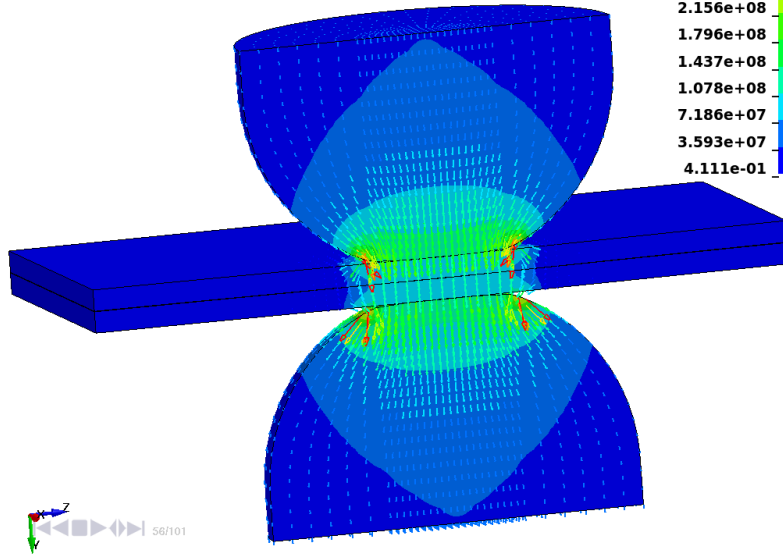
1.437e+08

1.078e+08

7.186e+07

3.593e+07

4.111e-01



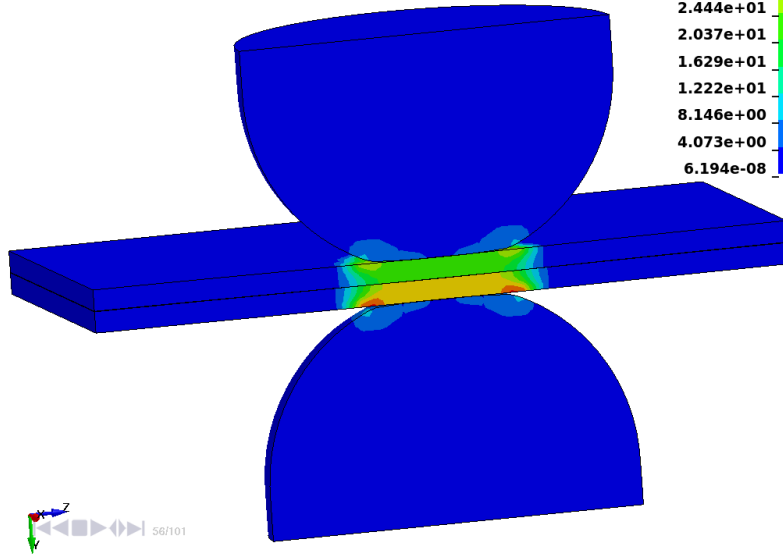
[zhang2005]

Contours and Vector Plot of the Electric Field

- Contours plot of the electric field
- Contours and vector plot of the electric field

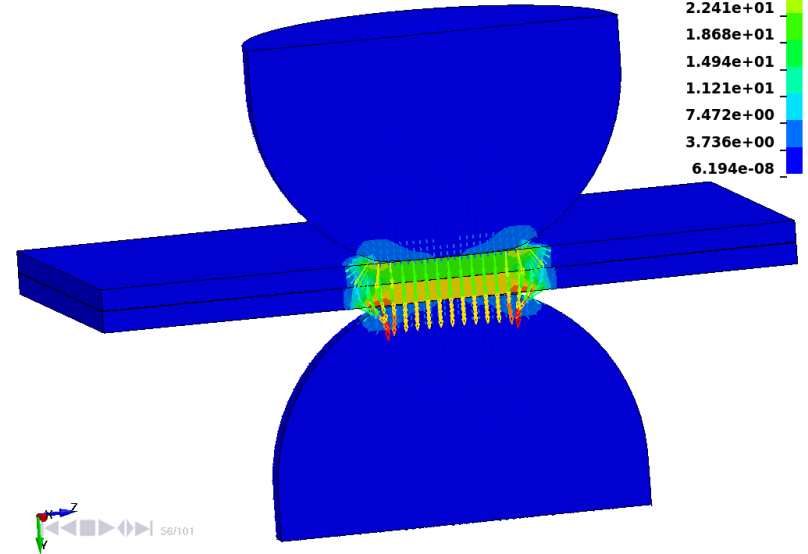
LS-DYNA keyword deck by LS-PrePost
Time = 0.11069
Contours of Electric field (magnitude)
min=6.19427e-08, at node# 44343
max=40.7322, at node# 47821

