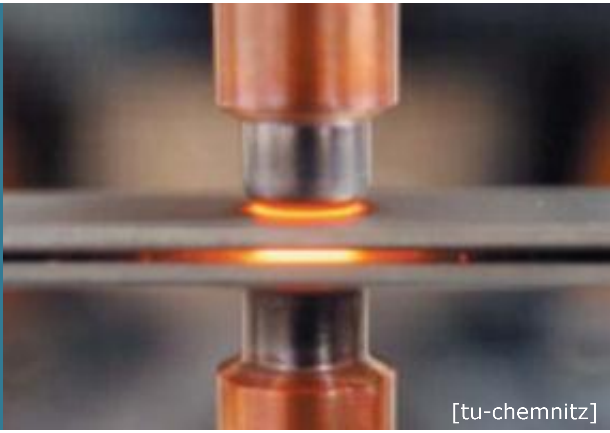
Process Simulation of Resistance Spot Welding



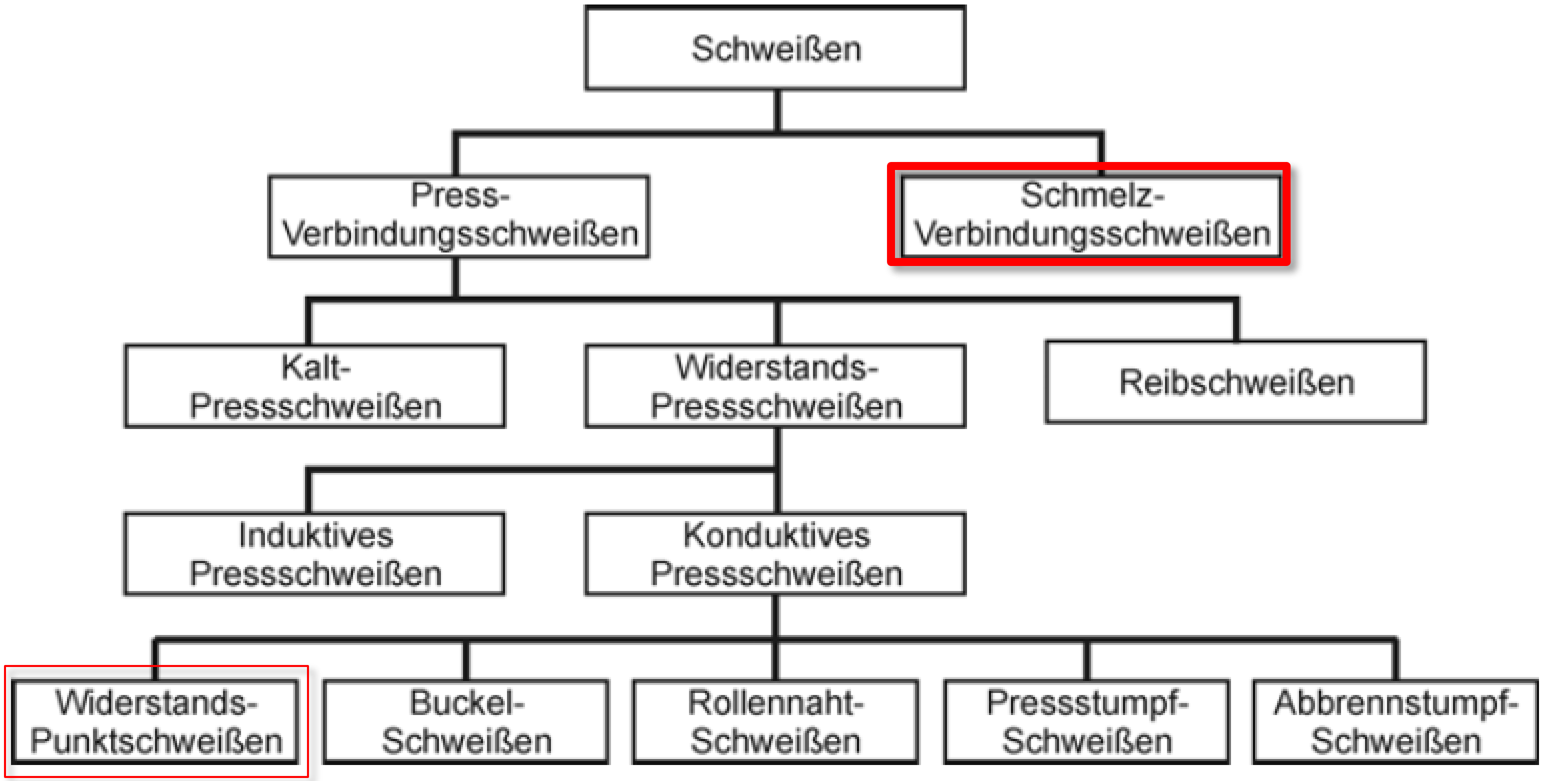
Ingolf Lepenies*
Krassen Anakiev

Multiphysics in LS-DYNA
17.03.2014

DYNA MORE

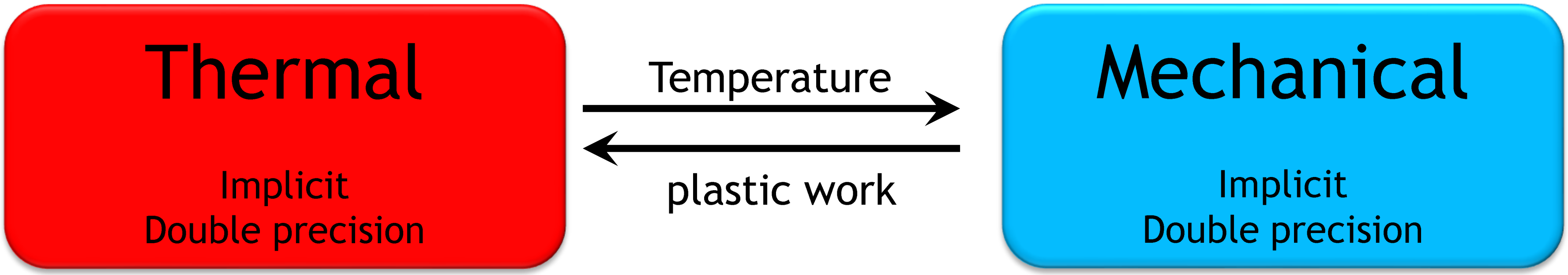
Contents

Types of welding



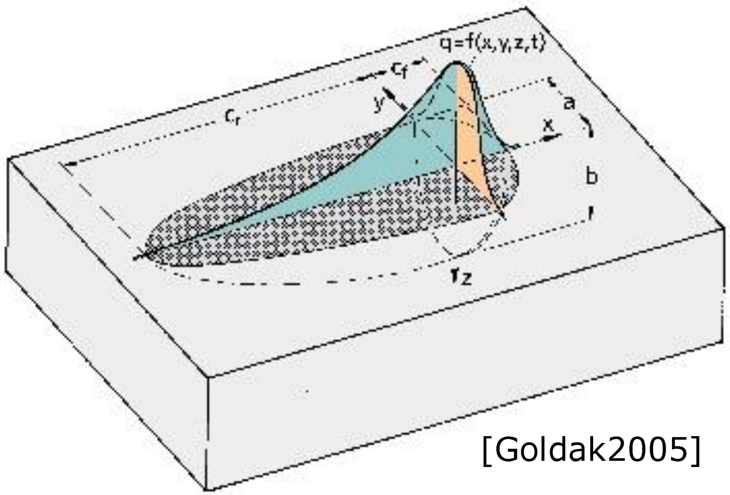
[dilthey2006]

coupled mechanical and thermal solvers

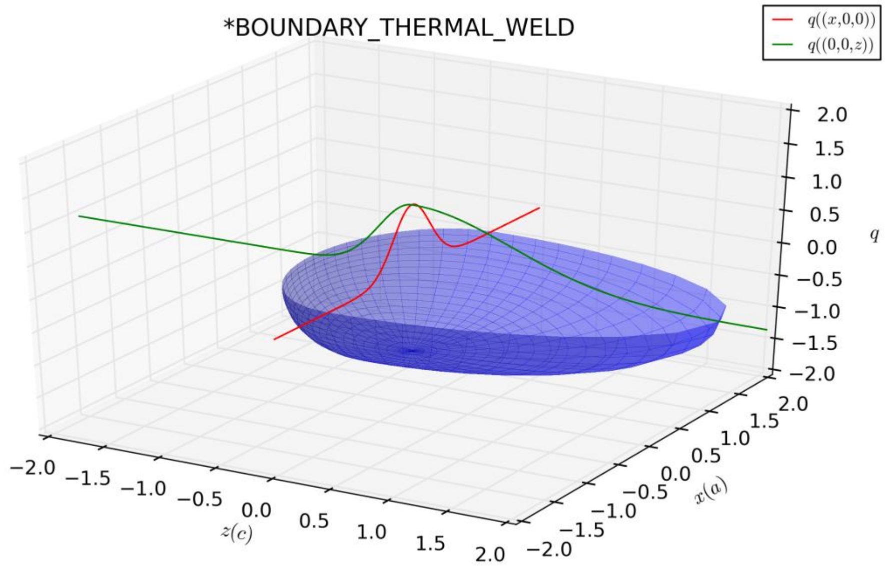


*BOUNDARY_THERMAL_WELD

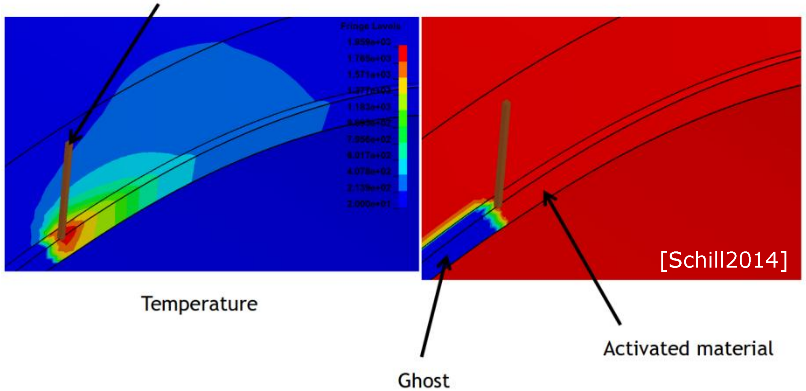
- **GOLDAK's** Double Ellipsoidal Power Density Distribution



[Goldak2005]



