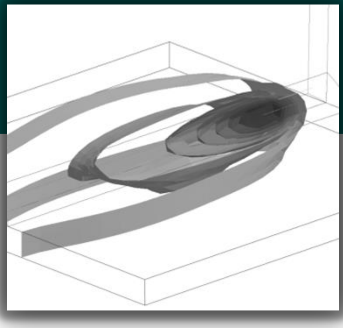

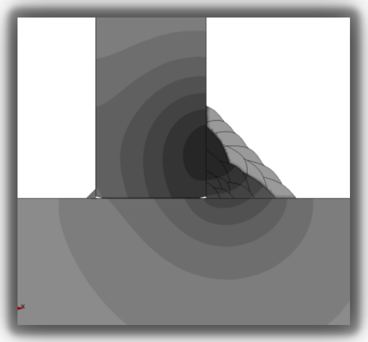

Recent Developments for Hot Stamping and Welding Processes in LS-DYNA

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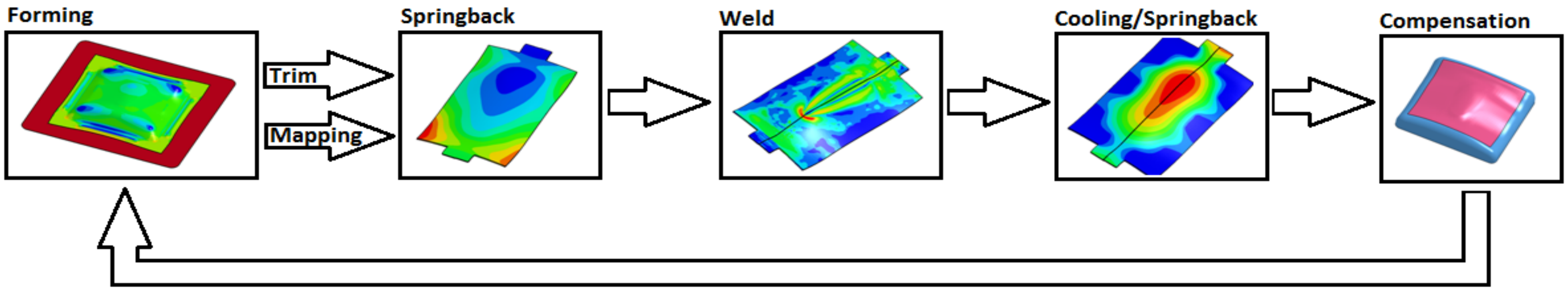
Ingenieurbüro Loose, Germany

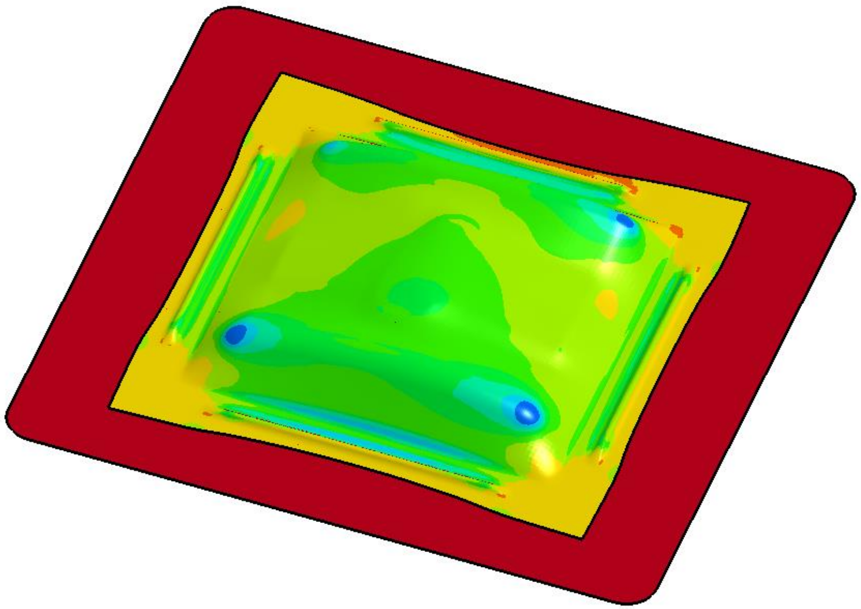
Simulation of the manufacturing process chain

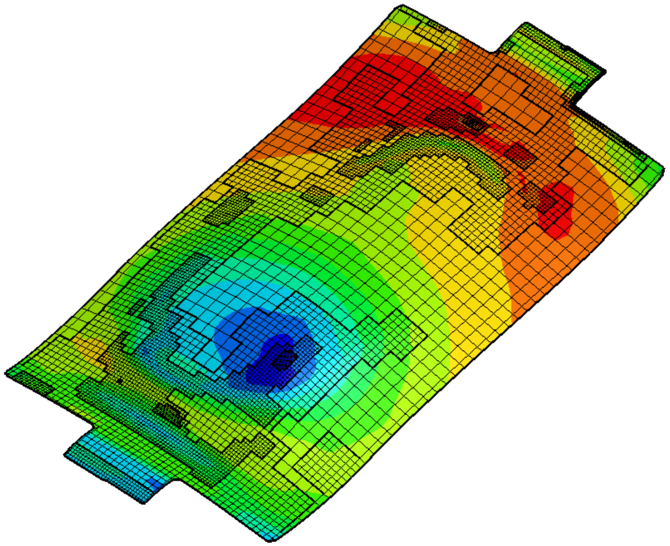
- For modern processes and materials, the mechanical properties of the finished part highly depend on the fabrication chain
- Tooling has to be compensated for springback and shape distortions which occur in the fabrication chain
- Numerical simulations of the complete process chain necessary to predict finished geometry and properties
  - Simulation of sheet metal forming, hot stamping, forging,… are state-of-the-art
  - Assembly by welding also leads to high distortions and furthermore changes the mechanical properties in the heat affected zone



Forming/trimming simulation

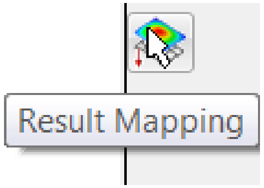
- Standard forming simulation use underintegrated shell elements, forming contacts and adaptivity
- The part can be trimmed using standard trimming functionality in LS-DYNA.

