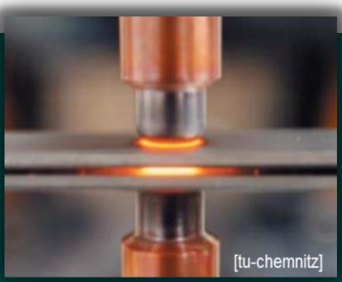
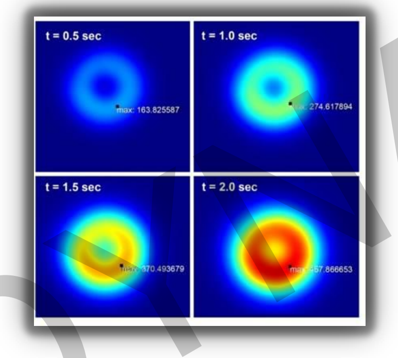
LS-DYNA – Anwendungsmöglichkeiten für die Fügesimulation





Thomas Klöppel

DYNAmore GmbH

Agenda

- Introduction to LS-DYNA
- Clinches and Rivets
- Friction Stir Welding
- Inductive Welding
- Resistive Welding

LS-DYNA – LSTC – DYNAmore History

1976: John Hallquist develops DYNA3D at Lawrence Livermore National Laboratories

1987: John Hallquist founds LSTC in Livermore CA, DYNA3D becomes LS-DYNA3D

1988: Prof. Schweizerhof + co-workers start with crash simulations in Germany

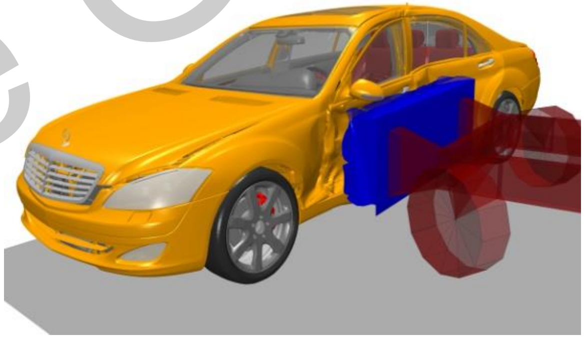
2001: DYNAmore is established

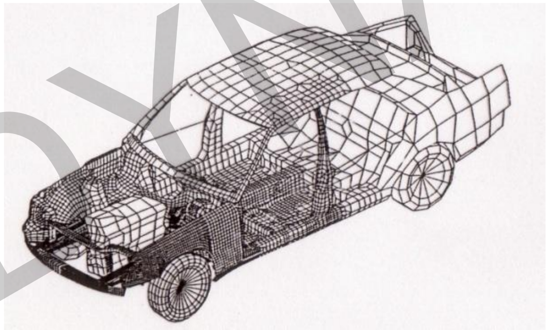
2011: DYNAmore acquires ERAB Nordic

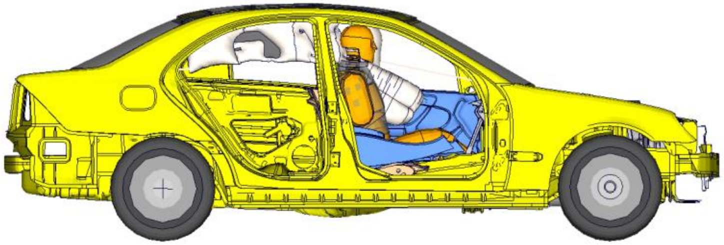
2011: DYNAmore assigned as Master distributor

2011: DYNAmore SWISS established

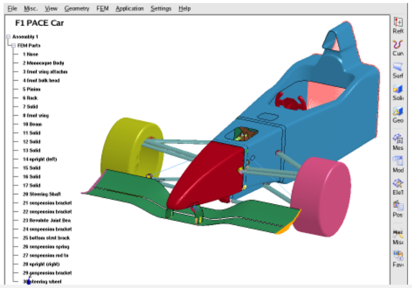
2013: DYNAmore Italia S.r.l. established



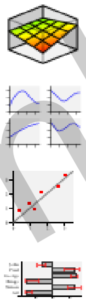




LSTC Product Range



LS-PrePost



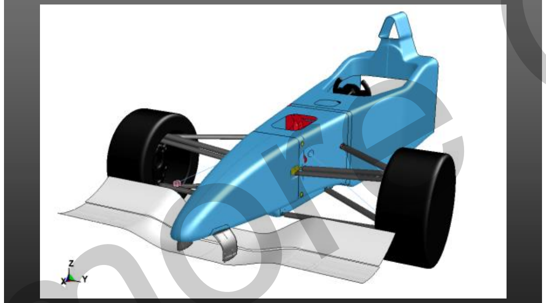
Surface

2D Interpolator

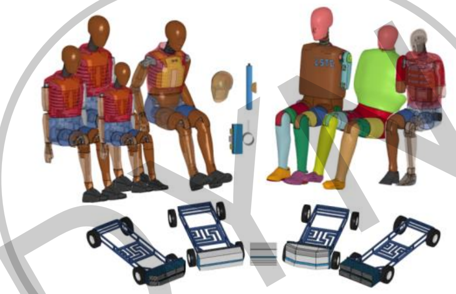
Accuracy

Sensitivity

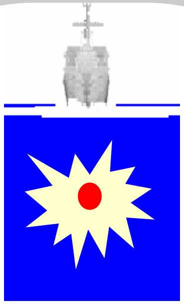
LS-OPT/LS-TaSC



LS-DYNA



Dummies & Barriers



USA

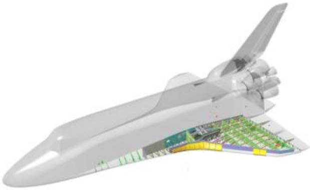
FREE OF CHARGE!

LS-DYNA R8 – The Applications

Automotive

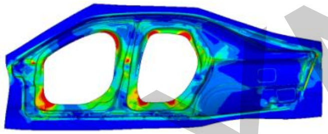
- Crash and Safety
- NVH
- Durability

Aerospace



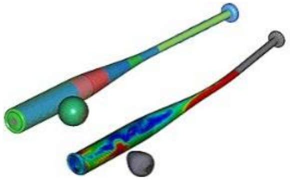
- Bird strike
- Containment
- Crash

Manufacturing

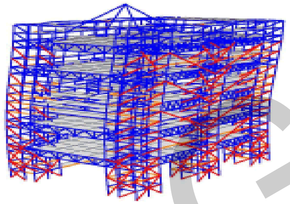


- Stamping
- Forging

Consumer Products

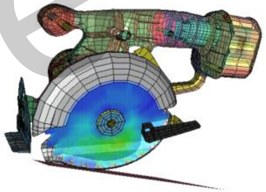


Civil Engineering



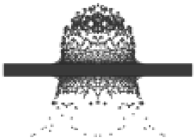
- Concrete structures
- Earthquake safety
- Wind- & Waterpower

Elektronics



- Drop analysis
- Package analysis
- Thermal

Defense

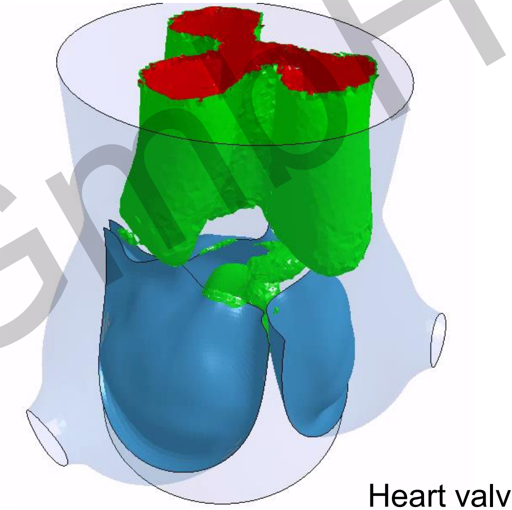


- Detonations
- Penetrations

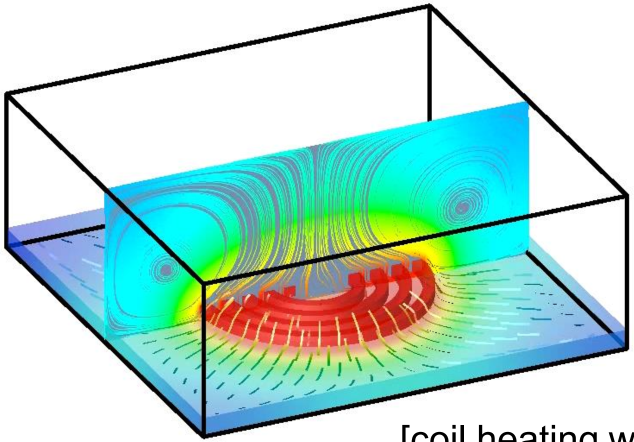
Biomechanics

LS-DYNA R8 – The Multiphysics Solver

- Combine the capabilities
  - Explicit/ Implicit **structural** solver
  - **Thermal** solver & heat transfer
  - **Incompressible fluid** solver (ICFD)
  - **Compressible fluid** solver (CESE)
  - **Electromagnetics** solver (EM)
  - Frequency domain, acoustics, modal analysis
  - Finite elements, iso-geometric elements, ALE, EFG, SPH, DEM, CPM, …
  - User elements, materials, loads
- Into **one** scalable **code** for
  - highly **nonlinear transient** problems
  - **static** problems
- To enable the solution of
  - coupled **multi-physics** and
  - **multi-stage** problems
- On **massively parallel** systems



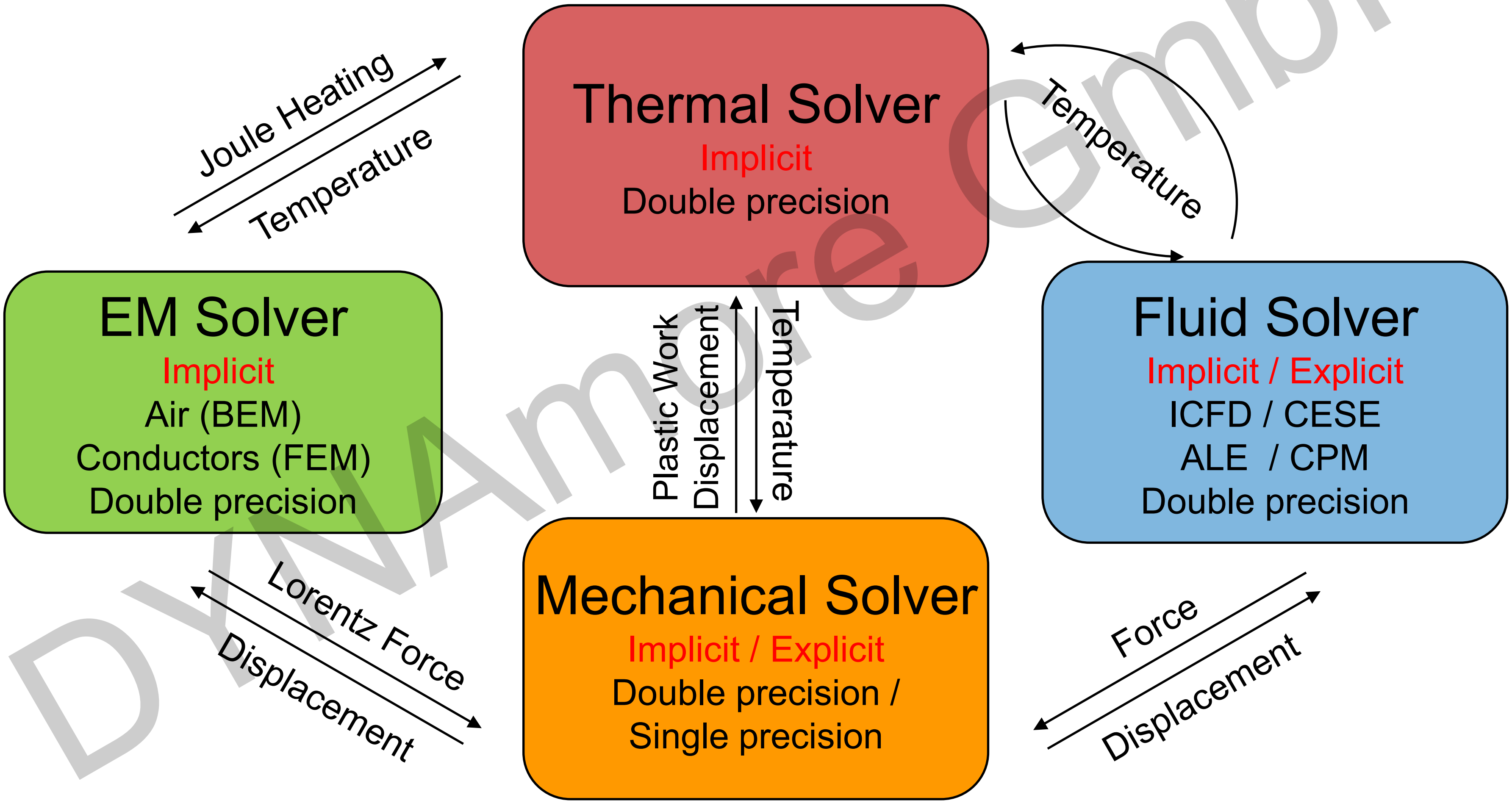
Heart valve:
Courtesy of H. Mohammadi,
McGill University



[coil heating water]

LS-DYNA R8 – The Multiphysics Solver

- No need for co-simulation, as all solvers are included!