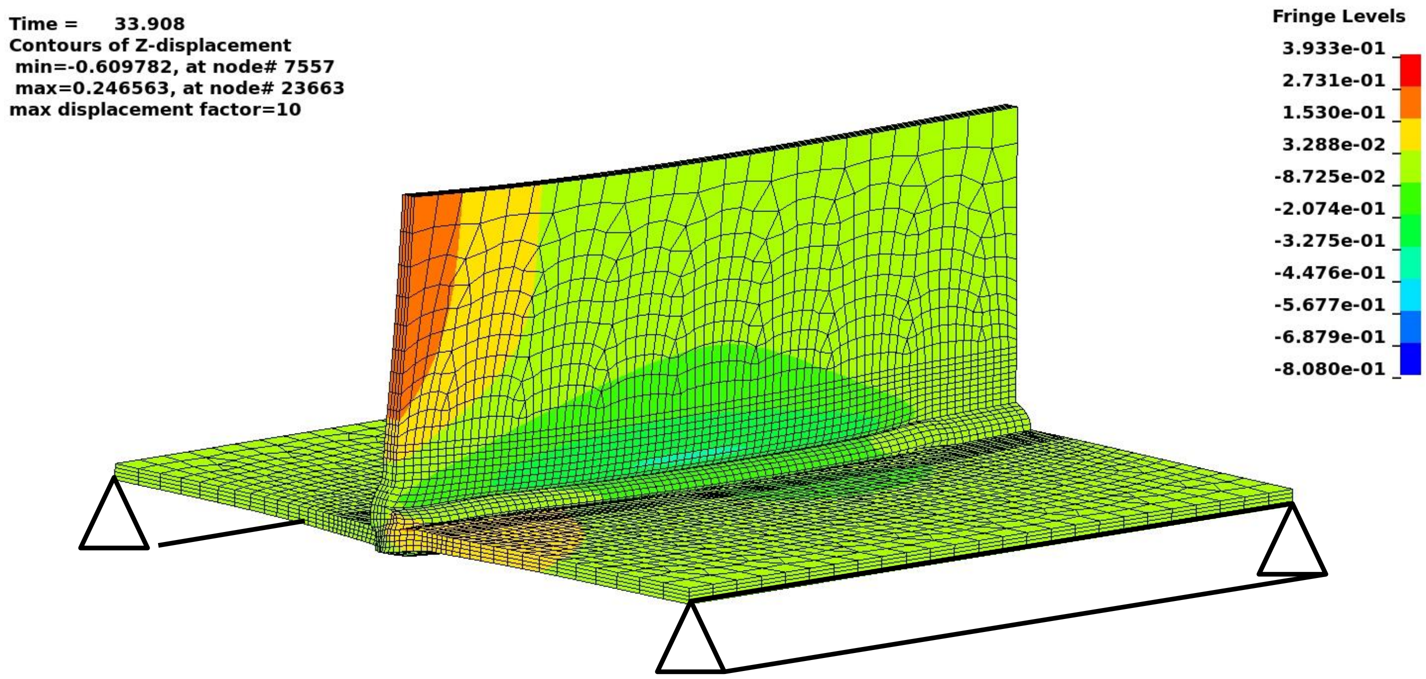
- **definition of the heat source in LS-DYNA with *BOUNDARY_THERMAL_WELD**
- **relative movement of heat source and parts**



[Schill2014]

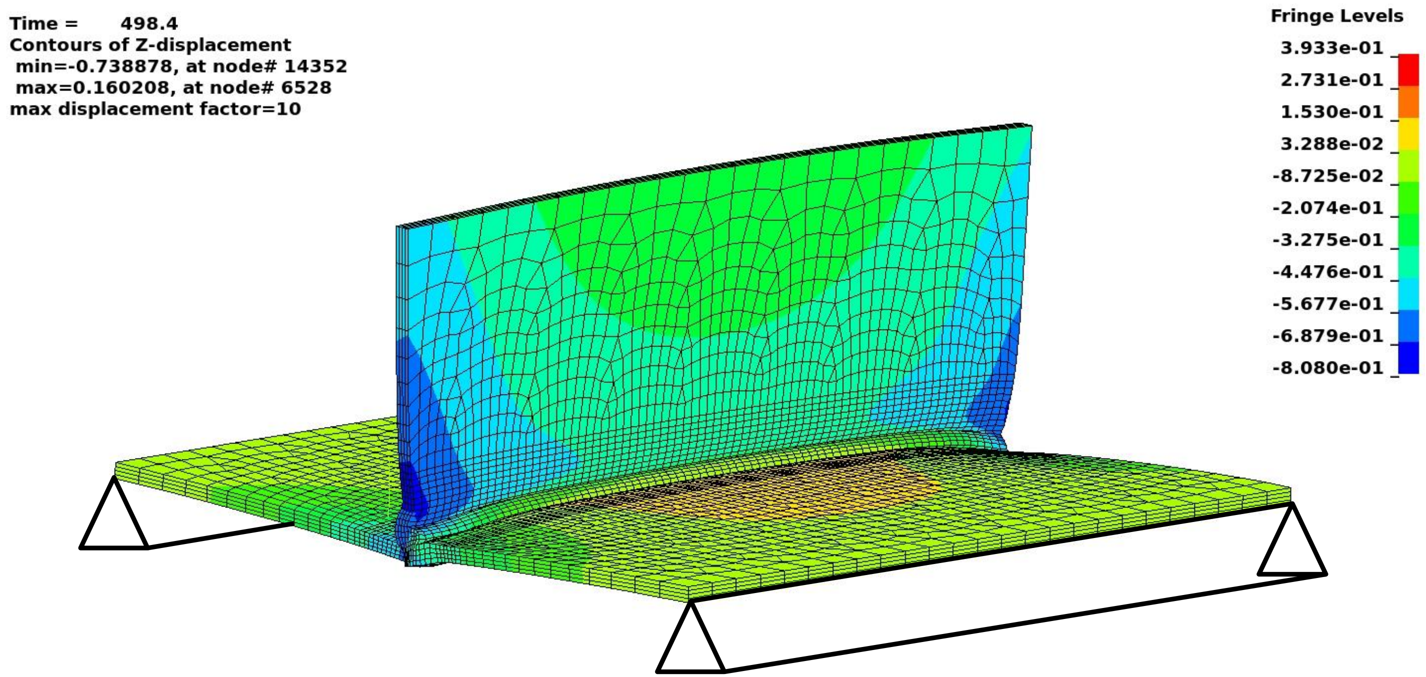
LS-DYNA: Deformation (t=33.9 s)

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



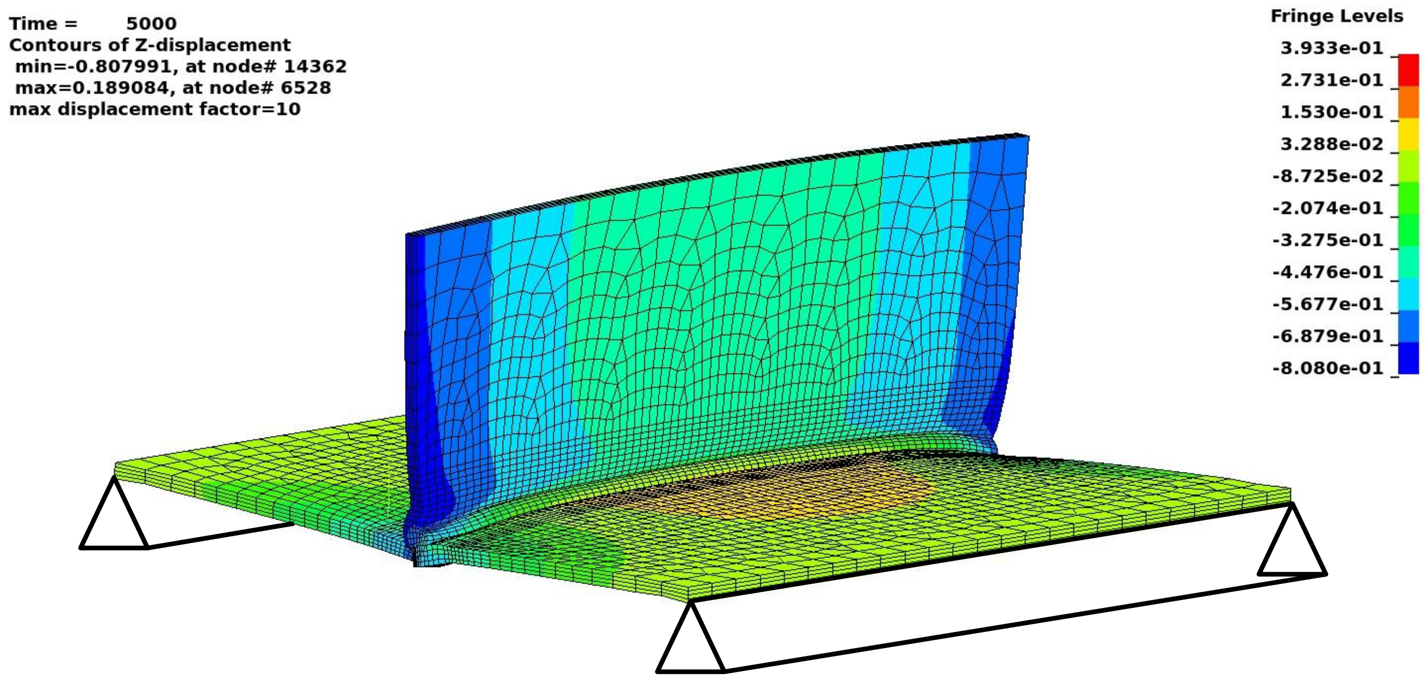
LS-DYNA: Deformation (t=499.0 s)

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

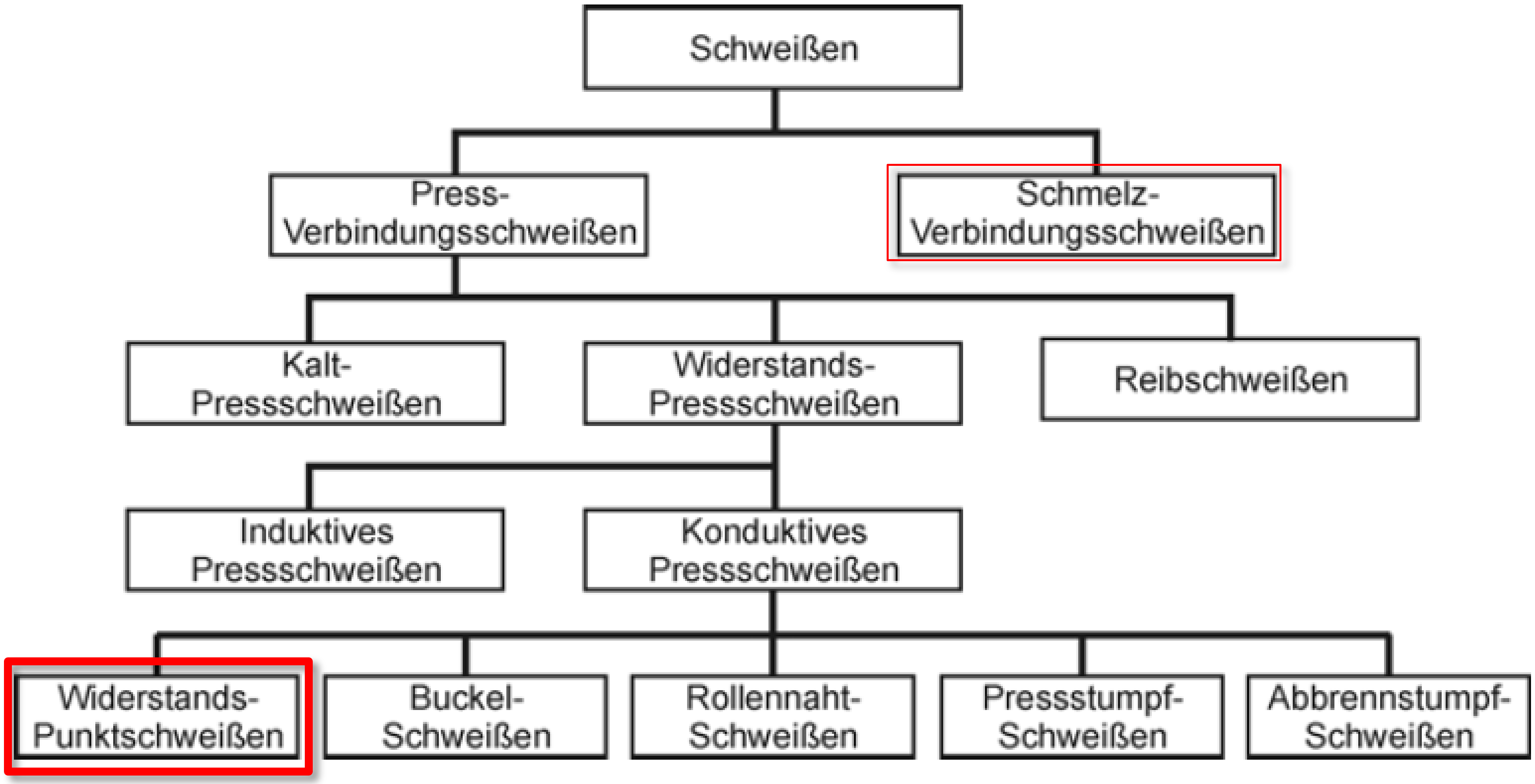


LS-DYNA: Deformation (t=5000. s)

