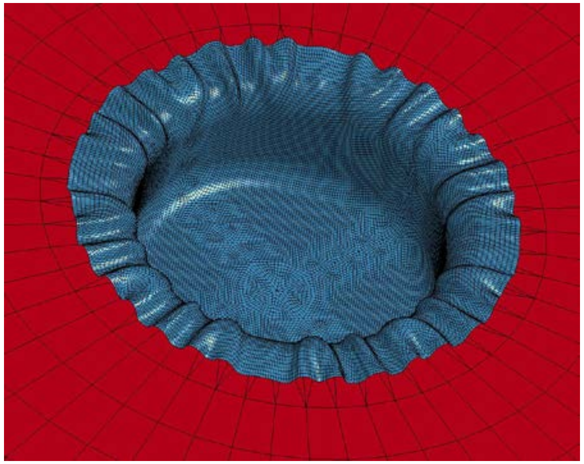
Simulations of materials processing using LS-DYNA – A journey

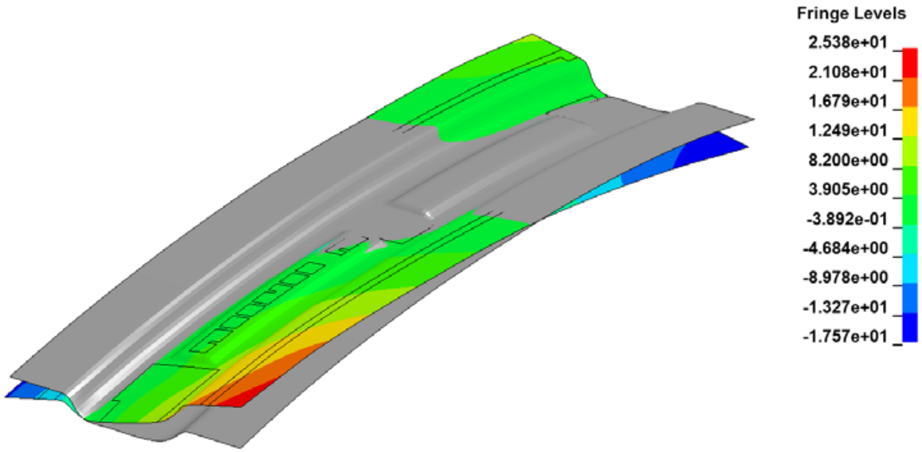
Mikael Schill, Dynamore Nordic AB

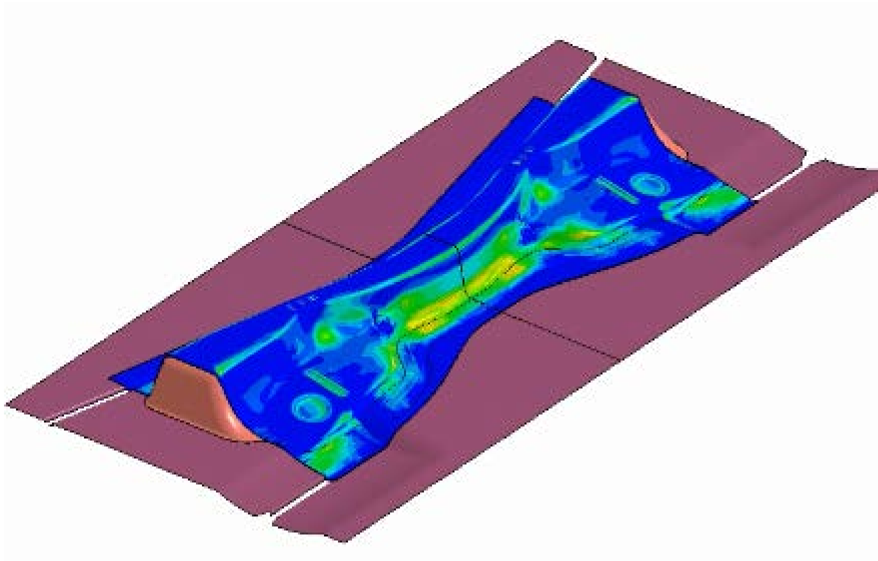
DYNAMORE NORDIC

First Step - Simulation of sheet metal forming

- Quasi static simulations of the deep drawing process
- Rigid tooling
- Predicting wrinkling, thickness, rupture, springback, blank geometry etc.

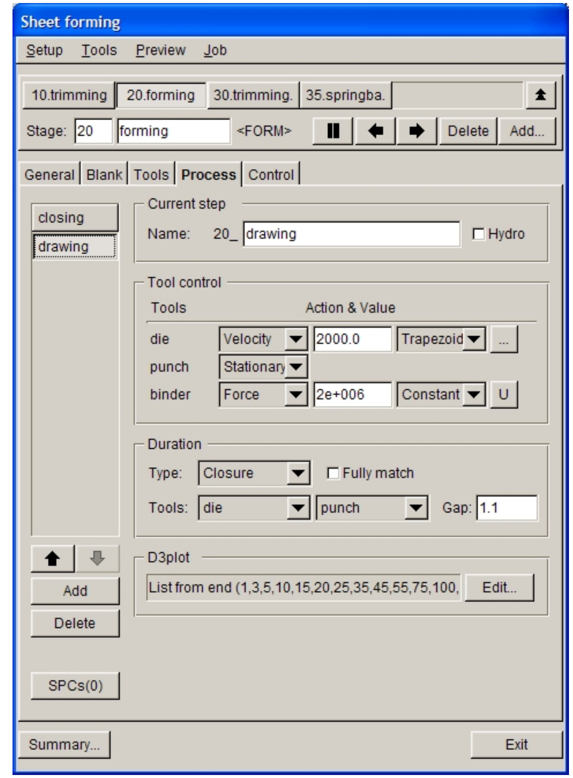


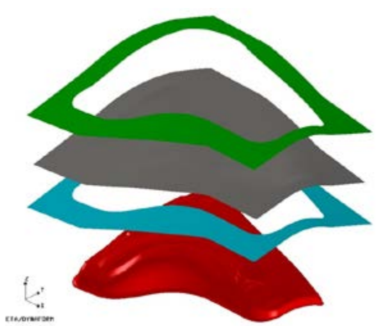


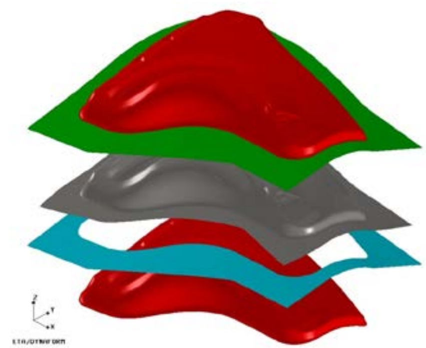


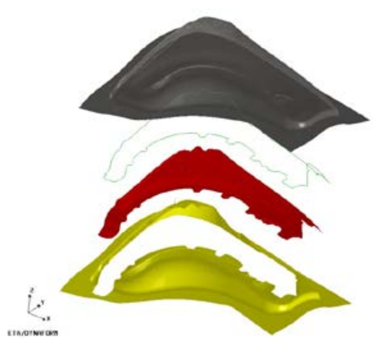
Simulation of sheet metal forming

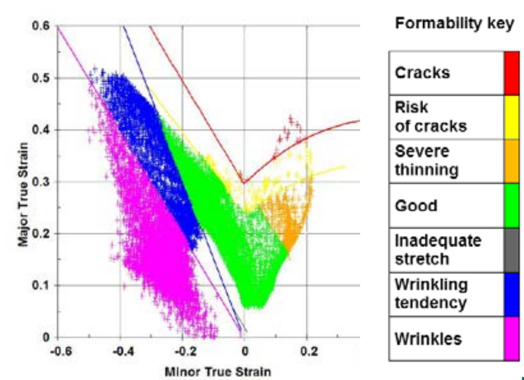
- Automated setup using tailored pre-processors
- Formability is evaluated through FLD diagram
- Automatic report generation
- Material databases are included