Fringe Levels
4.073e+01
3.666e+01
3.259e+01
2.851e+01
2.444e+01
2.037e+01
1.629e+01
1.222e+01
8.146e+00
4.073e+00
6.194e-08



LS-DYNA keyword deck by LS-PrePost
Time = 0.11069
Contours of Electric field (magnitude)
min=6.19427e-08, at node# 44343
max=40.7322, at node# 47821
Vector of Electric field:EM solid integ. pts
min=6.19427e-08, at node# 2064396
max=37.3577, at node# 2054846

Fringe Vector Fr
3.736e+01
3.362e+01
2.989e+01
2.615e+01
2.241e+01
1.868e+01
1.494e+01
1.121e+01
7.472e+00
3.736e+00
6.194e-08

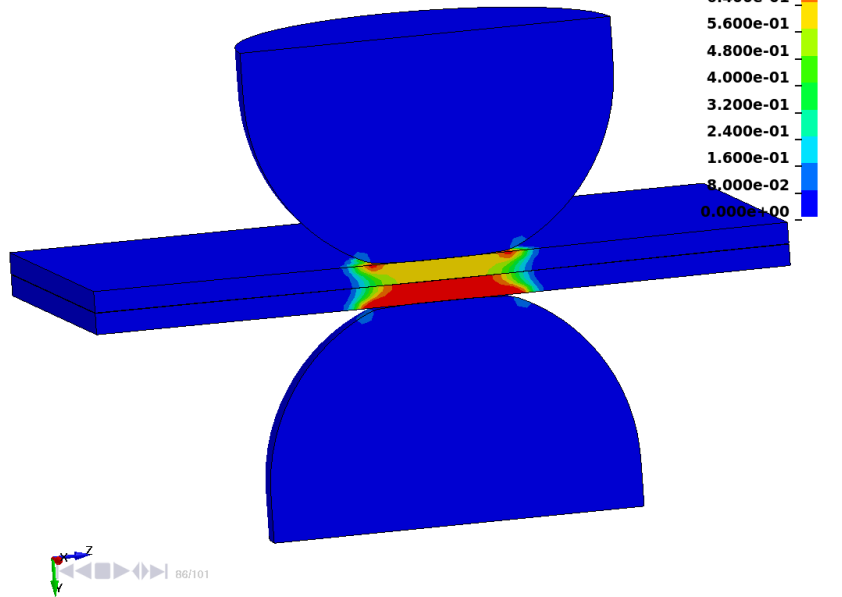


Contours plot of Heating Power and Electrical Conductivity

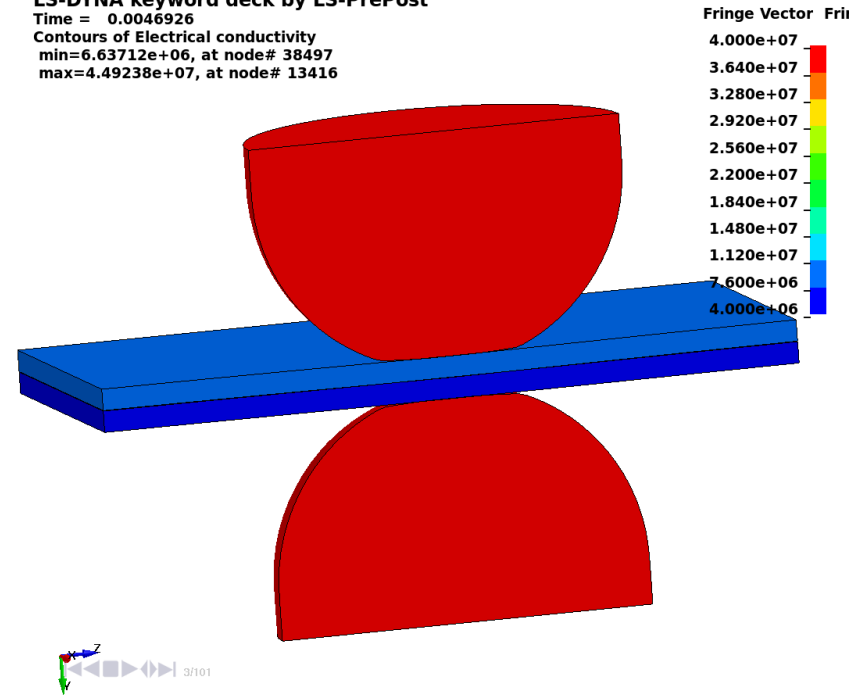
■ Contours plot of heating power

■ Contours plot of electrical conductivity