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

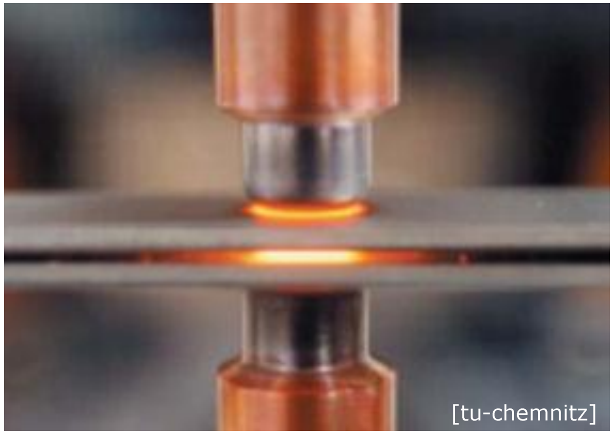


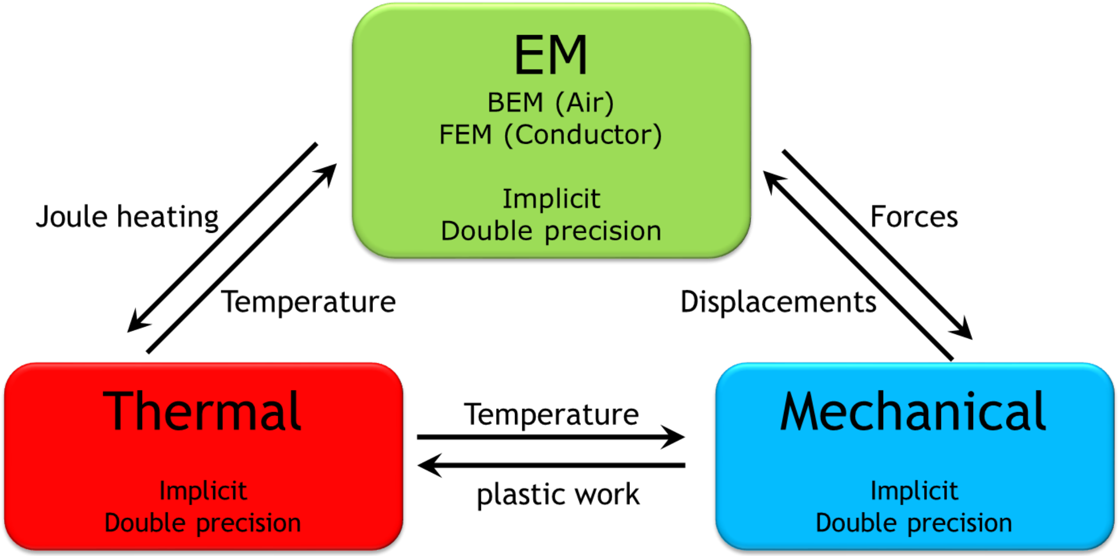
Types of welding



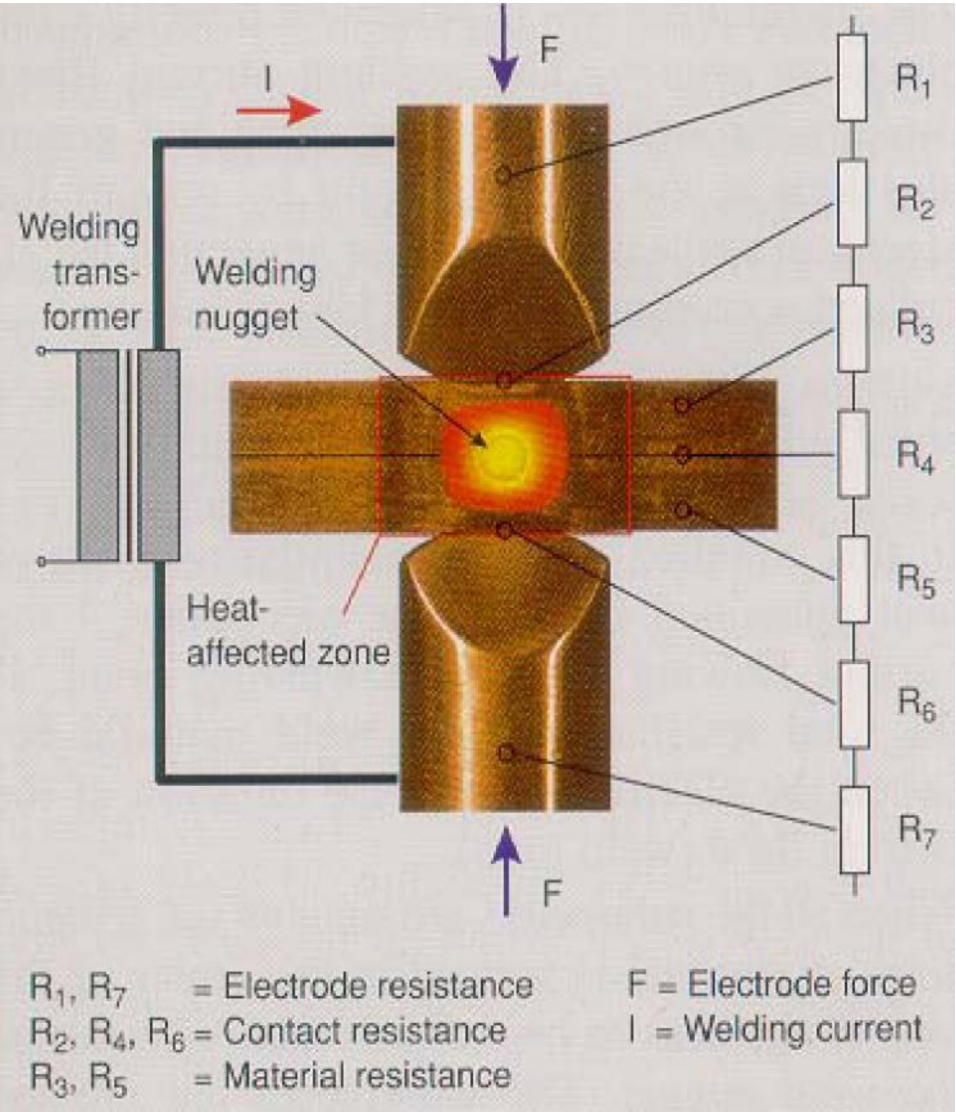
[dilthey2006]

