

DYNAmore Nordic Breakfast Seminar 2019

State of the art modelling of thermo-mechanical coupling in LS-DYNA

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Luleå, 12.11.2019

Motivation – Assembly Simulation

- State of the art digital process chain contains
 - (Hot) forming and press hardening simulations
 - Clamping simulations
 - Mechanical assembly steps, i.e. clinching, roller hemming, ...
 - Thermal assembly steps, i.e. resistance spot welds, laser welds, line weld (MIG, MAG), ...
 - Springback analysis

- Closed virtual process chain within LS-DYNA by data transfer from one stage to the next
 - Assembly of whole side-panel of a car
 - Hundreds of spot-weld, dozens of parts and multiple level of assemblies

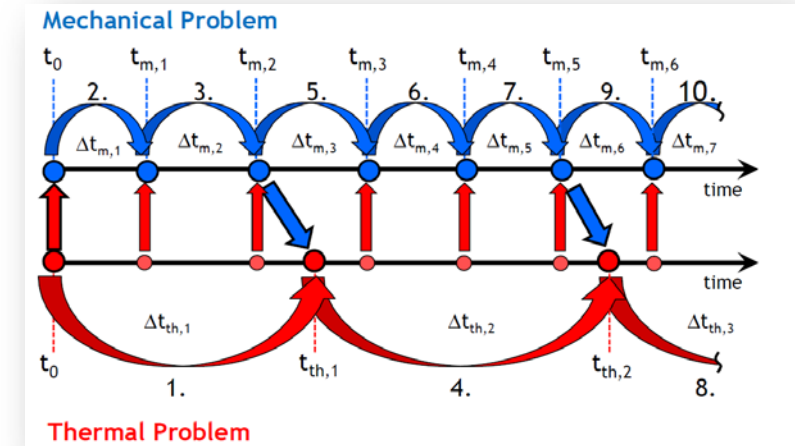
- Tailored simulation strategies for each of the individual steps
 - As efficient as possible for each process, but without neglecting the critical effects
 - Keep track of material properties that might change significantly during process (e.g. phase evolution)

Content

- 2-way coupled approaches
 - Data transfer and simulation principles
 - Application example: laser cutting
- Interlude: Hot forming and press-hardening simulations
- 1-way coupled approaches
 - Motivation and data transfer
 - New keyword *LOAD_THERMAL_BINOUT
 - Application example
- Prescribed thermal loading conditions for resistance spot welding
 - Motivation
 - New keyword *LOAD_THERMAL_RSW

Data Transfer and Simulation Principles

- Default strategy in LS-DYNA is a 2-way coupling
 - Staggered weak approach
 - Two solvers run in parallel and share data
 - Thermal time step is independent of the mechanical time step
- Data transfer



Thermal Calculations

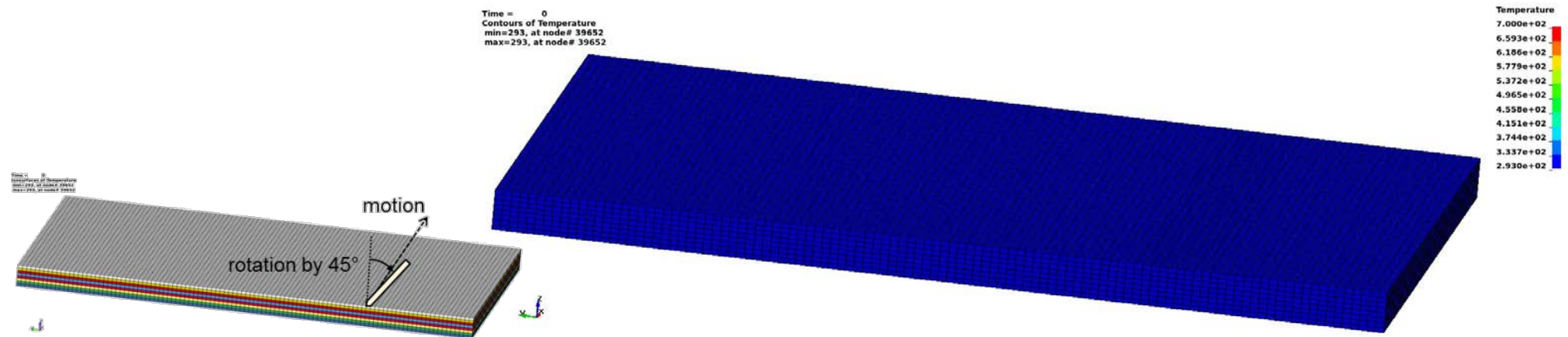
- Based on current geometry, calculate:
 - Heat from plastic work and phase changes
 - Contact conductance from gap thickness and contact pressure
 - Heat from interface friction
- Update temperature field

Mechanical Calculations

- Based on current temperature, calculate:
 - Plastic work and phase changes
 - Part contact gap thickness
 - Temperature dependent material
 - Thermal expansion
- Update geometry

2-way Coupled Application: Laser Cutting

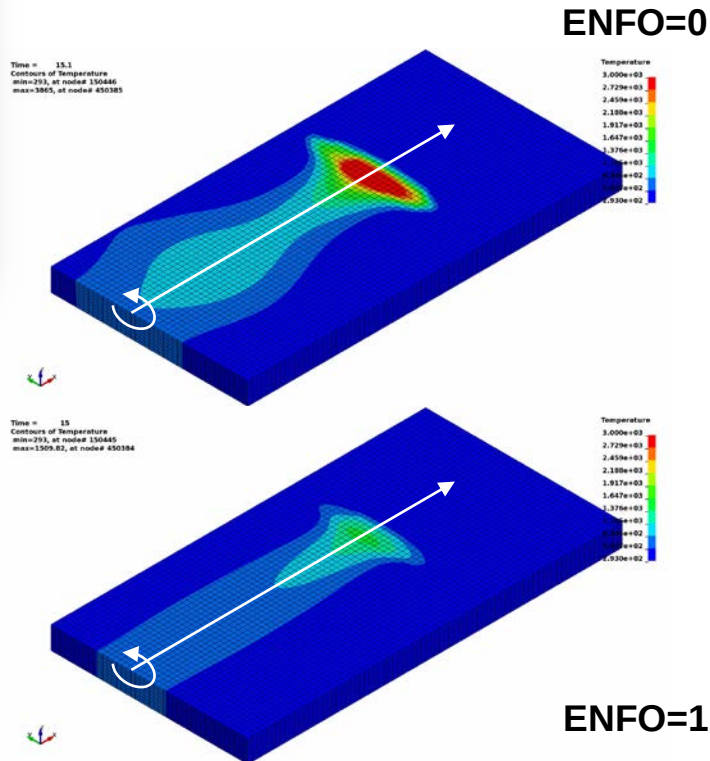
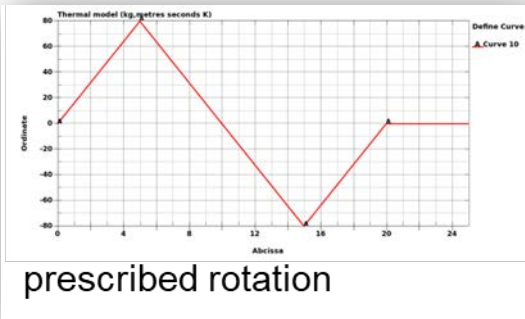
- Strong coupling between structure and temperature field
 - local heating of a surface by a laser with a certain position and orientation
 - material evaporates and topology of cut part changes
- LS-DYNA implementation with *BOUNDARY_FLUX_TRAJECTORY
 - surface flux boundary conditions that follows a prescribed path (node set)
 - resulting surface heat distribution depends on base distribution and current orientation of laser and surface
 - element erosion based on maximum temperature
 - newly exposed segments are accounted for



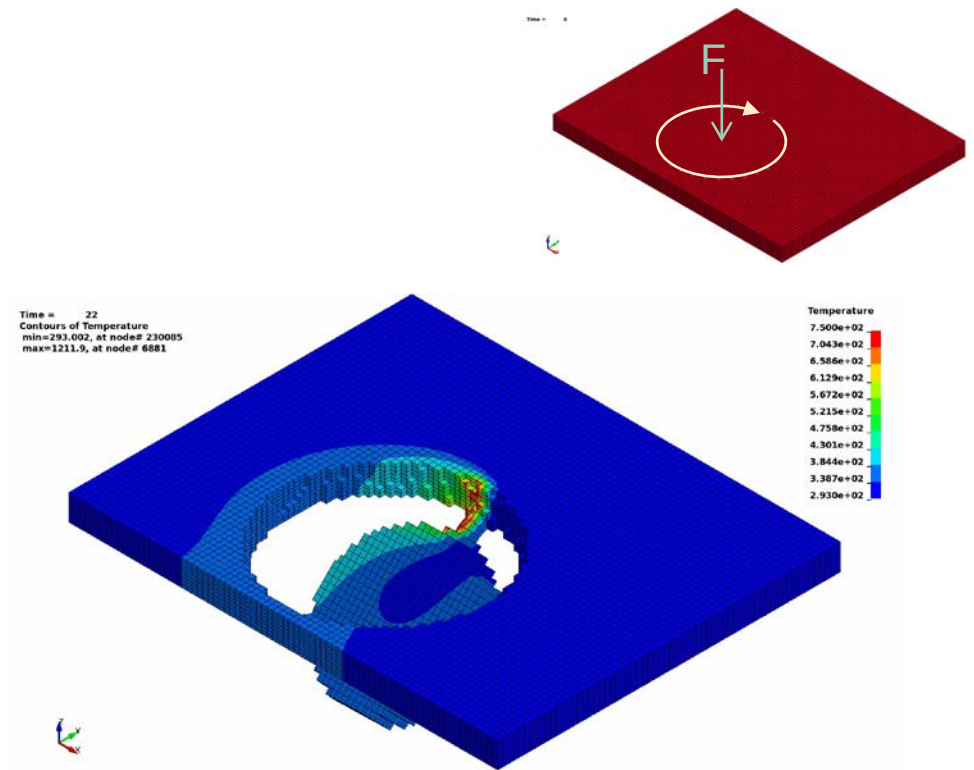
2-way Coupled Application: Laser Cutting

■ *BOUNDARY_FLUX_TRAJECTORY

- tilting changes projection on the surface
- change of intensity can be balanced