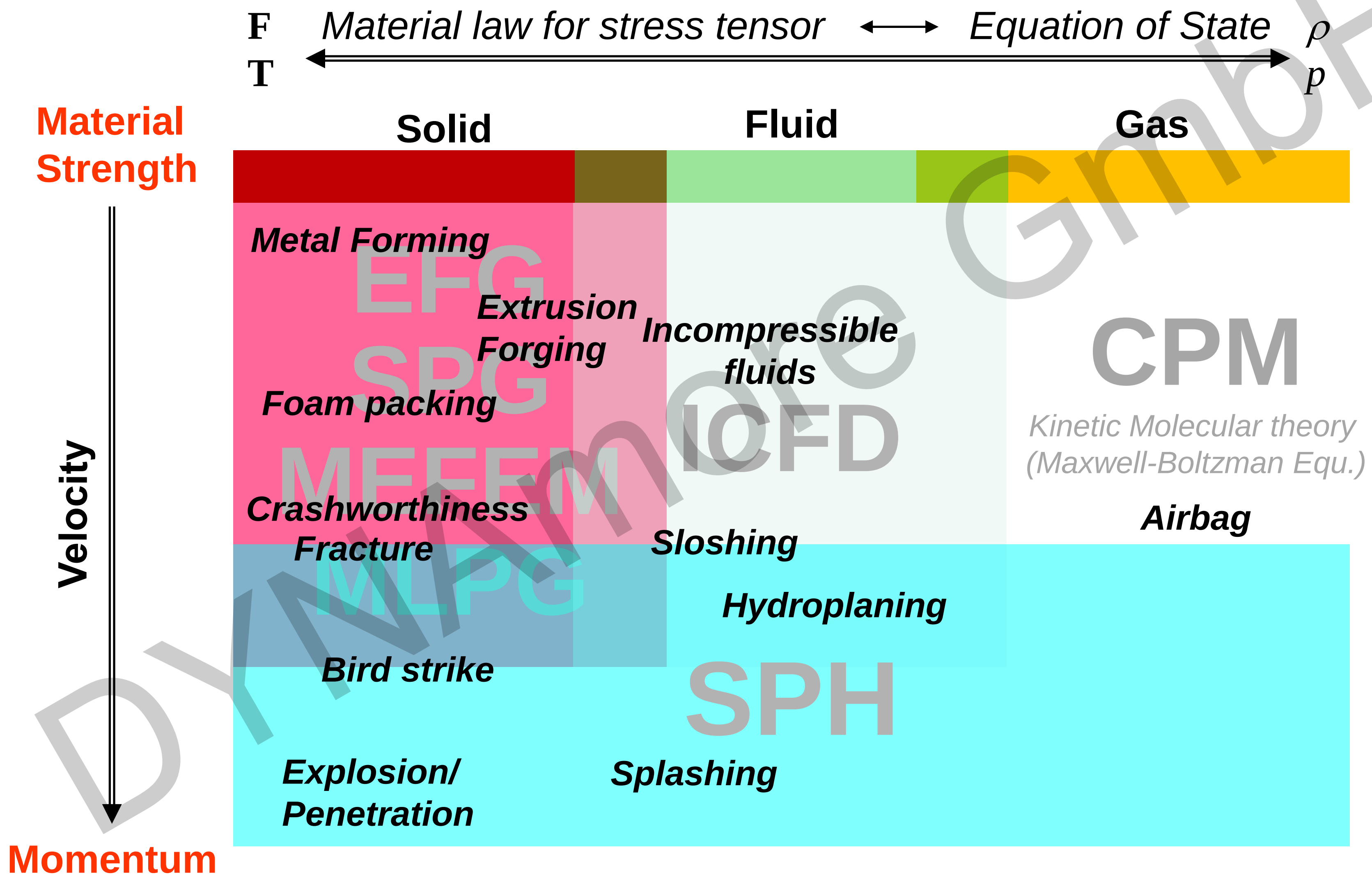
Thermal Solver
Implicit
Double precision

EM Solver
Implicit
Air (BEM)
Conductors (FEM)
Double precision

Fluid Solver
Implicit / Explicit
ICFD / CESE
ALE / CPM
Double precision

Mechanical Solver
Implicit / Explicit
Double precision /
Single precision

LS-DYNA R8 – Continuum Meshfree Methods



F T *Material law for stress tensor* ⟷ *Equation of State* ρ p

Material Strength

Velocity

Momentum

Solid

Fluid

Gas

EFG

SPG

MEFEM

MLPG

ICFD

SPH

CPM

Kinetic Molecular theory (Maxwell-Boltzman Equ.)

Metal Forming

Extrusion Forging

Foam packing

Crashworthiness Fracture

Incompressible fluids

Sloshing

Hydroplaning

Bird strike

Explosion/ Penetration

Splashing

Airbag

Agenda

- Introduction to LS-DYNA
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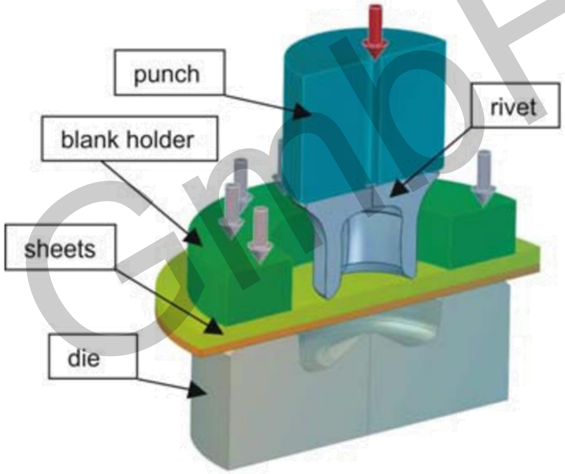
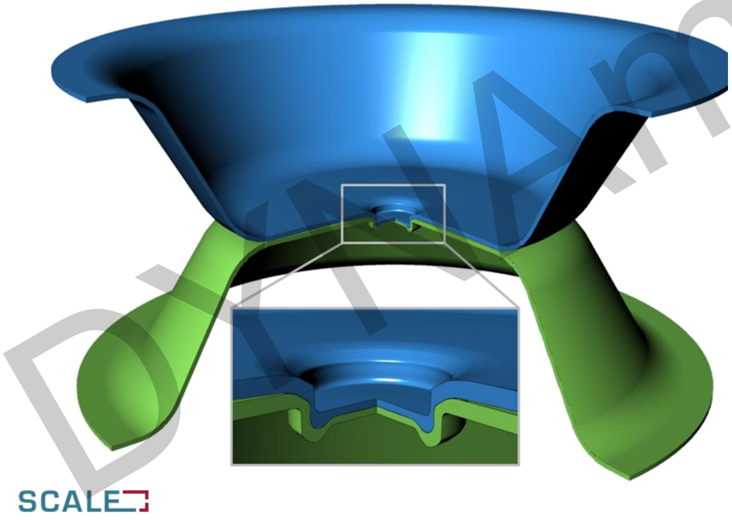
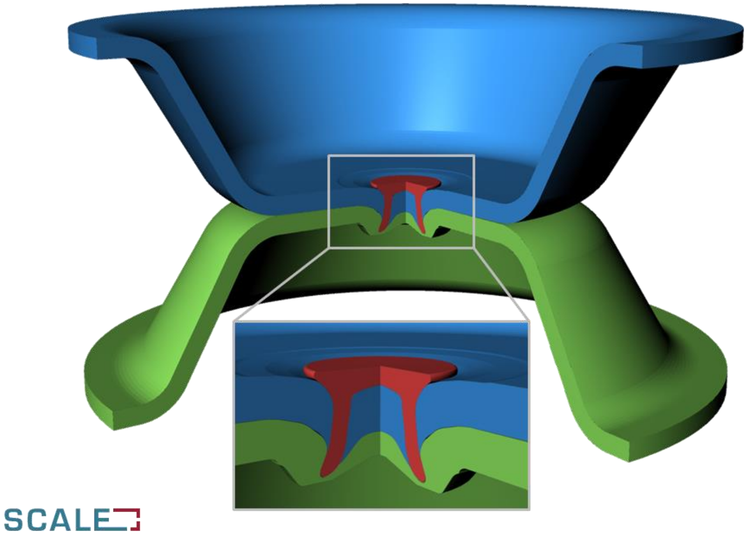
Clinches and Rivets

- 2 or more sheets are to be joined together
- Highly distorted structures
- Topology changes for self piercing rivets

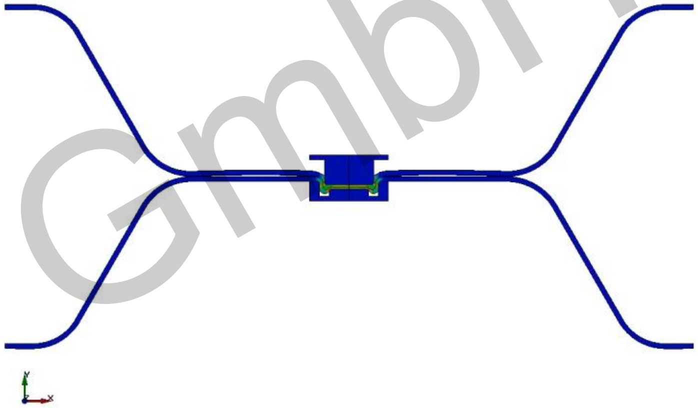


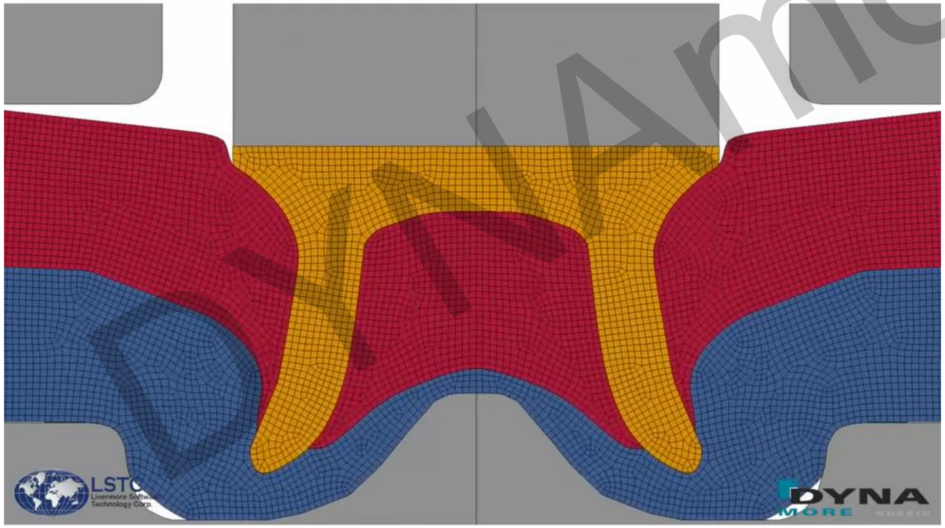


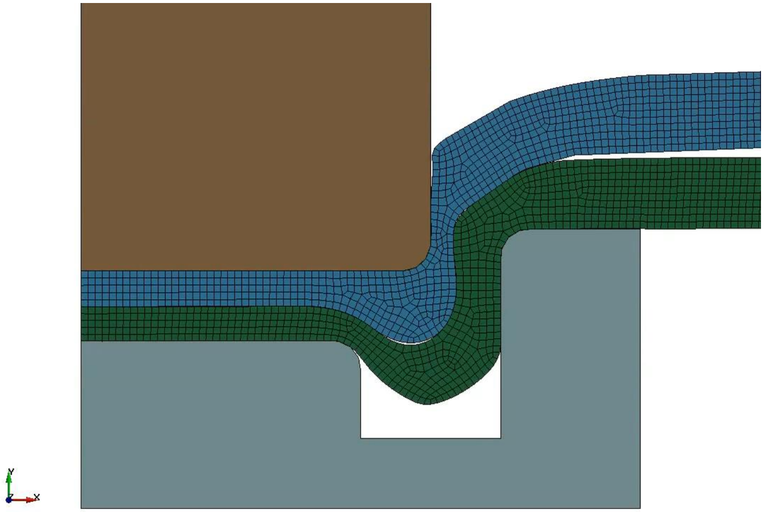


2D axisymmetric model

- METHOD 1: Use 2D axisymmetric remeshing:
  - Switch on R-adaptivity
    in *PART set adpopt=2
  - Use volume-weighted axisymmetric solid
    in *SECTION_SHELL set eltyp=15
  - Use reasonable values for adaptivity
    *CONTROL_ADAPTIVE
    *PART_ADAPTIVE_FAILURE