coupled mechanical, thermal and electro-magnetic solvers



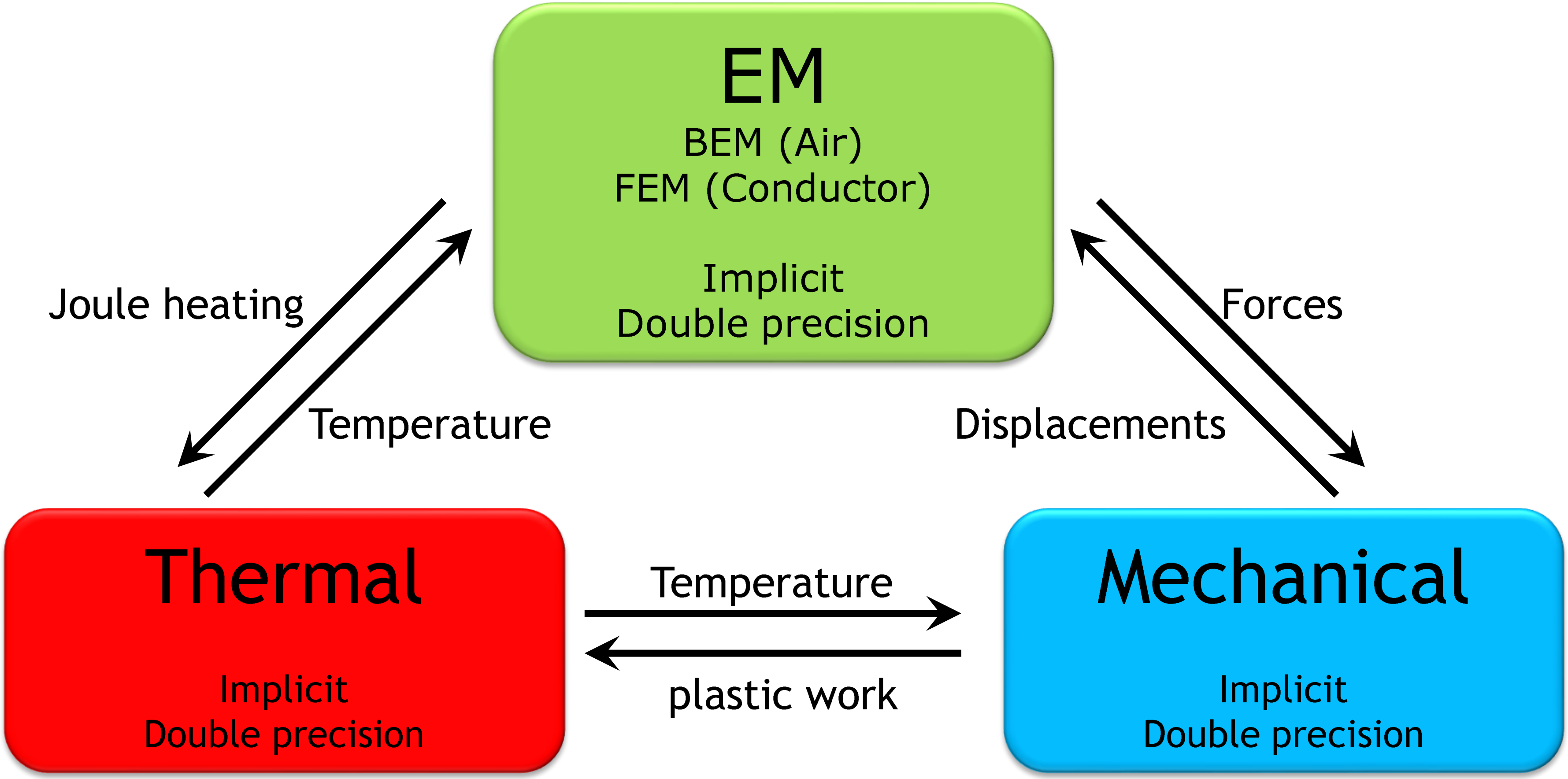


Analysis of the welding process



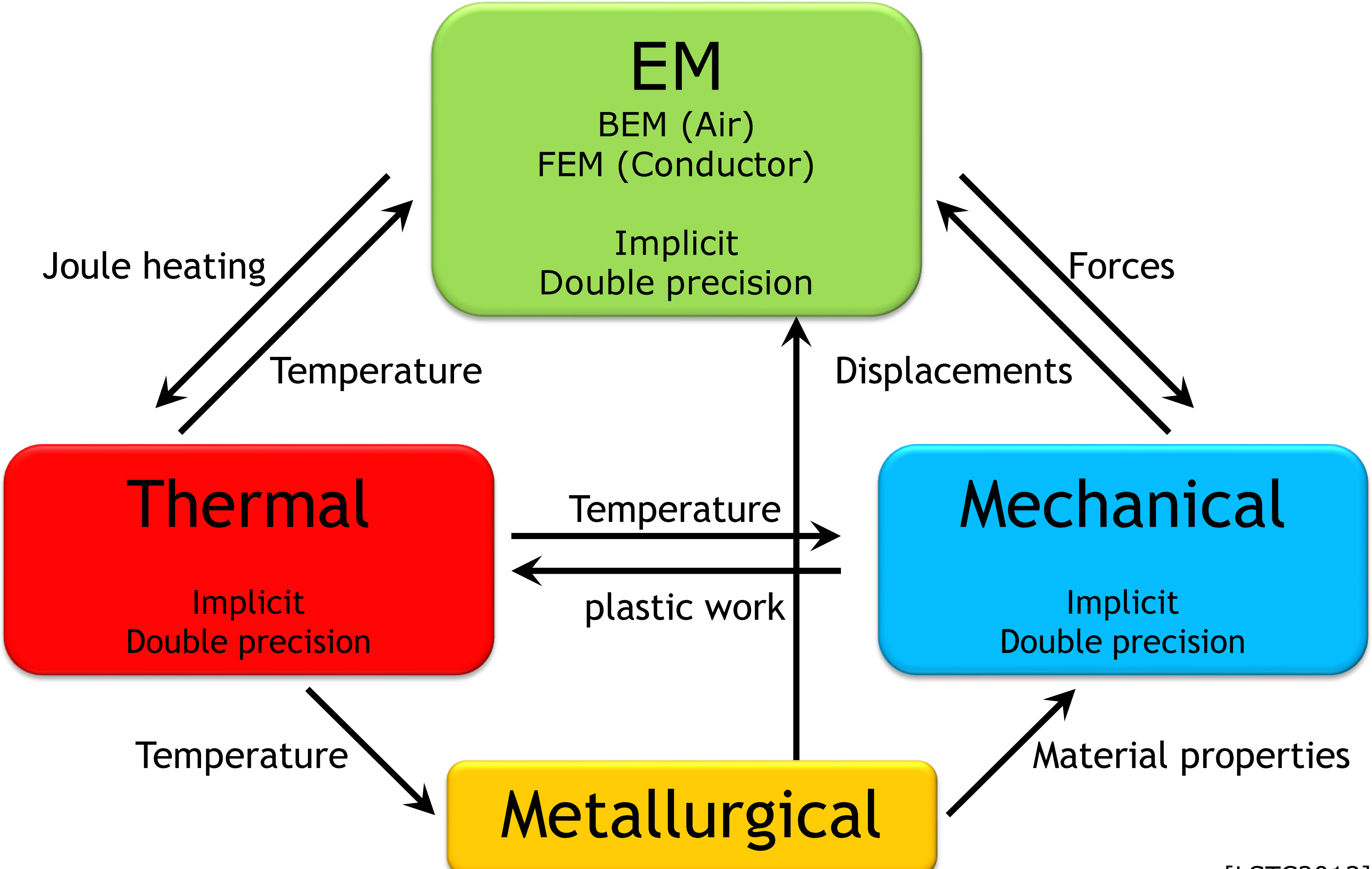
[greitmann2013]

coupled mechanical, thermal and electro-magnetic solvers



[LSTC2013]

coupled mechanical, thermal and electro-magnetic solvers



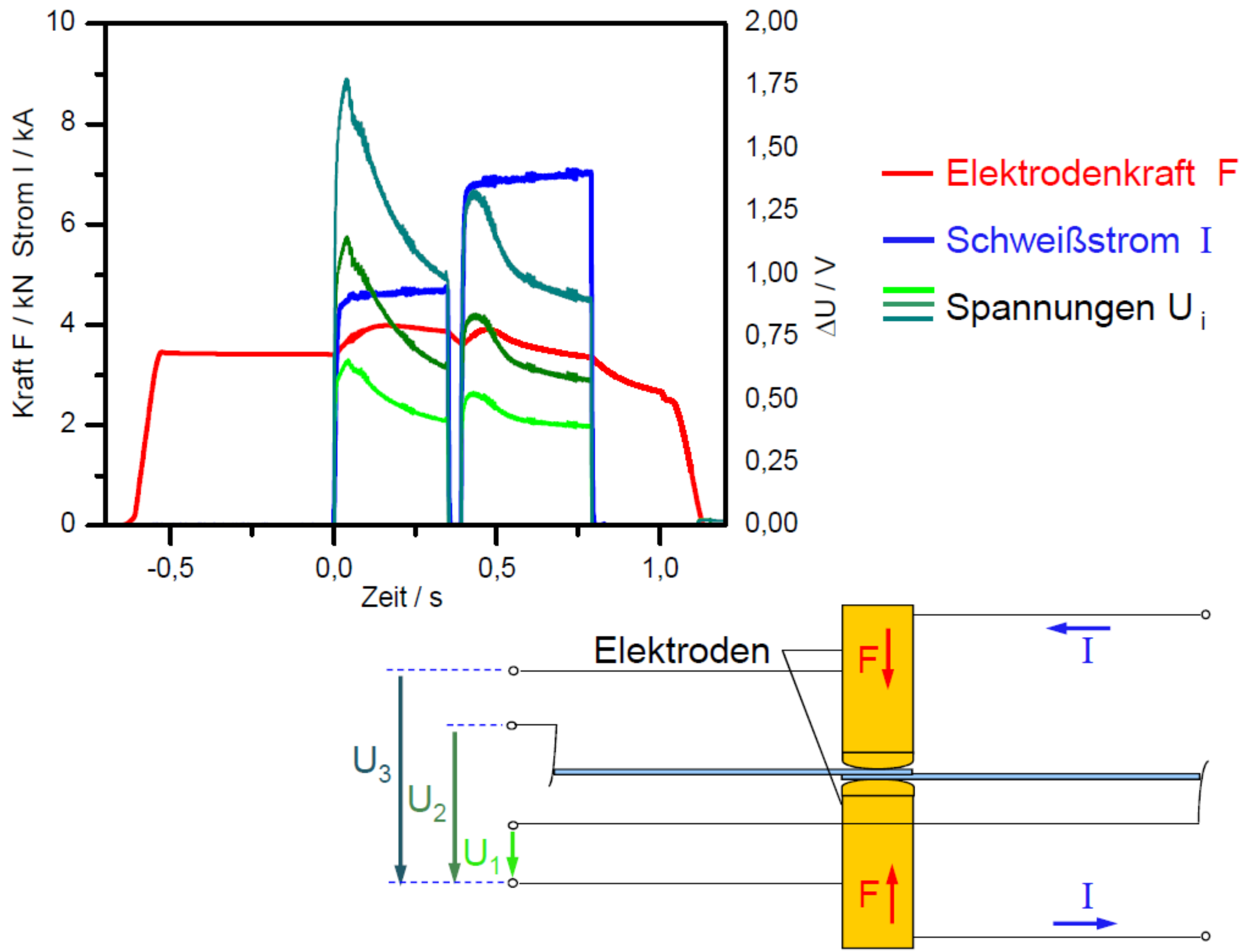
[LSTC2013]

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

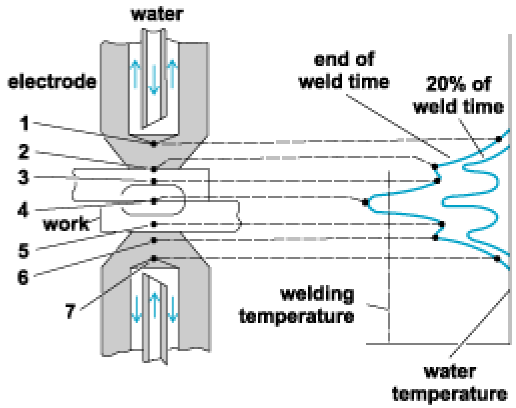
- **Typical force, current and voltage curves during the resistance spot welding (from [wick2012])**



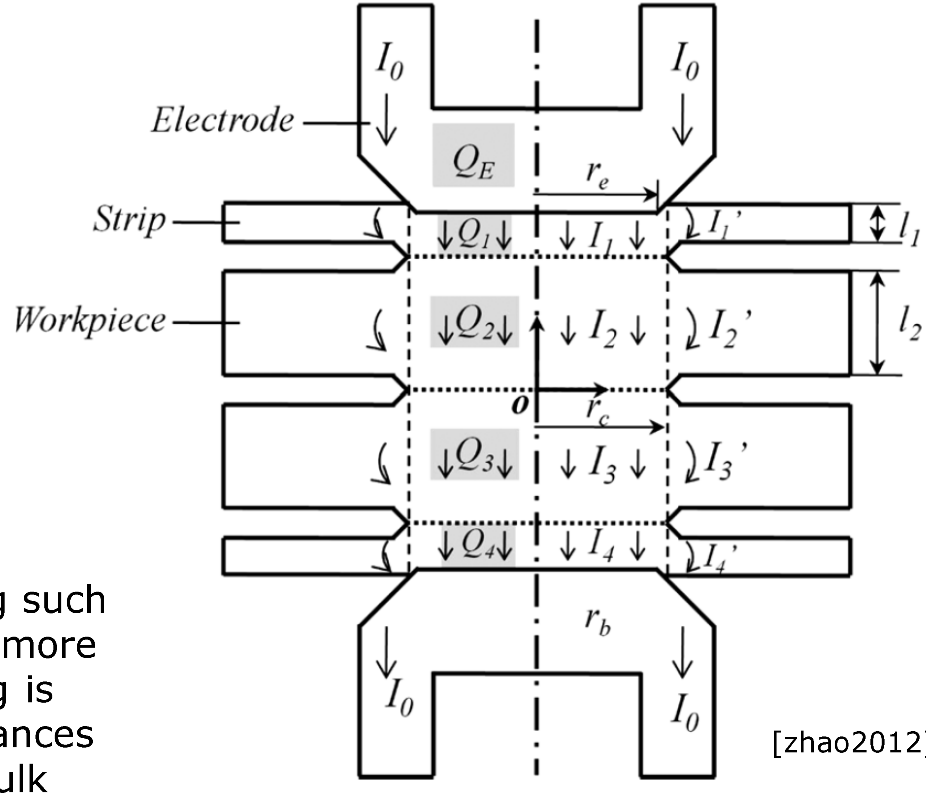
[wick2012]

Aim of the process simulation

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



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



[zhao2012]