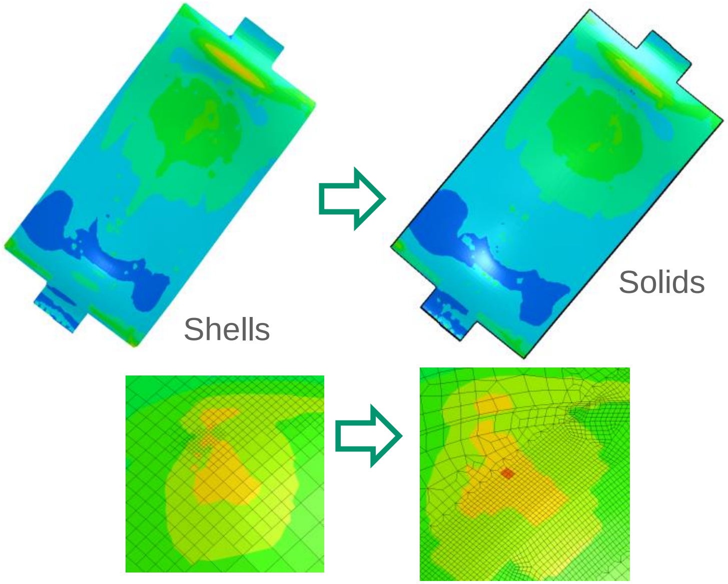




Preprocessing of Welding Step

- Welding simulations usually with a solid discretization
- Most preprocessors can generate solid elements from a shell mesh
- Results from forming simulations have to mapped onto the solid mesh for welding
  - A mapping algorithm has been implemented in LS-PREPOST v4.2
  - DYNAmore works on a multi-purpose mapping tool





- For now, it is assumed that the necessary information is available on the solid mesh

Agenda

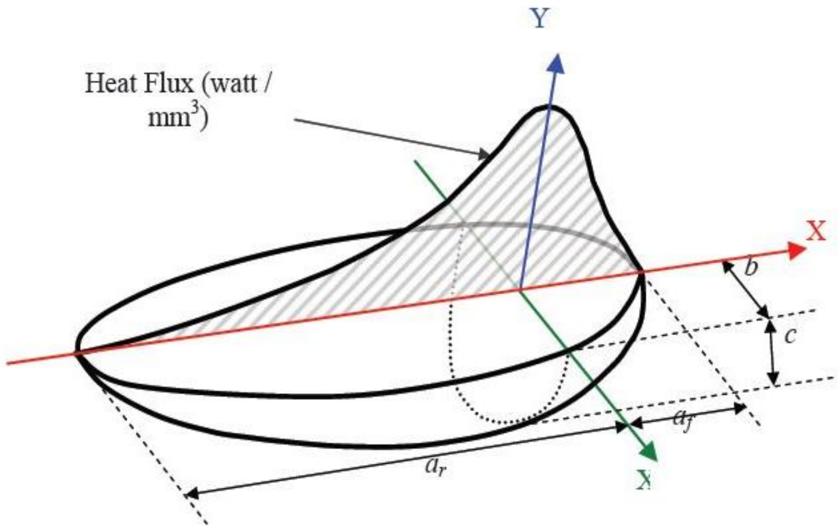
- Modeling Heat Sources
  - *BOUNDARY_THERMAL_WELD
  - *LOAD_HEAT_GENERATION_*OPTION*
  - *BOUNDARY_FLUX_*OPTION*

- Material formulations
  - *MAT_CWM (*MAT_270)
  - *MAT_THERMAL_CWM (*MAT_T07)
  - *MAT_UHS_STEEL (*MAT_244)

- Summary and Outlook

*BOUNDARY_THERMAL_WELD

- Keyword allows to define a Goldak Double Ellipsoid heat source



$$q = \frac{6\sqrt{3}FQ}{\pi\sqrt{\pi}abc} \exp\left(\frac{-3x^2}{a^2}\right) \exp\left(\frac{-3y^2}{b^2}\right) \exp\left(\frac{-3z^2}{c^2}\right)$$

q = weld source power density

(x, y, z) = coordinates of point p in weld material

$$F = \begin{cases} F_f \text{ if point } p \text{ is in front of beam} \\ F_r \text{ if point } p \text{ is behind beam} \end{cases}$$

$$c = \begin{cases} c_f \text{ if point } p \text{ is in front of beam} \\ c_r \text{ if point } p \text{ is behind beam} \end{cases}$$

- Coordinate system XYZ can be associated with a beam and thus moving heat sources can be simulated in thermo-mechanically coupled simulations

*BOUNDARY_THERMAL_WELD

	1	2	3	4	5	6	7	8
Card 1	PID	PTYP	NID	NFLAG	X0	Y0	Z0	N2ID
Card 2	a	b	cf	cr	LCID	Q	Ff	Fr
Opt.	Tx	Ty	Tz					

- NID: Node ID giving the location of weld source
- NFLAG: Flag controlling motion of source
  EQ.1: source moves with node
  EQ.0: fixed in space
- N2ID: Second node ID for weld beam aiming direction
  GT.0: beam is aimed from N2ID to NID
  EQ.-1: beam aiming direction is (tx, ty, tz)

LOAD_HEAT_GENERATION_*OPTION

	1	2	3	4	5	6	7	8
Card 1	SID	LCID	CMULT	WBLCID	CBLCID	TBLCID		

- In some cases the standard Goldak heat source is not suitable
- LCID accepts a function id, that returns `heat(t,x,y,z)`

*DEFINE_FUNCTION

- Define arithmetic expressions involving a combination of independent variables and other functions
- Function name must be unique (`heat` for heat generation)
- Can be referenced in other functions
- C-type or FORTRAN-style code is possible

LOAD_HEAT_GENERATION_*OPTION

- Example: Define moving (along x) spherical heat source

```
*LOAD_HEAT_GENERATION_SET
      1001      1001       1.0          0         0         0
*DEFINE_FUNCTION
      1001
float heat(float time, float x, float y, float z)
{   float xl,rl,f;
    xl=x-xt(time);
    if (xl**2+y**2+z**2>=1) f=0;
     else f= sqrt(1- xl**2+y**2+z**2);
     return f;}
*DEFINE_FUNCTION
      4001
float xt(float time)
{  float f = 10*time;
   return f;}
```

x distance from center (reference)

No heat generation outside sphere

Spherical heat source

Motion along x-axis with v=10

LOAD_HEAT_GENERATION_*OPTION

- Alternative input for spherical heat source

```
*DEFINE_FUNCTION
      1001
float heat(float time, float x, float y, float z)
{    float xl,rl,f;
    xl=x-xt(time);
    if (xl**2+y**2+z**2>=1) f=0:
     else f= sqrt(1- xl**2+y**2+z**2)
     return f;}
```

x distance from center (reference)