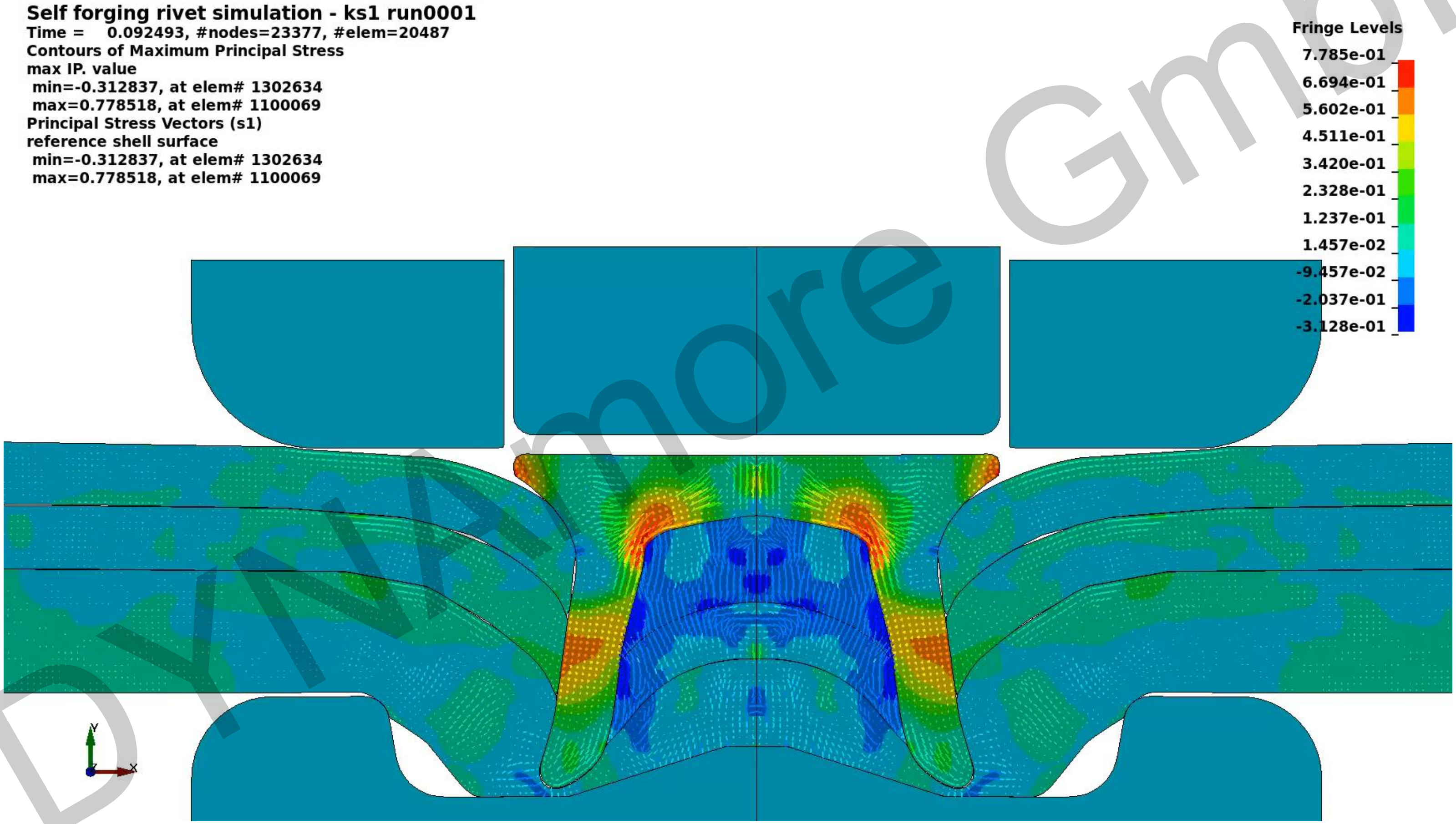






Extension to 3 blanks

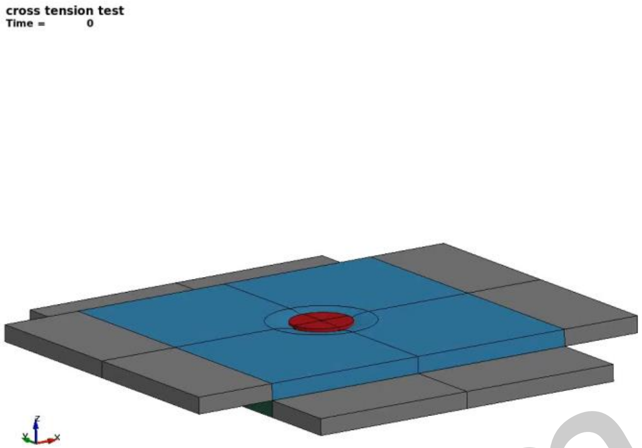
- Simulation not restricted to 2 blanks



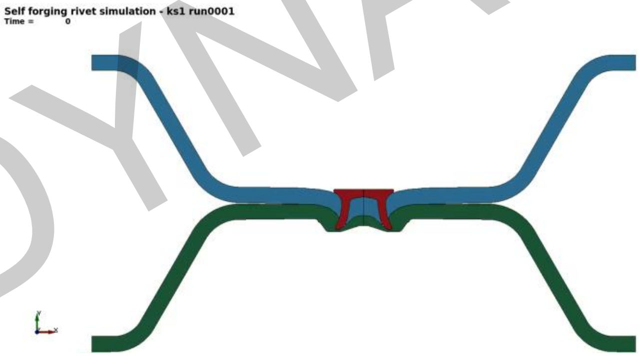
```
Self forging rivet simulation - ks1 run0001
Time =    0.092493, #nodes=23377, #elem=20487
Contours of Maximum Principal Stress
max IP. value
 min=-0.312837, at elem# 1302634
 max=0.778518, at elem# 1100069
Principal Stress Vectors (s1)
reference shell surface
 min=-0.312837, at elem# 1302634
 max=0.778518, at elem# 1100069
```

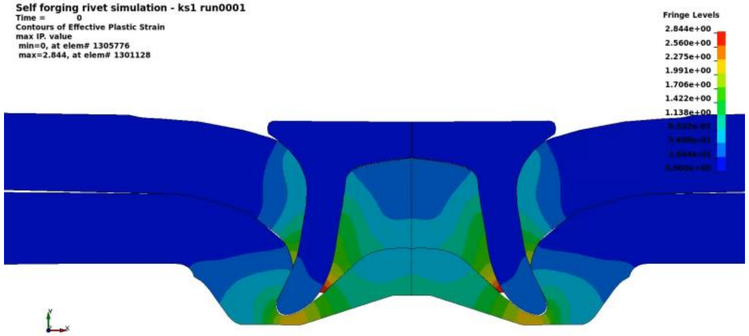
Serviceability analysis

- Cross tension test



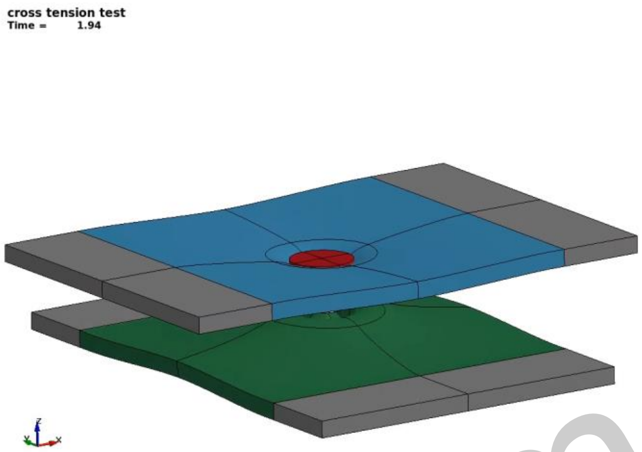
- Tension test

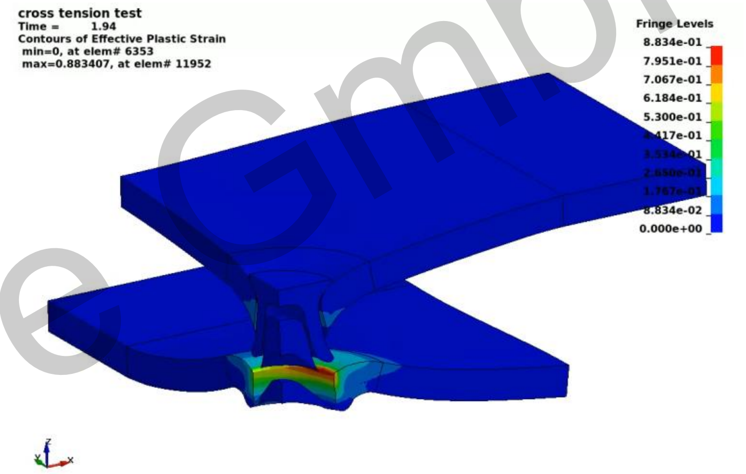




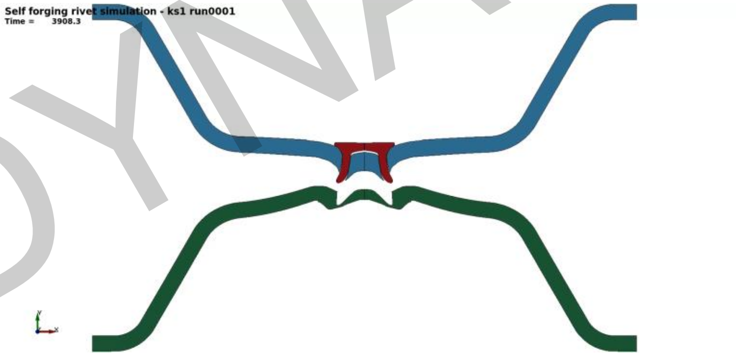
Serviceability analysis

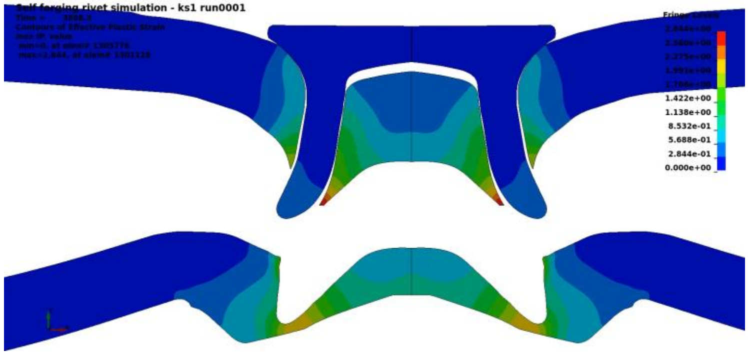
- Cross tension test





- Tension test



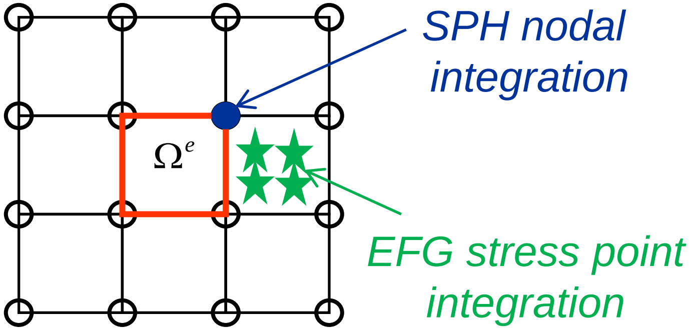


Modeling Clinches and Rivets in 3D with EFG

- For a 3D representation adaptive EFG seems to be promising

- Basic ideas
  - Replace the continuum by a set of particles
  - Construction of shape functions without a mesh [*Lucy* 1977, *Gingold* & *Monaghan* 1977, *Liu* 2003]

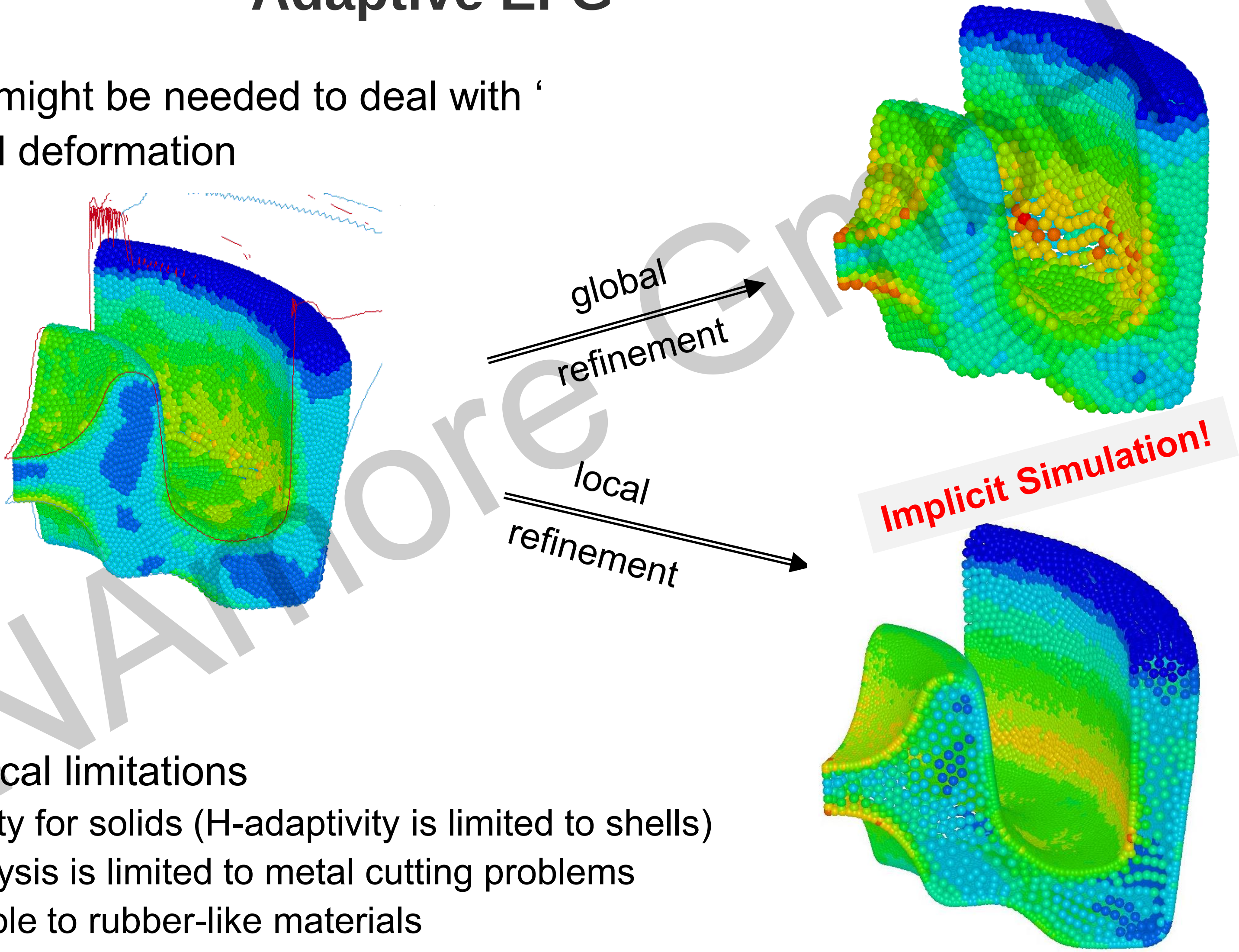
- In contrast to other element-free methods, a background mesh (or integration cells) is needed
  - Define the physical domain
  - Contact conditions
  - Impose boundary conditions
  - Perform volume integration via “stress points”