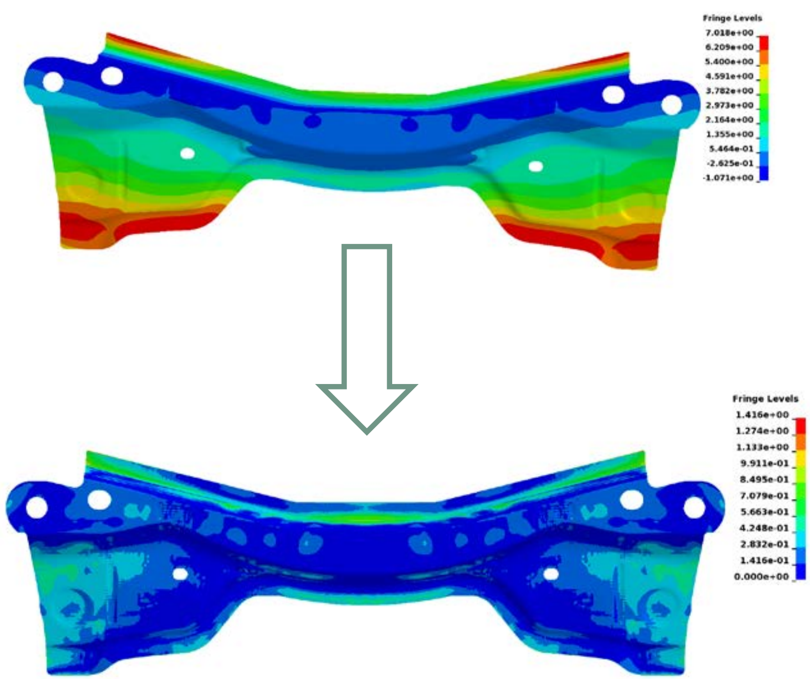


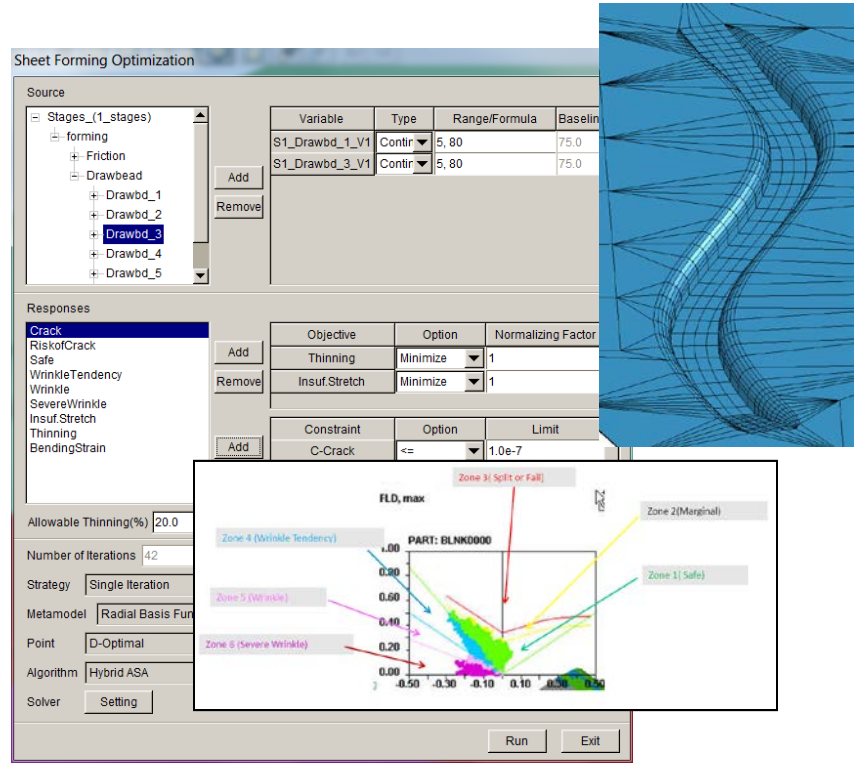


DYNA MORE NORDIC

Simulation of sheet metal forming

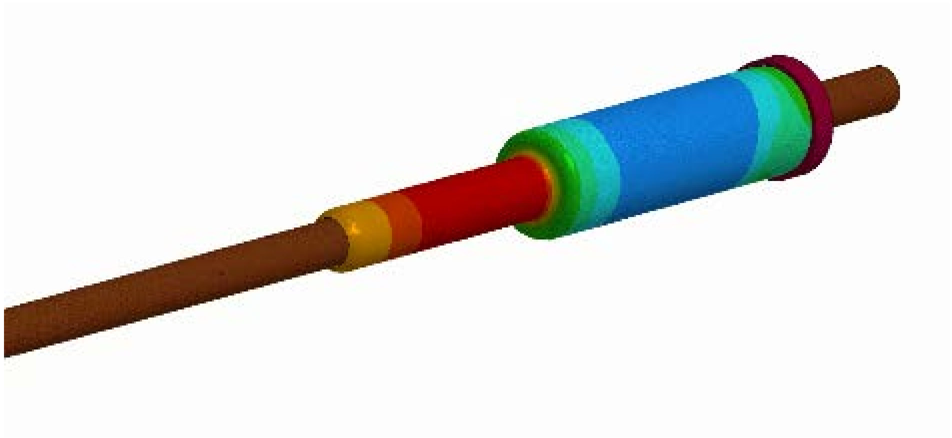
- Automatic optimization to find
  - Blank size geometry
  - Drawbead force and geometry
  - Springback compensated tools

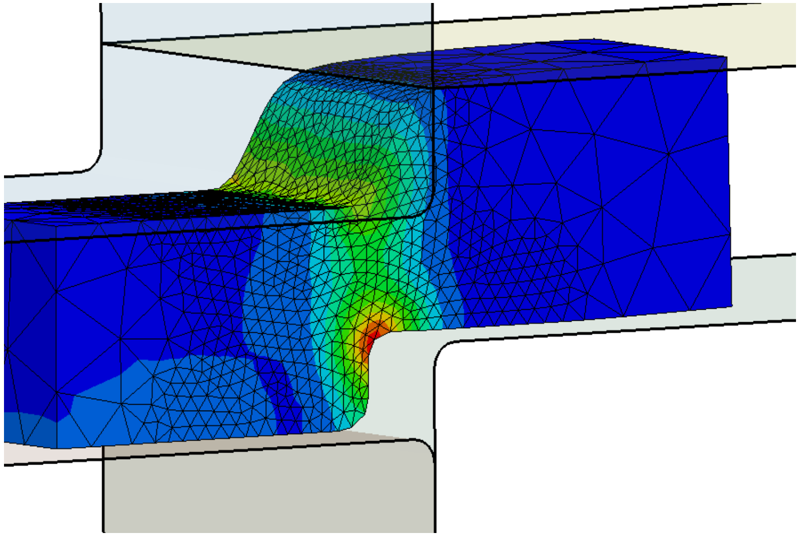




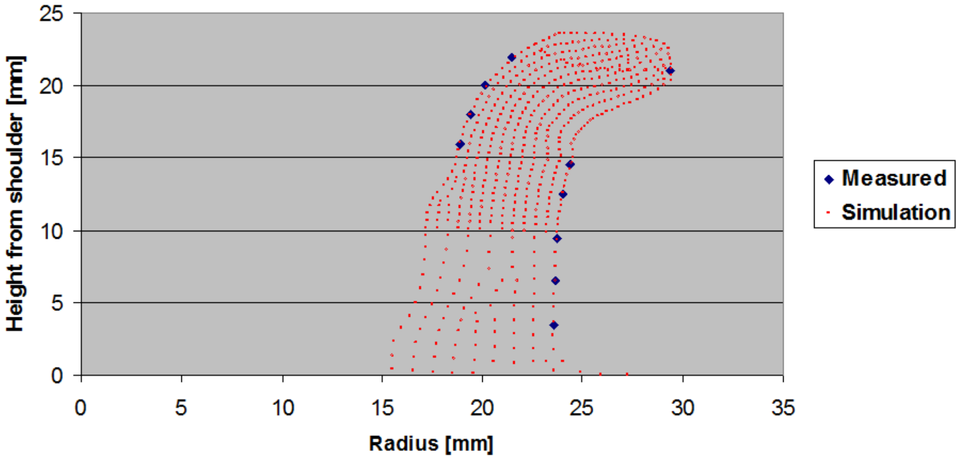
Simulation of ”bulk forming”

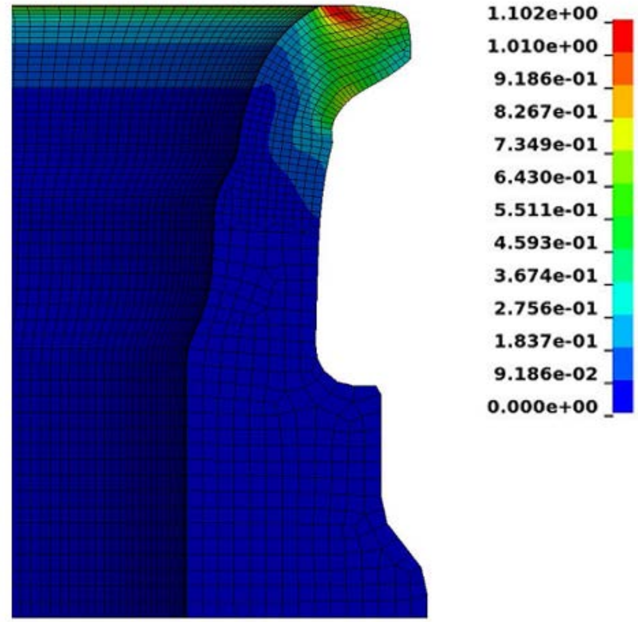
- Bulk forming is a generic term for forming processes with large deformations, e.g. ironing.
- Bulk forming typically involves (very) large deformations where distorted elements becomes an issue.
- In LS-DYNA there are several ways to deal with this problem.
  - Euler/Lagrange
  - 2D/3D Adaptivity
  - EFG/SPH meshless methods

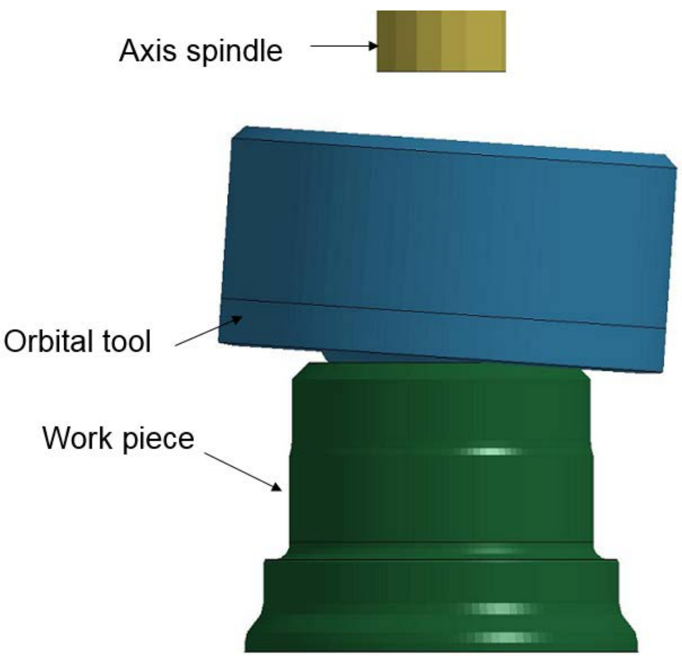




Bulk Forming - Orbital forming at SKF







11th European LS-DYNA Conference 2017, Salzburg, Austria

Orbital forming of SKF's hub bearing units

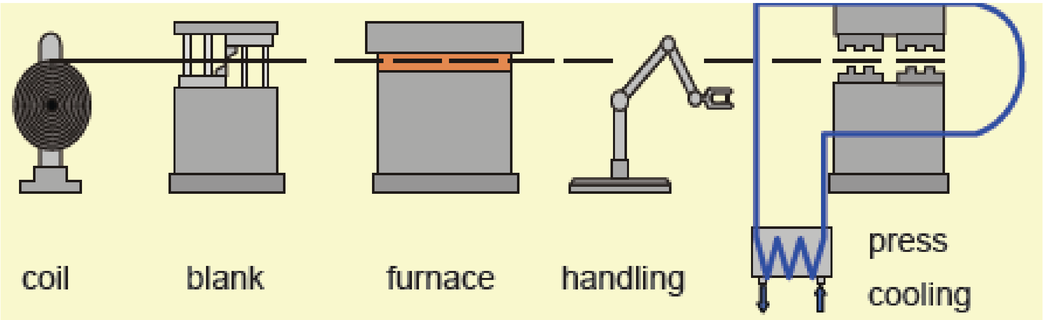
Edin Omerspahic[1], Johan Facht[1], Anders Bernhardsson[2]

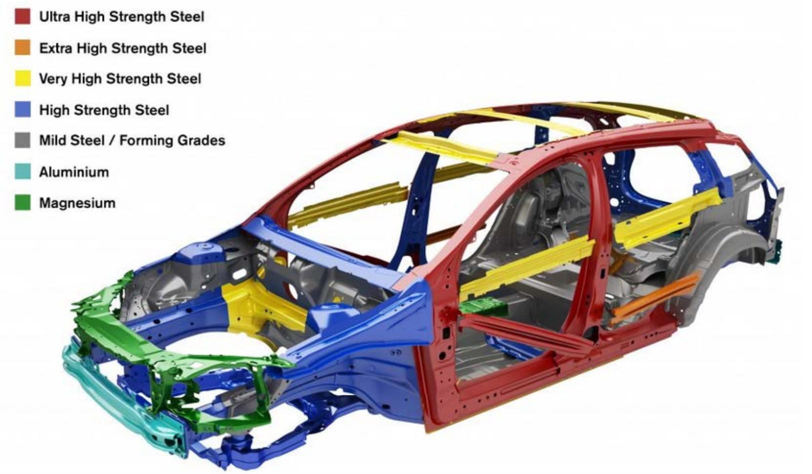
[1]Manufacturing Development Centre, AB SKF