No heat generation outside sphere

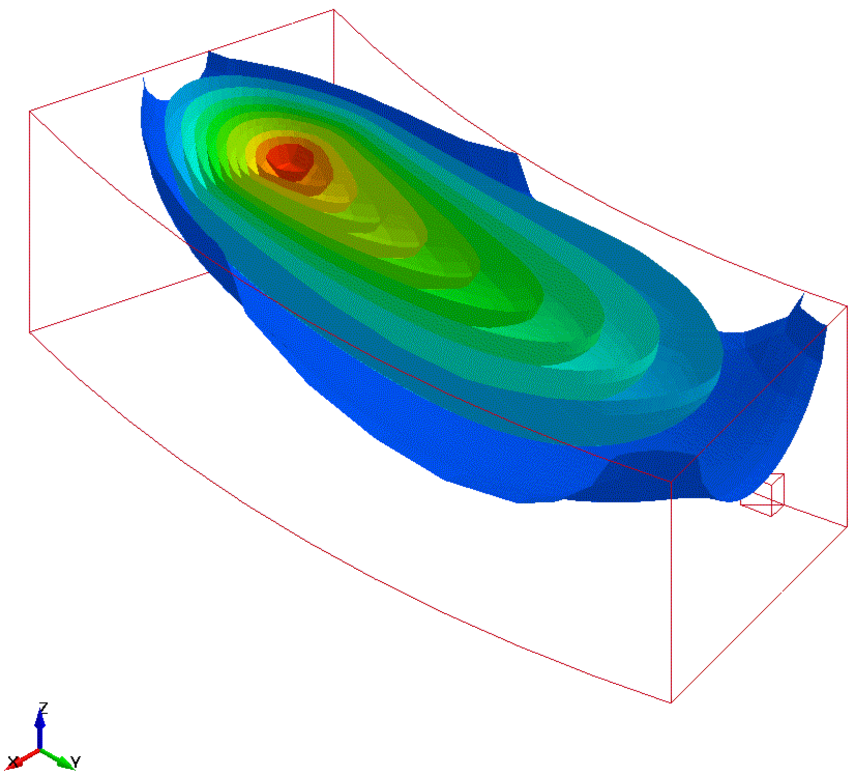
Spherical heat source

```
*DEFINE_FUNCTION_TABULATED
      4001      (t,y) data pairs
$# title
xt
                    0.                    0.
                    5.                   50.
                   10.                  100.
```

Motion along x-axis with v=10
Load curve input

*LOAD_HEAT_GENERATION_*OPTION**

- Example:
  Temperature fields for a Goldak and a double cone-shaped heat source



*BOUNDARY_FLUX_SET

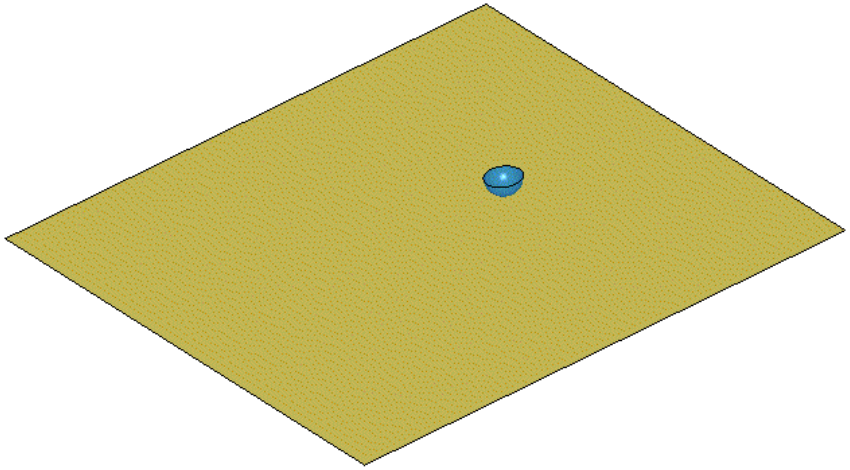
	1	2	3	4	5	6	7	8
Card 1	SID							
Card 2	LCID	MLC1	MLC2	MLC3	MLC4	LOC	NHISV	
Card x	HISV1	HISV2	HISV3	HISV4	HISV5	HISV6	HISV7	HISV8

- Apply a flux boundary condition on a SEGMENT_SET
- Accepts function ID in `LCID`, declaration
  `float flux(float x,float y,float z,float vx,float vy,float vz,float tinf,float time)`

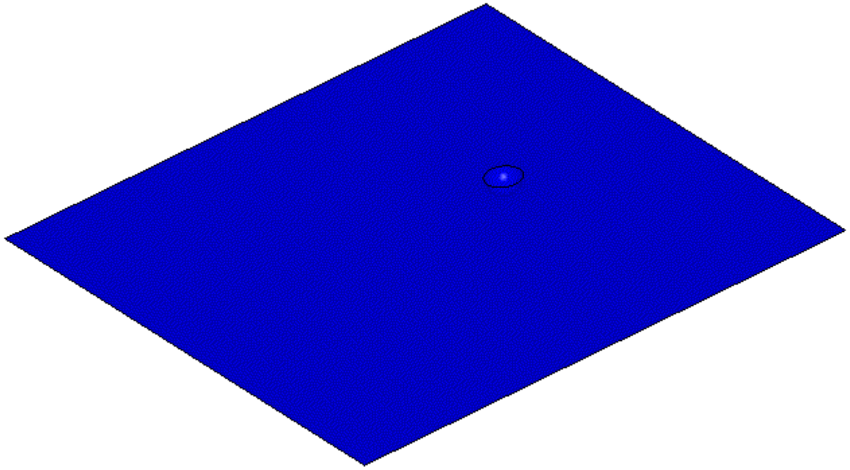
- Application for welding or laser assisted forming processes

*BOUNDARY_FLUX_SET

- Laser assisted sheet forming:
  - the laser heats the material and softens it for forming
  - Energy from the laser is modeled using a flux boundary condition



Deformation



Temperature

Agenda

- Modeling Heat Sources
  - *BOUNDARY_THERMAL_WELD
  - *LOAD_HEAT_GENERATION_*OPTION*
  - *BOUNDARY_FLUX_*OPTION*

- Material formulations
  - *MAT_CWM (*MAT_270)
  - *MAT_THERMAL_CWM (*MAT_T07)
  - *MAT_UHS_STEEL (*MAT_244)

- Summary and Outlook

Materials for welding simulations

- Usually, the weld seam is completely discretized with solid elements at the beginning of the simulation