LS-DYNA keyword deck by LS-PrePost
Time = 0.17069
Contours of Ohm heating power
min=2.11007e-18, at node# 45243
max=1.12913, at node# 47821



LS-DYNA keyword deck by LS-PrePost
Time = 0.0046926
Contours of Electrical conductivity
min=6.63712e+06, at node# 38497
max=4.49238e+07, at node# 13416



EM Solver

- 3 EM-Solver available in LS-DYNA v7
 - Eddy Current Solver
 - Induced heating Solver
 - Resistive heating Solver

*EM_CONTROL

Purpose: Enables the EM solver and sets its options.

EMSOL	NUMLS	DTINIT	DTMAX	T_INIT	T_END	NCYCLFEM	NCYCLBEM

EMSOL :Electromagnetism solver selector:

EQ.1: Eddy current solver

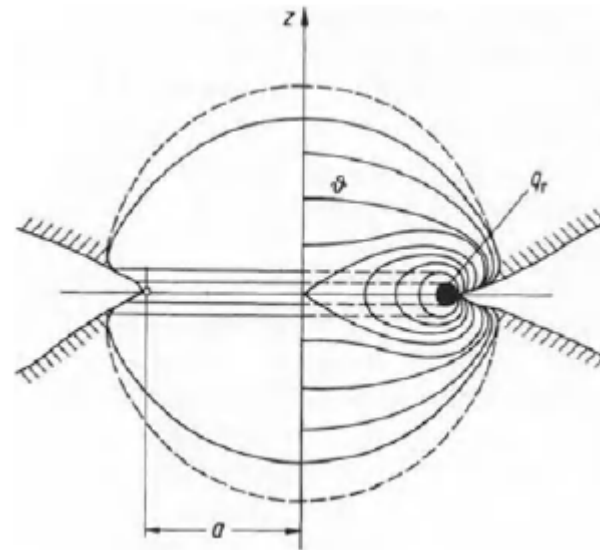
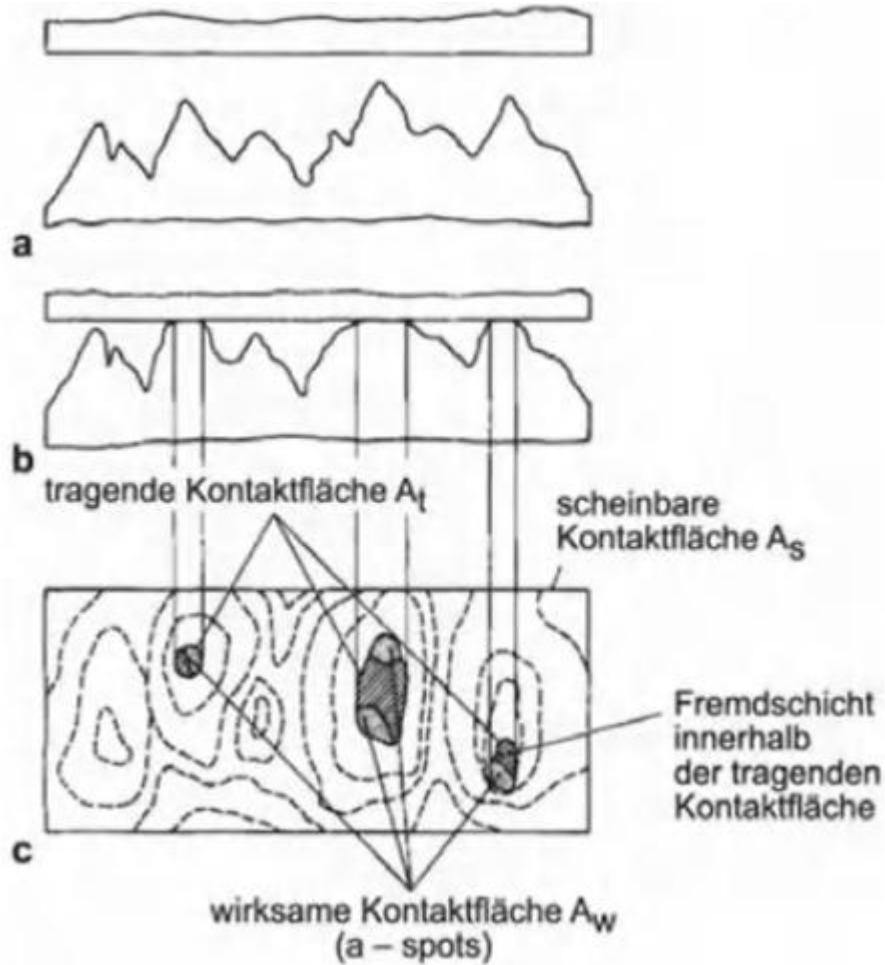
EQ.2: Induced heating solver