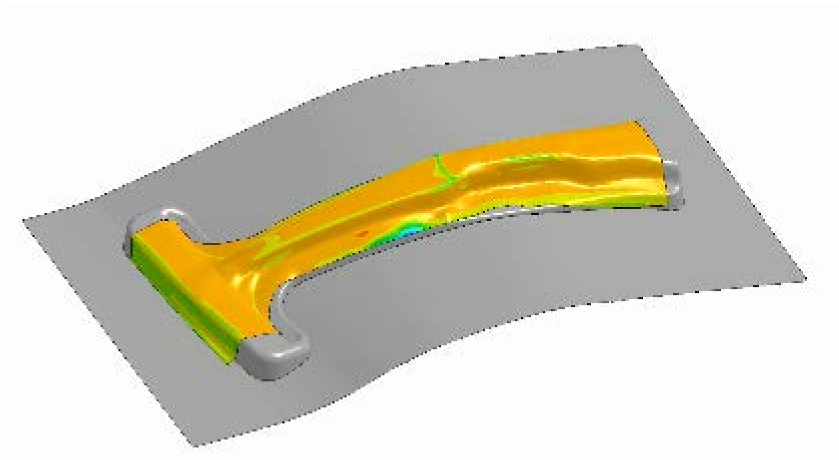
[2]DYNAmore Nordic

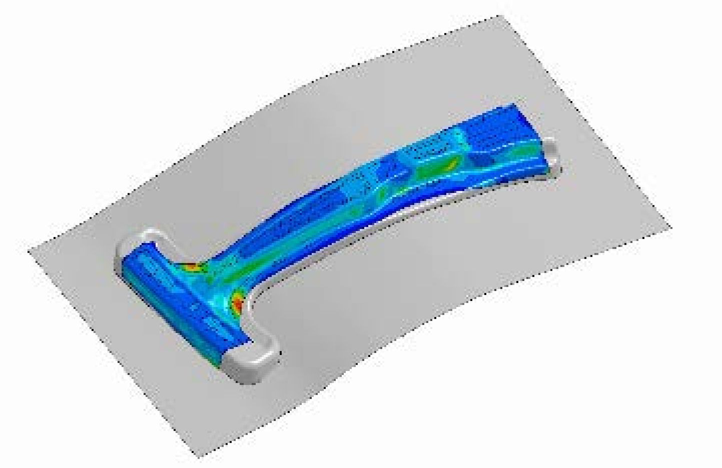
Second step - Hot Stamping of Boron Steel

- Boron steel blanks are heated to austenite phase and the formed and subsequently cooled to form martensite



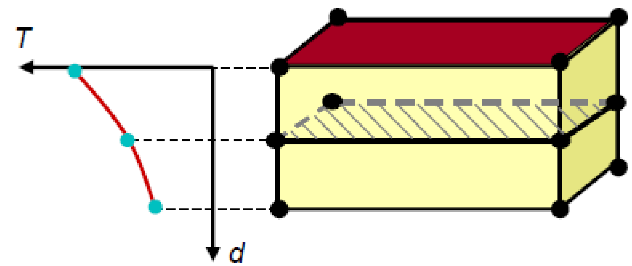


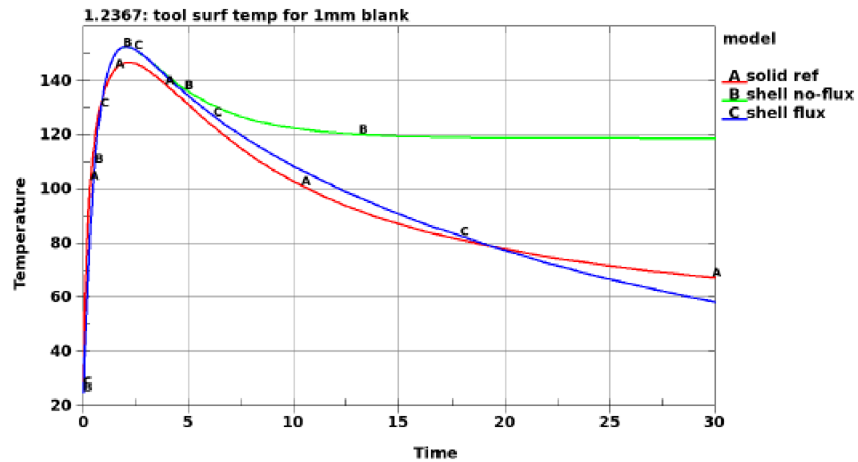


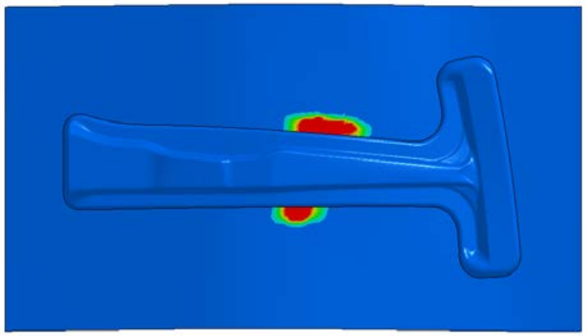


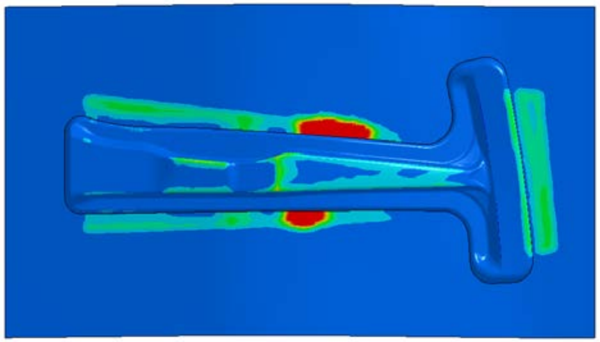
Using thick shell elements in tooling

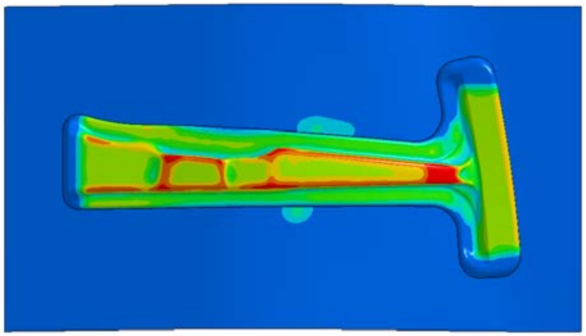
- By using thick thermal elements with appropriate boundary conditions and properties, it is possible to mimic the solid tooling temperatures using a shell element tool mesh.







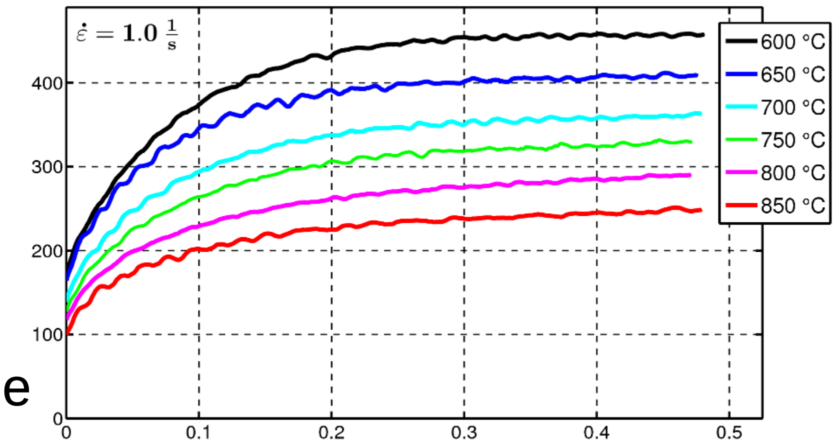




Hot stamping with conventional simulation methods

Capabilities

- correct prediction of forming in the austenitic state:
  - stresses and strains
  - thinning
  - forces
- prediction of temperature history in the blank/part



Limits

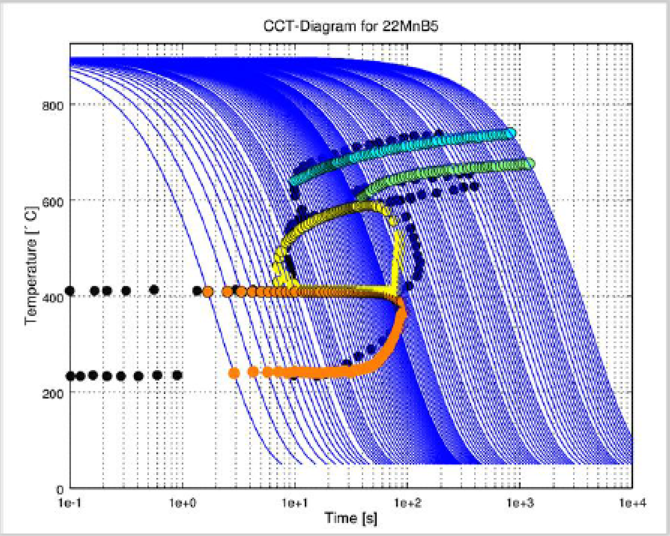
- prediction of microstructure (phase fractions) and hardness:
  - only rough estimations based on CCT diagram can be made
  - not possible for tailored tempering processes

➔ only rough estimations of final part properties like strength and hardness

*MAT_244 / *MAT_UHS

- Based on the work by Åkerström and Bergman, Luleå.

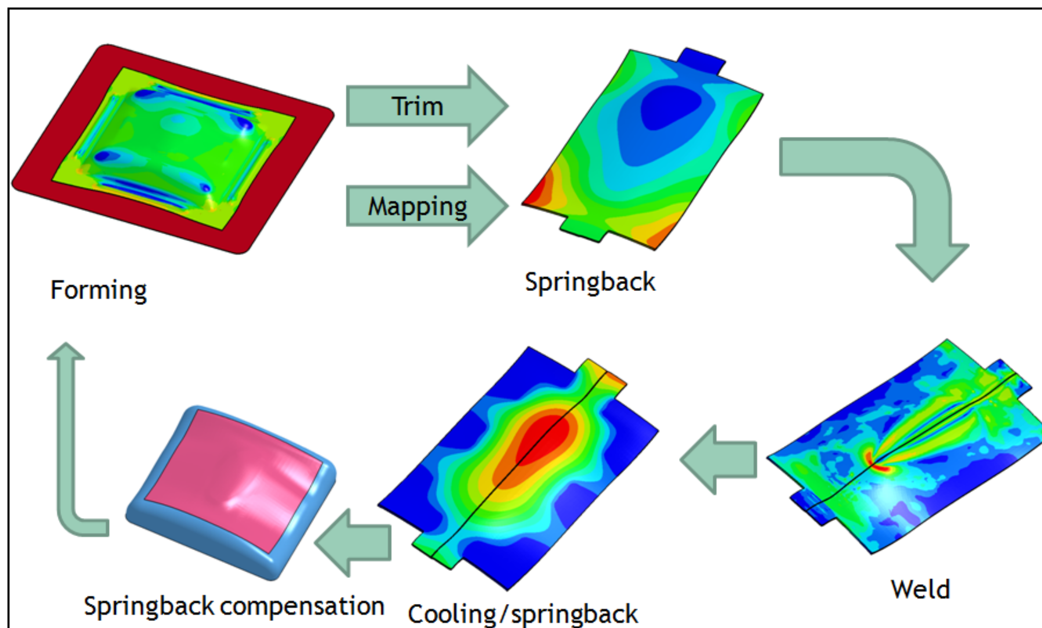
- Material tailored for hot stamping / press hardening processes
  - Phase transition of austenite into ferrite, pearlite, bainite and martensite for cooling
  - Strain rate dependent thermo-elasto-plastic properties defined for individual phases
  - Transformation induced plasticity algorithm
  - Re-austenitization during heating
  - User input for microstructure computations is chemical composition alone