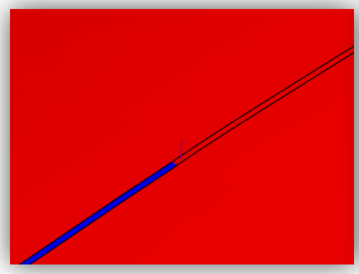
- Properties of the filler material change dramatically during the process:
  - Before the weld torch has reached the material, filler should not influence the outcome
    - Very low mechanical stiffness
    - Very low heat transfer
  - As soon as the material is affected by the heat it should act as a standard thermo-mechanical material

- Annealing as soon as temperature reaches a specific value

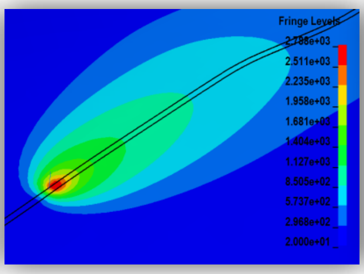
*MAT_CWM / *MAT_270

	1	2	3	4	5	6	7	8
Card 1	MID	RO	LCEM	LCPR	LCSY	LCHR	LCAT	BETA
Card 2	TASTART	TAEND	TLSTART	TLEND	EGHOST	PGHOST	AGHOST	
Opt.	T2PHASE	T1PHASE						

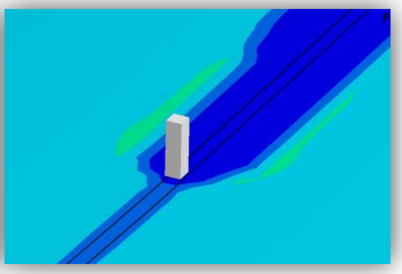
- Elements can be ”Ghost” or ”Silent” until activated at a specific temp.
- Anneal at specific temperature
- All input is temperature dependent
- Arbitrary isotropic/kinematic hardening
- Specific heat and thermal expansion can be input as a function of maximum temperature to simulate phase transformation effects



activation



temperatures

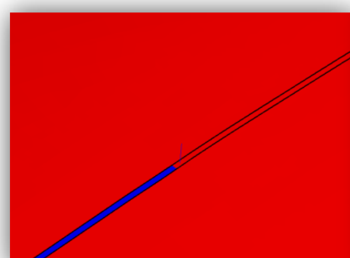


annealing

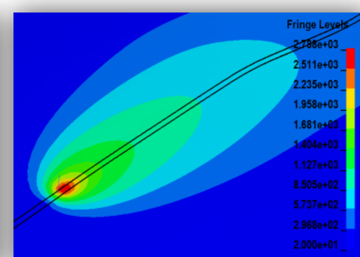
*MAT_THERMAL_CWM / *MAT_T07

	1	2	3	4	5	6	7	8
Card 1	TMID	TRO	TGRLC	TGRMULT	HDEAD	TDEAD		
Card 2	LCHC	LCTC	TLSTART	TLEND	TISTART	TIEND	HGHOST	TGHOST

- Elements have birth time TISTART and TIEND
- After birth material is in a “Ghost” state until activated at a specific temperature
- All input is temperature dependent
- TGR stands for thermal generation rate