- nodal path not necessarily defined on the cut part



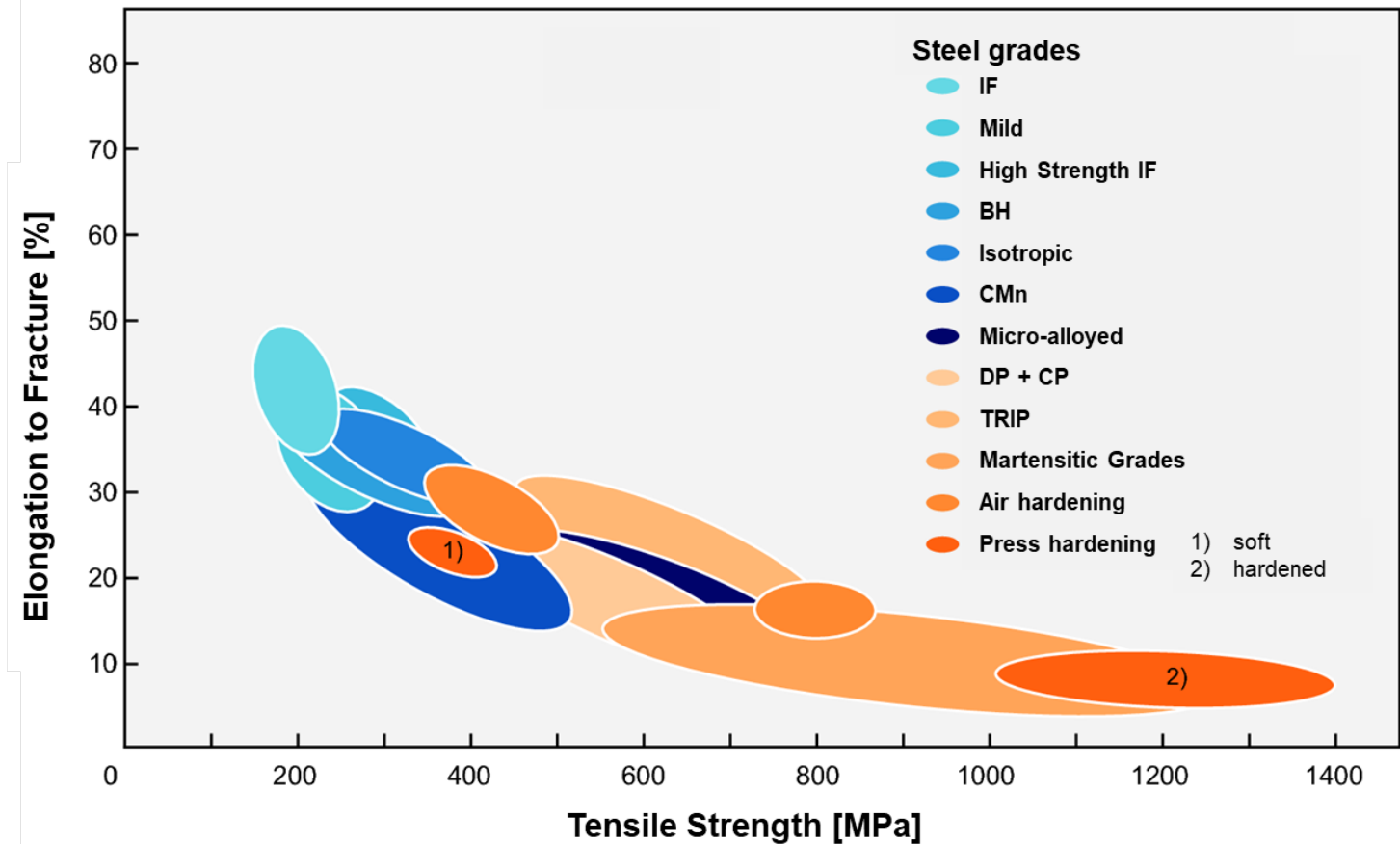
Interlude: Hot forming and press-hardening simulations

- Motivation
- Selected simulation topics
 - Thermal thick shell
 - Heat transfer in contact
 - Direct vs iterative solvers and tolerances
- Material modeling
 - MAT_244
 - MAT_254

Motivation I: Steel Grades

- goal: benefit from the advanced characteristics of UHS steels
- properties of the product are process dependent (mainly of cooling rate)
- relatively well-known and well-controlled environment

[source: Hochholdinger 2012]

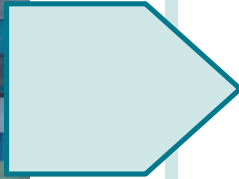


Motivation: “Real” Process



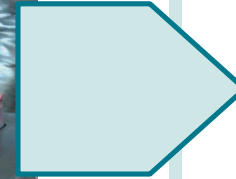
Courtesy of Daimler AG

Coupled Warmforming Simulations



■ Transfer

- heat loss by
 - convection
 - radiation



■ Positioning

- heat loss by
 - convection
 - radiation
 - contact to lower die
- temperature gradient through blank



■ Hot forming & quenching

- heat change by
 - contact conductance
 - contact friction
 - solid – solid phase transition
 - die cooling

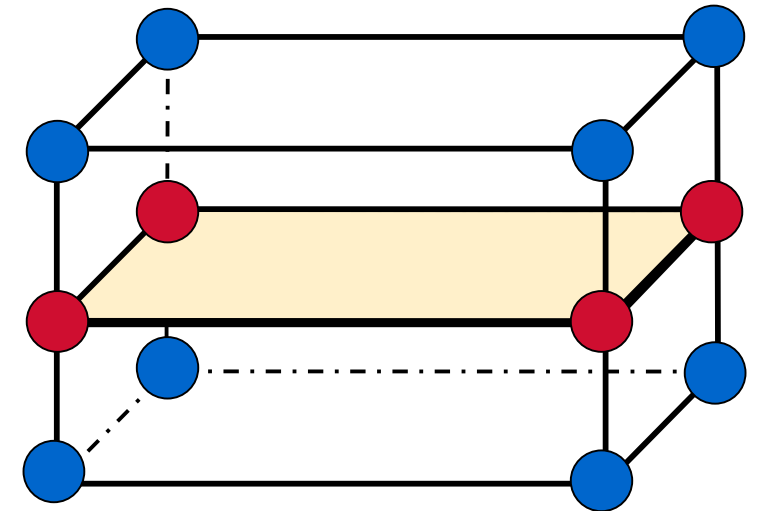
Interlude: Hot forming and press-hardening simulations

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Thermal Thick Shell Element

- standard shell element has a constant temperature over thickness
- LS-DYNA features a twelve-node thermal thick shell element formulation
 - bi-linear shape functions in-plane, quadratic shape function in thickness direction (G. Bergman & M. Oldenburg, Luleå University of Technology)
 - user only specifies standard four node shell element
 - LS-DYNA automatically generates top and bottom virtual nodes
 - new temperature degrees of freedom assigned to virtual nodes

nodes provided by user ●
virtual nodes ●

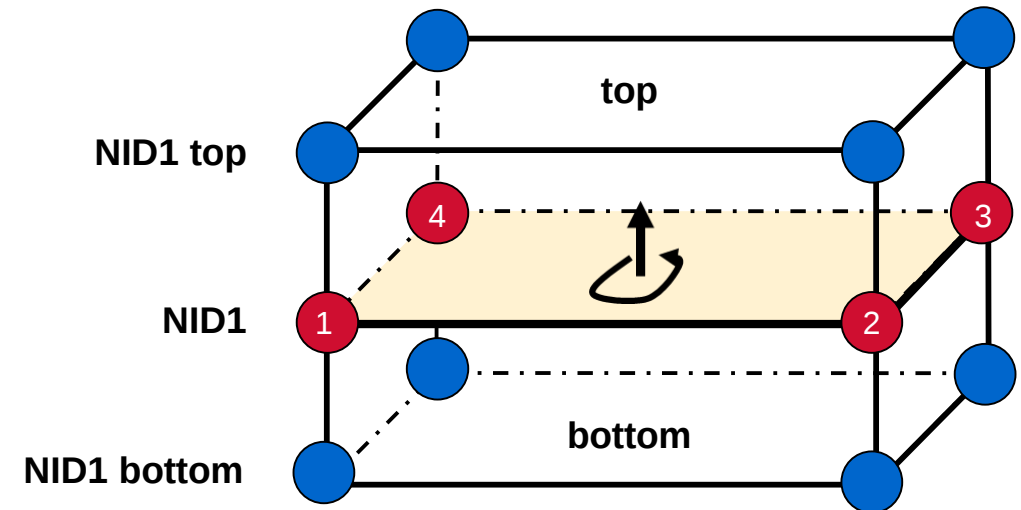


Thermal Thick Shell Element

■ Implications on initial and boundary conditions

- shell has top, middle and bottom layer
→ surface conditions have to be applied to the correct layer
- each node ID occurs 3-times (top, middle, bottom)
→ need input possibility for all three nodes to define nodal conditions

nodes provided by user ●
virtual nodes ●



Thermal Thick Shell Element

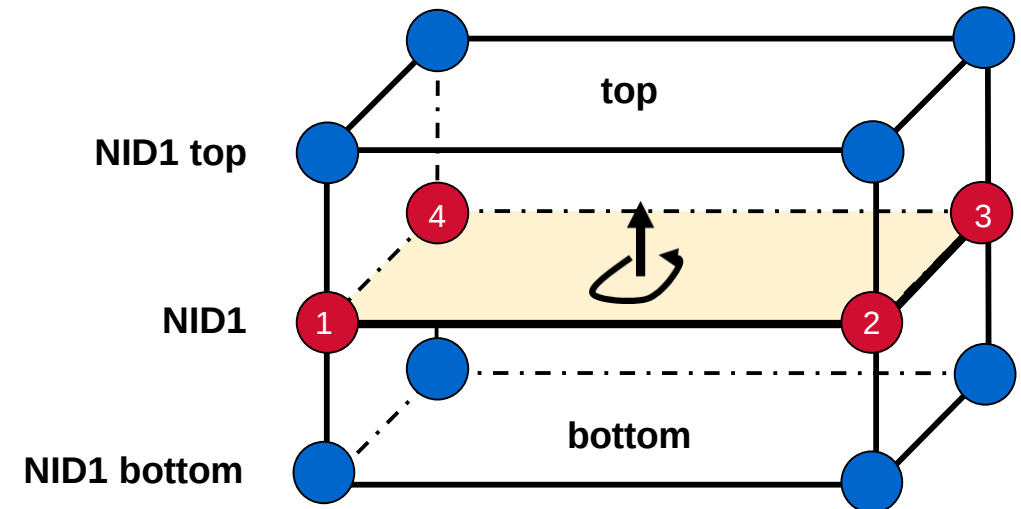
■ General keyword form of a thermal boundary/initial condition

...	LCID	MULT	LOC	...
-----	------	------	-----	-----

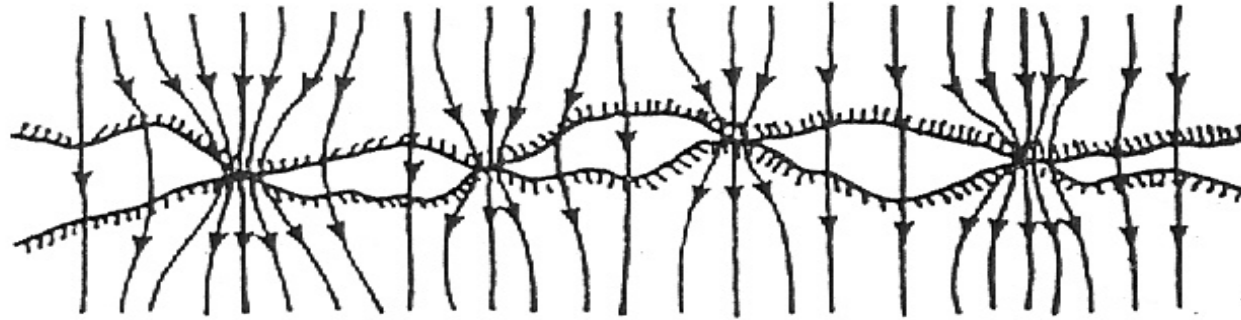
- LCID: load curve ID (function of time or temperature)
- MULT: load curve multiplier
- LOC: shell / node layer (-1: bottom, 0: middle, 1: top)

nodes provided by user ●

virtual nodes ●



Contact conductance

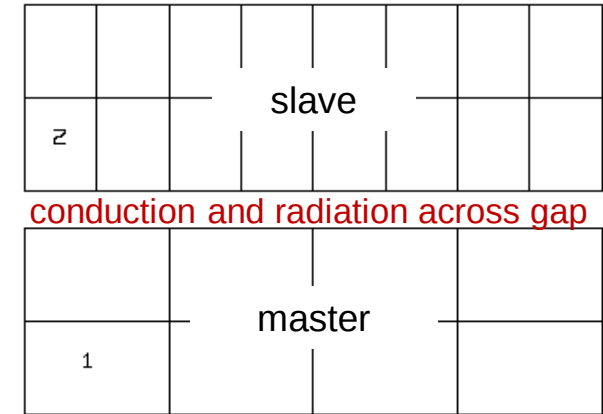


- Heat transfer between contacting parts is influenced by
 - contact pressure (elastic/plastic deformation)
 - contact temperature
 - material in gap (vacuum, gas, lubricant)
 - surface flatness
 - surface roughness
 - surface finish (e.g., oxide layer)