- Added:
  - Transformation induced strains
  - Welding functionality
  - Different transformation start temperatures for heating and for cooling

Third step - Simulation of Welding

- Virtual process chain including Forming and Welding
- Using implicit/explicit solvers, mechanical and thermo-mechanical coupling and solid and shell elements.
- Novel material models, heat sources for welding and pre-processing GUI
- *MAT_244 is tailored for press-hardening and Boron steels and is not necessarily useful for welding
- New material model for welding processes and heat treatment
  - MAT_254



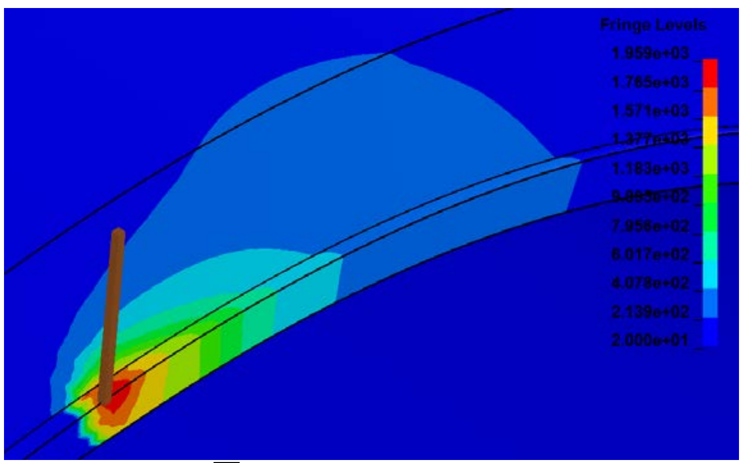
13th International LS-DYNA Users Conference | Session: Simulation

Simulation of Residual Deformation from a Forming and Welding Process using LS-DYNA®

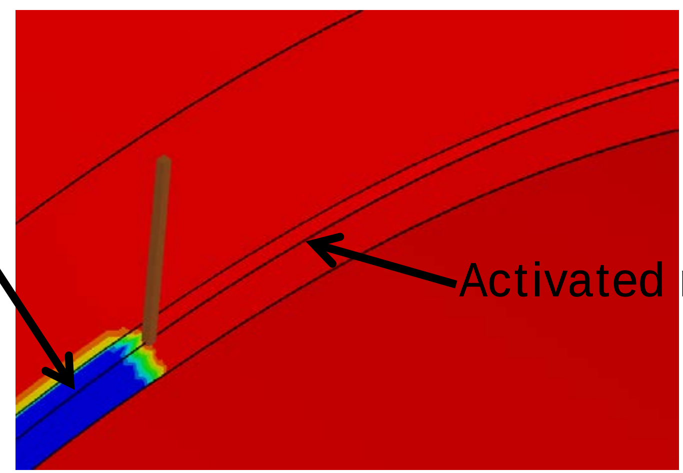
Mikael Schill[1], Eva-Lis Odenberger[2]
[1]*DYNAmore Nordic AB, Sweden*
[2]*Industrial Development Centre in Olofström AB, Sweden*

Welding Simulations – *MAT_CWM

- The element can either be ”solid”, ”Liquid” or ”Ghost”.
  - Solid: Material is activated in a previous weld pass
  - Liquid: Material will be activated in the current weld pass
  - Ghost: Material will not be activated in the current weld pass
- When the temperature reaches a specified temperature, material is activated and recieves ”material” properties.
- Apart from the ghost element function, the material model also includes Anneal functionality.
- Above the specified anneal temperature, all history variables such as hardening and back stress are set to zero.

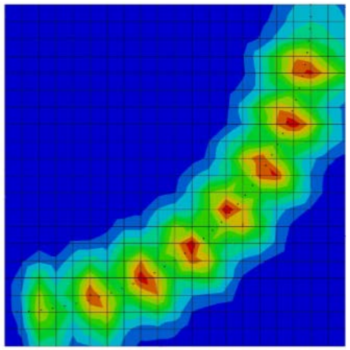


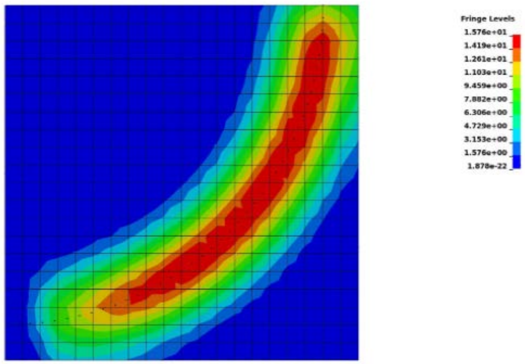
Temperature

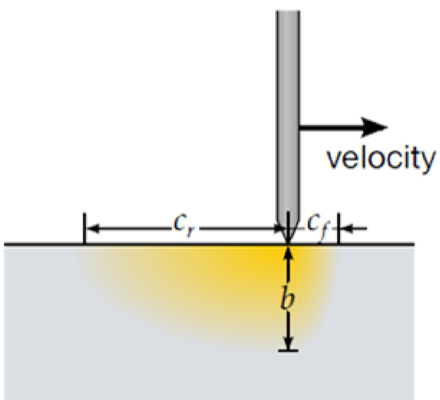


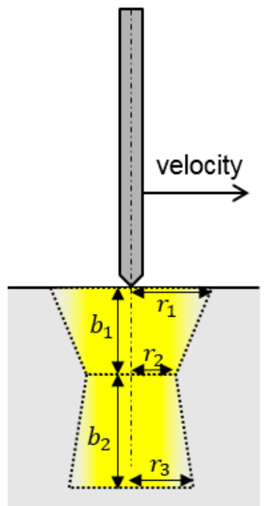
Heat source

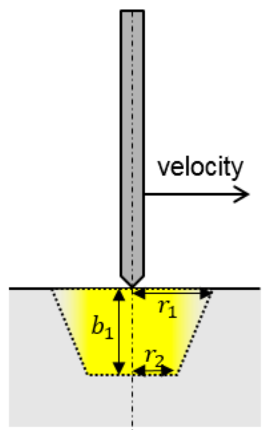
- Novel keyword *BOUNDARY_THERMAL_WELD_TRAJECTORY
- Heat source movement implemented in the thermal solver
- Heat source follows a node string defined in *SET_NODE
- Subcycling of the heat source
- User controlled integration for accurate heat input
- Goldak, cone and double cone heat sources


temperature field, NCYC = 1

temperature field, NCYC = 10


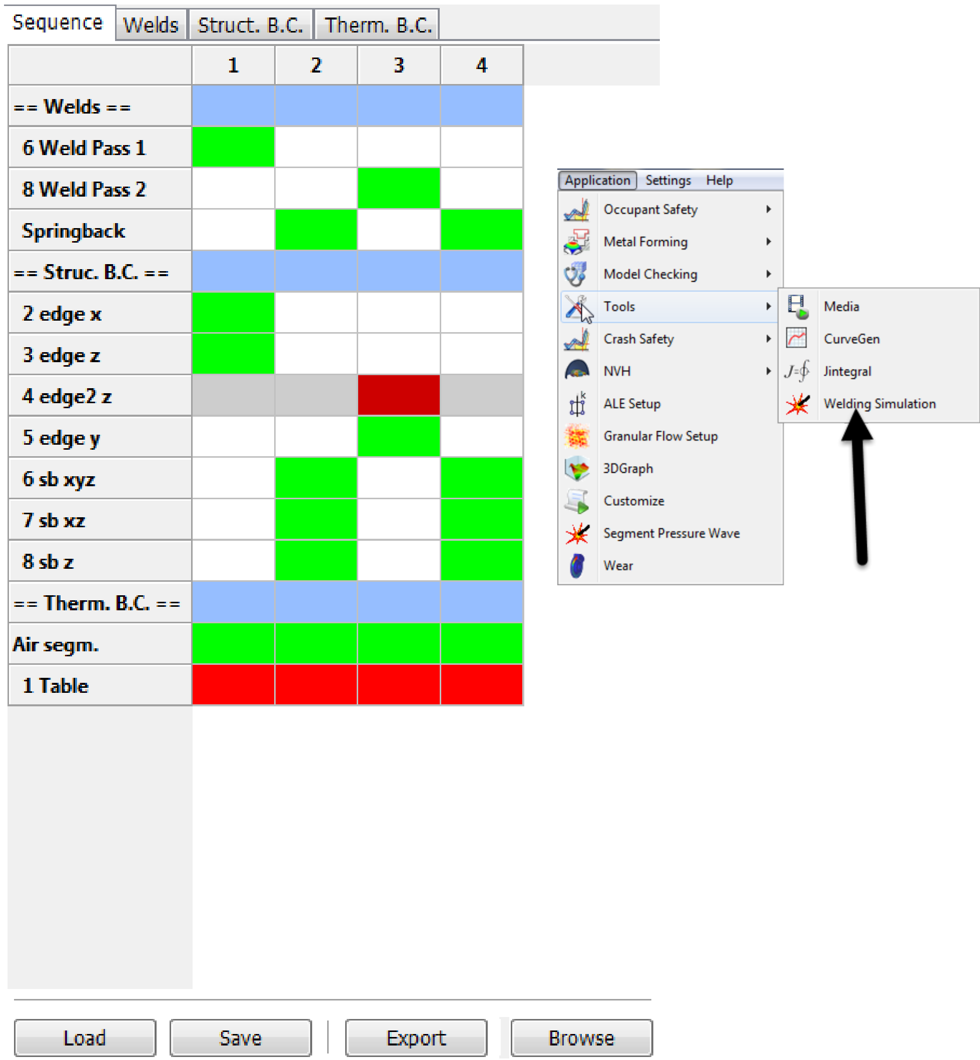






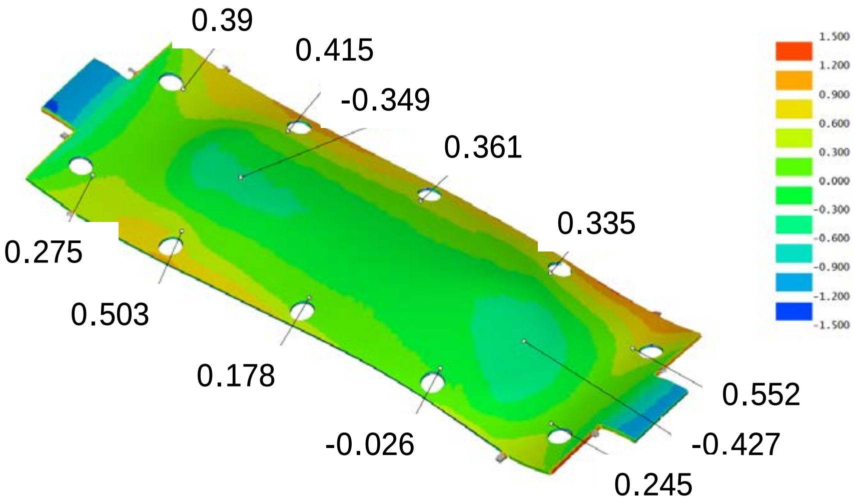
Pre-processing – Welding plan

- By clicking the boxes, the welding order is determined.
- Possibility to add or remove stages.
- To each step, corresponding clamping and thermal boundary condition can be chosen.
- Double clicking on the rows opens the corresponding definitions.
- If the properties are defined, the box is coloured green.
- When the process is set up, an LS-DYNA input file is exported.
- The setup of the welding simulation can be saved/loaded from an ASCII file.