- Based on Galerkin weak form of the problem

Adaptive EFG

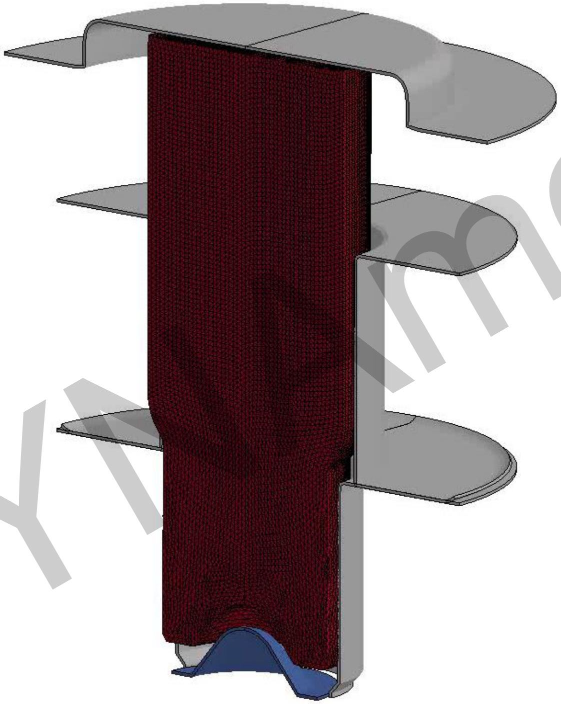
- Adaptive EFG might be needed to deal with ‘ severe material deformation

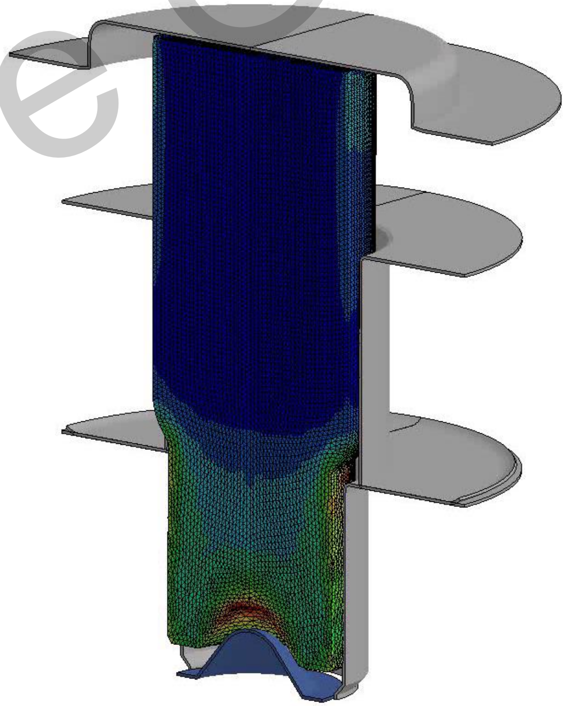


- Current numerical limitations
  - RH-adaptivity for solids (H-adaptivity is limited to shells)
  - Failure analysis is limited to metal cutting problems
  - Not applicable to rubber-like materials

Cold forming of a pre-stressed rivet head

- Computation times
  - LS-DYNA (explicit): 1 day on 6 CPU
  - LS-DYNA (implicit): 20 min on 6 CPU





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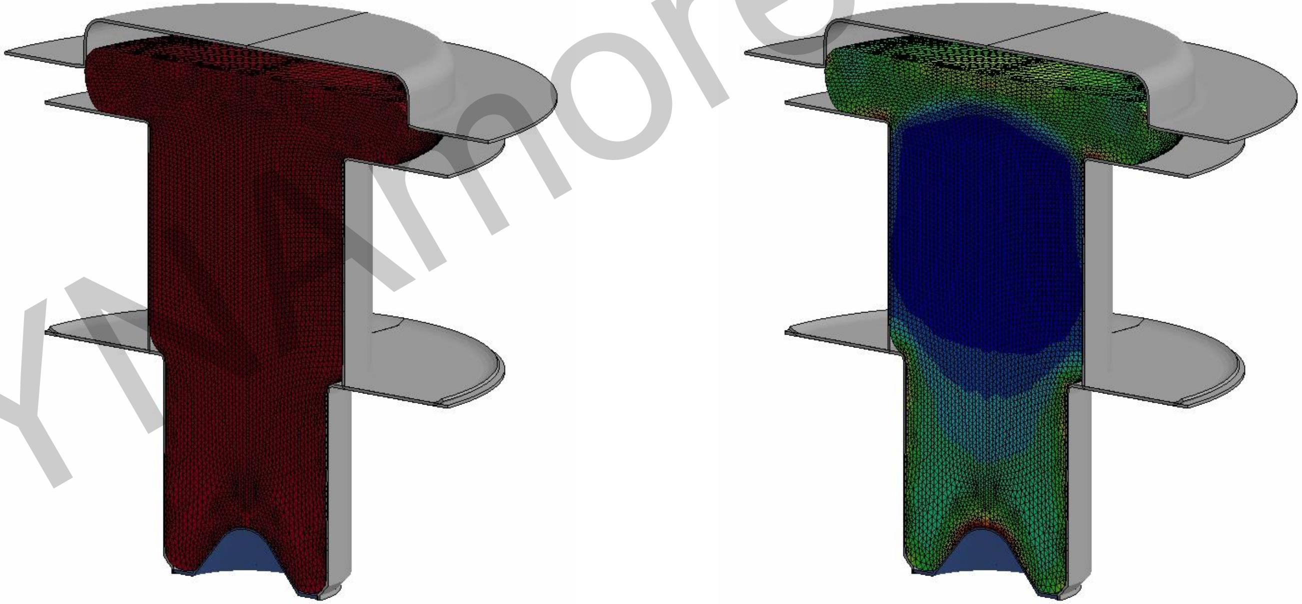
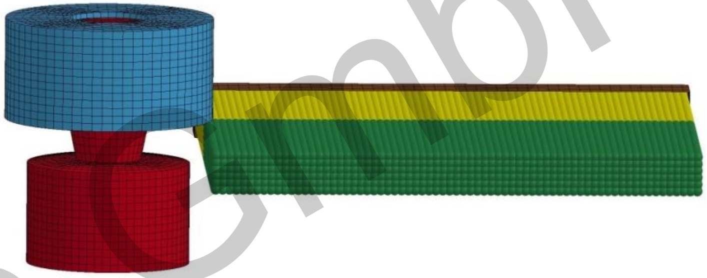


Agenda

- Introduction to LS-DYNA
- Clinches and Rivets
- Friction Stir Welding
- Inductive Welding
- Resistive Welding

Friction stir welding

- Process:
  - Two materials
  - Fast rotating cylinder
  - Cylinder is translated through the seam
  - Due to the friction, materials meld
  - Rotation mixes the materials



Courtesy Kirk Fraser (Predictive Engineering)

- Material mixing requires meshless methods

- The SPH method is most suitable for these high velocities

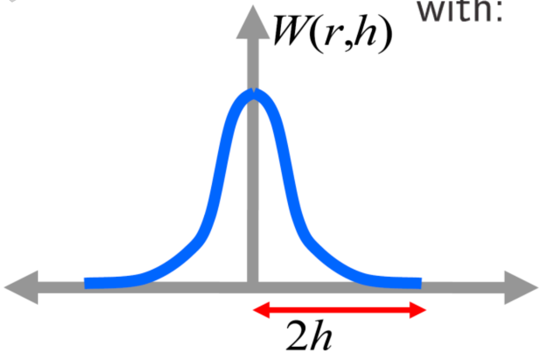
Smoothed-Particle Hydrodynamics (SPH)

- Basic ideas
  - Replace the continuum by a set of particles
  - Construction of shape functions without a mesh [*Lucy* 1977, *Gingold* & *Monaghan* 1977, *Liu* 2003]

- Integral interpolant as approximation function
  - Exploitation of the identities

$$u(x) = \int_\Omega u(y)\,\delta(x-y)\,\mathrm{d}y \qquad < u(x) > = \int_\Omega u(r)\,W(r,\,h)\,\mathrm{d}r$$

with: $\int_\Omega \delta(x-y)\,\mathrm{d}y = 1$ with: $\int_\Omega W(r,h)\,\mathrm{d}r = 1$

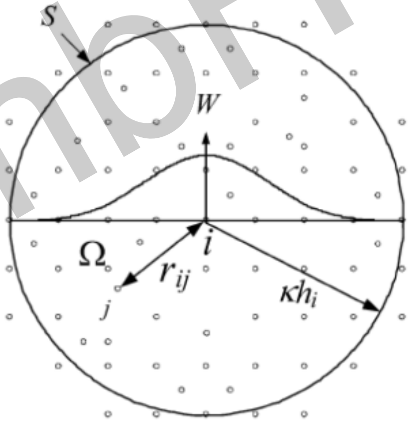


Smoothed-Particle Hydrodynamics (SPH)

- Approximation of the displacement/velocity

$$u^h_\alpha(\mathbf{x}_i) = \sum_j \frac{m_j}{\rho_j}\, u_\alpha(\mathbf{x}_j)\, W_{ij} \quad \text{with} \quad \mathbf{u}^h = u^h_\alpha\, \mathbf{e}_\alpha \quad \forall\, \alpha = 1, 2, 3$$

$$\text{with} \quad W_{ij} = W_i(r_{ij}, h_i) = \frac{1}{h_i^3}\,\Theta\!\left(\frac{r_{ij}}{h_i}\right) \quad \begin{cases} r_{ij} = |\mathbf{x}_i - \mathbf{x}_j| \\ 2h_i \;:\; \text{smoothing length} \\ m_i \;:\; \text{particle mass} \\ \rho_i \;:\; \text{density} \end{cases}$$

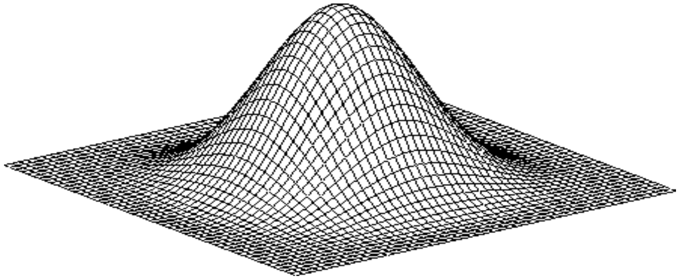


- Approximation of the displacement/velocity gradient

$$\operatorname{grad} \mathbf{u}^h(\mathbf{x}_i) = \frac{\mathrm{d}u^h_\alpha(\mathbf{x}_i)}{\mathrm{d}x_\beta} = \sum_j \frac{m_j}{\rho_j}\left[u_\alpha(\mathbf{x}_j)\, W_{ij,\beta} - u_\alpha(\mathbf{x}_i)\, W_{ji,\beta}\right]$$

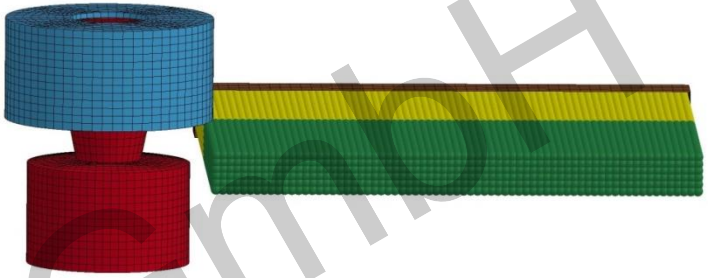
$$\text{with} \quad W_{ij,\beta}(r_{ij}, h_i) = \frac{1}{h_i^4}\,\frac{\mathrm{d}}{\mathrm{d}x_\beta}\Theta\!\left(\frac{r_{ij}}{h_i}\right)$$

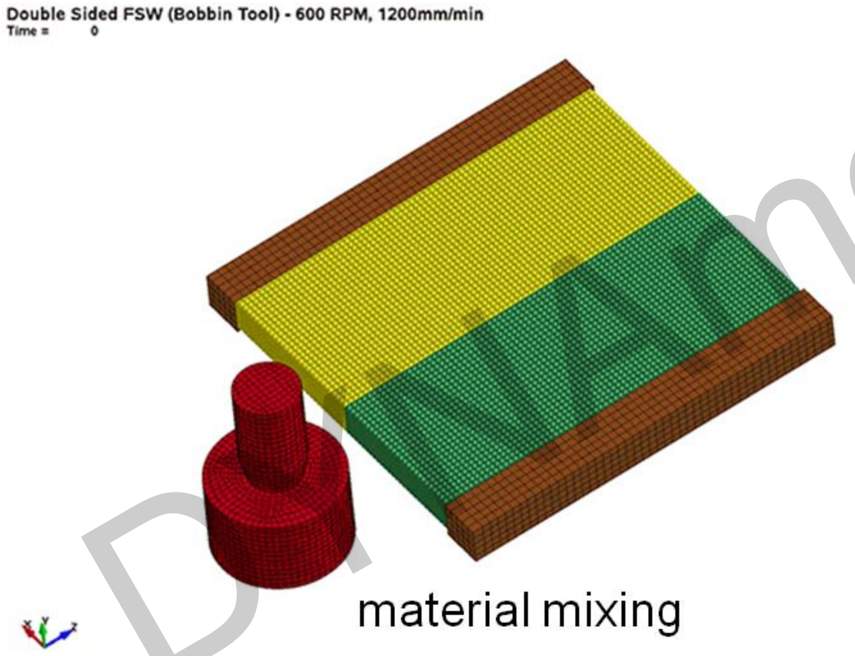
Kernel function θ

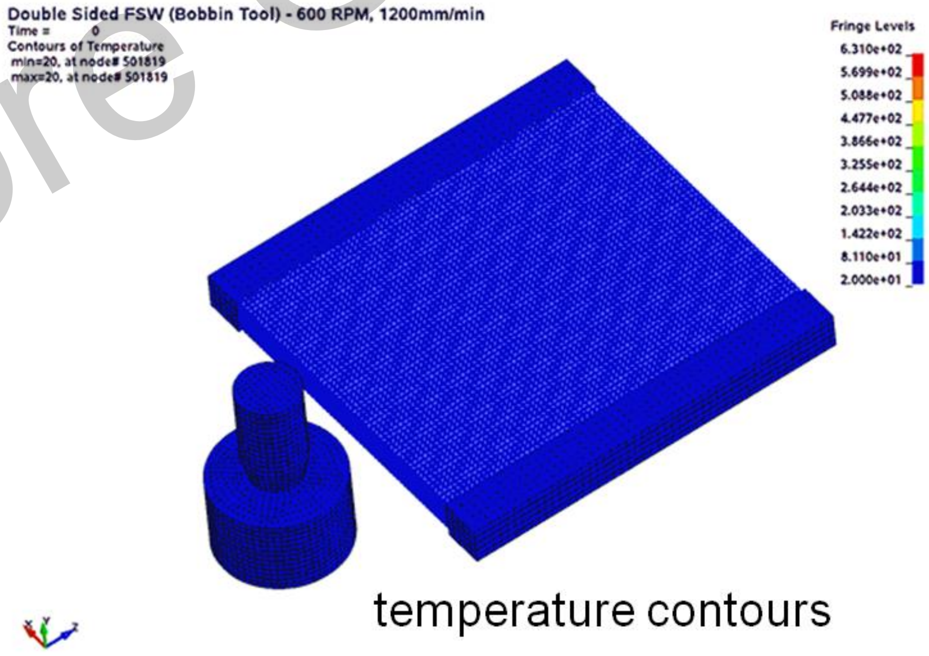


Friction Stir Welding Example

- Double sided FSW @ 600 RPM, 1200 mm/min
- Plastic work and friction energy to heat