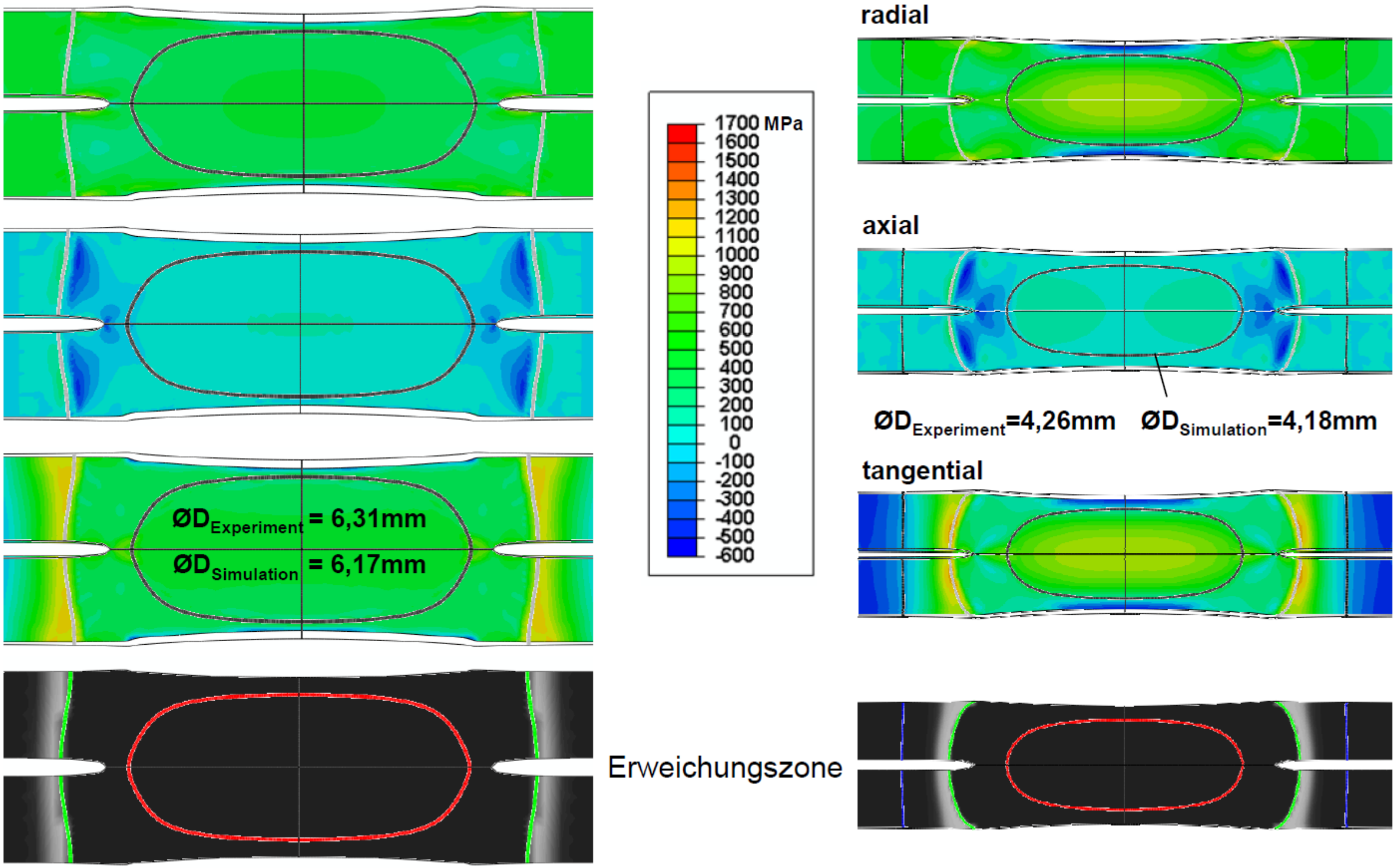
"Furthermore, with aluminium metal being such a good electrical conductor (~three times more than steel), heat generated during welding is primarily obtained from the contact resistances at the faying surfaces, and not from the bulk material resistance.

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]

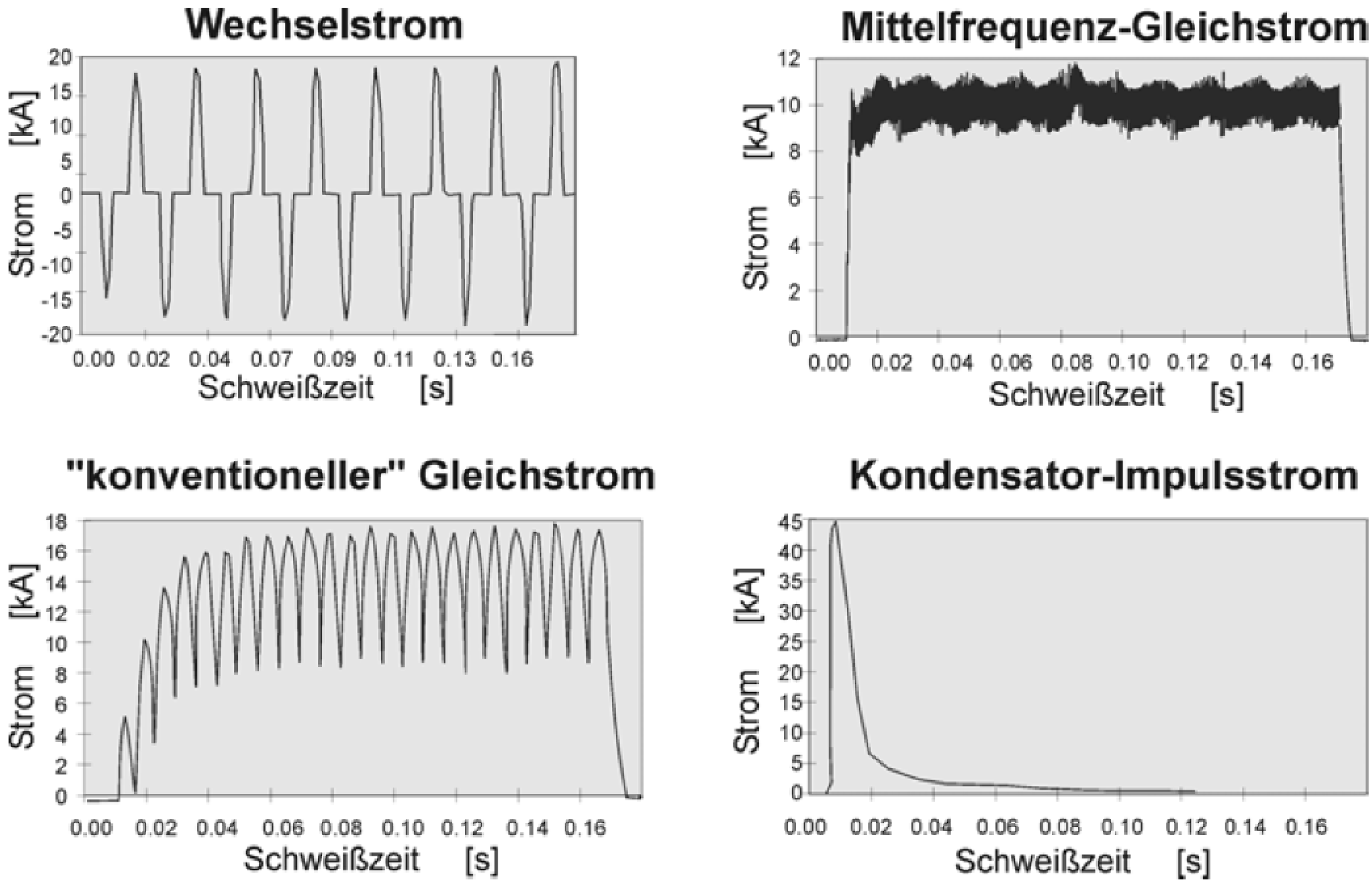


22MnB5+AS / 22MnB5+AS, Blechdicke 1,5 mm

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

Aim of the process simulation

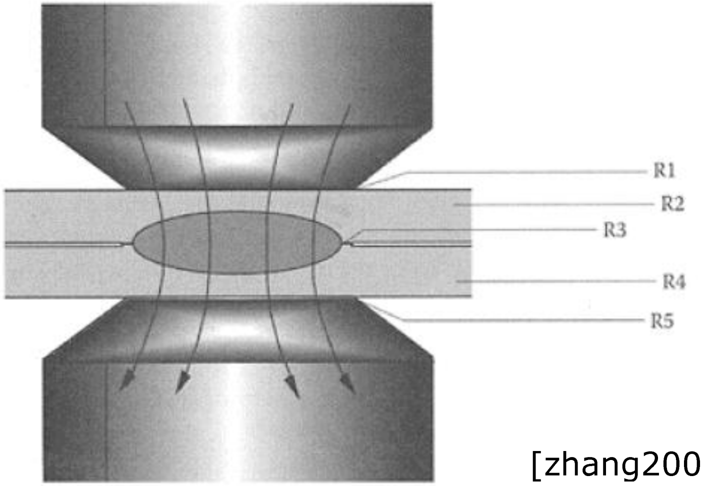
- Influence of the current type



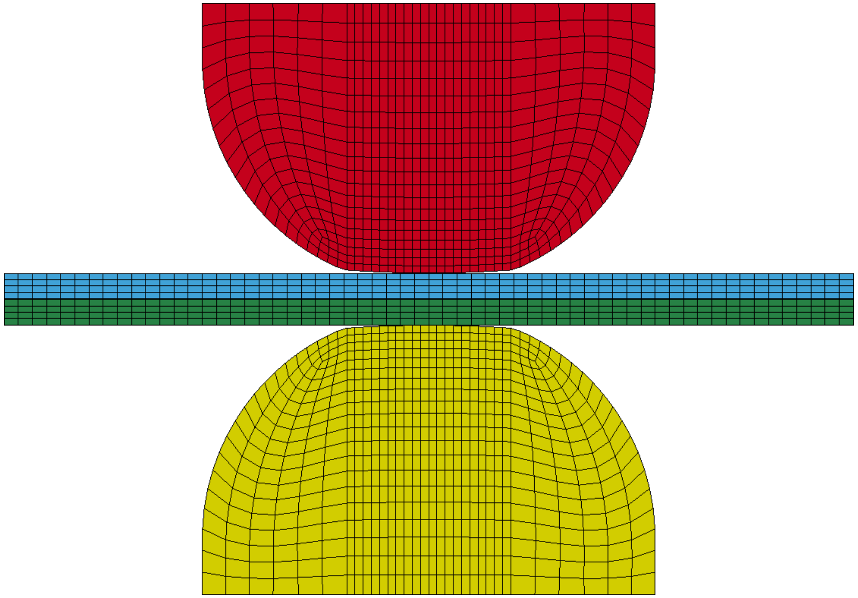
[dilthey2006]

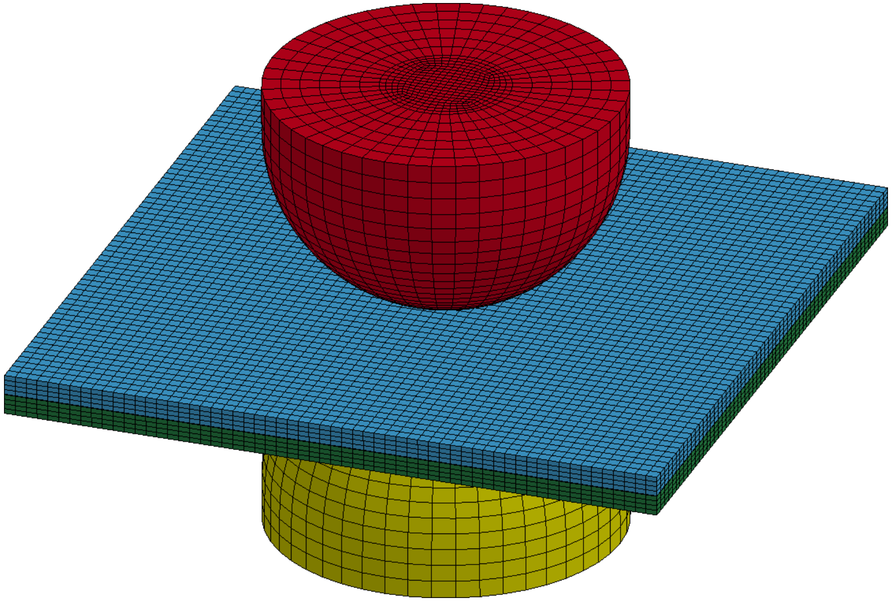
Geometry

- 2 Electrods
  - only foot of the electrode meshed
  - electrode shape according DIN 5821
- 2 metal sheets



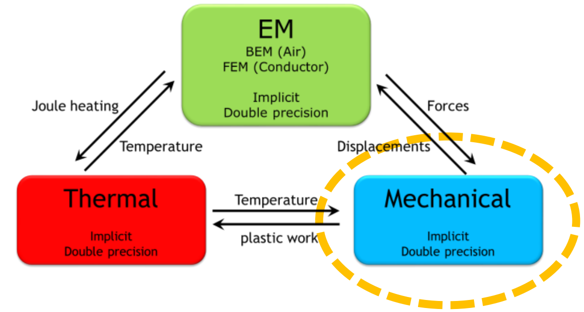
[zhang2005]