EQ.3: Resistive heating solver

- Since no diffusive effects are taken into account, there is no limiting CFL condition and the time step can take a very high value.

Electric contacts

■ Contact of rough surfaces, cp. [Holm1967]



[vinaricky2002]

EM contact according [holm1967]

*EM_CONTROL_CONTACT

EMCT							

EMCT : Electromagnetic contact :

EQ.0 : no contact detection

EQ.1 : contact detection

- Due to a user's request, a contact resistance can be calculated based on the book "Electric Contacts" by Ragnar Holm :

$$R_{contact} = R_{constriction} + R_{film}$$
$$R_{film} = \frac{\rho_{oxy}}{\sqrt{faceA_{film} \times ContactArea}}$$
$$R_{constriction} = \frac{\rho_{prob} + \rho_{sub}}{\sqrt{faceA_{cte} \times ContactArea}}$$

where ρ_{prob} , ρ_{oxy} , ρ_{sub} respectively probe, film and substrate resistivity, $faceA_{film}$, $faceA_{cte}$ are all parameters to be defined by the user.

- The user can then choose to add this calculated contact resistance to the total resistance calculated by the solver of a given circuit or not.

EM contact resistance

*EM_CONTACT_RESISTANCE

CRID	CONTID	RHOprobe	RHOsub	RHOoxi	FaceActe	FaceAfilm	CIRCID

CRID : Resistive contact ID