Courtesy Kirk Fraser (Predictive Engineering)

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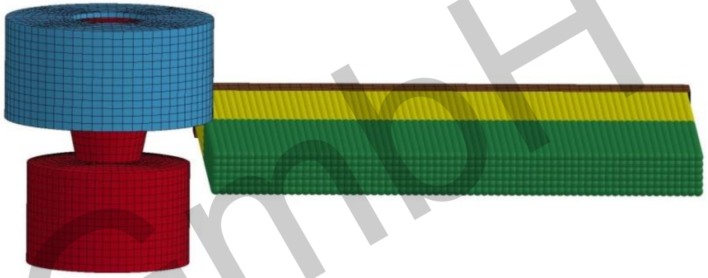
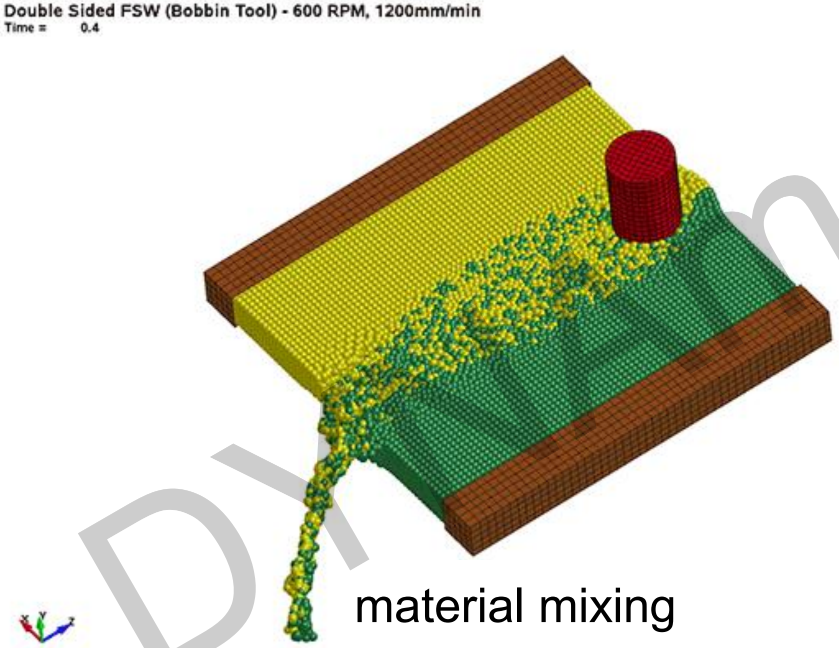
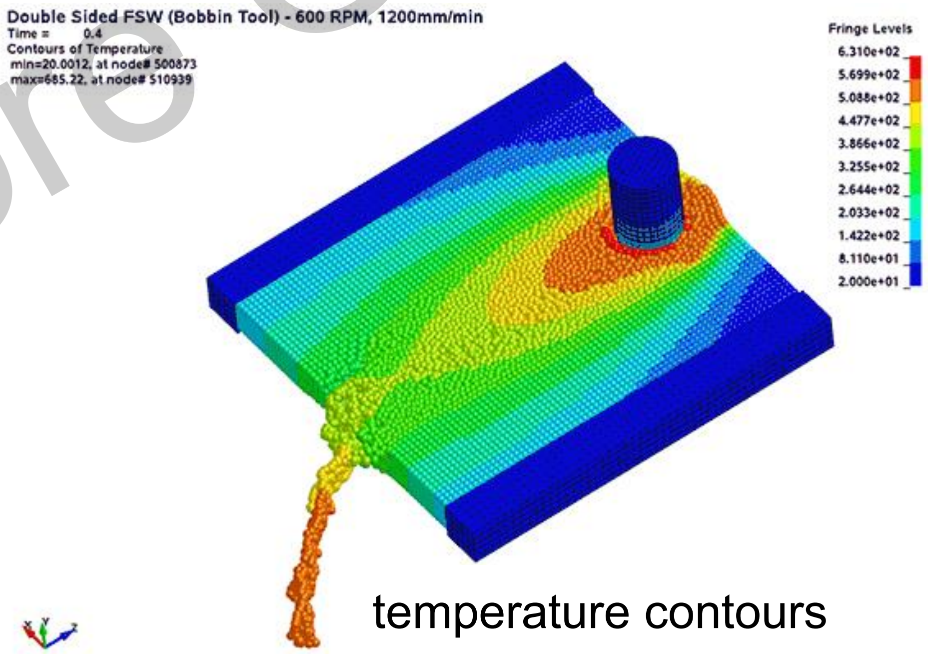




material mixing



temperature contours

Courtesy Kirk Fraser (Predictive Engineering)

Agenda

- Introduction to LS-DYNA
- Clinches and Rivets
- Friction Stir Welding
- **Inductive Welding**
- Resistive Welding

Electromagnetism (EM) Solver in LS-DYNA

- Electro-magnetic solver at a glance and its connection to the other solvers

EM Solver

Implicit
(SMP & MPP)

Air (BEM)
Conductor (FEM)

Ampere‘s Law: $\mathrm{rot}\,\frac{1}{\mu}\mathbf{B} = j + \varepsilon\cancel{\frac{\partial \mathbf{E}}{\partial t}}$

Eddy-current formulation

Faraday‘s Law: $\mathrm{rot}\,\mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$

Gauss law: $\mathrm{div}\,\mathbf{B} = 0$

Gauss flux theorem: $\mathrm{div}\,\mathbf{E} = 0$

Continuity: $\mathrm{div}\,\mathbf{j} = 0$

Maxwell Equations

Ohm’s law: $\mathbf{j} = \sigma\mathbf{E} + \mathbf{j}_s$

$\mathrm{rot}\,(\cdot)$: rotation

$\mathrm{div}\,(\cdot)$: divergence

$\mathbf{E}$: electric field

$\mathbf{B}$: magnetic flux density

$\mathbf{j}$: total current density

$\mathbf{j}_s$: source current density

ε, μ, and σ : material electrical properties

Displacement

Lorentz forces

$$\mathbf{F} = \rho_e\mathbf{E} + \mathbf{j}\times\mathbf{B}$$

Temperature

Joule heating

$$p = \frac{dQ}{dt} = j^2R$$

Mechanical Solver

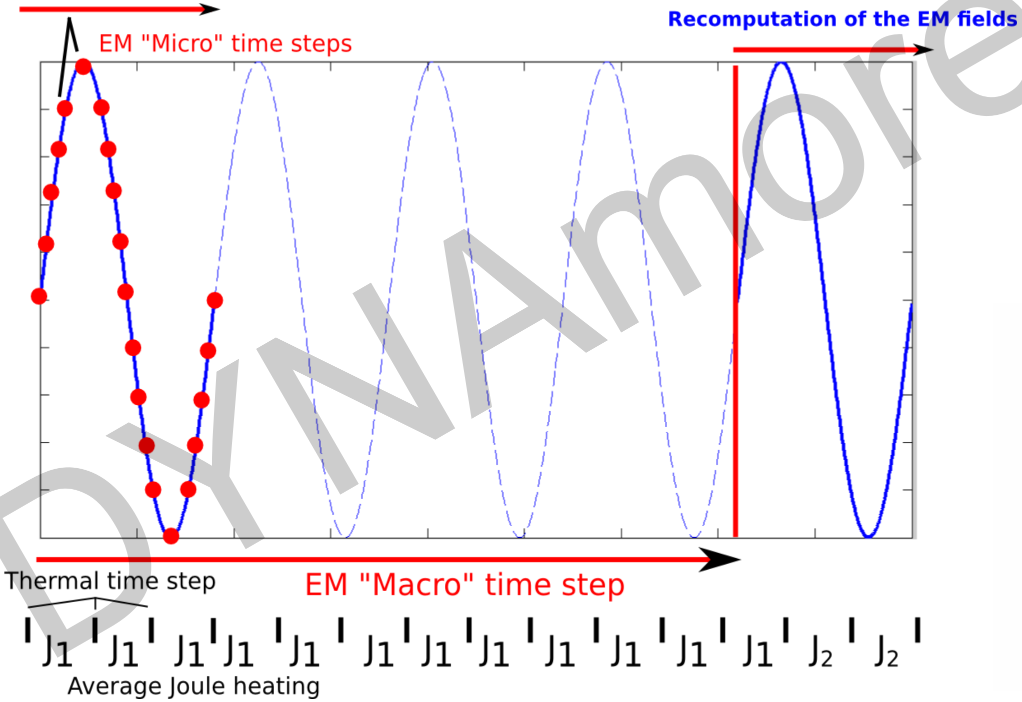
Explicit / Implicit
(SMP & MPP)

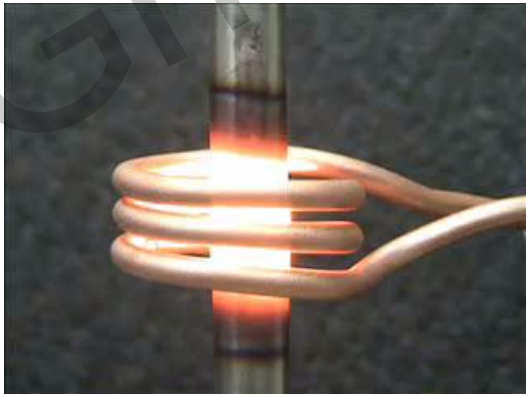
Thermal Solver

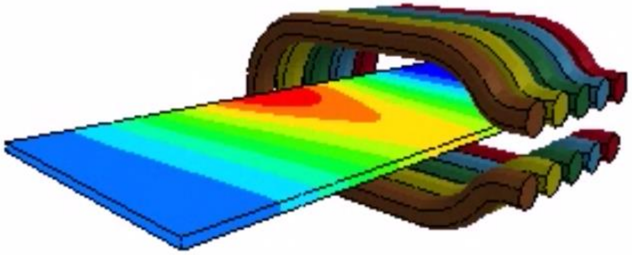
Implicit
(SMP & MPP)

Electromagnetism

- Subcycling for the Joule (induced) heating problem
  - Timescale of oscillating coil is much smaller than for the total problem
  - Many small EM time steps would be needed
  - Introduction of a “micro” and “macro” time step

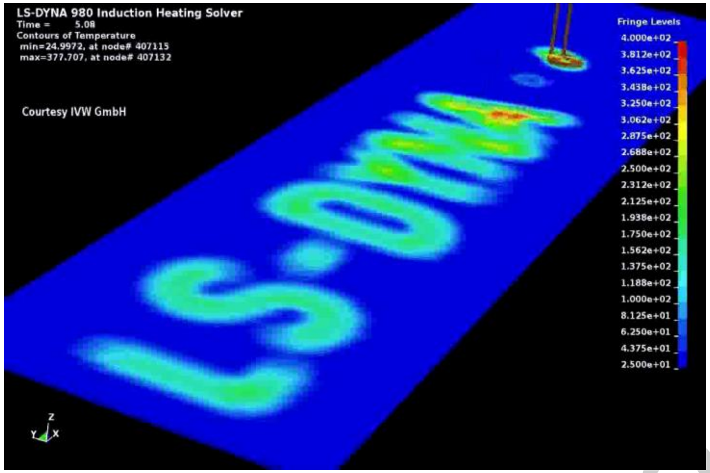


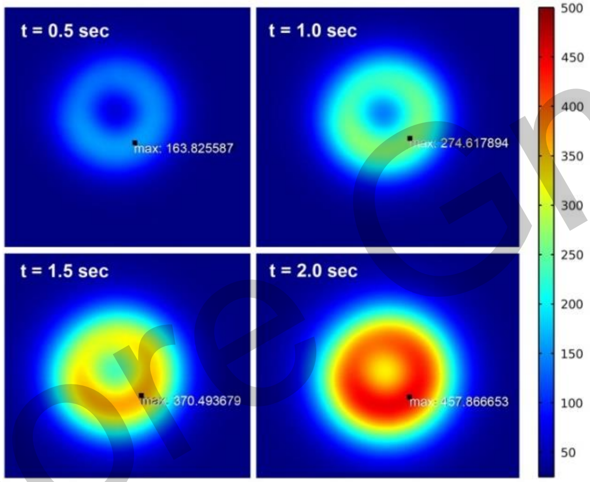




Electromagnetism

- Preparation for welding applications





LS-DYNA

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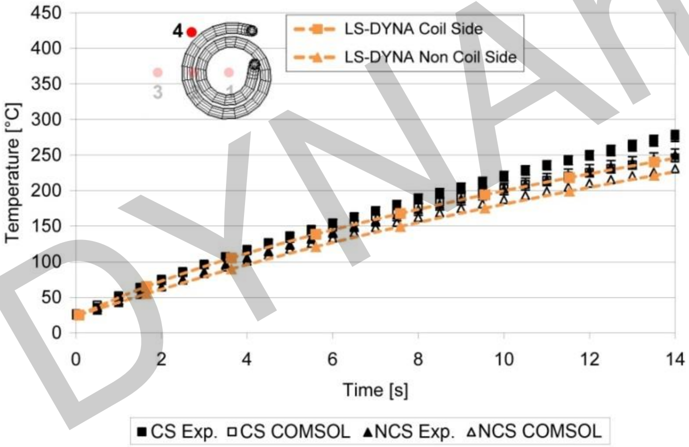
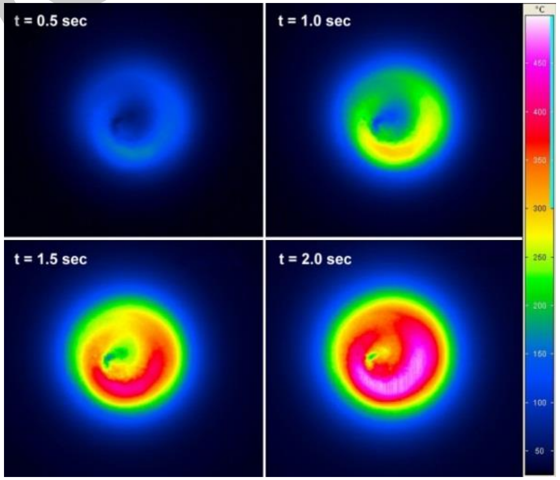
Courtesy of Miro Duhovic