Mechanical Input

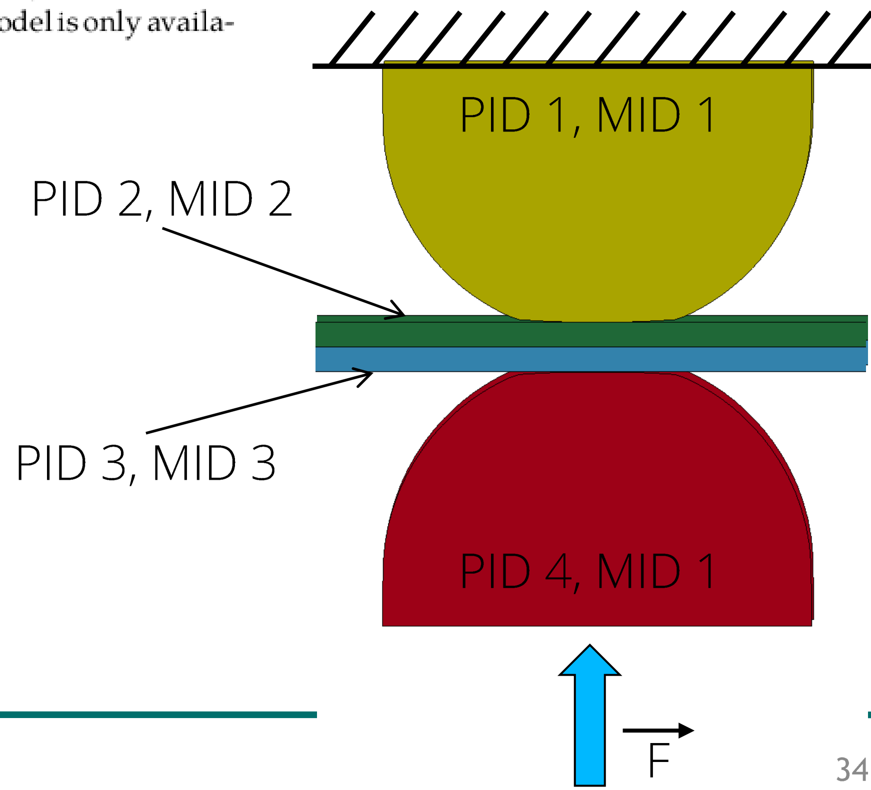
- Part definition
- Material definition (mechanical properties)



***MAT_CWM**

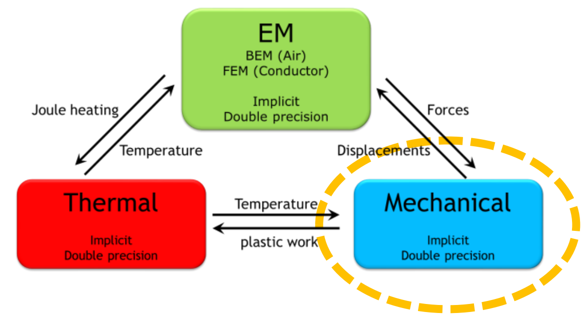
This is material type 270. This is a thermo-elastic-plastic model with kinematic hardening that allows for material creation as well as annealing triggered by temperature. The acronym CWM stands for Computational Welding Mechanics, Lindström (2013), and the model is intended to be used for simulating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

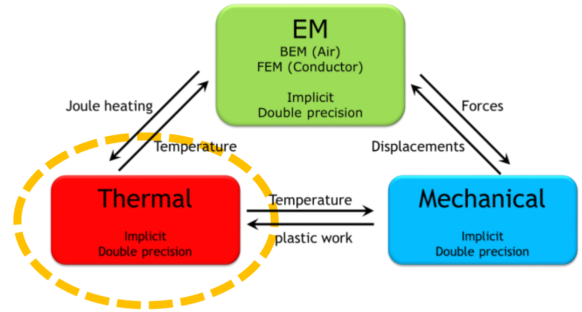
Card 2	1	2	3	4	5	6	7	8
Variable	TASTART	TAEND	TLSTART	TLEND	EGHOST	PGHOST	AGHOST	

RO	Material density
LCEM	Load curve for Young's modulus as function of temperature
LCPR	Load curve for Poisson's ratio as function of temperature
LCSY	Load curve for yield stress as function of temperature
LCHR	Load curve for hardening modulus as function of temperature
LCAT	Load curve (or table) for thermal expansion coefficient as function of temperature (and maximum temperature up to current time)
BETA	Fraction isotropic hardening between 0 and 1 EQ.0: Kinematic hardening EQ.1: Isotropic hardening

TASTART	Annealing temperature start
TAEND	Annealing temperature end
TLSTART	Birth temperature start
TLEND	Birth temperature end
EGHOST	Young's modulus for ghost (quiet) material
PGHOST	Poisson's ratio for ghost (quiet) material
AGHOST	Thermal expansion coefficient for ghost (quiet) material
T2PHASE	Temperature at which phase change commences
T1PHASE	Temperature at which phase change ends

Thermal Input

- Initial temperature
- Material definition (thermal properties)



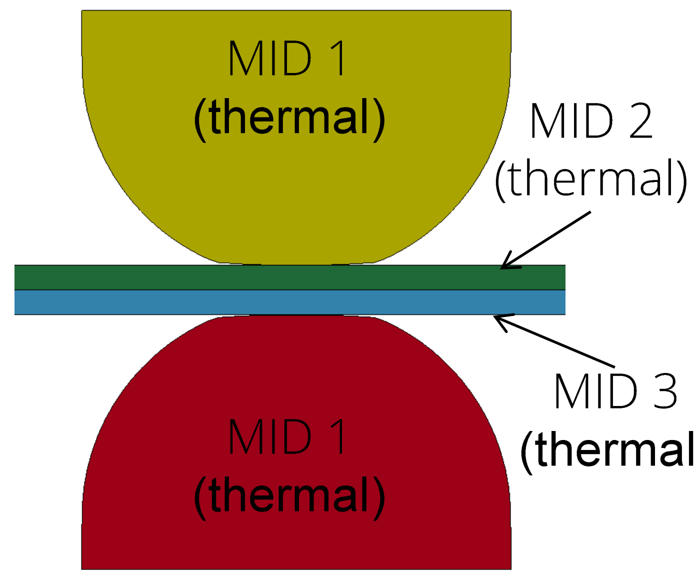
***MAT_THERMAL_CWM**

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

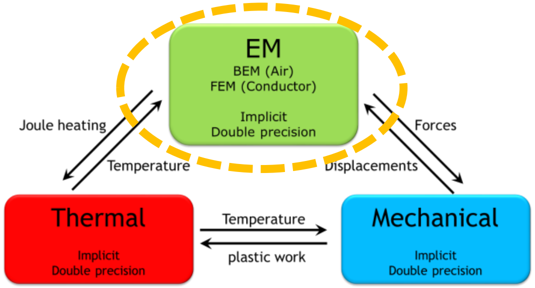
- **Material definitions (incl. electromagnetical properties)**

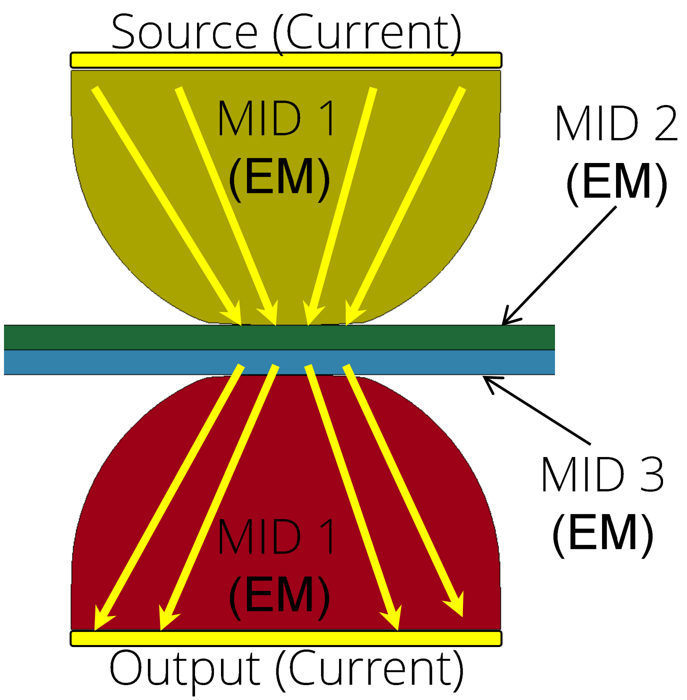
***EM_MAT_001**

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

***EM_EOS_TABULATED1**

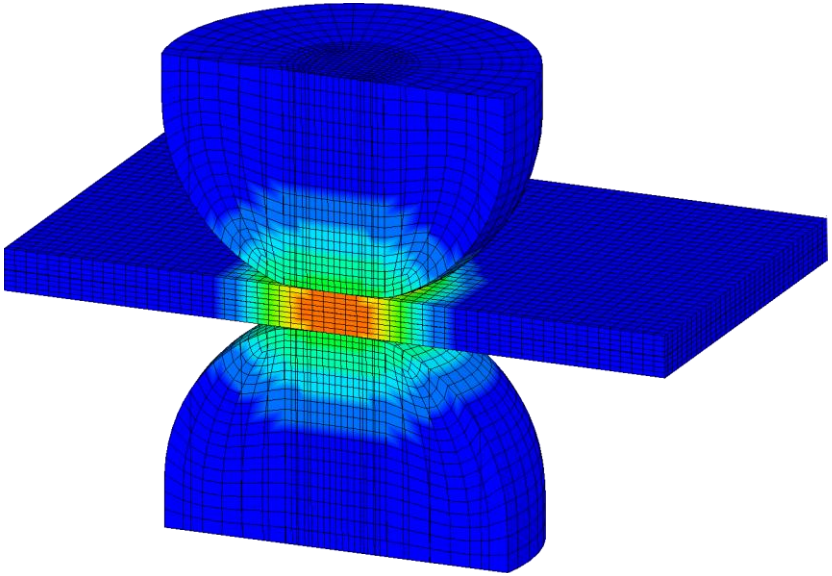
Purpose: Define the electrical conductivity as a function of temperature by using a load curve.