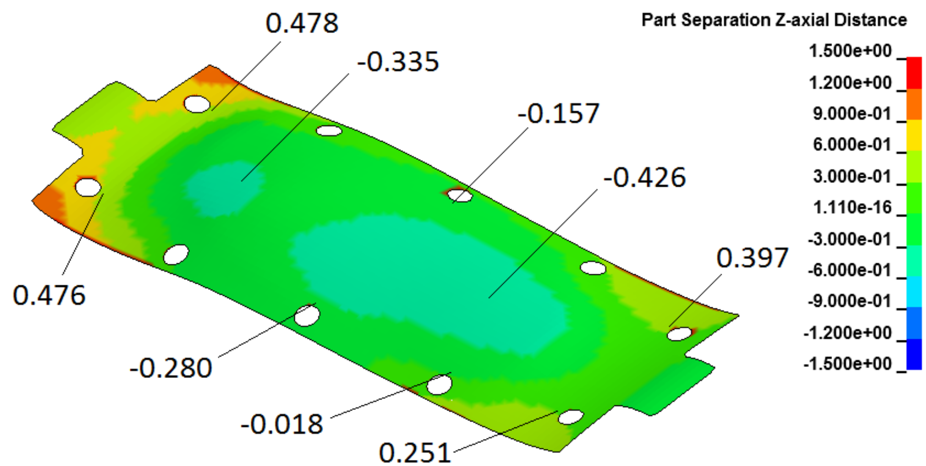


Welding Example - Simulation results after forming

- The measured springback after forming are determined using a 3D scanning and best fit CAD evaluation method in a least square sense.



Measured

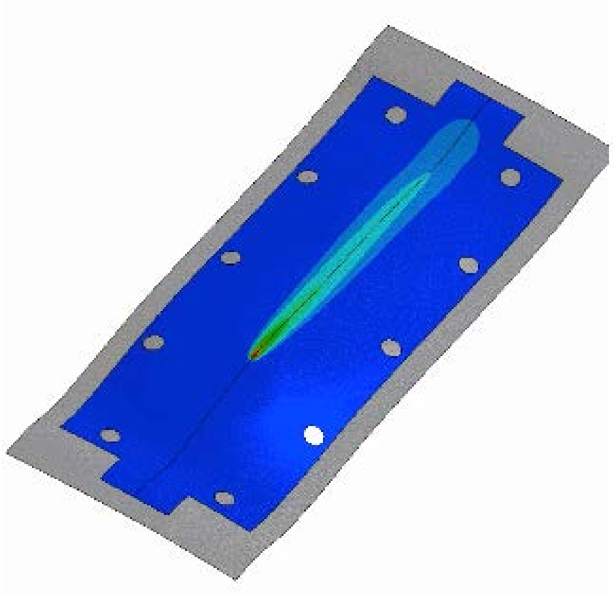


Simulated

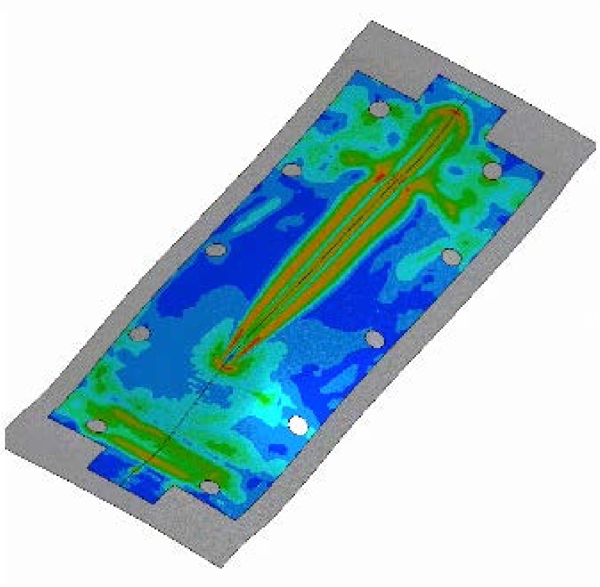
Measured and predicted shape deviation after forming (mm).

Lluís Pérez Caro, ”Modelling of Forming and Welding in Alloy 718”, Licentiate thesis, ISSN 1402-1757
Luleå University of Technology, 2017

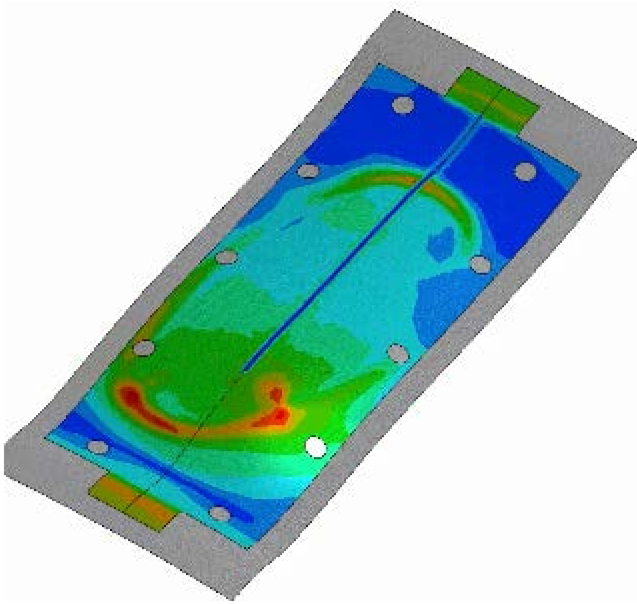
Welding Example



Temperature



Stress



Effective plastic strain

Lluís Pérez Caro, ”Modelling of Forming and Welding in Alloy 718”, Licentiate thesis, ISSN 1402-1757
Luleå University of Technology, 2017

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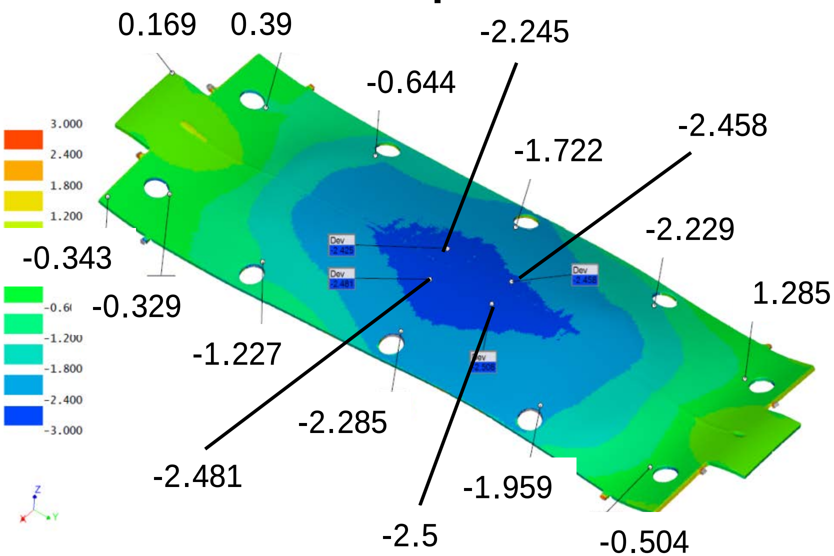
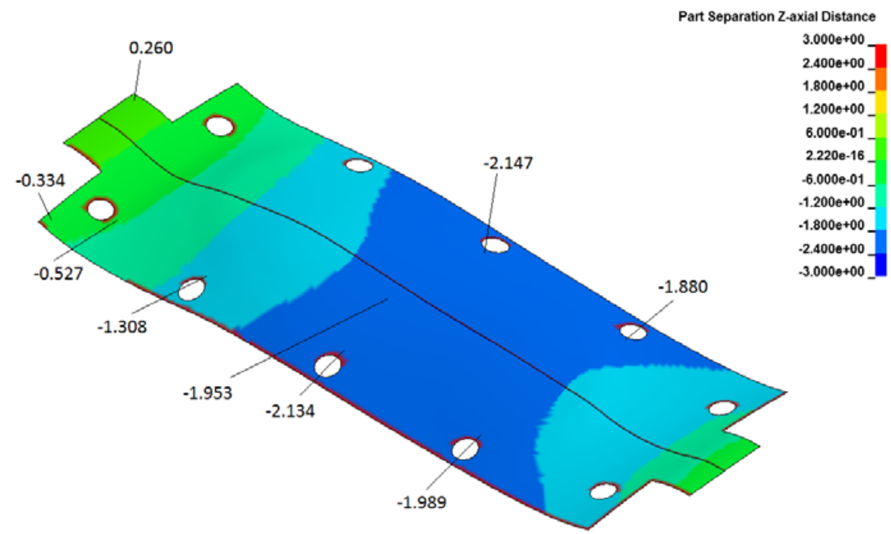


Measured



Simulated

Measured and predicted shape deviation after welding (mm).

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Luleå University of Technology, 2017

Fourth step - *MAT_254 – Generalized phase change

- New material formulation in LS-DYNA with:
  - Up to 24 individual phases
  - List of generic phase change mechanisms for each possible phase change in both cooling and heating
  - Material incorporates all features of *MAT_244
  - Phase change parameters are given in tables and are not computed by chemical composition
- Parameters of the material might come from a material database or a microstructure calculation
- Will be suitable for a wider range of steel alloys and aluminum alloys

*MAT_254 – Generalized phase change

- JMAK
- Koistinen Marburger
- Kirkaldy
- Oddy
- ..