Experiment

Electromagnetism

- Continuous induction welding [*Moser & Mitschang* 2012]
  - Carbon-fiber reinforcements form conductive loops
  - Joule heating to the melting point
  - Pressure application for consolidation

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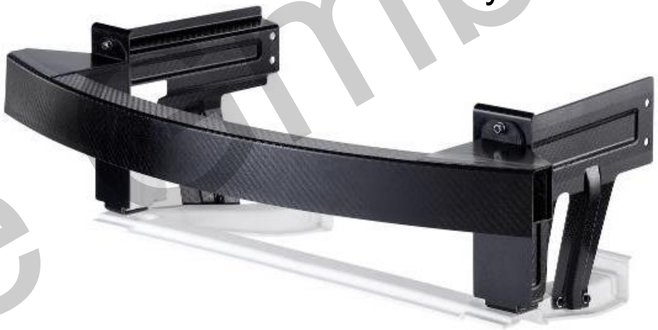
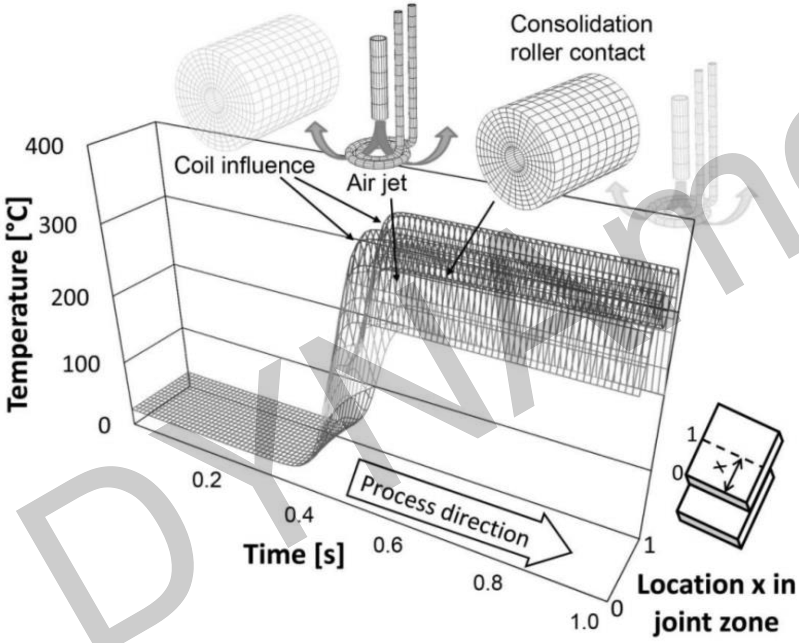
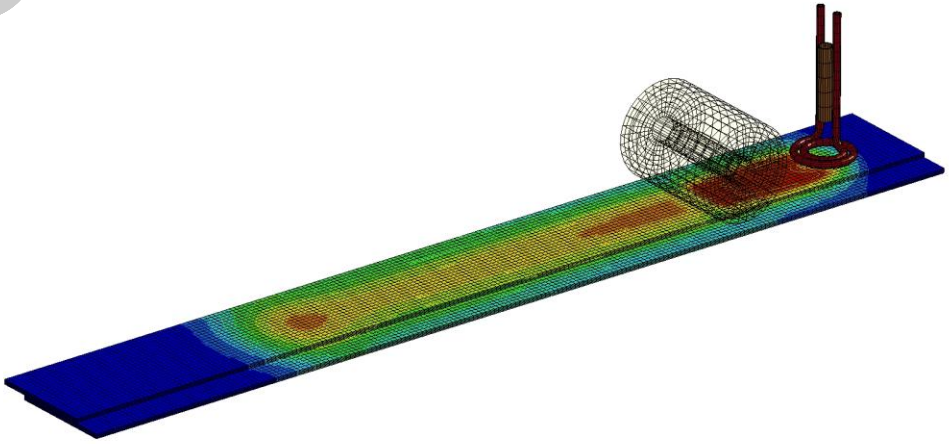
Courtesy of Miro Duhovic





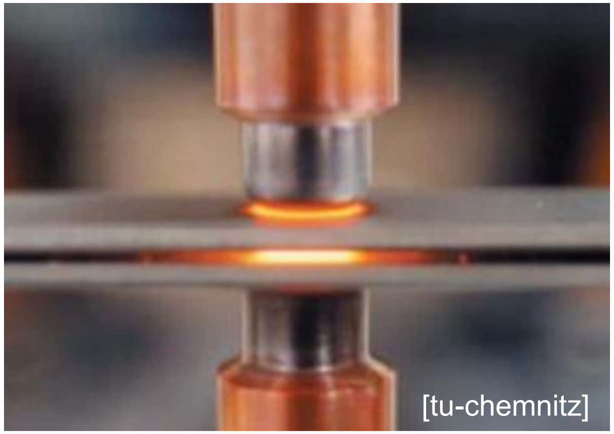


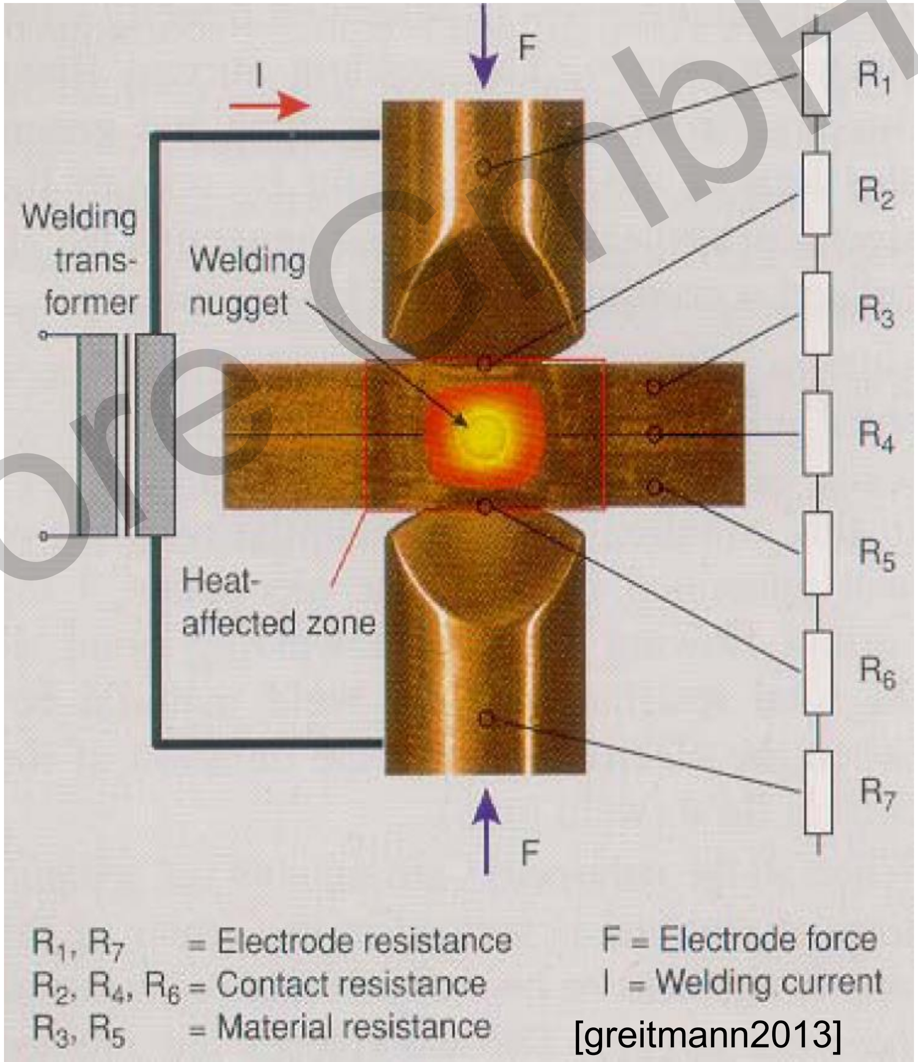
[*Duhovic et al.* 2013]

Agenda

- Introduction to LS-DYNA
- Clinches and Rivets
- Friction Stir Welding
- Inductive Welding
- Resistive Welding

Analysis of the welding process


[tu-chemnitz]



R_1, R_7 = Electrode resistance

R_2, R_4, R_6 = Contact resistance

R_3, R_5 = Material resistance

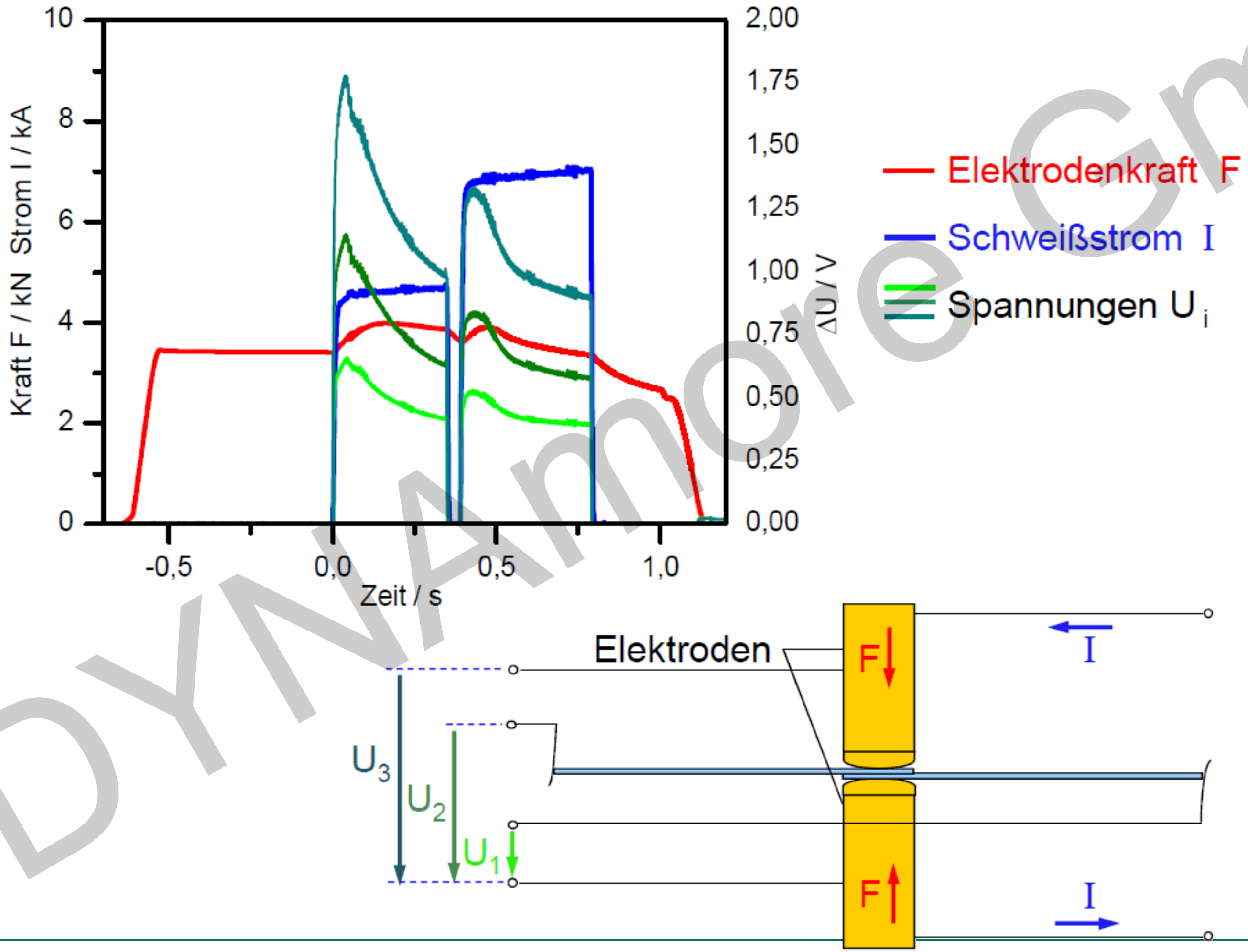
F = Electrode force

I = Welding current

[greitmann2013]