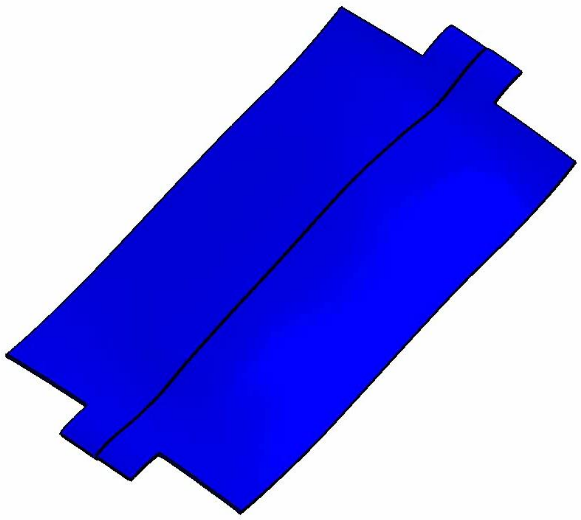


activation

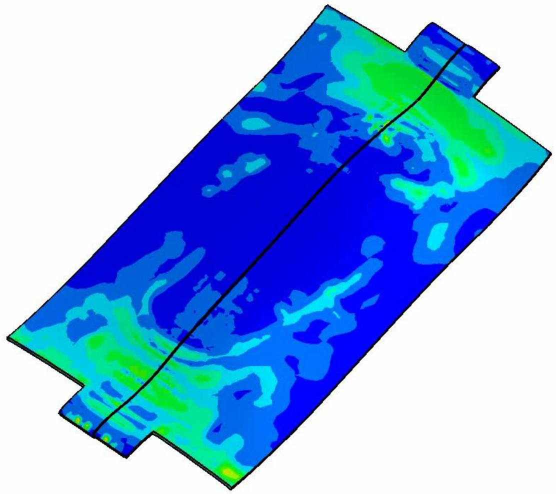


temperatures

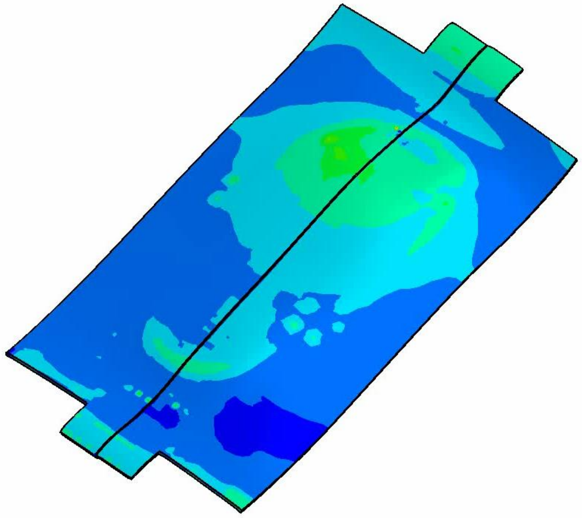
Welding simulation



Temperature



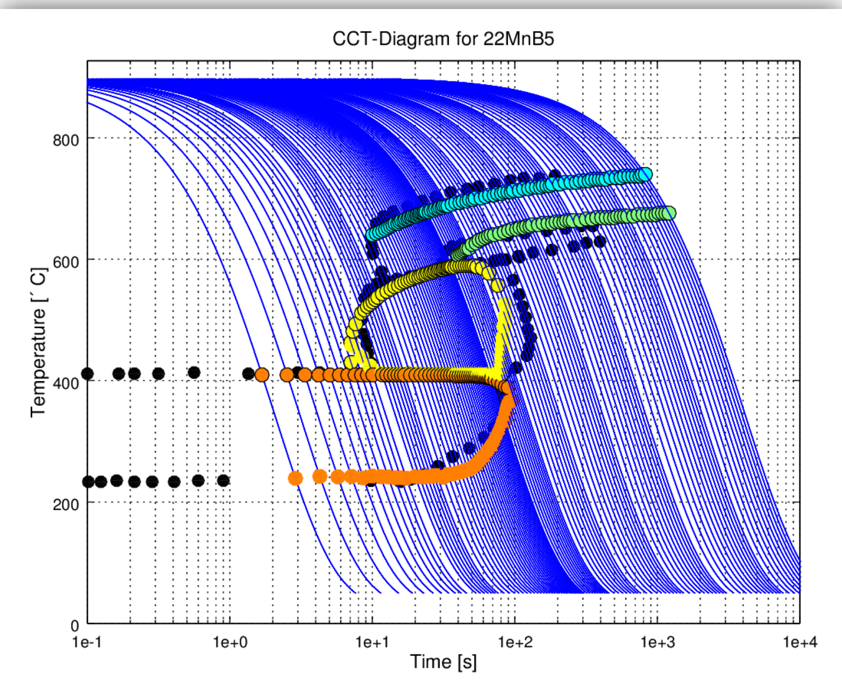
Von Mises stress



Effective plastic strain

*MAT_UHS_STEEL / *MAT_244

- Material has originally been implemented for hot stamping formulations
- Constitutive model based on work of Akerstrom for 22MnB5
- Five phases: austenite, ferrite, pearlite, bainite and martensite
- Phase transitions in heating and cooling can be simulated
- Thermo-visco-elasto-plastic properties can be defined for individual phases (now compatible to *MAT_106)
- Transformation induced plasticity (TRIP) algorithm
- Latent heat computation
- Hardness calculation



*MAT_UHS_STEEL / *MAT_244

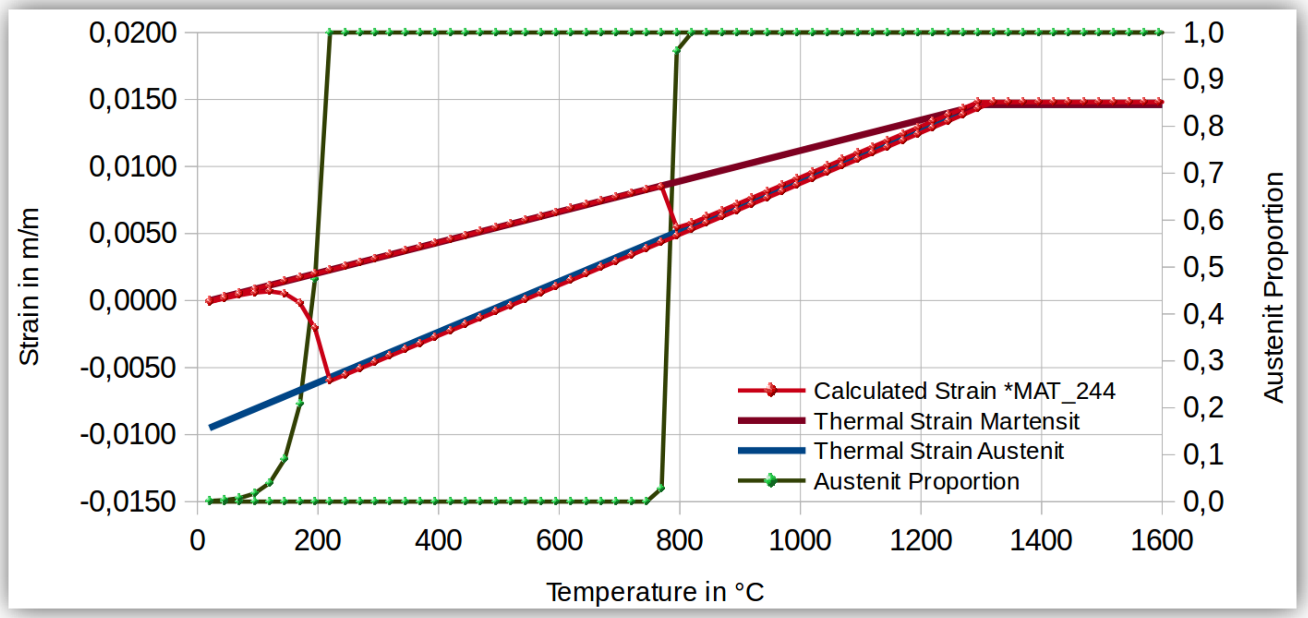
- The start temperatures for phase transitions can be
  - calculated automatically by the material using the chemical composition
  - Defined manually using the advanced reaction kinetics input (REACT=1)
  - By default, same start temperature is used for heating and cooling

	1	2	3	4	5	6	7	8
REACT	FS	PS	BS	MS	MSIG	LCEPS23	LCEPS4	LCEPS5

- Now, advanced reaction kinetics input accepts LCID for FS,PS, BS, MS
  - First ordinate value is start temperature for cooling
  - Last ordinate defines start temperature for heating

*MAT_UHS_STEEL / *MAT_244

- Temperature dependent definition for thermal expansion for austenite and hard phases
- Dilatometer experiments show transformation induced strains as temperature dependent jumps
- Added parameter `LCTRE` in card 4 on position 8 defining temperature dependent offset between austenite and martensite dilatometer curve



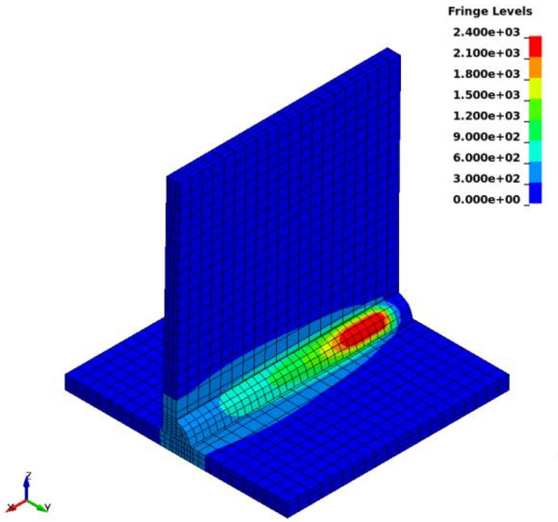
*MAT_UHS_STEEL / *MAT_244

- New features for welding have been implemented
- Can be used by setting flag `CWM` in card 4 parameter 7 to 1
- Optional CWM card reads