Contact conductance

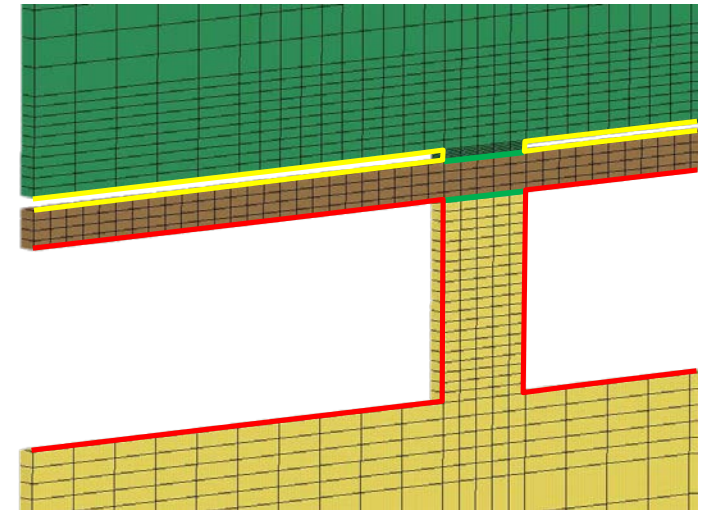
■ Three modes of heat transfer:

- Conduction across fluid filling gap with variable gap thickness
- Radiation across gap
- (Metal-to-metal) contact with voids, i.e. closed contact



■ Heat exchange by radiation

- Contact radiation, where a segment can see one surface on the other body
- Enclosure radiation, where a segment can see many other segments on the other body
- Borderline between the above cases



*CONTACT_FORMING_ONE_WAY_SURFACE_TO_SURFACE_THERMAL_FRICTION

■ FORMING

- do not account for master surface shell thickness
- special mesh adaptivity algorithms available

■ ONE_WAY

- only affects contact treatment of mechanical solver
- consider only slave penetration into master surfaces



■ THERMAL

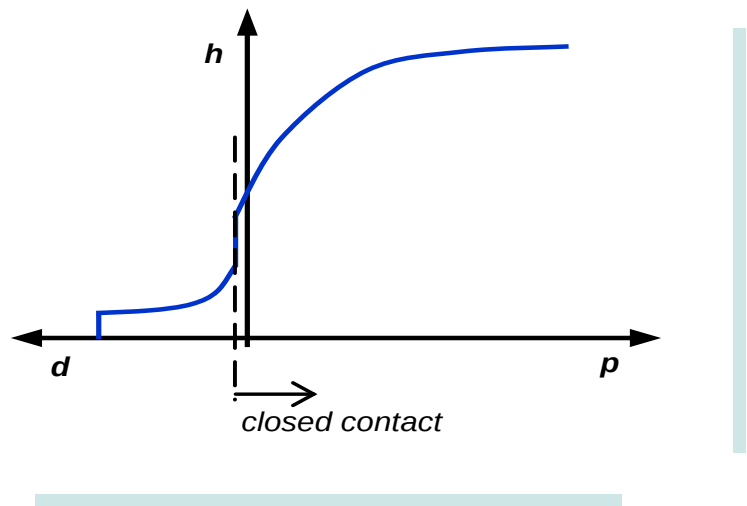
- additional card required to input parameters for heat transfer across contact area
- switch for thermal one-/two-way

■ FRICTION

- additional card is expected
- define coefficient of static and dynamic friction as function of temperature and pressure
- define heat transfer coefficient as function of temperature and pressure

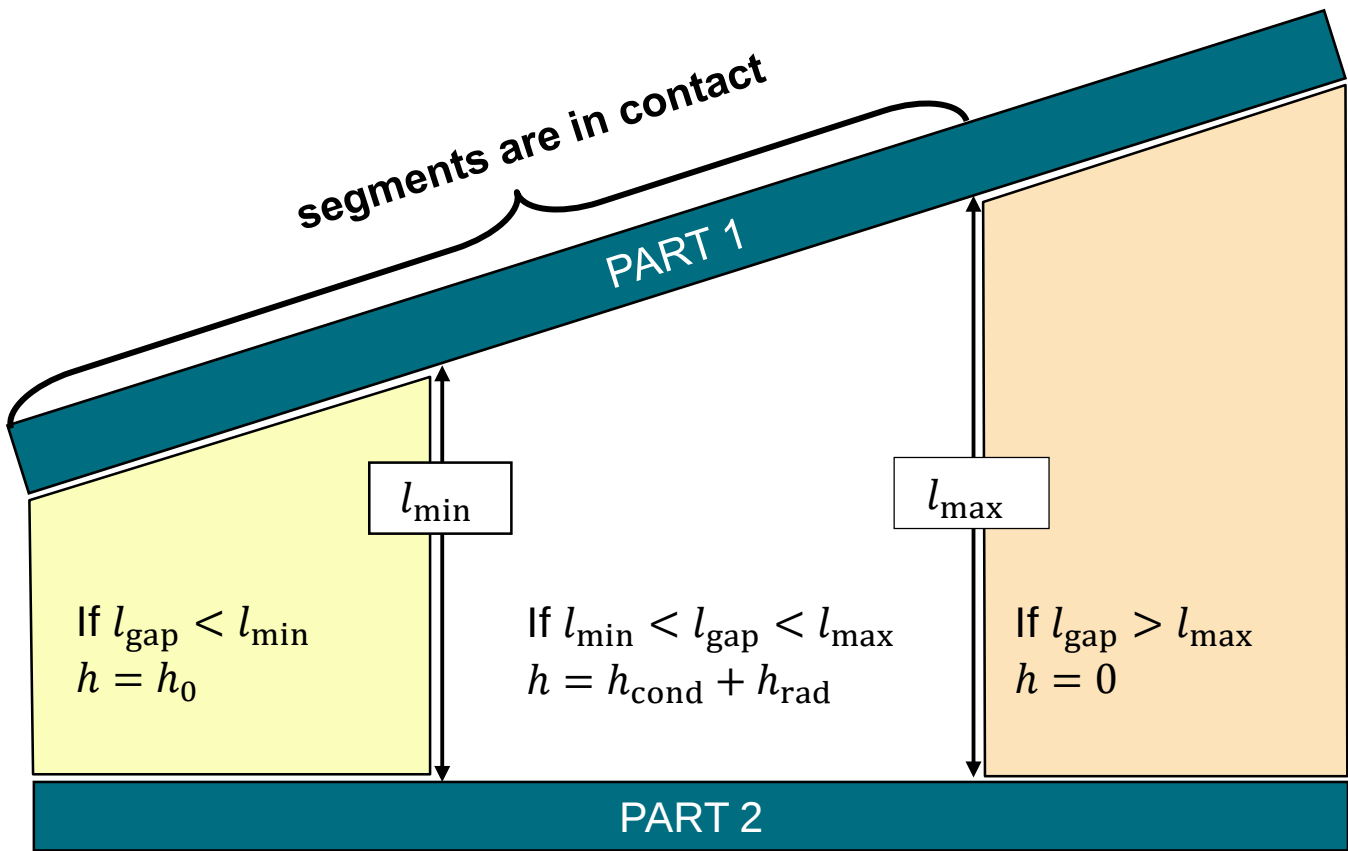
Thermal contact keyword

	1	2	3	4	5	6	7	8
Therm.	K	FRAD	H0	LMIN	LMAX	FTOSLV	BCFLAG	ALGO



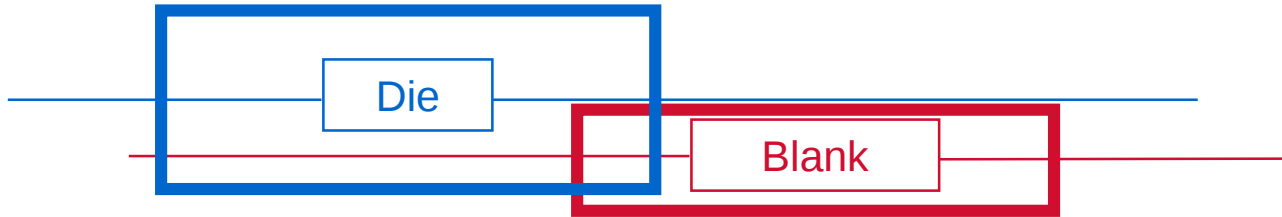
$$h_{\text{cond}} = \frac{k}{l_{\text{gap}}}$$

$$h_{\text{rad}} = f_{\text{rad}}(T_m + T_s)(T_m^2 + T_s^2)$$

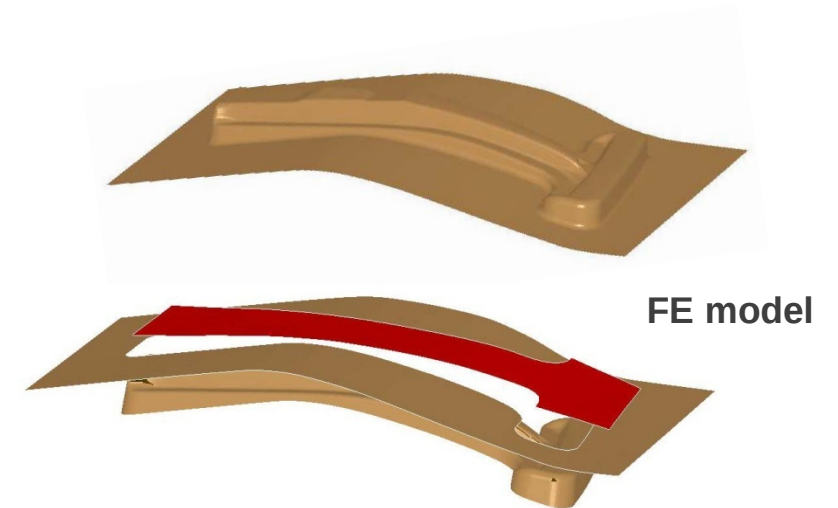
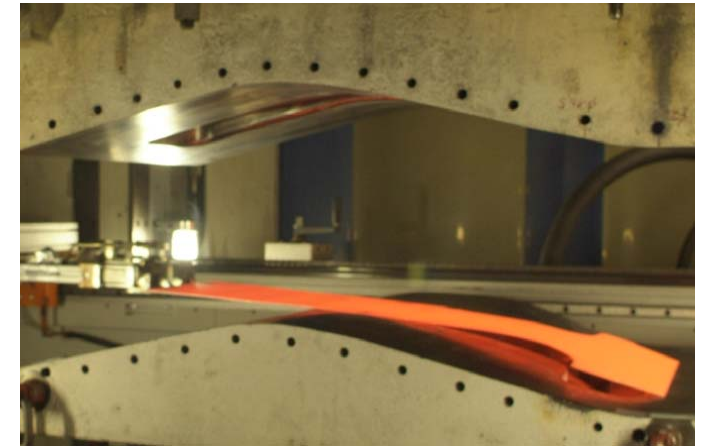
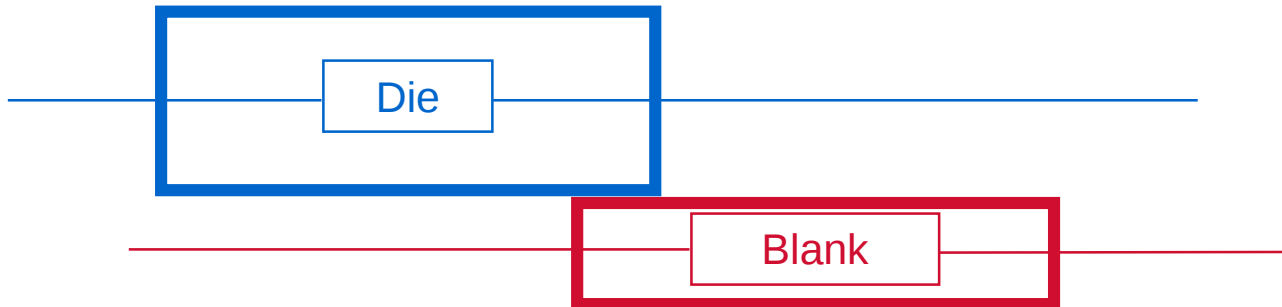