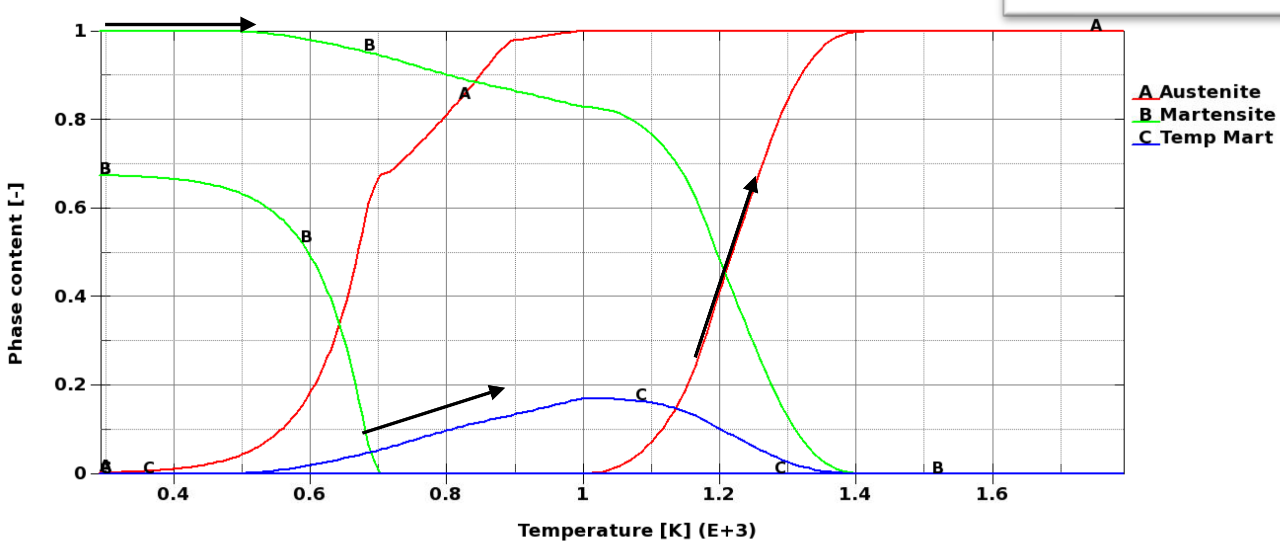
$$\frac{dx_b}{dt} = n(T)(k_{ab}x_a - k'_{ab}x_b)\left(\ln\left(\frac{k_{ab}(x_a + x_b)}{k_{ab}x_a - k'_{ab}x_b}\right)\right)^{\frac{n(T)-1.0}{n(T)}}$$

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

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

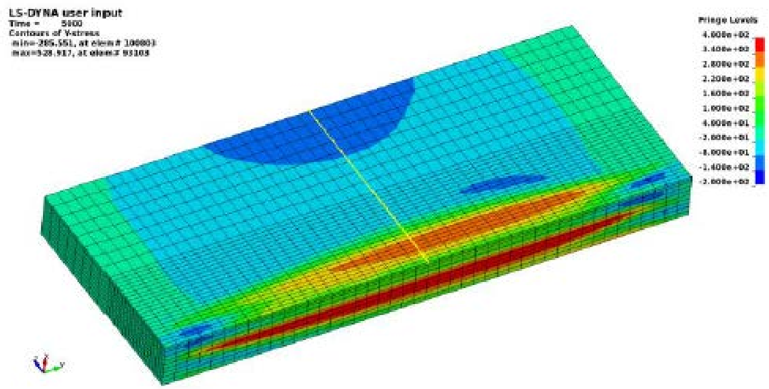
$$\frac{dX_b}{dt} = 2^{0.5(G-1)} f(C)(T_{start} - T)^{n_T} D(T) \frac{X_b^{n_1(1.0-X_b)}(1.0 - X_b)^{n_2 X_b}}{Y(X_b)}, x_b = X_b x_{eq}(T)$$

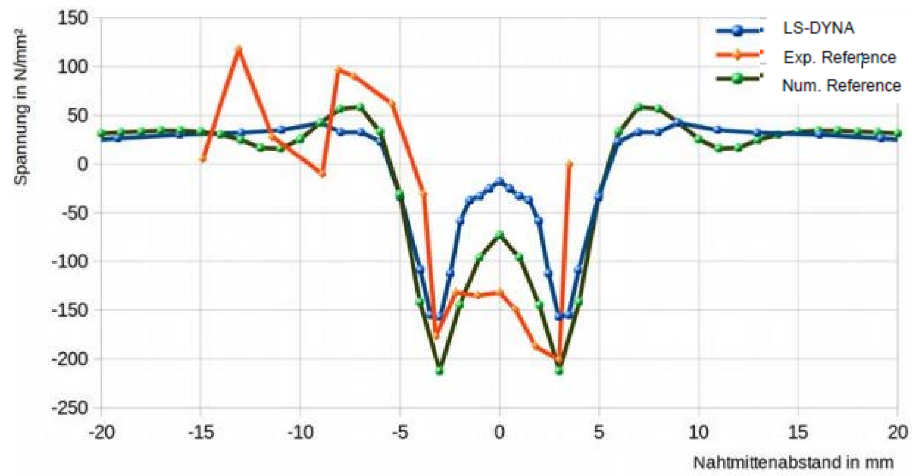
$$\frac{dx_b}{dt} = n \cdot \frac{x_a}{c_1(T - T_{start})^{-c_2}} \cdot \left(\ln\left(\frac{(x_a + x_b)}{x_a}\right)\right)^{\frac{n-1.0}{n}}$$

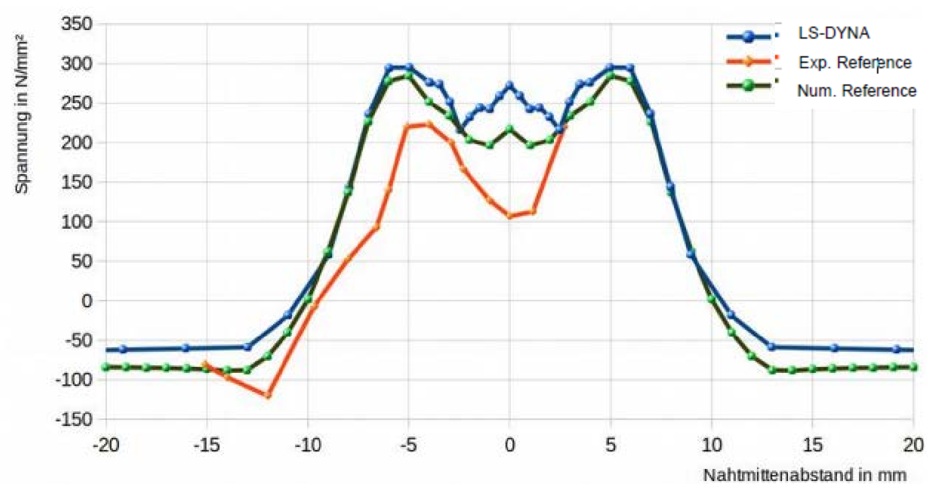


Residual stresses with *MAT_254

- Nitschke-Pagel test

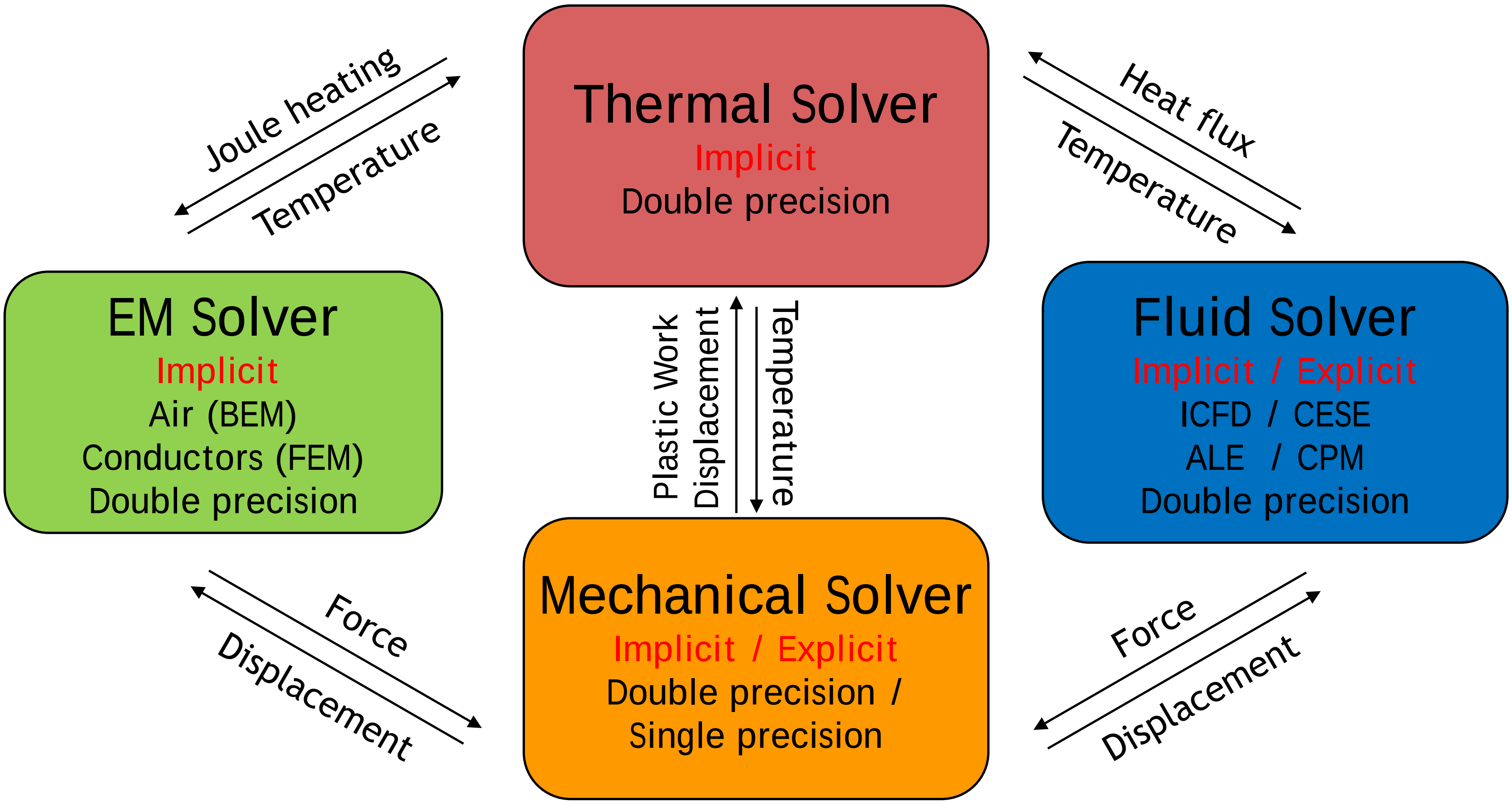






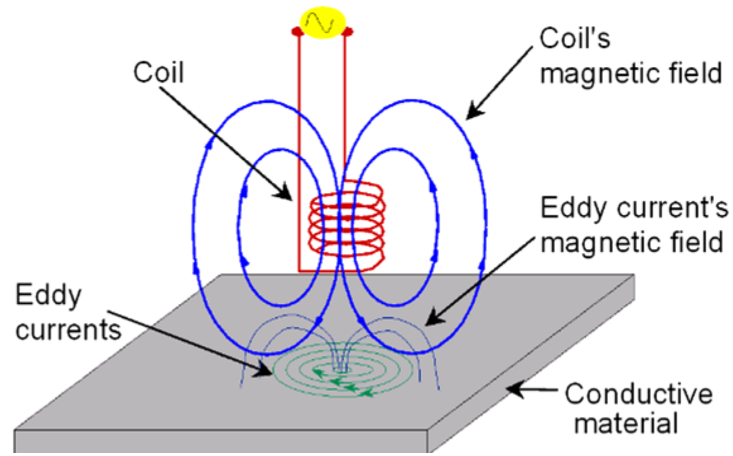
Loose, T.: Einfluß des transienten Schweißvorganges auf Verzug, Eigenspannungen und Stabiltiätsverhalten axial gedrückter Kreiszylinderschalen aus Stahl, Diss, Karlsruhe, 2008