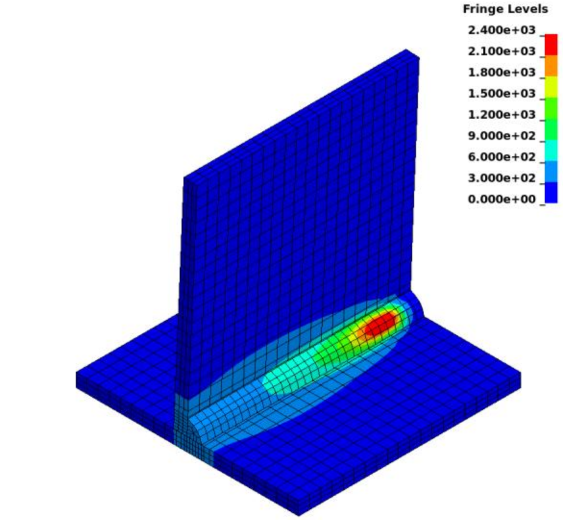
	1	2	3	4	5	6	7	8
CWM	TASTART	TAEND	TLSTART	TLEND	EGHOST	PGHOST	AGHOST	

- Ghost material approach, cf *MAT_270
  - Material is inactive at the beginning, but is activated if temperature reaches a starting temperature
  - Properties of ghost material should not influence the outcome, but should yield suitable mesh movement within the weld seam
- Annealing is also considered
- Can be combined with *MAT_THERMAL_CWM