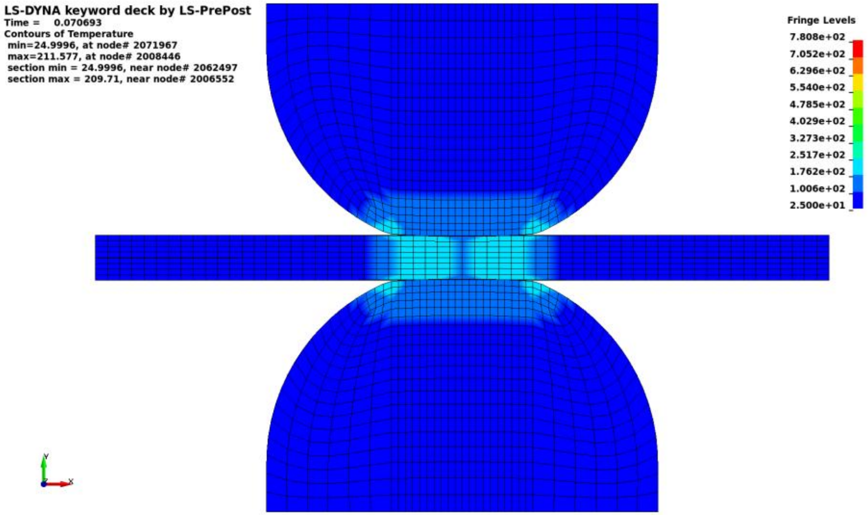


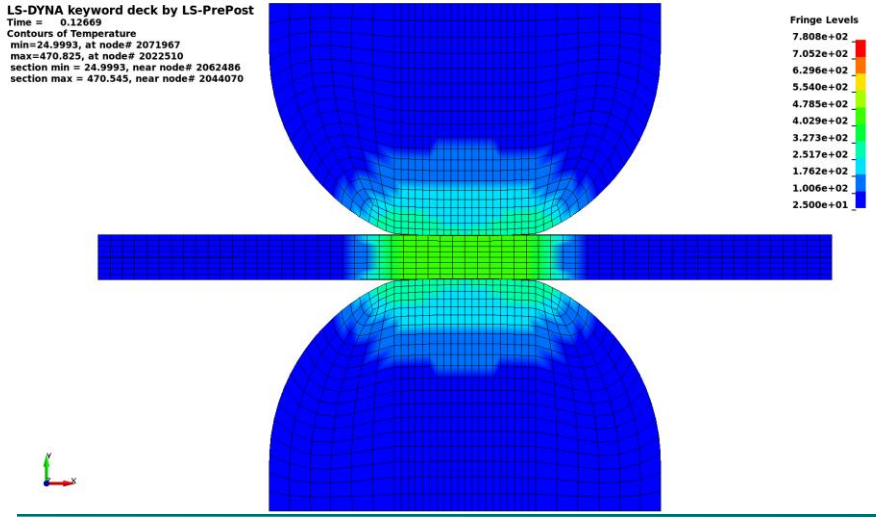


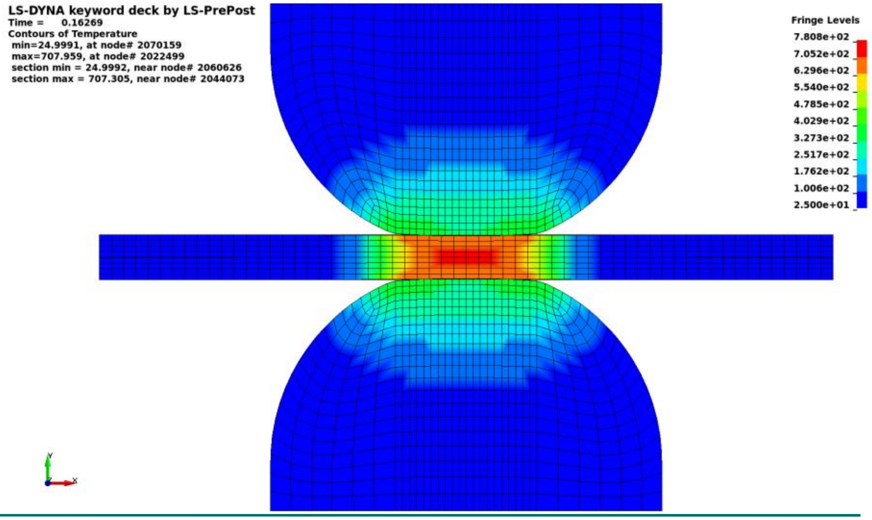
- **Definition of an electrical circuit**
- **Definition of an electro-magnetic contact**

History of the 3d temperature field



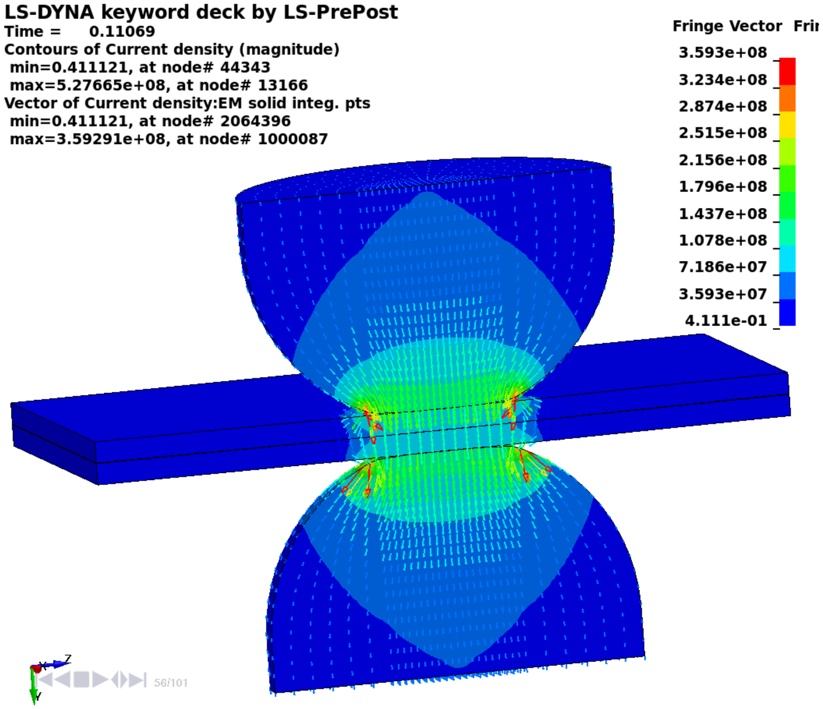


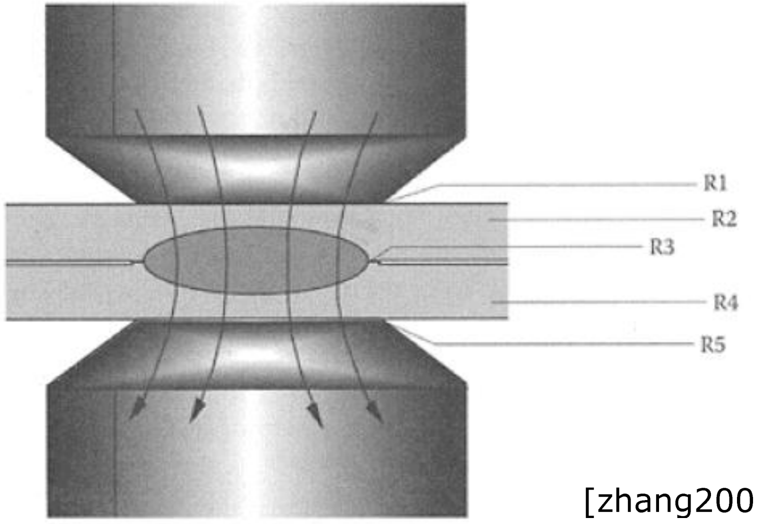




Contours and Vector Plot of the Current Density

- Contours and vector plot of the current density

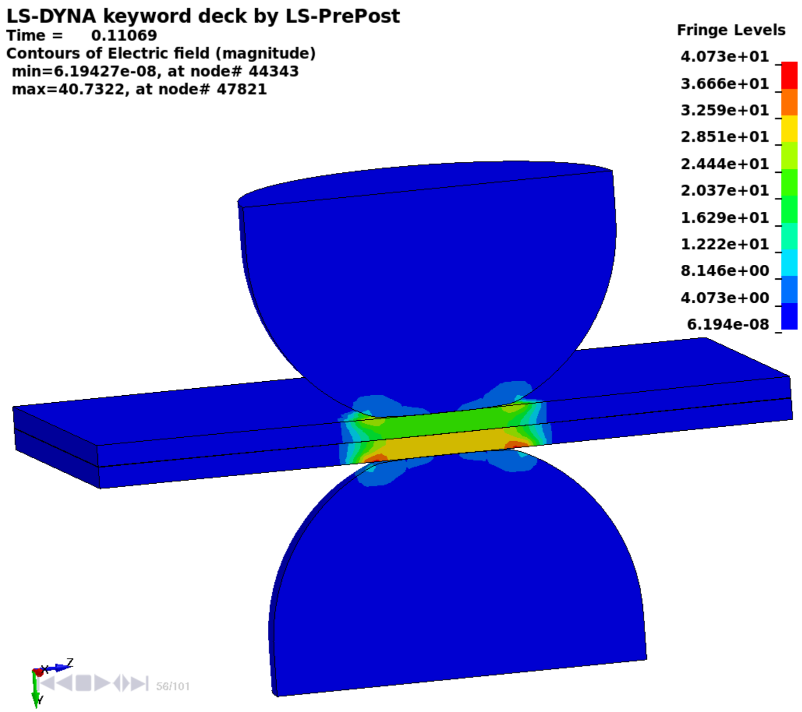




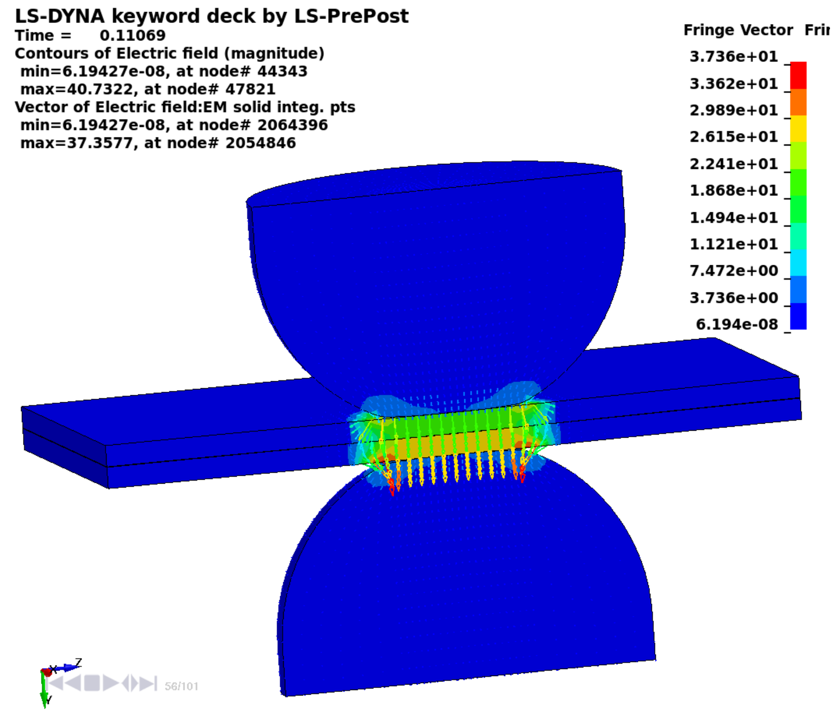
[zhang2005]