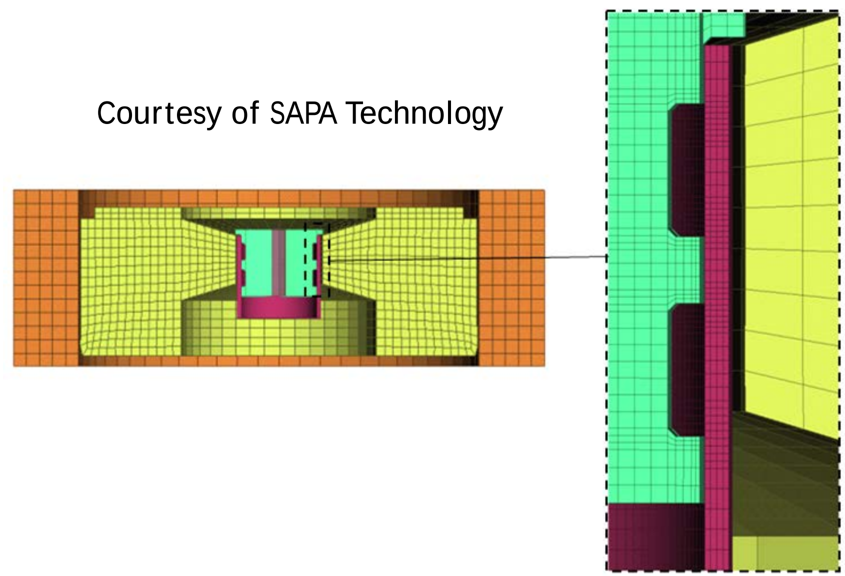
Fifth step – Going into multiphysics



Coupling with the electromagnetics solver

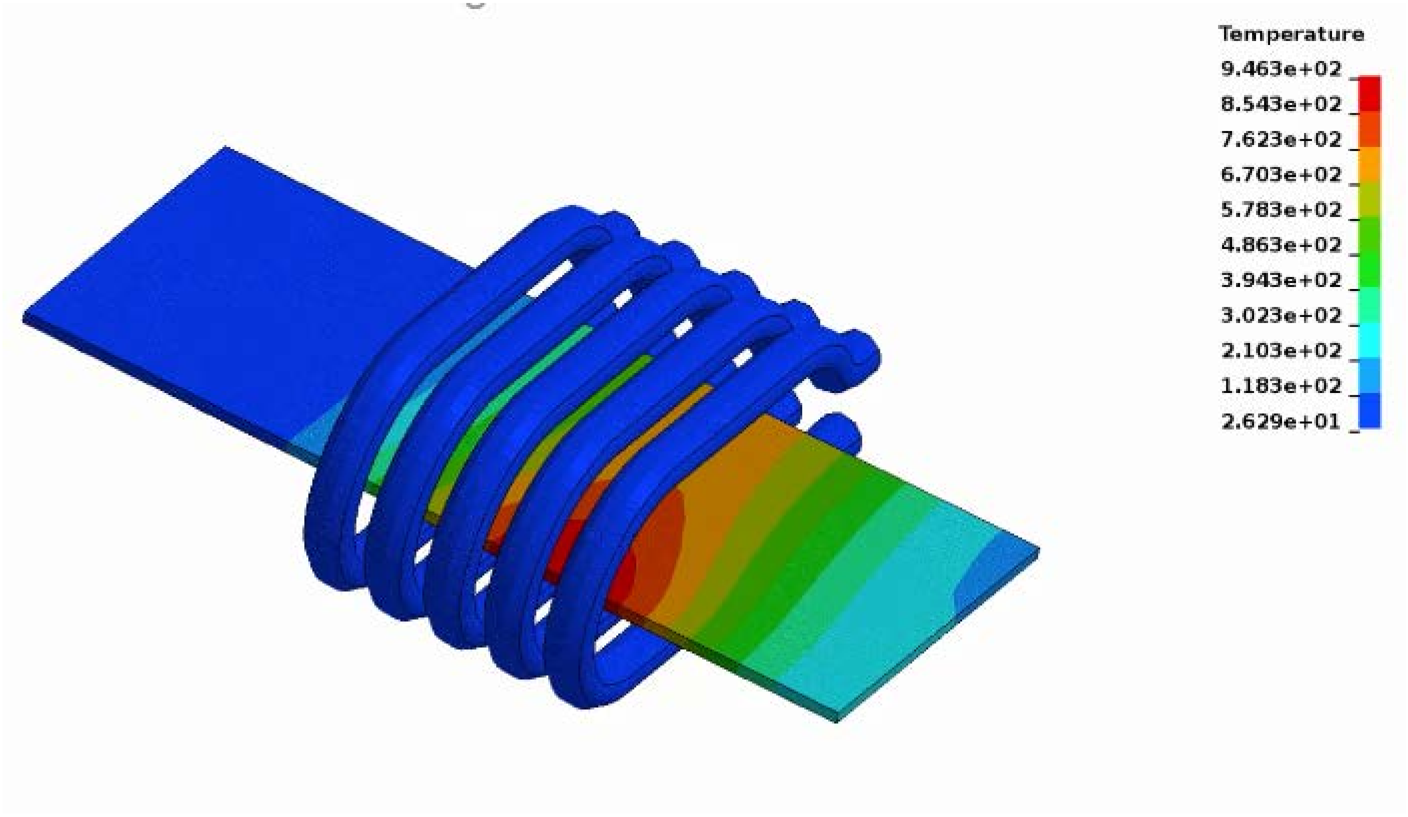
- Electromagnetic solver coupled with the mechanical and thermal solver
- LS-DYNA solves the EMF problem using a FEM+BEM method.
  - The Maxwell equations for the solid conductors are solved with FEM
  - The Maxwell equations for the insulators and air are solved with BEM
- Advantages with BEM:
  - No air mesh is needed and thus avoids meshing problems such as:
    - Mesh around complex conductors.
    - Re-mesh of air surrounding moving conductors.
    - Mesh in small gaps between conductors.
    - It does not need introduction of boundary infinite boundary condition



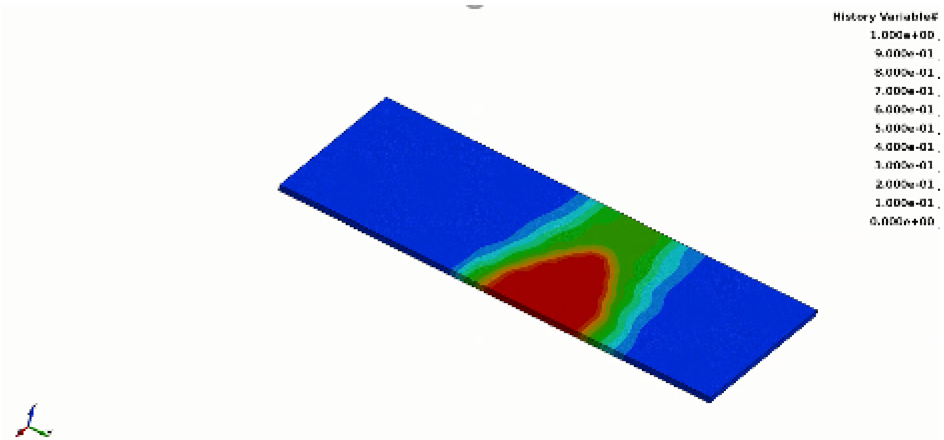


Courtesy of SAPA Technology

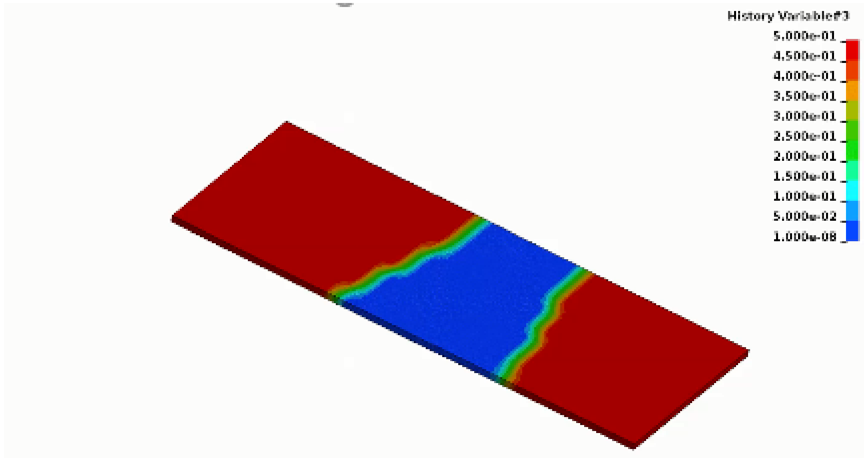
Coupling with the electromagnetics solver



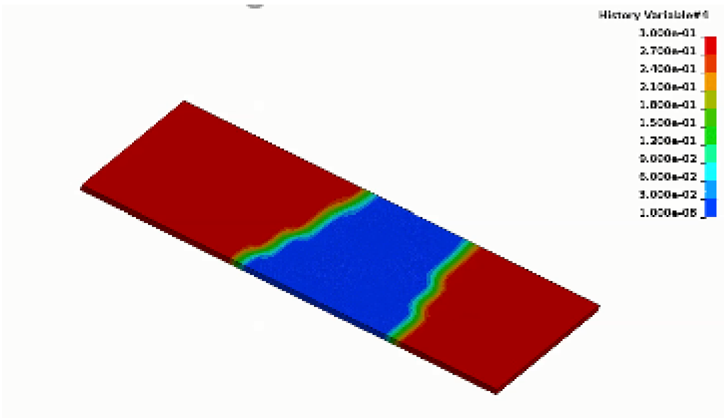
Coupling with the electromagnetics solver