Typical welding process

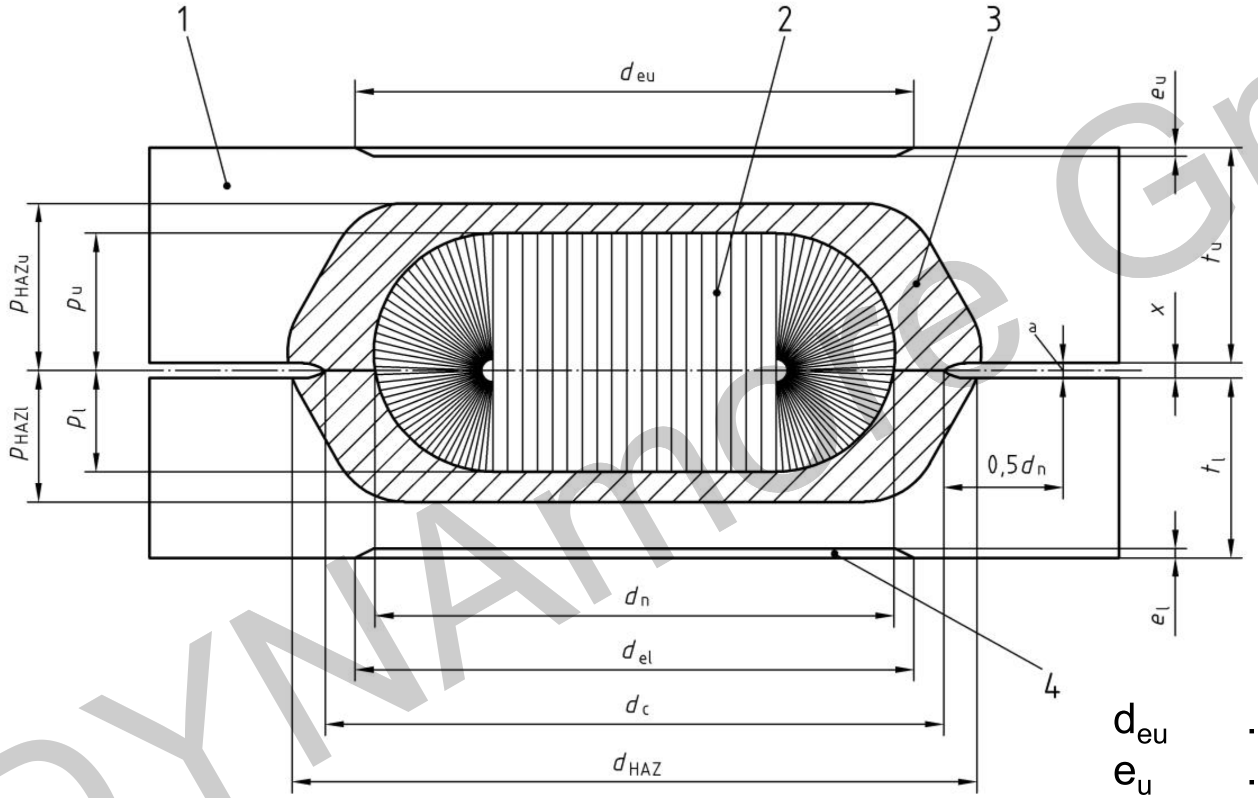
- Typical force, current and voltage curves during the resistance spot welding



[wick2012]

Aim of the process simulation

- Determination of the nugget geometry according to DIN 4329



Legende

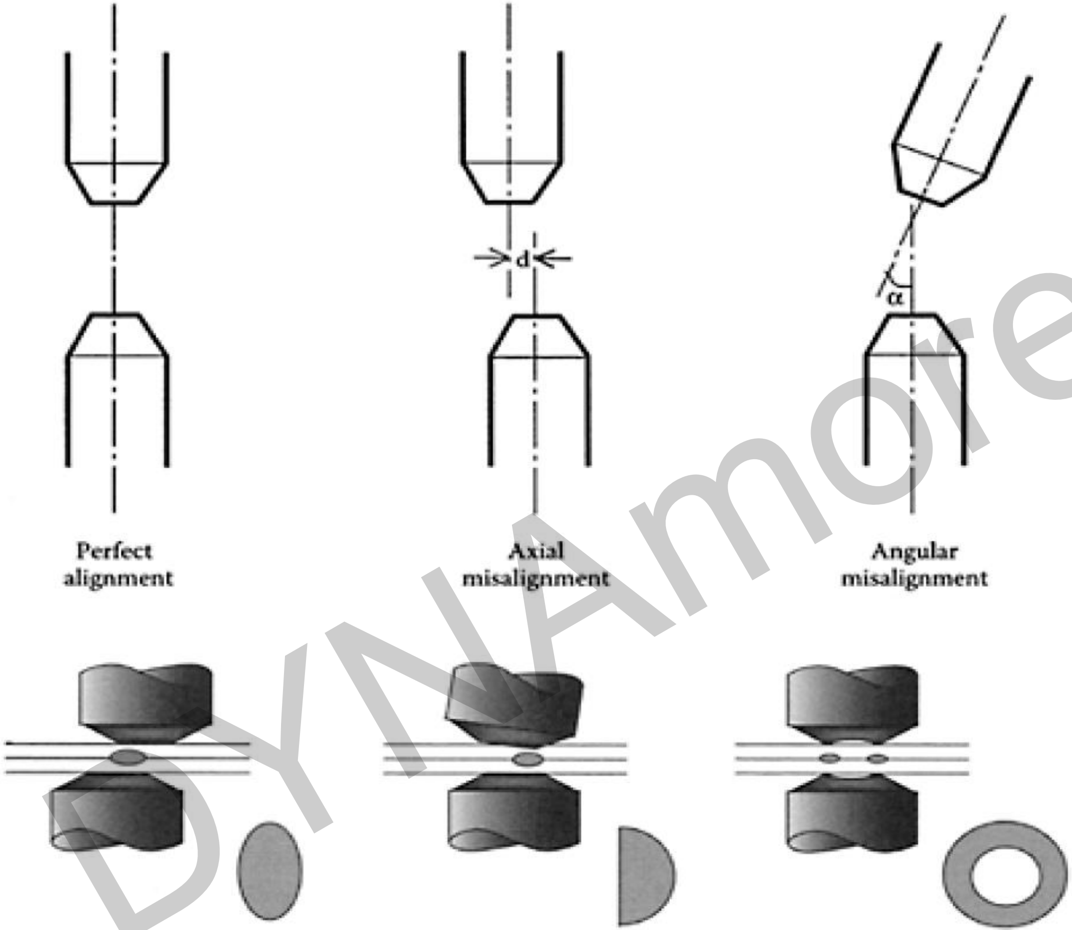
1 Grundwerkstoff
2 Linse
3 Wärmeeinflusszone (HAZ)
4 Elektrodeneindruck

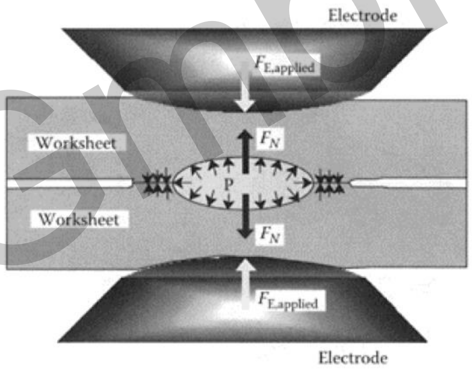
d_{eu} .. indentation width
e_u .. indentation depth
d_n .. nugget width
p .. penetration

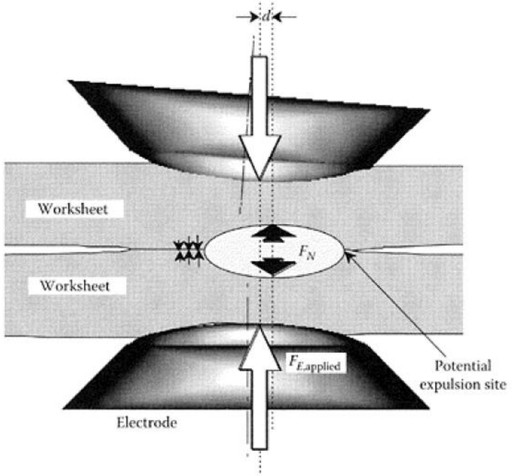
[DIN14329]

Aim of the process simulation

- Influence of electrode contact angle on the nugget size and shape



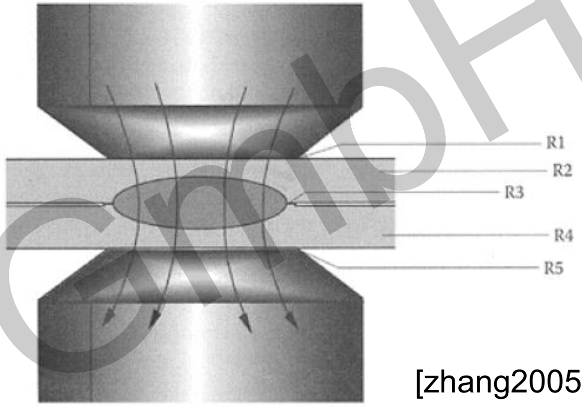




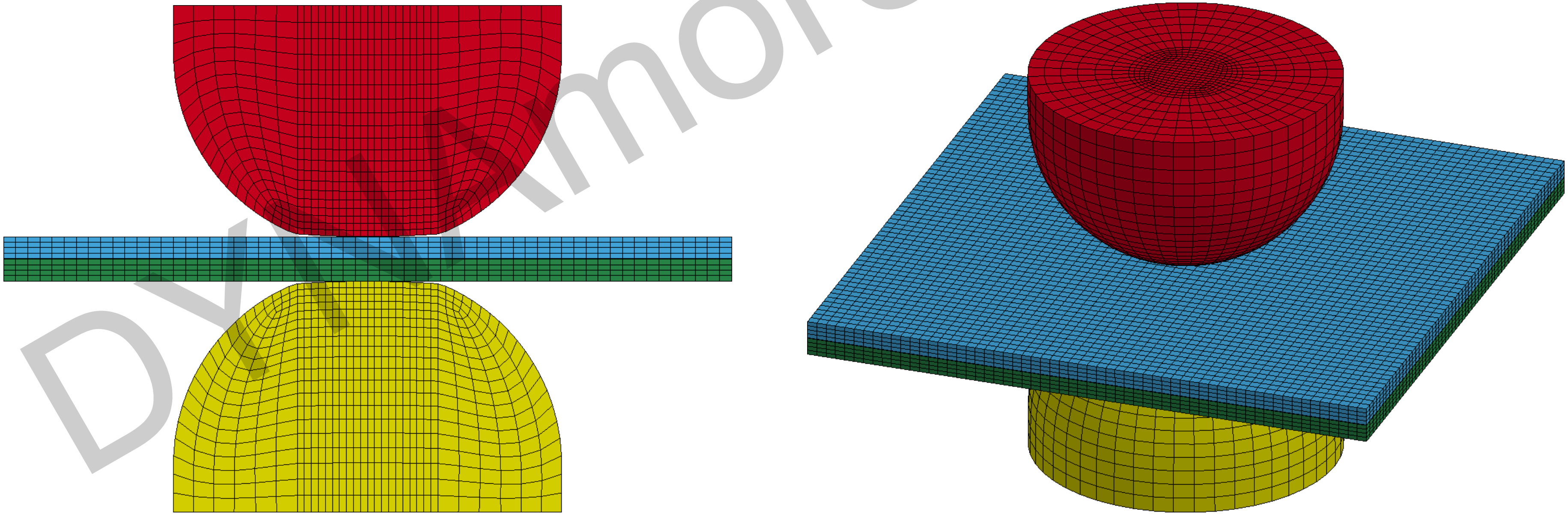
[zhang2005]

Geometry

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

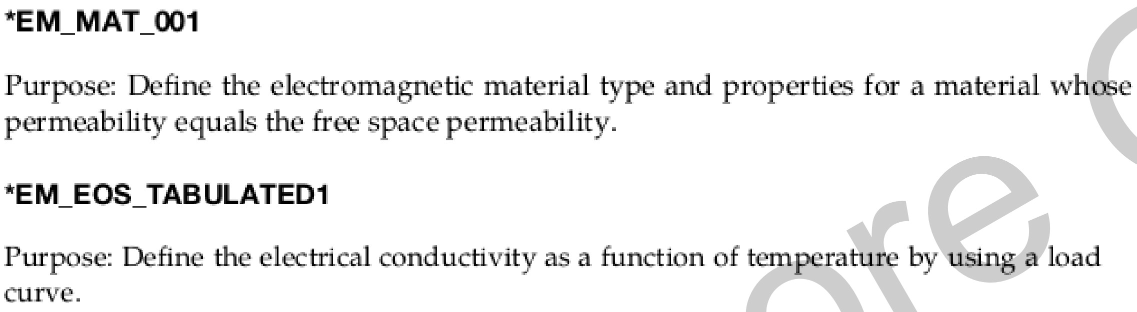


[zhang2005]



Electro-Magnetical Input

- Material definitions
  (incl. electromagnetical properties)

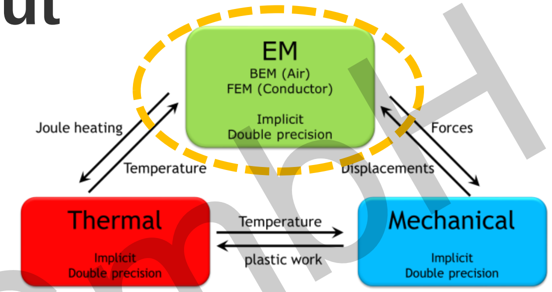


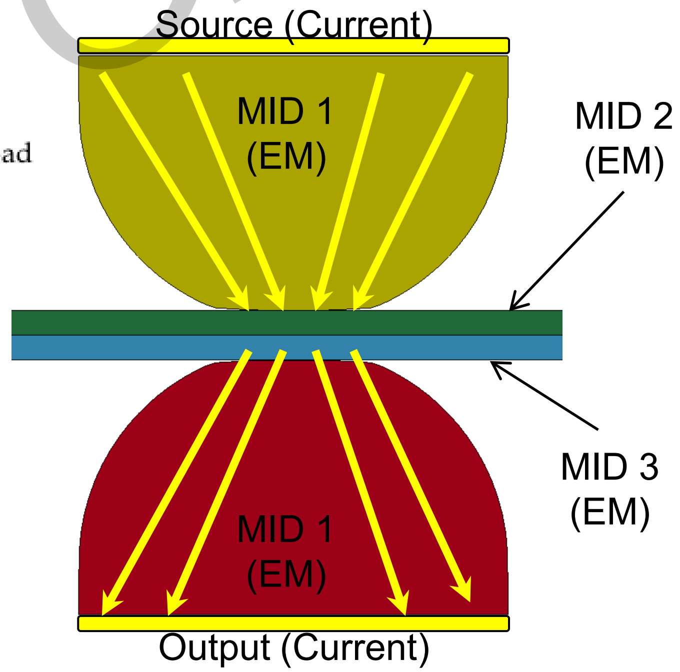
***EM_MAT_001**

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.