Defining surfaces in contact

- There are two choices for structural contact between shells
 - die mid-plane (CAD defined surface) contacts blank surface



- die surface contacts blank surface



Defining surfaces in contact

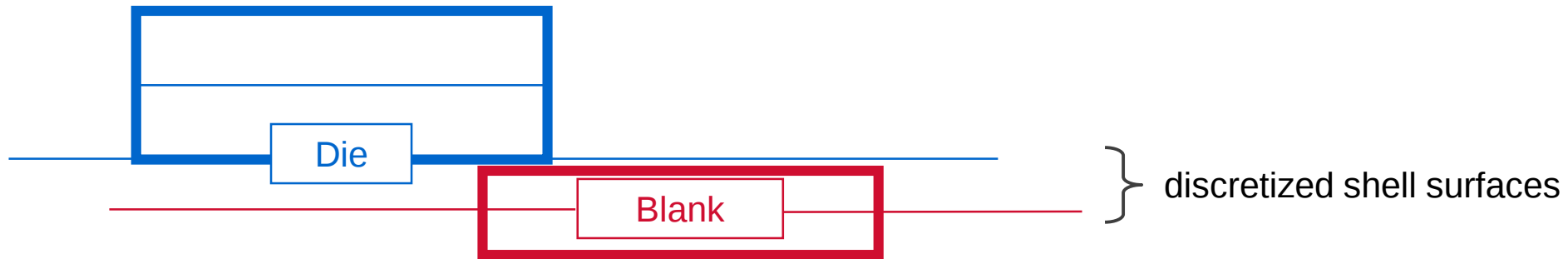
- die mid-plane contacts blank surface



- CAD software precisely defines the coordinates of the die mid-plane surface
- activated with
 - *CONTACT_FORMING_SURFACE_TO_SURFACE
- modelling technique
 - die is a rigid material and does not deform.
 - thermal analog is that the die does not change temperature (ALGO=1).
 - die is given a rigid body motion and a temperature boundary condition.
 - mid-plane of the die is the reference surface for mechanical and thermal contact.

Defining surfaces in contact

- offset die surface contacts blank surface



- activated with
 - *CONTACT_FORMING_SURFACE_TO_SURFACE
 - *CONTACT_SURFACE_TO_SURFACE
 - *CONTROL_CONTACT attribute THOFF=1
- Modeling technique
 - die is a rigid material or an elastic material.
 - die is given an initial temperature.
 - due to contact, a temperature gradient is calculated through the die thickness.

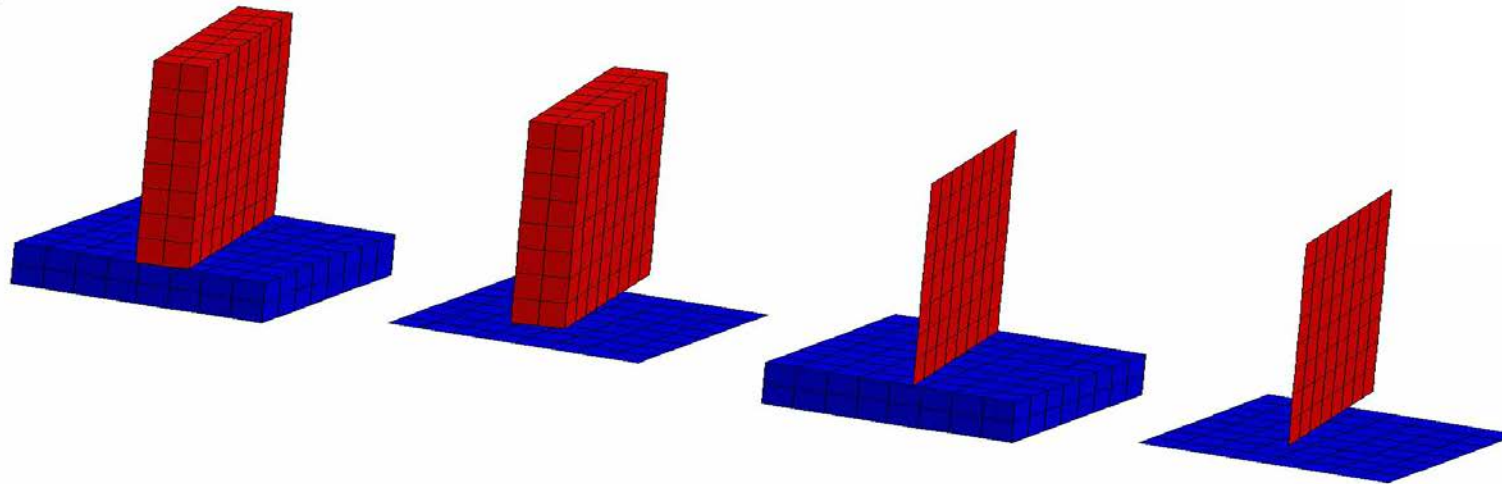
Heat Transfer over Shell Edges in Contact

■ Situation so far:

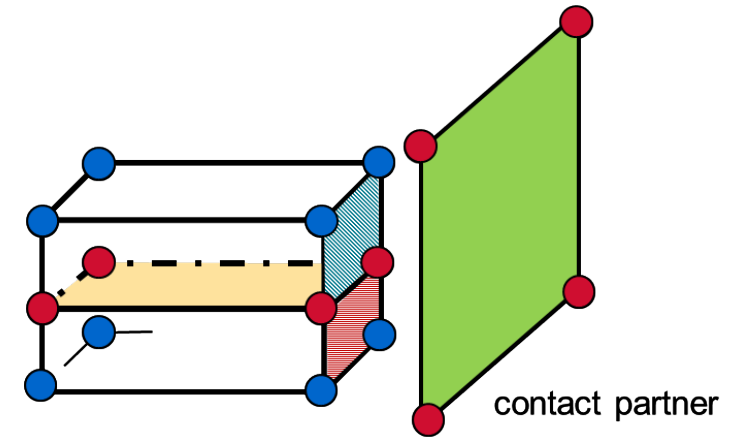
- heat transfer only available for surface to surface type contact formulations
- for shell contacts only heat flux normal to shell surface implemented

■ Thermal thick shells allow for reconstruction of two four-node surfaces at each shell edges for contact

Time = 0
Contours of Temperature, middle
min=0, at node# 31
max=1, at node# 111

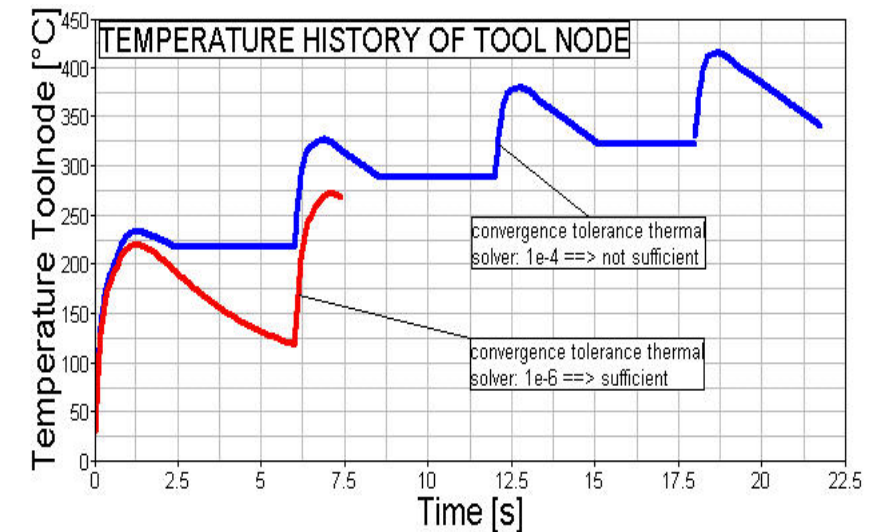
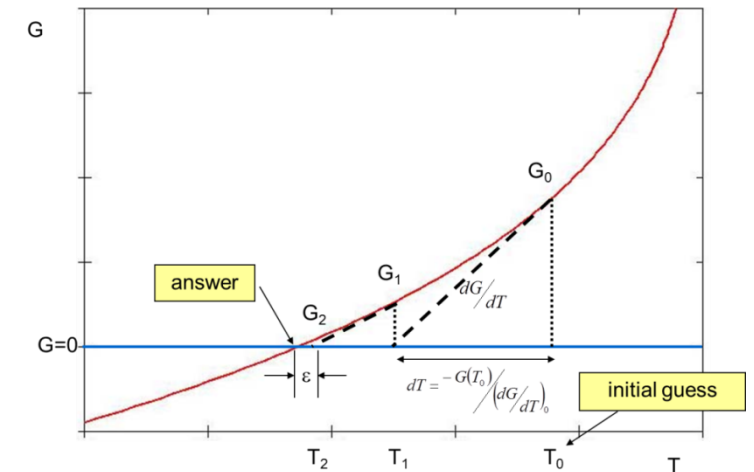


- contact segment 1
- contact segment 2
- nodes provided by user
- virtual nodes



Linear Solver Settings for thermal solution in LS-DYNA

- For non-linear problems, a Newton's method is applied
 - iterative solution scheme to find the root of a function
 - sequence of linear problems to be solved
 - solution always with respect to a certain tolerance
- Linear solution controlled by *CONTROL_THERMAL_SOLVER
 - direct and iterative solvers are available
 - direct solvers
 - find “exact” root up to numerical precision
 - relatively high CPU and memory consumption
 - iterative solvers
 - efficient in terms of CPU and memory
 - iteration converged if error is below a given tolerance
 - Tolerances of iterative solvers problem and unit system specific



Interlude: Hot forming and press-hardening simulations

- Motivation
- Selected simulation topics
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*MAT_UHS_STEEL / *MAT_244 – Overview