*MAT_UHS_STEEL / *MAT_244

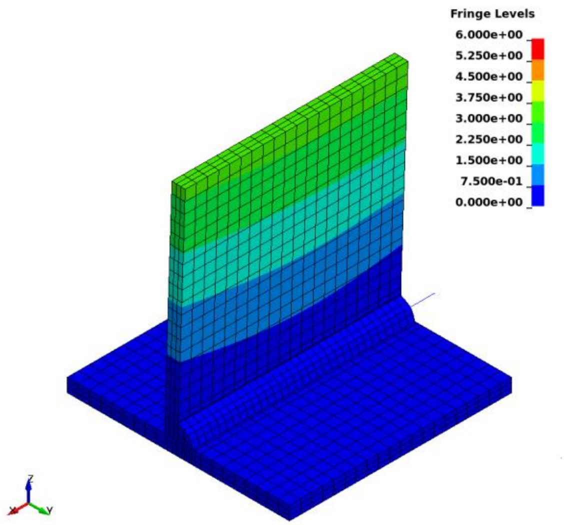


temperature

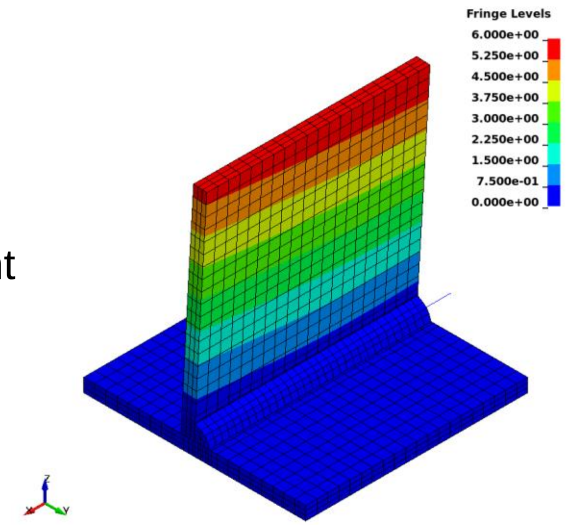


no ghosting

with ghosting



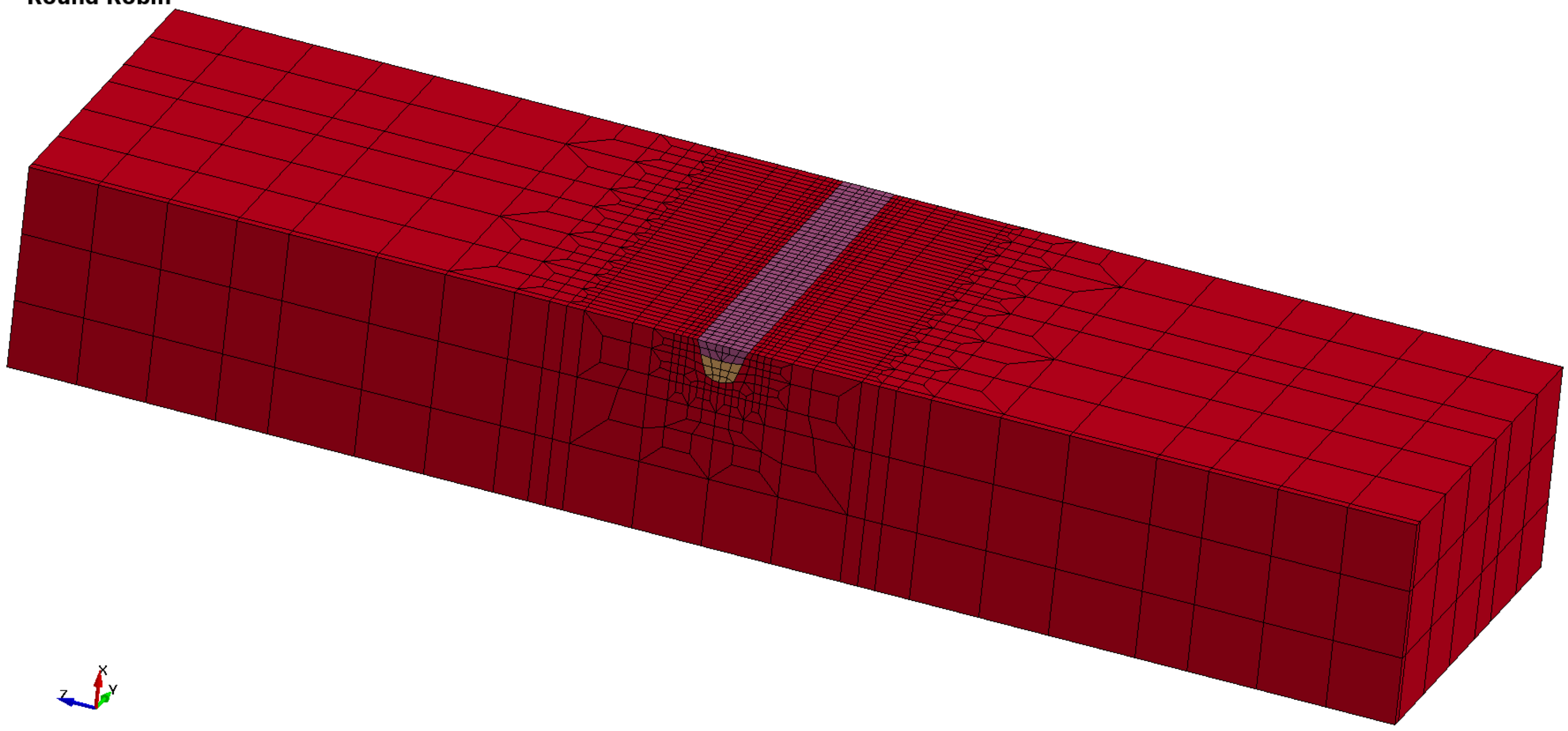
displacement



*MAT_UHS_STEEL / *MAT_244

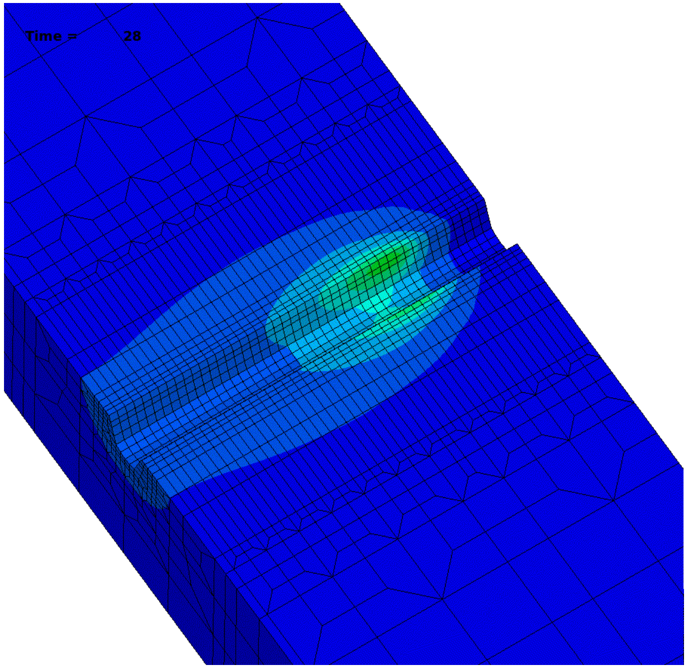
Example: Round Robin

- Geometry: notched block with 2 weldseams
- All materials are initialized in ferrite phase