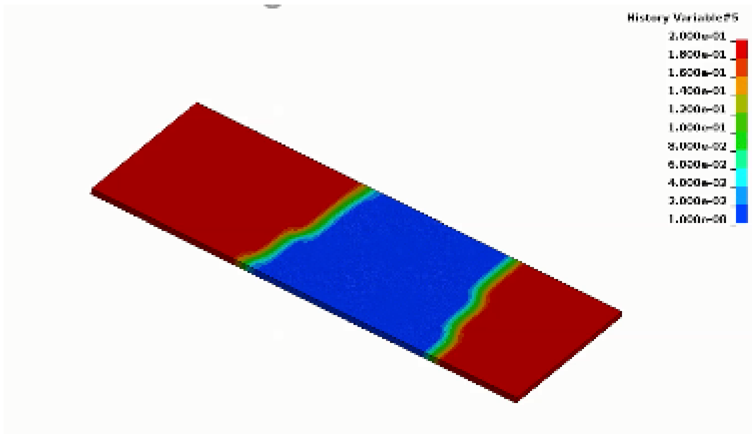
Austenite



Pearlite



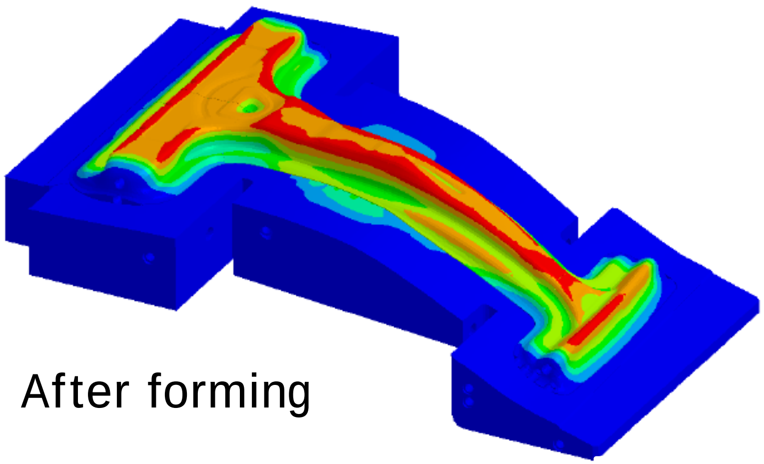
Bainite



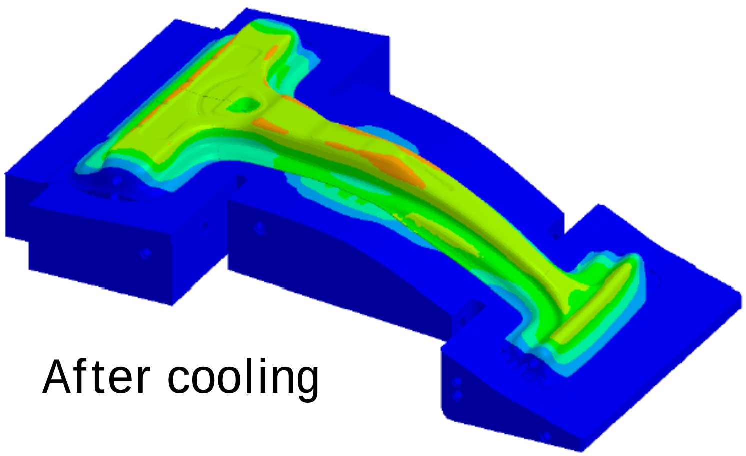
Martensite

Coupling with the ICFD solver

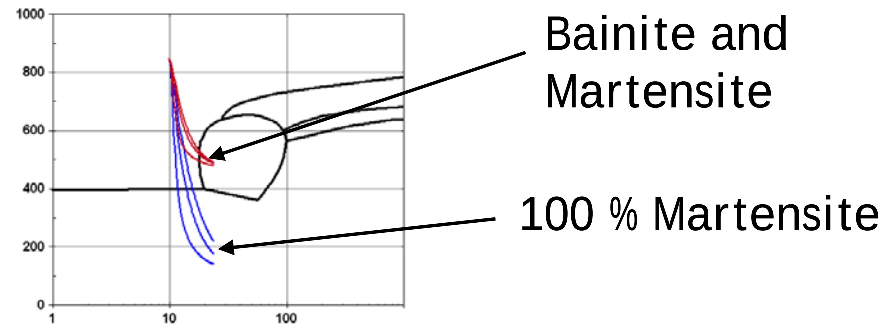
- Cycled hardening simulations identifies hot spots in tooling.

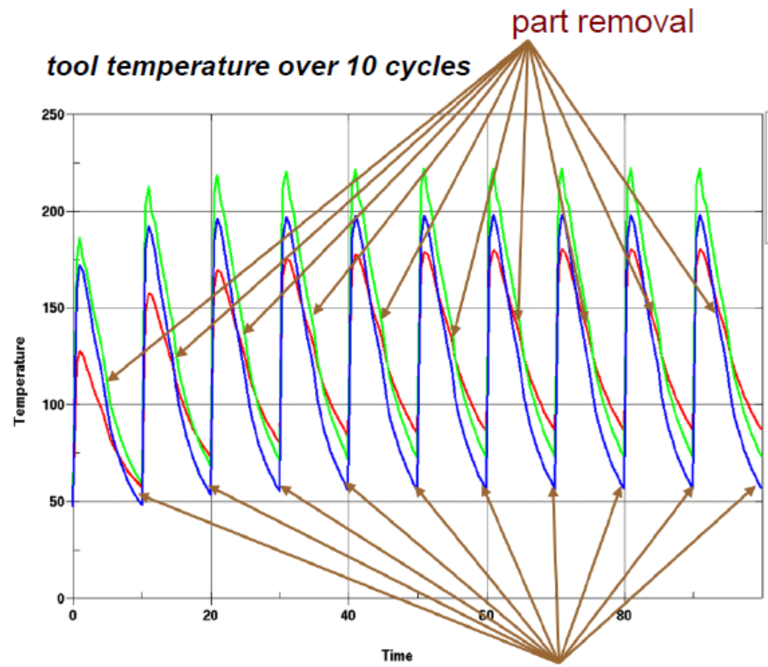


After forming



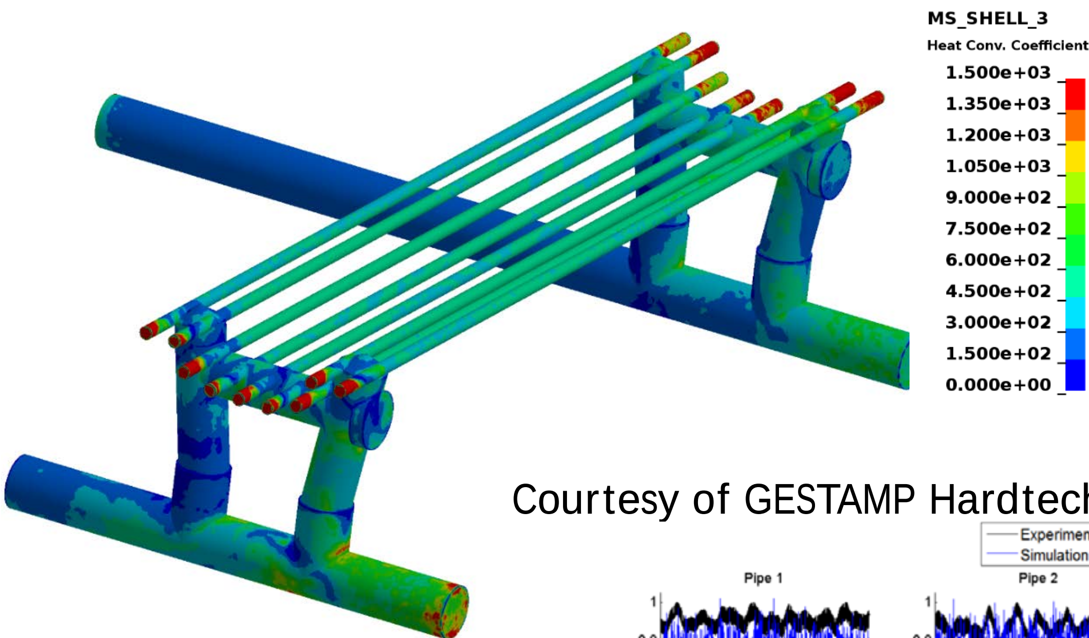
After cooling

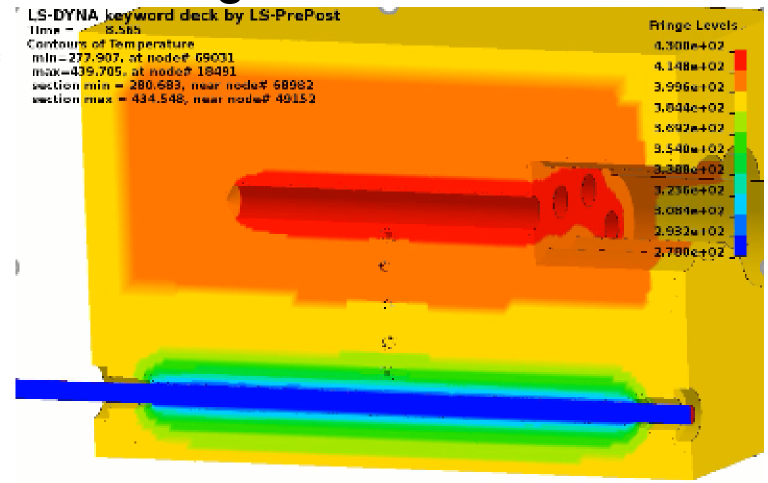




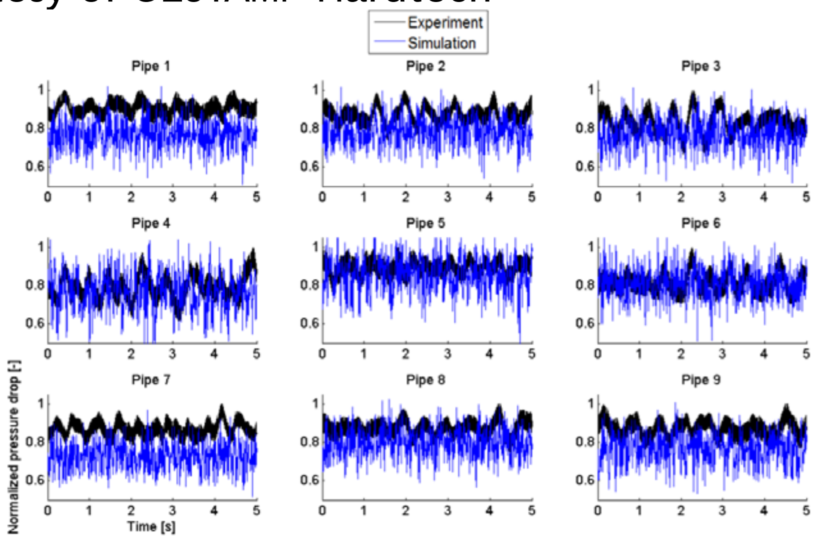
Cooling channel simulation - CFD

- Determine heat transfer coefficients using CFD





Courtesy of GESTAMP Hardtech



Summary

- Simulation of the virtual process chain will involve
  - Different physical fields
  - Different type of solvers
  - Different resolution
  - Different descriptions
- Simulation of the virtual process chain involves moving the material properties through the simulations ensuring that the complete history of the material is predicted.
- The simulations need to be solved in a coupled manner where the different solvers communicate within the same code
- The solvers need to be scalable over several cores in order to run the simulations in a reasonable timeframe.

Thank you!