- based on the work by P. Åkerström
- tailored for hot stamping / press hardening processes
- accounts for austenite decomposition into ferrite, pearlite, bainite, and martensite as well as re-austenitization
- mechanical features:
 - elasto-plastic material with a von-Mises plasticity model
 - temperature and strain-rate effects
 - transformation induced strains and plasticity
 - thermal expansion
- any mechanical quantity α is determined by a rule of mixtures based on the current phase fractions x_i and the quantity α_i of phase i :

$$\alpha = \sum_{i=1}^5 x_i \alpha_i$$

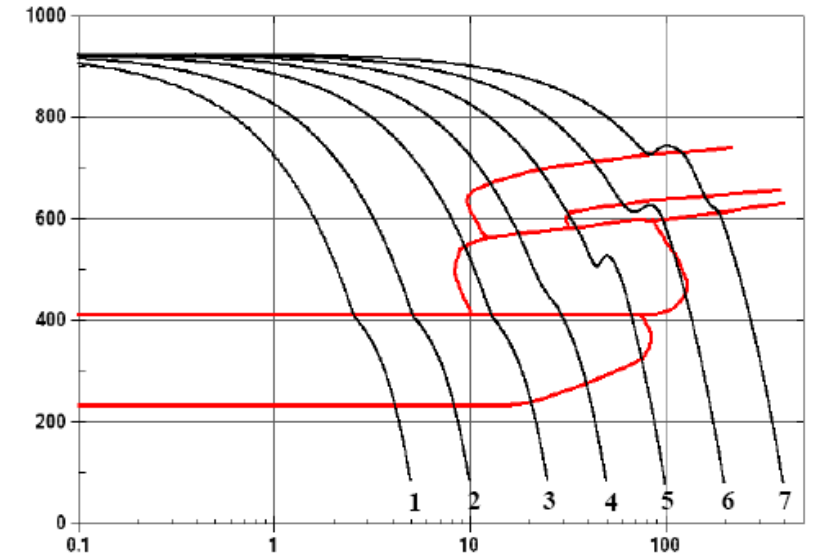
*MAT_UHS_STEEL / *MAT_244 – Overview

■ User input:

- alloying elements in mass percent
B, C, Co, Mo, Cr, Ni, V, W, Cu, P, Al, As, Ti
- latent heats for phase change reaction
- activation energy for phase transformation
- initial grain size
- yield curves for each phase
- coefficients of thermal expansion

■ material output

- current phase fraction of ferrite, pearlite, bainite and martensite
- computed Vickers hardness
- resulting yield strength



recalculated CCT diagramm

*MAT_UHS_STEEL / *MAT_244 – Limitations

■ Process limitations

- tailored for hot stamping / press hardening processes
- basic welding functionality with a ghosting approach has been added
- only limited capability for phase transformations during heating phases
- no methodology for tempering available

■ Material limitations

- restriction to five phases
- only feasible for 22MnB5:
 - heuristic formulas for start and end temperatures of phase transformation
 - empirical equations for the phase transformation parameters

*MAT_254 – Overview

- up to 24 individual phases (= 552 possible phase change scenarios)
- phase changes in heating, cooling or in a temperature window
- user can choose from a list of phase change models for each scenario
- basic mechanical features:
 - elasto-plastic material with a von-Mises plasticity model
 - temperature and strain-rate effects
 - transformation induced strains and plasticity
 - thermal expansion
- any mechanical quantity α is determined by a rule of mixtures based on the current phase fractions x_i and the quantity α_i of phase i :

$$\alpha = \sum_{i=1}^{24} x_i \alpha_i$$

*MAT_254 / *MAT_GENERALIZED_PHASE_CHANGE

	1	2	3	4	5	6	7	8
Card 1	MID	RHO	N	E	PR	MIX	MIXR	
Card 2	TASTART	TAEND	TABCTE				DTEMP	
Card 3	PTLAW	PTSTR	PTEND	PTX1	PTX2	PTX3	PTX4	PTX5
Card 4	PTTAB1	PTTAB2	PTTAB3	PTTAB4	PTTAB5	PTTAB6		
Card 5	PTEPS	TRIP			NUSHIS	GRAI	T1PHAS	T2PHAS
Card 6	FUNUSH1	FUNUSH2	FUNUSH3	FUNUSH4	FUNUSH5	FUNUSH6	FUNUSH7	FUNUSH8
Card 7	LCY1	LCY2	LCY3	LCY4	LCY5	LCY6	LCY7	LCY8
Card 8	LCY9	LCY10	LCY11	LCY12	LCY13	LCY14	LCY15	LCY16
Card 9	LCY17	LCY18	LCY19	LCY20	LCY21	LCY22	LCY23	LCY24

- very general material implementation to capture micro-structure evolution
- implementation available for solids and shells and for explicit and implicit

*MAT_254 – Overview

■ elaborate features:

- latent heat algorithm
- calculation and output of additional pre-defined post-processing histories
- calculation and output of additional user-defined history values
 - refers to *DEFINE_FUNCTION keyword
 - Possible input:
time, user-defined histories, phase concentrations, temperature, peak temperature, temperature rate, stress state, plastic strain data
- enhanced annealing option by evolution equation for plastic strain depending on time and temperature

*MAT_254 – Phase transformation

	1	2	3	4	5	6	7	8
Card 3	PTLAW	PTSTR	PTEND	PTX1	PTX2	PTX3	PTX4	PTX5
Card 4	PTTAB1	PTTAB2	PTTAB3	PTTAB4	PTTAB5			

■ microstructural phase evolution

- up to 24 individual phases
- parametrization of the phase transformation to be given in a matrix-like structures (*DEFINE_TABLE_2D/3D)
- matrix input for
 - phase transformation law (2D)
 - start and end temperatures (2D)
 - transformation constants (2D)
 - temperature dependent parameters (3D)

		to				
		ph. 1	ph. 2	ph. 3	...	ph. n
from	ph. 1	--	data	data	...	data
	ph. 2	data	--	data	...	data
	ph. 3	data	data	--	...	data
	⋮	⋮	⋮	⋮	--	⋮
	ph. n	data	data	data	...	--

*MAT_254 – Phase transformation

	1	2	3	4	5	6	7	8
Card 3	PTLAW	PTSTR	PTEND	PTX1	PTX2	PTX3	PTX4	PTX5
Card 4	PTTAB1	PTTAB2	PTTAB3	PTTAB4	PTTAB5	PTTAB6		

■ Johnson-Mehl-Avrami-Kolmogorov (JMAK):

■ Evolution equation:

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

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

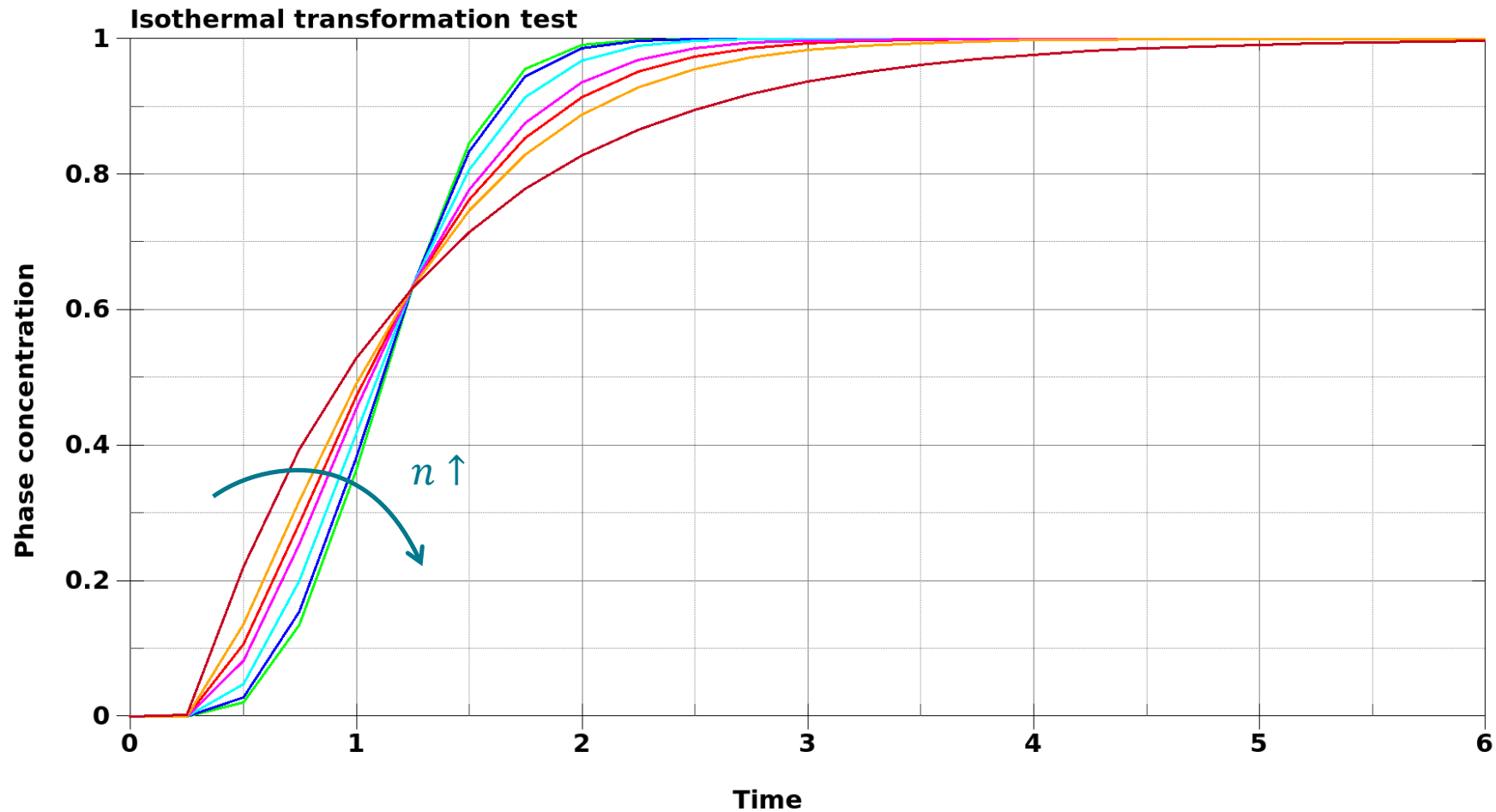
$$\tau(T, \varepsilon^p) = \tau^0(T) \cdot \alpha(\varepsilon^p)$$

■ Parameter:

- PTTAB1: $n(T)$
- PTTAB2: $x_{eq}(T)$
- PTTAB3: $\tau^0(T)$
- PTTAB4: $f(\dot{T})$
- PTTAB5: $f'(\dot{T})$
- PTTAB6: $\alpha(\varepsilon^p)$