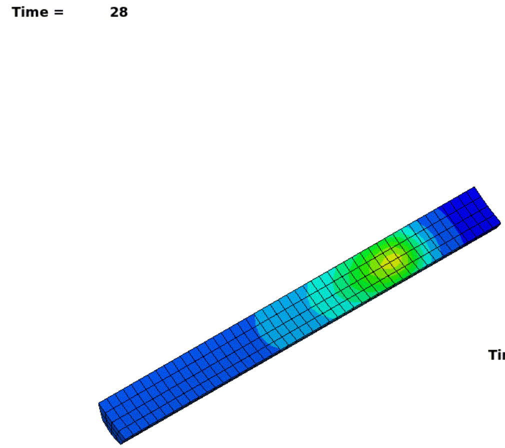


*MAT_UHS_STEEL / *MAT_244

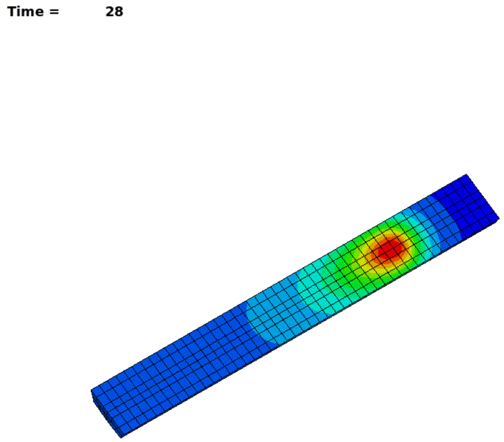
- Temperature t=28



block



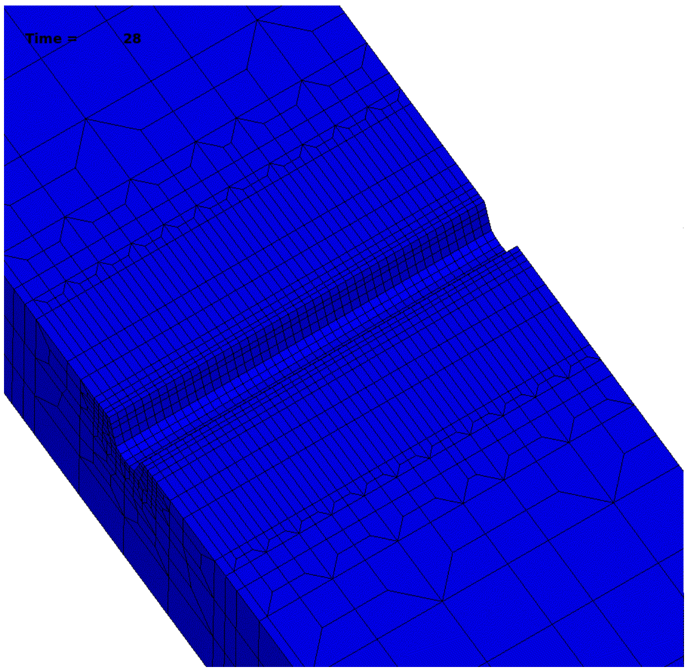
lower weld seam

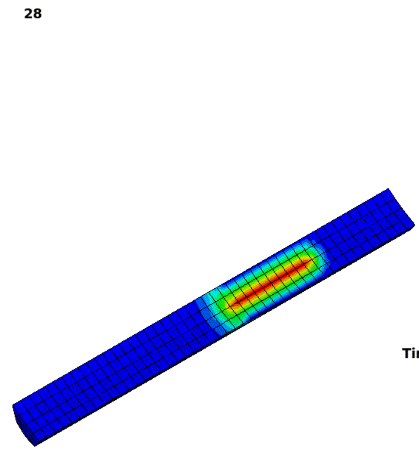


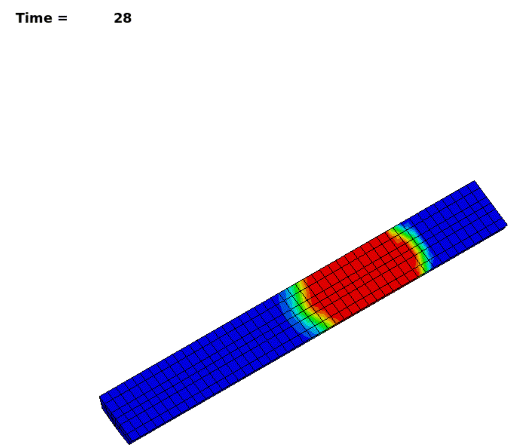
upper weld seam

*MAT_UHS_STEEL / *MAT_244

- Austenite concentration t=28







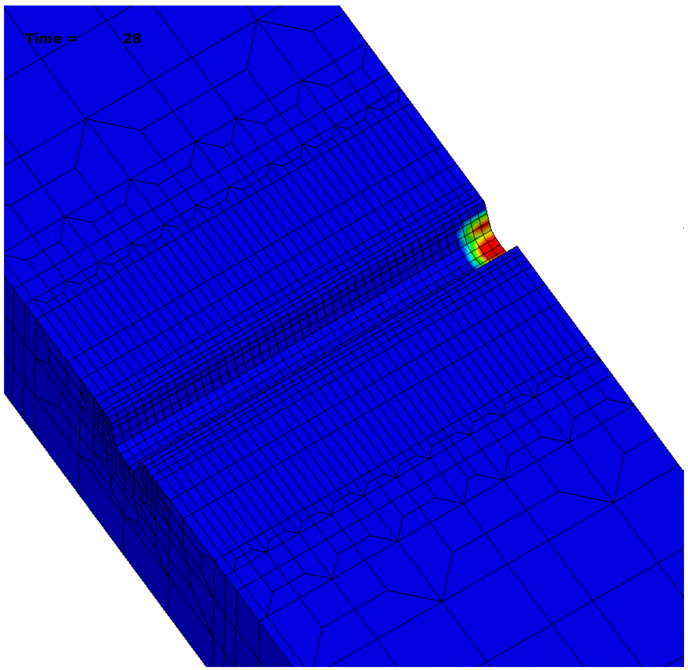
block

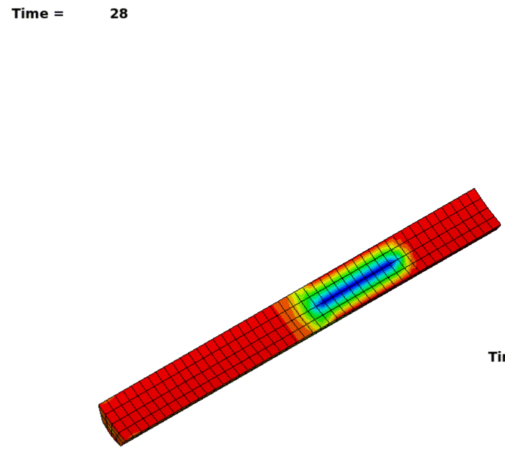
lower weld seam

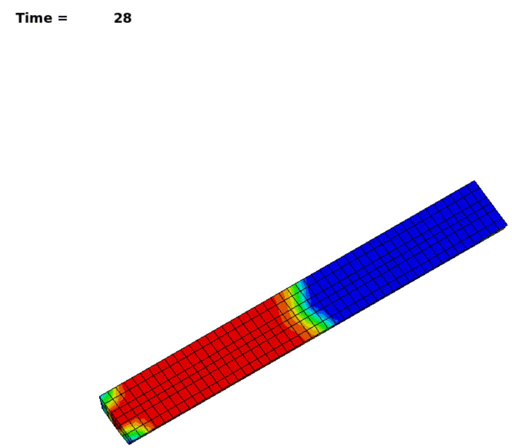
upper weld seam

*MAT_UHS_STEEL / *MAT_244

- Martensite concentration t=28







block

lower weld seam

upper weld seam

Agenda

- Modeling Heat Sources
  - *BOUNDARY_THERMAL_WELD
  - *LOAD_HEAT_GENERATION_*OPTION*
  - *BOUNDARY_FLUX_*OPTION*

- Material formulations
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  - *MAT_UHS_STEEL (*MAT_244)

- Summary and Outlook

Summary

- LS-DYNA provides the necessary tools to include welding stages into the virtual process chain

- The standard Goldak model for the weld torch is implemented
- Great flexibility to input arbitrary models for the heat source using the *DEFINE_FUNCTION keyword

- *MAT_CWM and *MAT_THERMAL_CWM have been tailored for welding simulation and use a ghost material approach to model inactive filler material

- *MAT_UHS_STEEL implements features for CWM and additionally accounts for phase transformation in the material

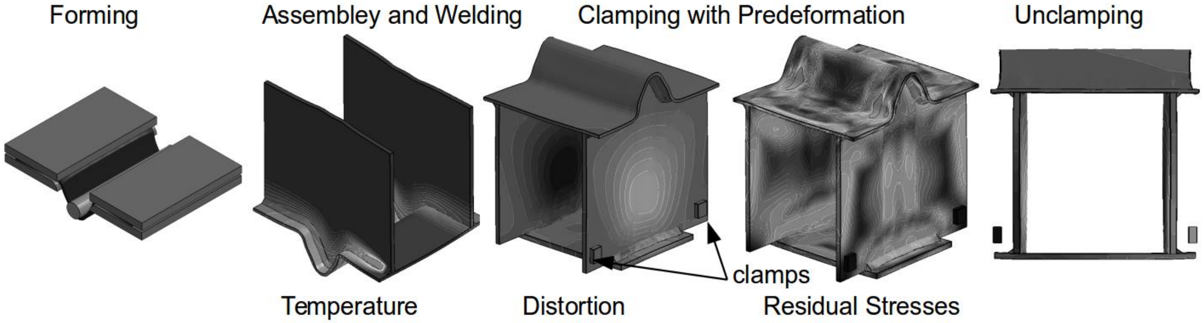
Outlook

- A generalization of *MAT_244 will be implemented
  - Suitable for a wider range of materials
  - More phases can be defined
  - Multiple phase transformations
  - …
- Special welding contact in currently under development at LSTC

Don’t miss the presentation by Tobias Loose:

Gekoppelte Simulation des Umformens und des Schweißens mit LS-DYNA zur Auslegung der Schweißverzugskompensation

Tuesday, 4 pm



Thank you!