CONTID : EM Contact ID defined in *EM_CONTACT

RHO_n : Different resistivities

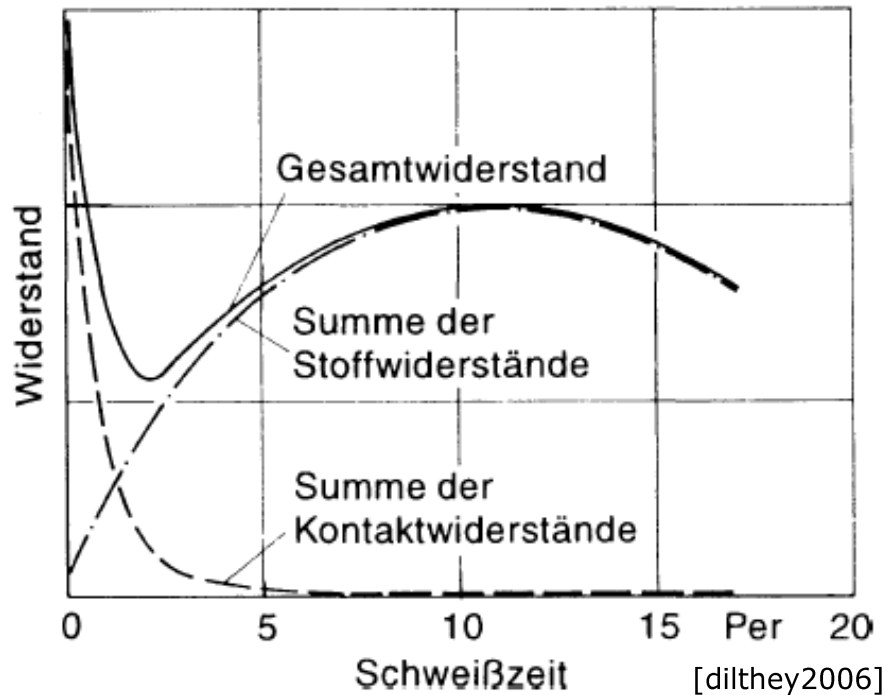
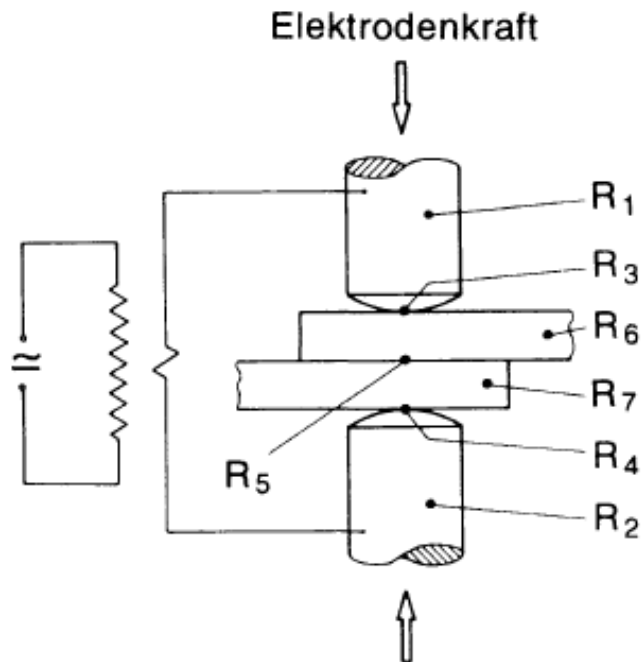
FaceActe/FaceAfilm : Scale factors on the constriction area when calculating the constriction and the film resistance. When negative, it becomes time dependent using the absolute value for load curve ID.

CIRCID : When defined, the contact resistance will be added to the corresponding circuit ID total resistance and taken into account by the solver in the circuit equations.

Most relevant modell parameters for process simulation

■ Electrical contact resistance

- temperature dependend
- pressure dependend



Thank you

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	USI	Equivalence ($[kg]^\alpha * [m]^\beta * [s]^\gamma$)		
Mass	kg	$[kg]^\alpha$	$[m]^\beta$	$[s]^\gamma$
Length	m			
Time	s			
Energy	J	1	2	-2
Force	N	1	1	-2
Stress	Pa	1	-1	-2
Density	$\frac{kg}{m^3}$	1	-3	0
Heat capacity	$\frac{J}{kgK}$	0	2	-2
Thermal Cond.	$J m^{-1} s^{-1}$	1	1	-3
Current	A	0.5	0.5	-1
Resistance	Ohm	0	1	-1
Inductance	H	0	1	0
Capacity	F	0	-1	1
Voltage	V	0.5	1.5	-2
B field	T	0.5	-0.5	-1
Conductivity	$Ohm^{-1} m^{-1}$	0	-2	1