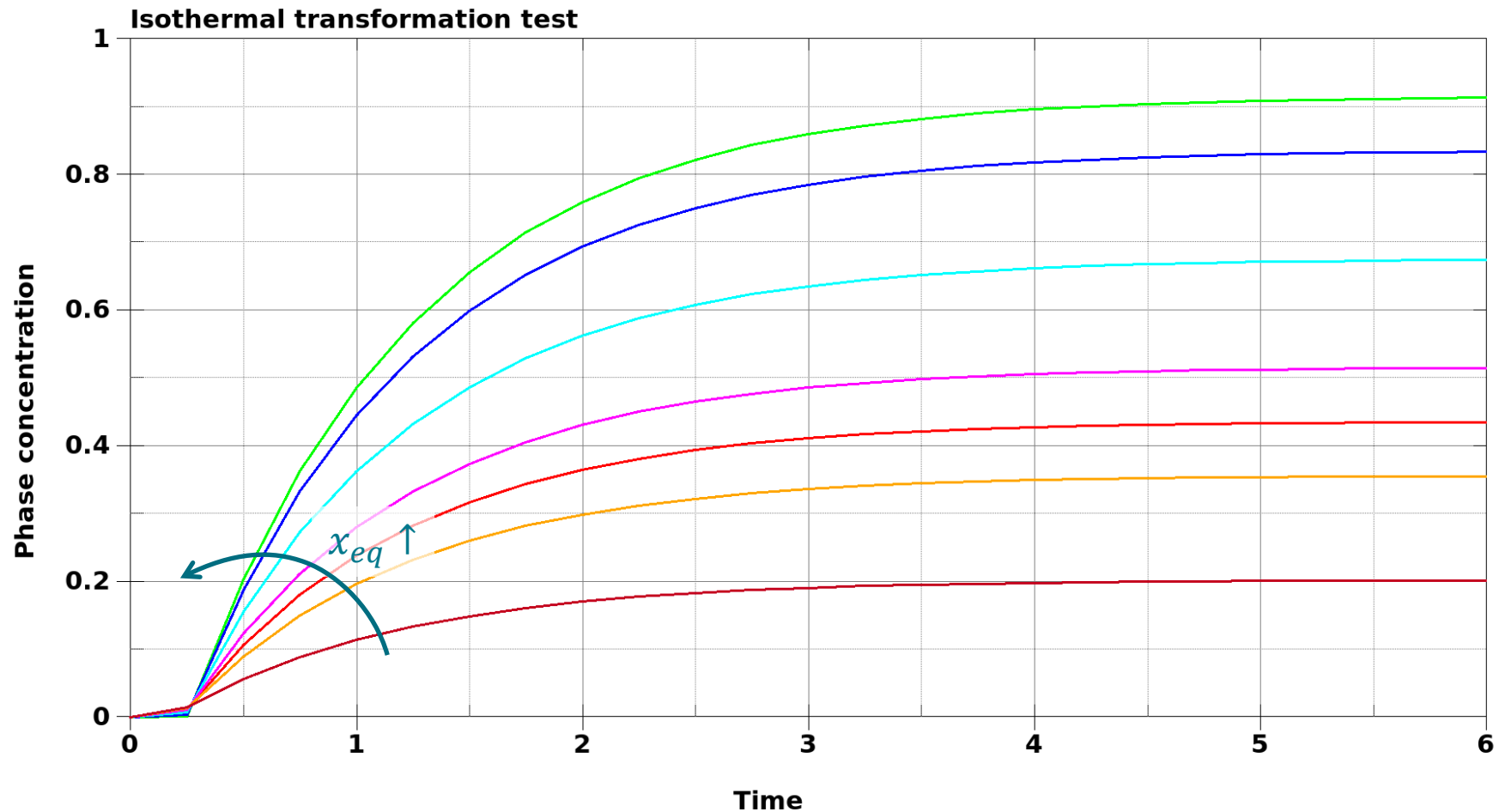
*MAT_254 – Phase transformation validation

- influence of parameter $n(T)$ on isothermal transformation



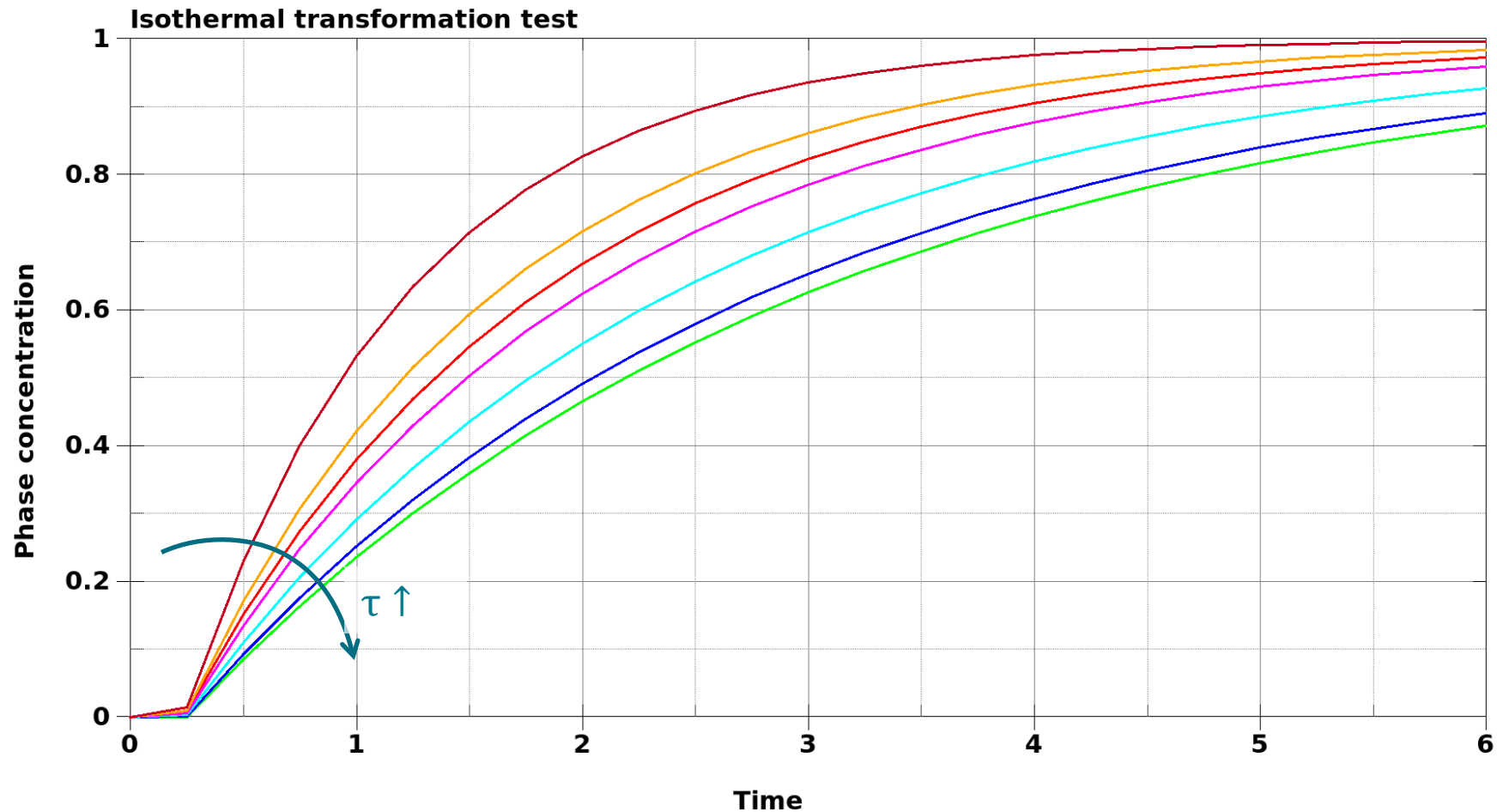
*MAT_254 – Phase transformation validation

- influence of parameter $x_{eq}(T)$ on isothermal transformation



*MAT_254 – Phase transformation validation

- influence of parameter $\tau(T)$ on isothermal transformation



Applications

- Different steel grades in welding simulations
- New UHS steels in press-hardening and hot forming
- Bake hardening of aluminum 6xxx

12th EUROPEAN LS-DYNA CONFERENCE

**Simulation of process-dependent properties with
*MAT_254 demonstrated for the 'bake-hardening'
of an aluminum 6xxx alloy**

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¹DYNAMore GmbH, ²Novelis Germany GmbH, ³Novelis Switzerland SA

14 - 16 May 2019 | Koblenz, Germany

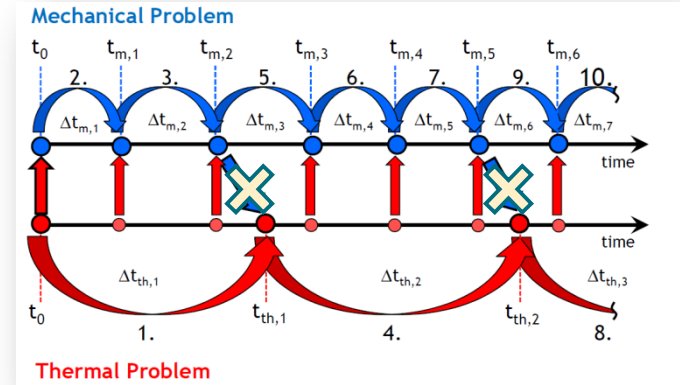


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 - Application example: laser cutting
- Interlude: Hot forming and press-hardening simulations
- 1-way coupled approaches
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 - New keyword *LOAD_THERMAL_BINOUT
 - Application example
- Prescribed thermal loading conditions for resistance spot welding
 - Motivation
 - New keyword *LOAD_THERMAL_RSW

Motivation for 1-way Coupling

- For some assembly stages the effect of structural deformation onto the thermal simulation is negligible
 - Distortion and/or material phase evolution due the thermal distribution are of interest to the user



- Results of a thermal run serves as loading for structure simulation with `*LOAD_THERMAL_D3PLOT`
 - Evolution in time of temperature distribution linearly interpolated between the output time steps
 - Thermal thick shell feature is supported also for the structure-only simulation
 - Temperature results are read from the d3plot file of the thermal run

Challenges with this approach:

- Complex input file format (d3plot) to be generated by a mapping tool
 - Meshes (models!) for both simulations have to coincide
 - Time scaling has to match as well
- Implemented more flexible `*LOAD_THERMAL_BINOUT` to read data from one or more LSDA database(s)

*LOAD_THERMAL_BINOUT

	1	2	3	4	5	6	7	8
Card 1	DEFTMP							
Card 2	Filename							
Card 3	START	TSF						

■ Aims and scope of the new keyword

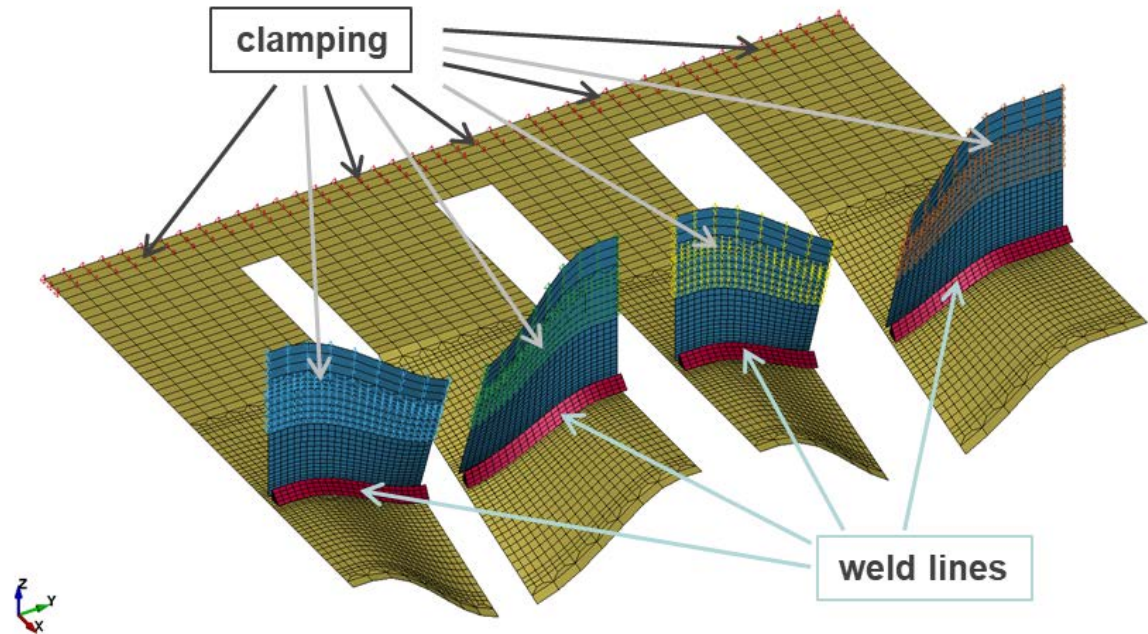
- Use flexible and open LSDA data format to define thermal loading of a structure
- Required structure of LSDA files matches the TPRINT section in LS-DYNA binout file, so results from thermal and from coupled LS-DYNA runs can be used without further modification
- Only partial overlap between meshes should be required
- Allow for a sequential thermal loading and for an easy modification of the sequence