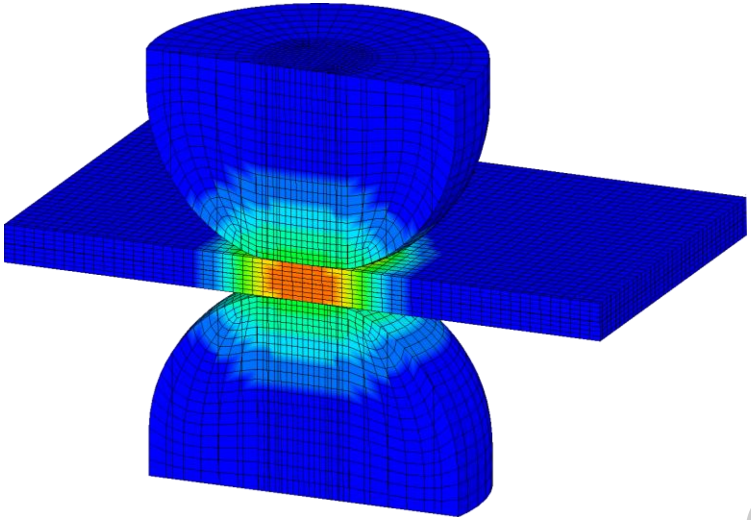


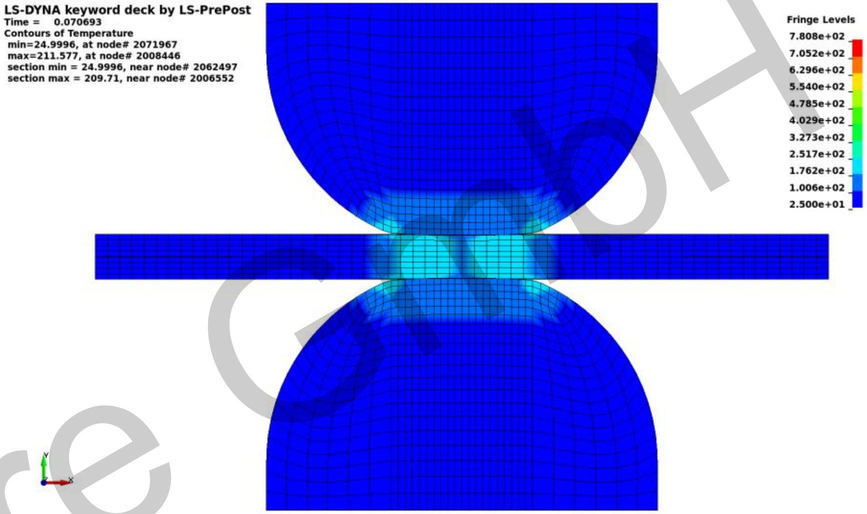


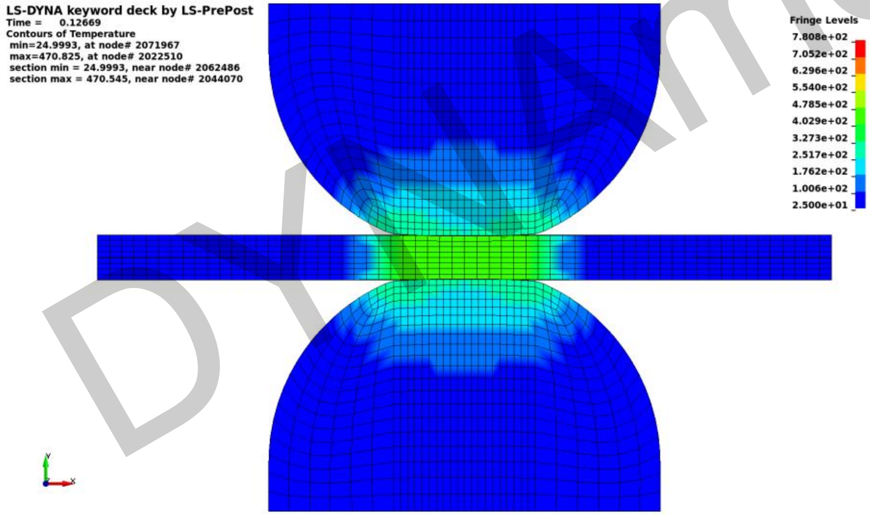
- Definition of an electrical circuit

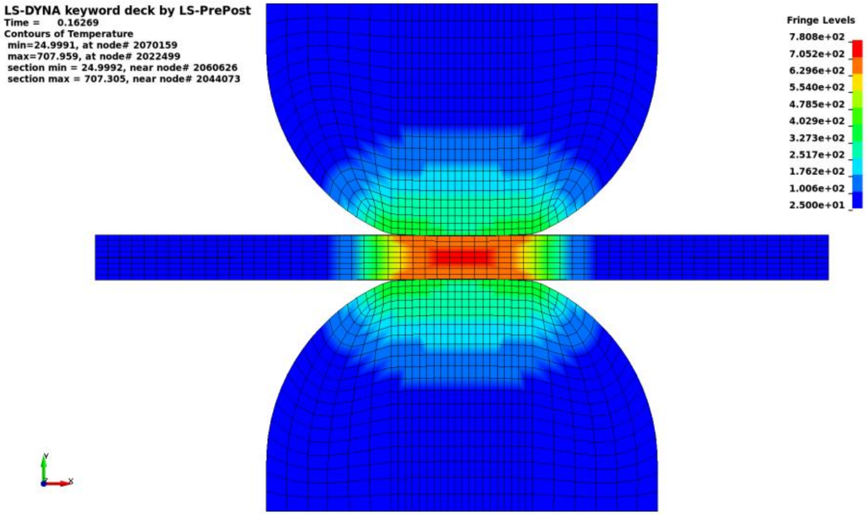
- Definition of an electro-magnetic contact

History of the 3d temperature field



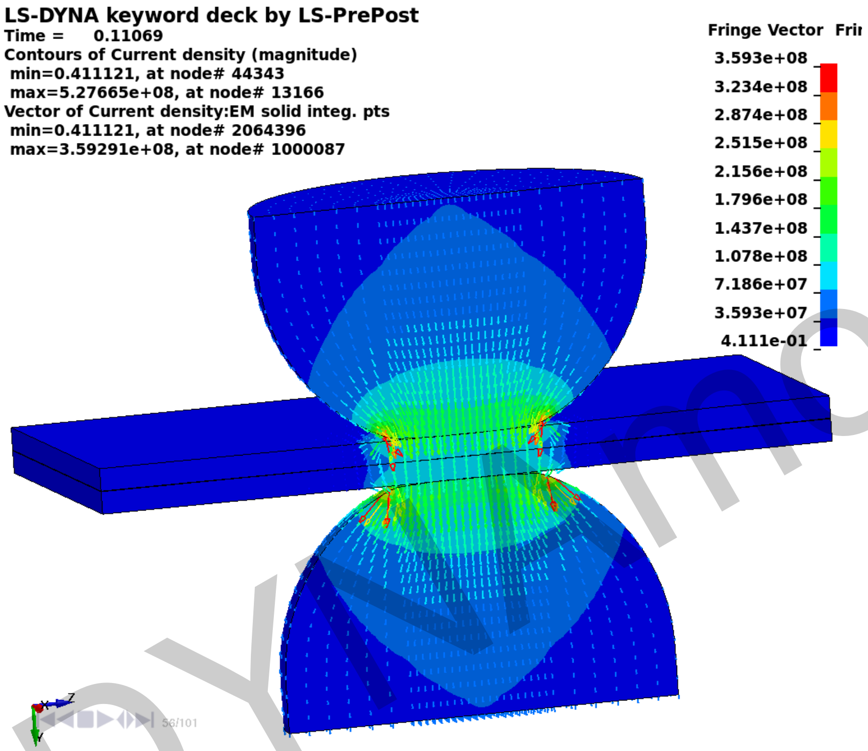




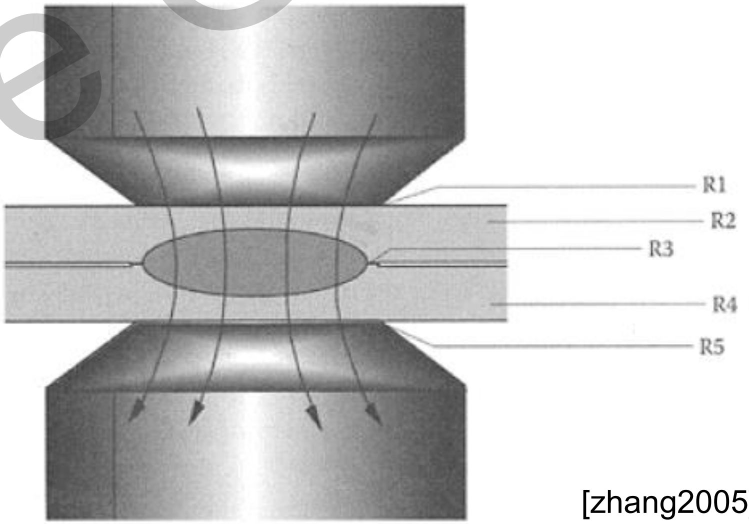


Contours and Vector Plot of the Current Density

- Contours and vector plot of the current density



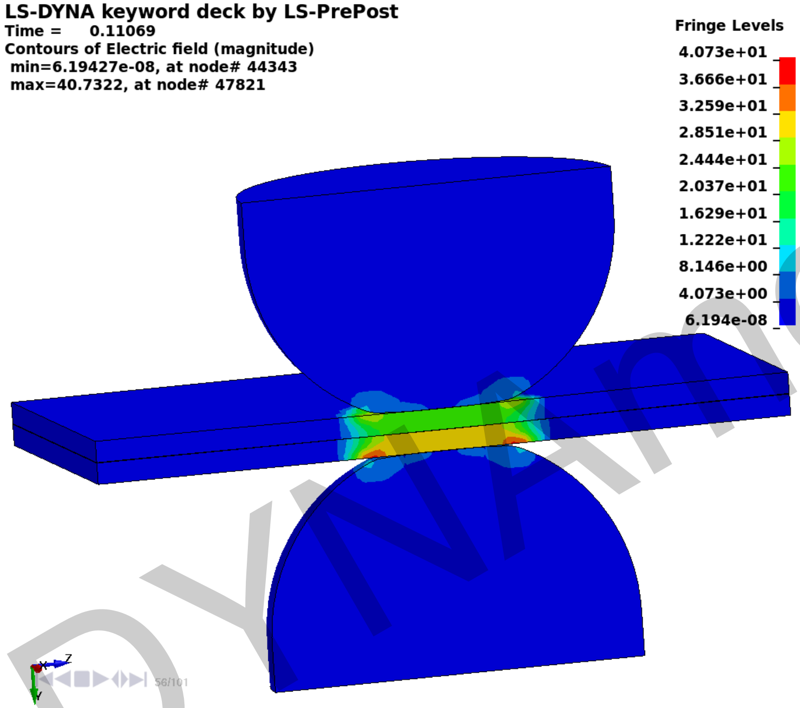
LS-DYNA keyword deck by LS-PrePost
Time = 0.11069
Contours of Current density (magnitude)
min=0.411121, at node# 44343
max=5.27665e+08, at node# 13166
Vector of Current density:EM solid integ. pts
min=0.411121, at node# 2064396
max=3.59291e+08, at node# 1000087



[zhang2005]

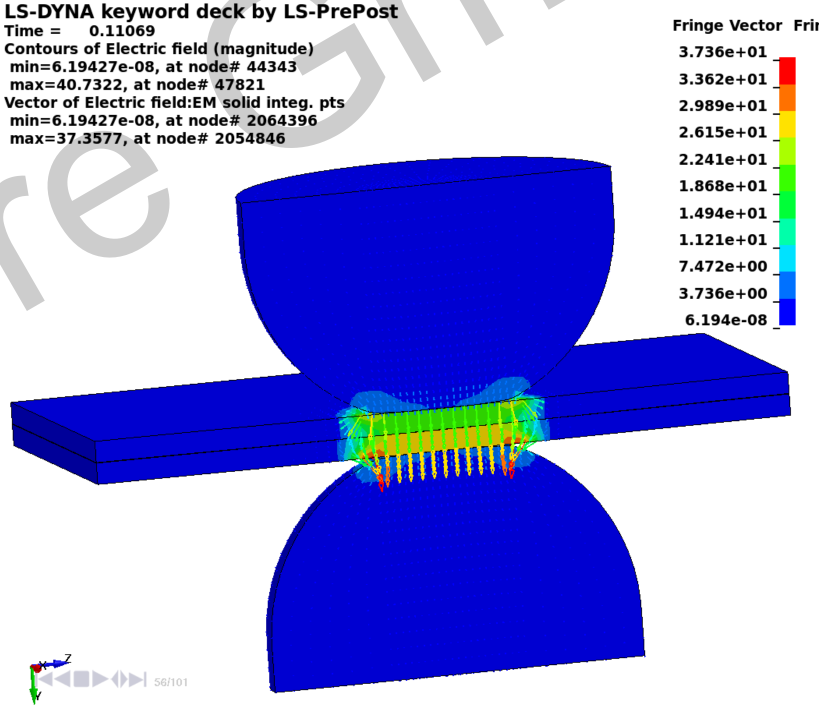
Contours and Vector Plot of the Electric Field

- Contours 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

- 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
Vector of Electric field:EM solid integ. pts
min=6.19427e-08, at node# 2064396
max=37.3577, at node# 2054846

Thank you!