Contours and Vector Plot of the Electric Field

- Contours plot of the electric field

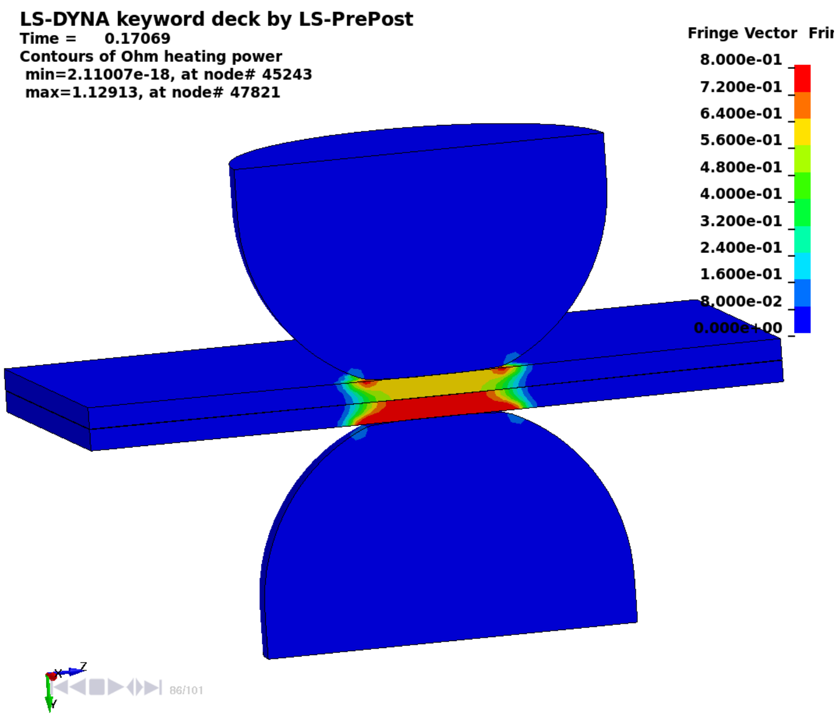


- Contours and vector plot of the electric field

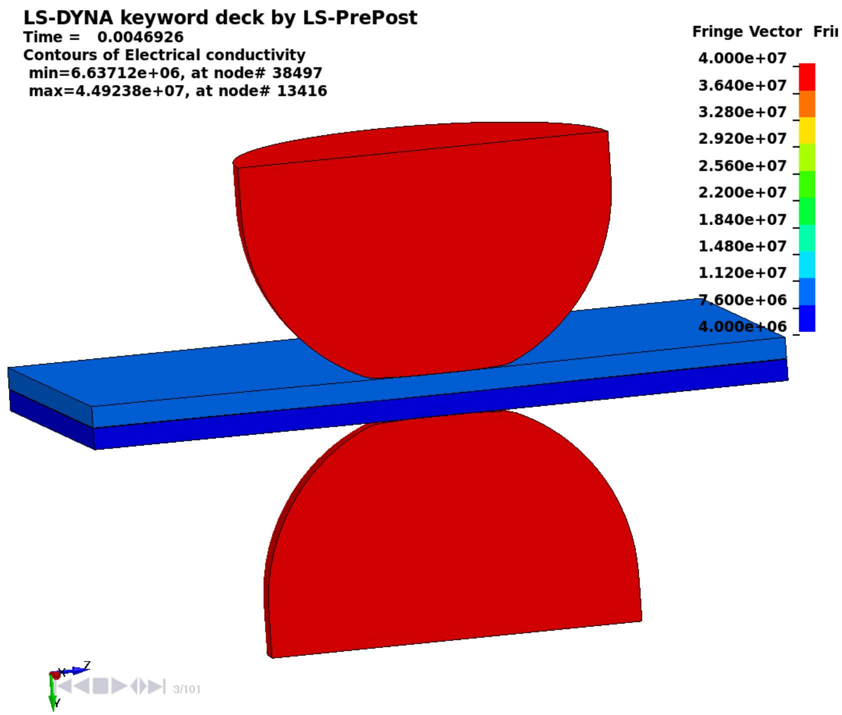


Contours plot of Heating Power and Electrical Conductivity

- Contours plot of heating power



- Contours plot of electrical conductivity



DYNA MORE

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

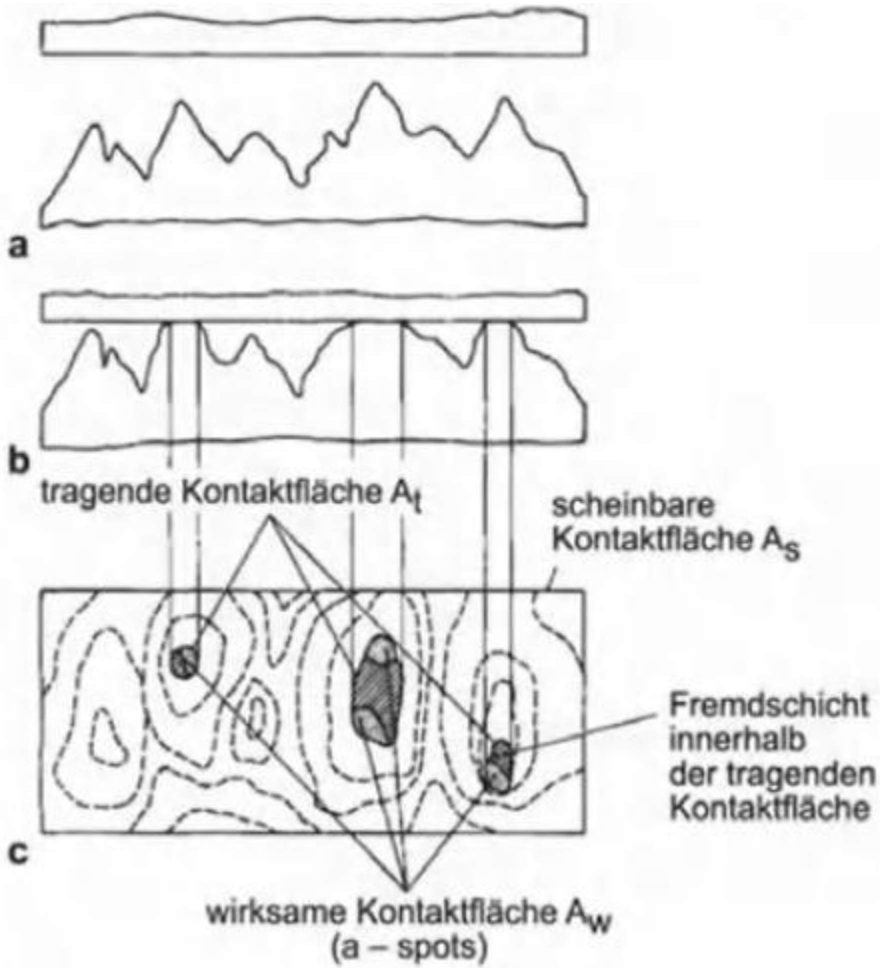
EMSOL :Electromagnetism solver selector:

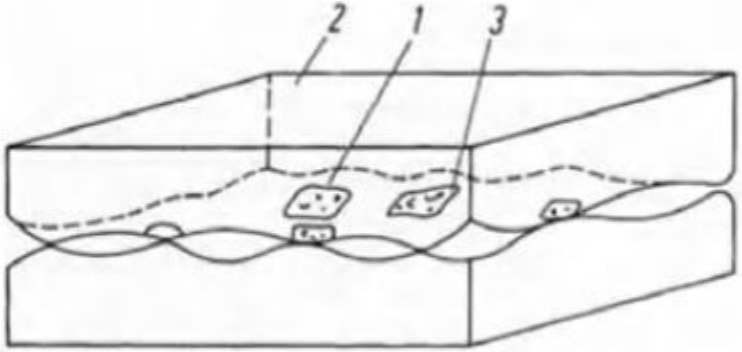
EQ.1: Eddy current solver
EQ.2: Induced heating solver
EQ.3: Resistive heating solver

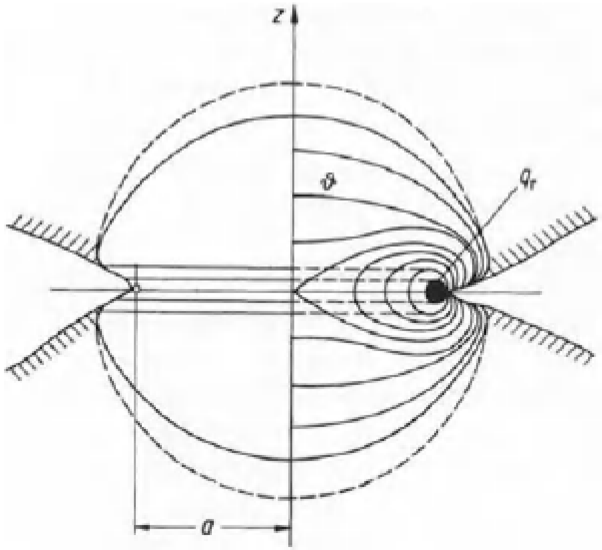
- Since no diffusive effects are taken into account, there is no limiting CFL condition and the time step can take a very high value.

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 :

$$R_{contact} = R_{constriction} + R_{film}$$

$$R_{film} = \frac{\rho_{oxy}}{\sqrt{faceAfilm \times ContactArea}}$$

$$R_{constriction} = \frac{\rho_{prob} + \rho_{sub}}{\sqrt{faceActe \times ContactArea}}$$

where $\rho_{prob}, \rho_{oxy}, \rho_{sub}$ respectively probe, film and substrate resistivity, $faceAfilm, faceActe$ 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

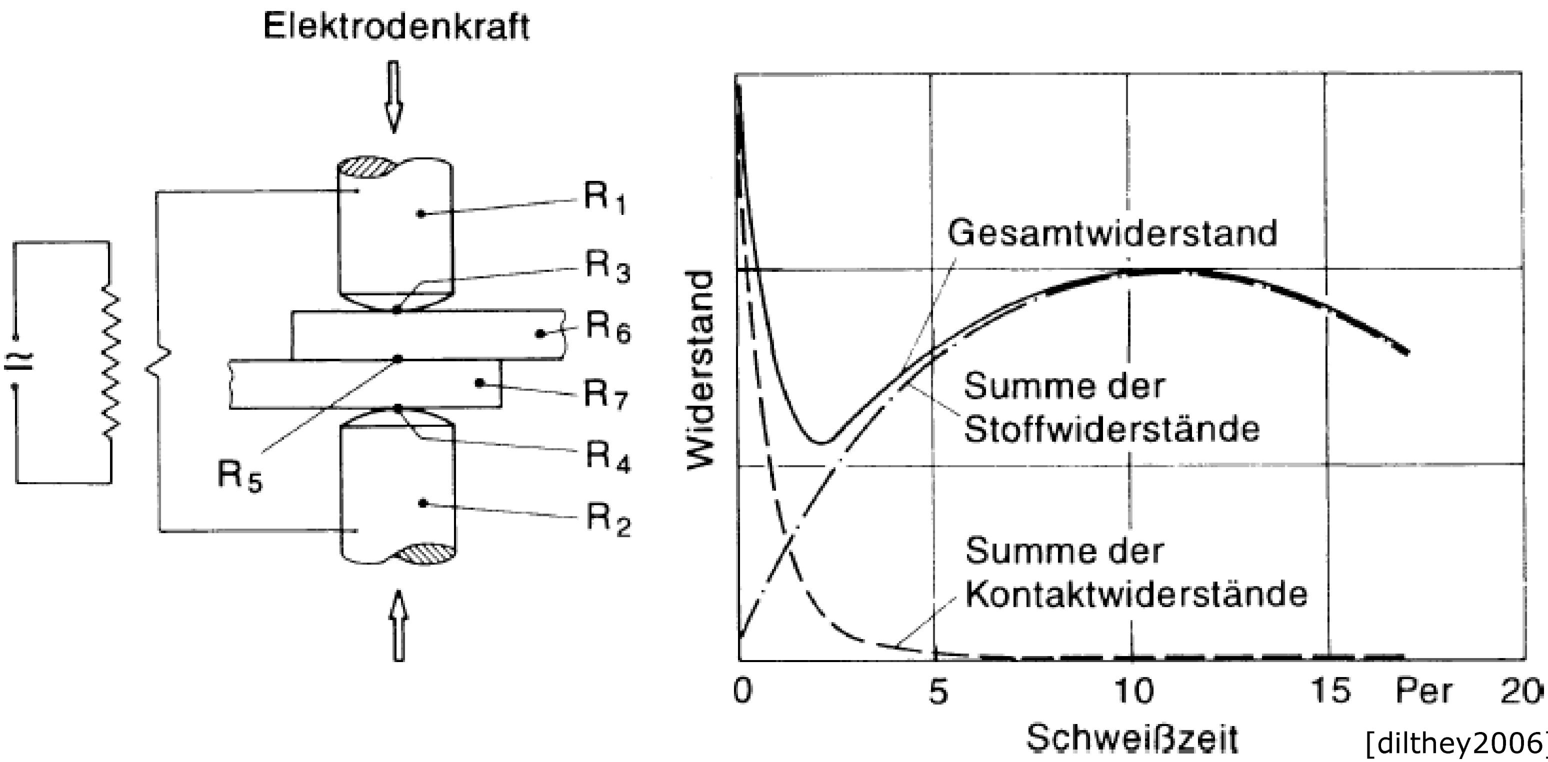
RHOn : Different resistivities

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



[dilthey2006]

Thank you

il@dynamore.de

	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