*LOAD_THERMAL_BINOUT

	1	2	3	4	5	6	7	8
Card 1	DEFTMP							
Card 2	Filename							
Card 3	START	TSF						

- File name of thermal run given in keyword
- Thermal thick shells are accounted for
- Time step sizes do not have to match

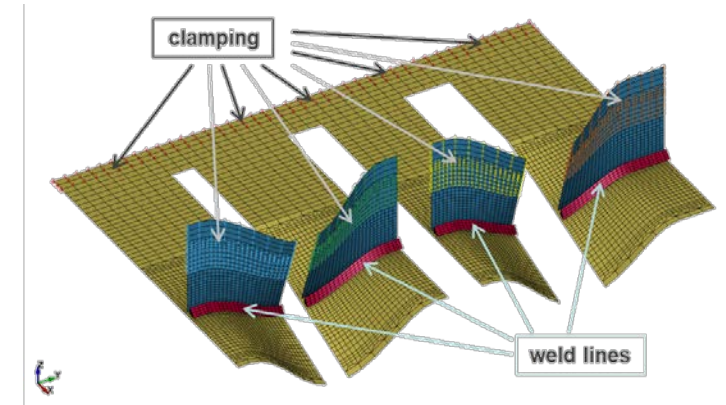
Welding Example:



*LOAD_THERMAL_BINOUT

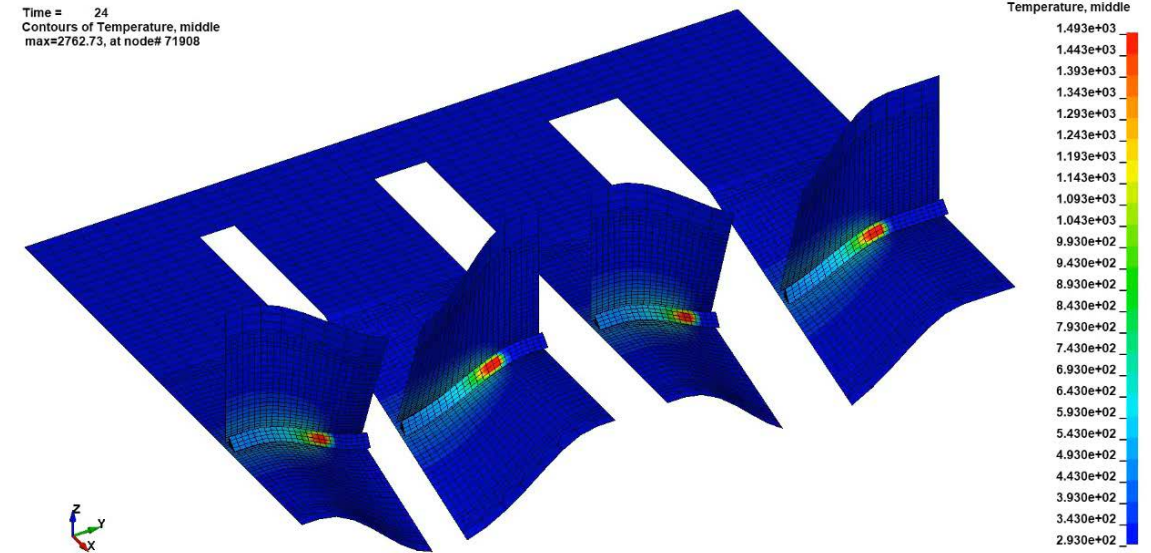
	1	2	3	4	5	6	7	8
Card 1	DEFTEMP							
Card 2	Filename							
Card 3	START	TSF						

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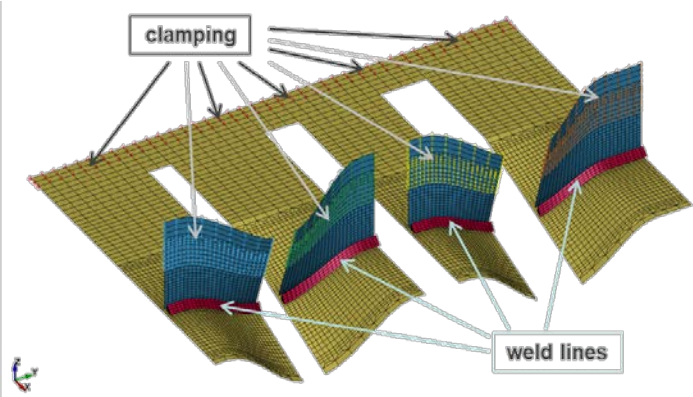
Thermal run:

Time = 24
Contours of Temperature, middle
max=2762.73, at node# 71908



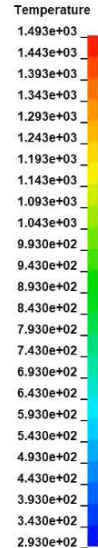
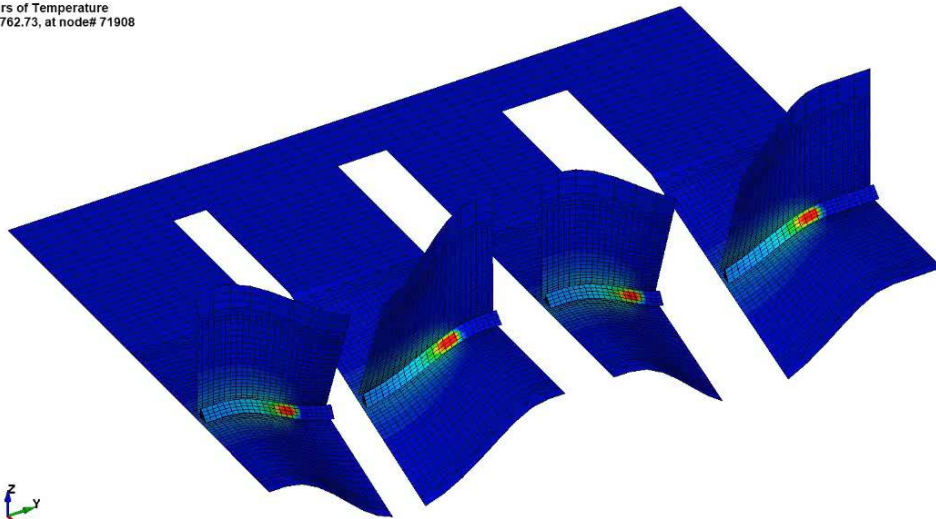
*LOAD_THERMAL_BINOUT

	1	2	3	4	5	6	7	8
Card 1	DEFTMP							
Card 2	Filename							
Card 3	START	TSF						



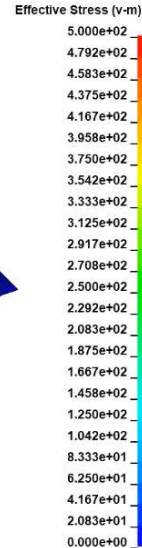
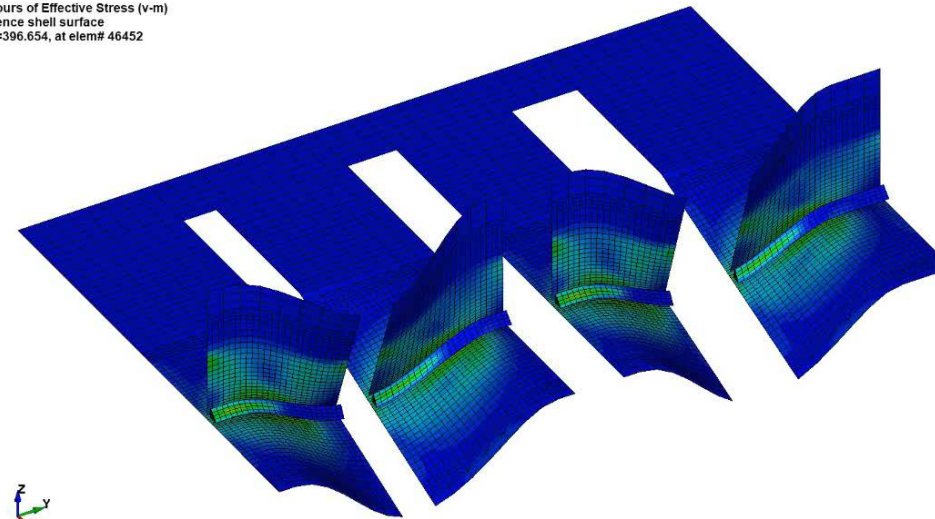
Structure run with thermal loading:

Time = 24
Contours of Temperature
max=2762.73, at node# 71908



Temperature

Time = 24
Contours of Effective Stress (v-m)
reference shell surface
max=396.654, at elem# 46452



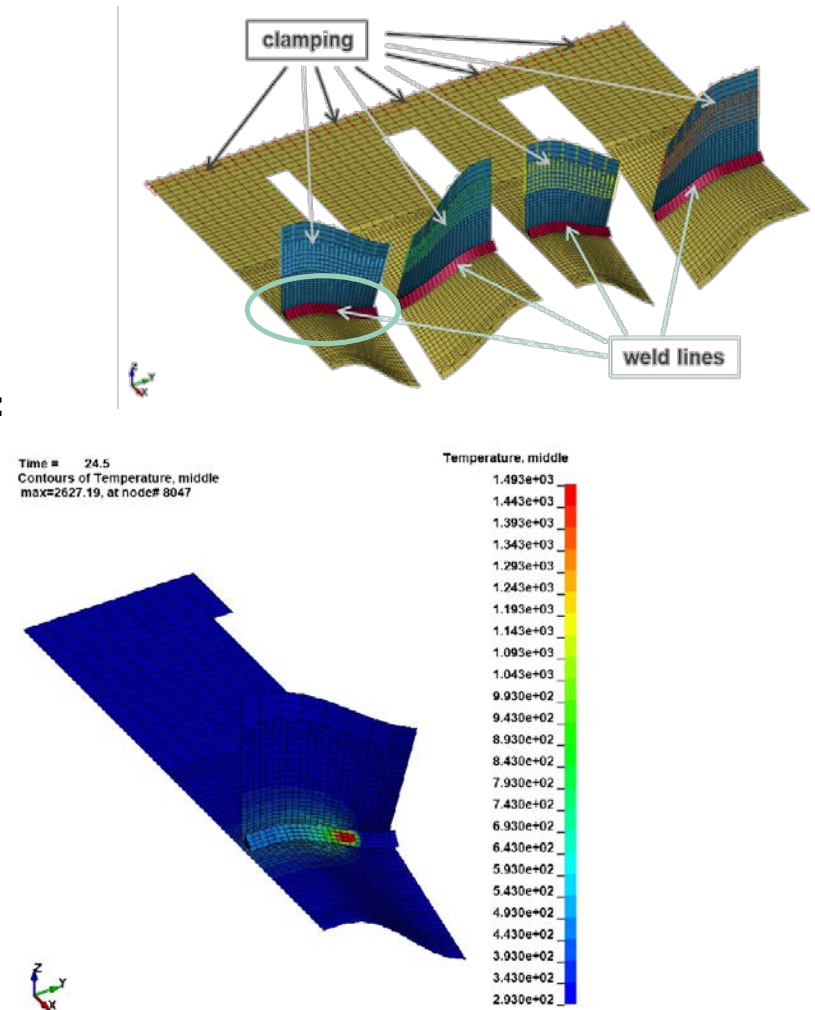
von Mises stress

*LOAD_THERMAL_BINOUT

	1	2	3	4	5	6	7	8
Card 1	DEFTEMP							
Card 2	Filename							
Card 3	START	TSF						

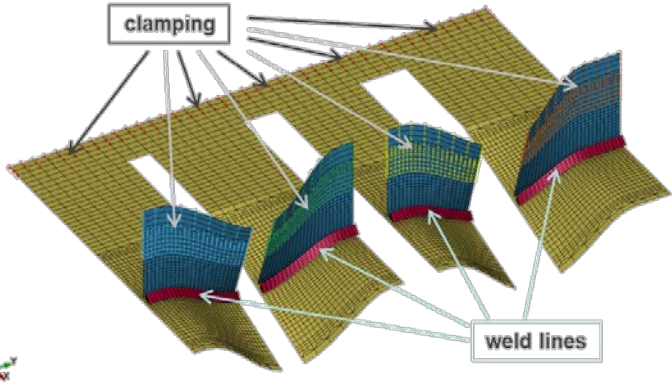
- File name of the input is to be given in the keyword
- Thermal thick shells are accounted for
- Time step sizes do not have to match
- Only **partial overlap** of the meshes is required
 - Data transfer based on user given ID of the nodes
 - Default temperature is used for those nodes of the structure simulations that are not included in the thermal run

Thermal Run:



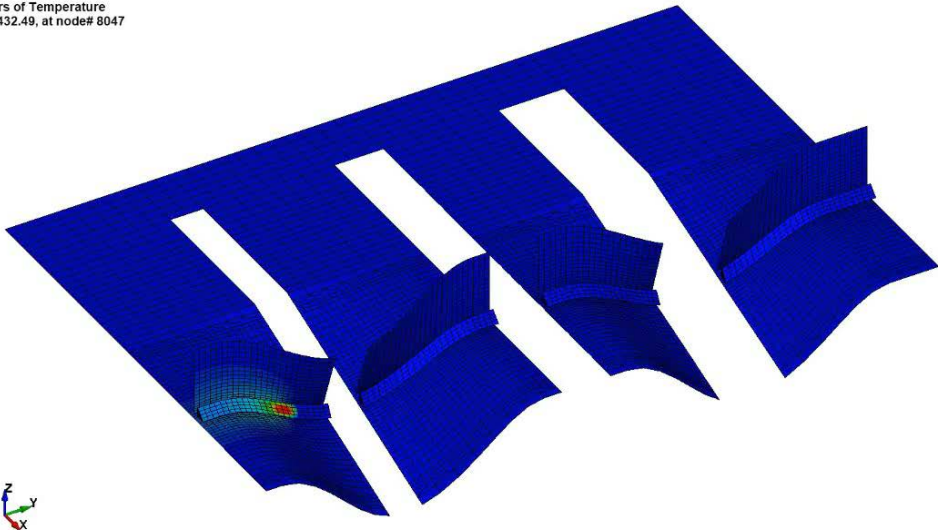
*LOAD_THERMAL_BINOUT

	1	2	3	4	5	6	7	8
Card 1	DEFTEMP							
Card 2	Filename							
Card 3	START	TSF						



Structure Run with partial overlap and DEFTEMP:

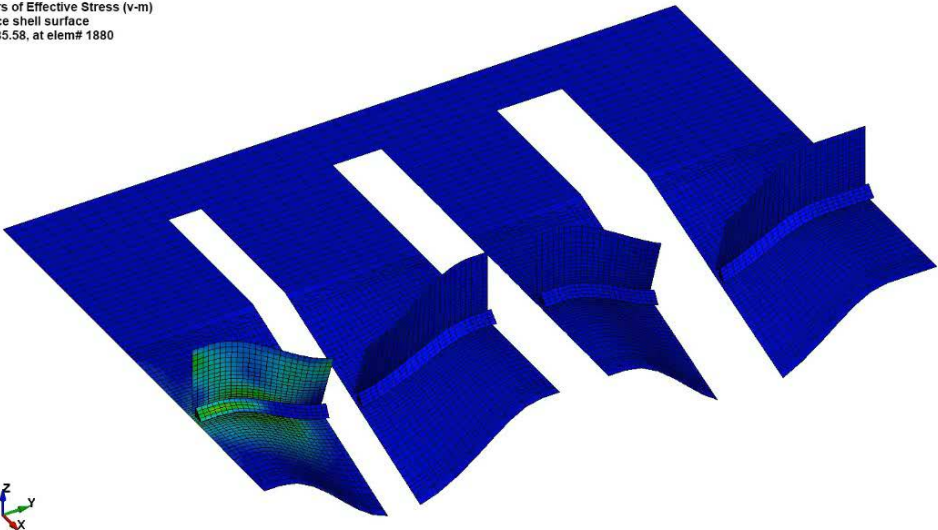
Time = 24
Contours of Temperature
max=2432.49, at node# 8047



Temperature
1.493e+03
1.443e+03
1.393e+03
1.343e+03
1.293e+03
1.243e+03
1.193e+03
1.143e+03
1.093e+03
1.043e+03
9.930e+02
9.430e+02
8.930e+02
8.430e+02
7.930e+02
7.430e+02
6.930e+02
6.430e+02
5.930e+02
5.430e+02
4.930e+02
4.430e+02
3.930e+02
3.430e+02
2.930e+02

Temperature

Time = 24
Contours of Effective Stress (v-m)
reference shell surface
max=385.58, at elem# 1880



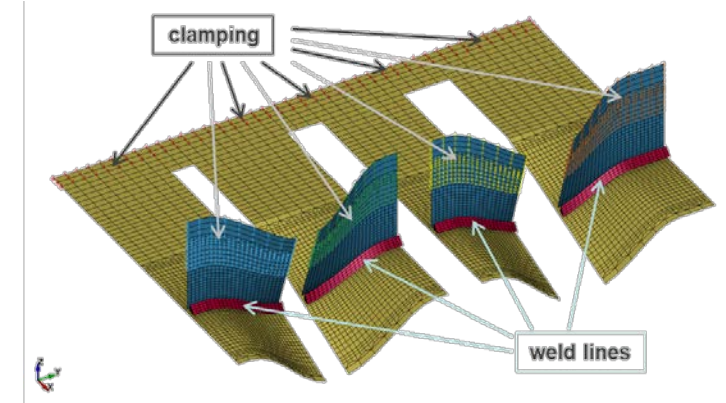
Effective Stress (v-m)
5.000e+02
4.792e+02
4.583e+02
4.375e+02
4.167e+02
3.958e+02
3.750e+02
3.542e+02
3.333e+02
3.125e+02
2.917e+02
2.708e+02
2.500e+02
2.292e+02
2.083e+02
1.875e+02
1.667e+02
1.458e+02
1.250e+02
1.042e+02
8.333e+01
6.250e+01
4.167e+01
2.083e+01
0.000e+00

von Mises stress

*LOAD_THERMAL_BINOUT

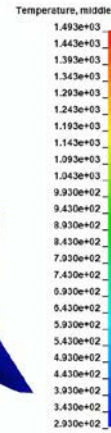
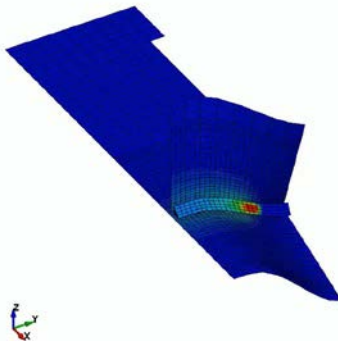
	1	2	3	4	5	6	7	8
Card 1	DEFTEMP							
Card 2	Filename							
Card 3	START	TSF						

- Multiple thermal runs can be read in
- Each thermal run with time offset START
- Compensation for a scaling in time with TSF

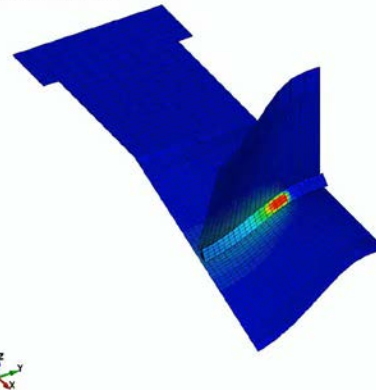


Thermal Runs:

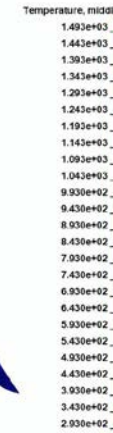
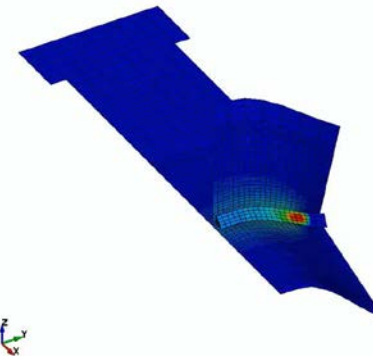
Time = 24.5
Contours of Temperature, middle
max=2627.19, at node# 8047



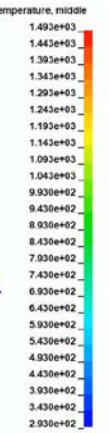
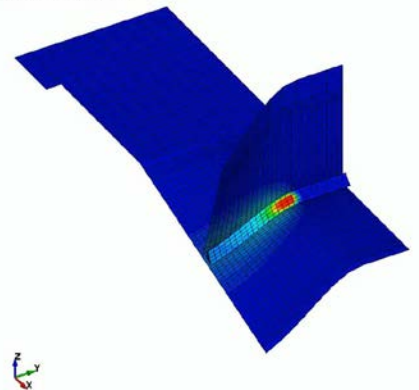
Time = 23.75
Contours of Temperature, middle
max=2719.58, at node# 17899



Time = 24
Contours of Temperature, middle
max=2671.67, at node# 71530



Time = 24
Contours of Temperature, middle
max=2652.07, at node# 71908

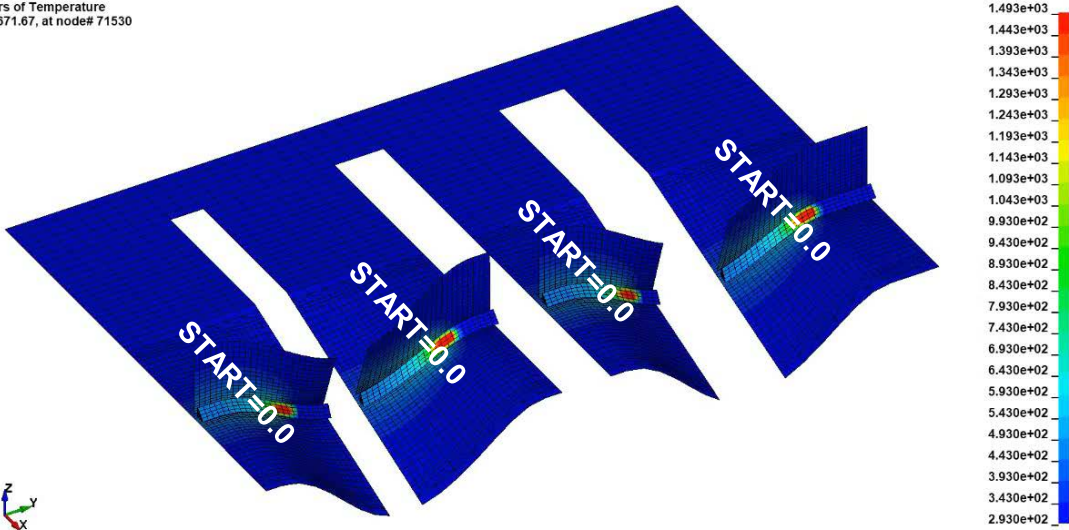


*LOAD_THERMAL_BINOUT

	1	2	3	4	5	6	7	8
Card 1	DEFTEMP							
Card 2	Filename							
Card 3	START	TSF						

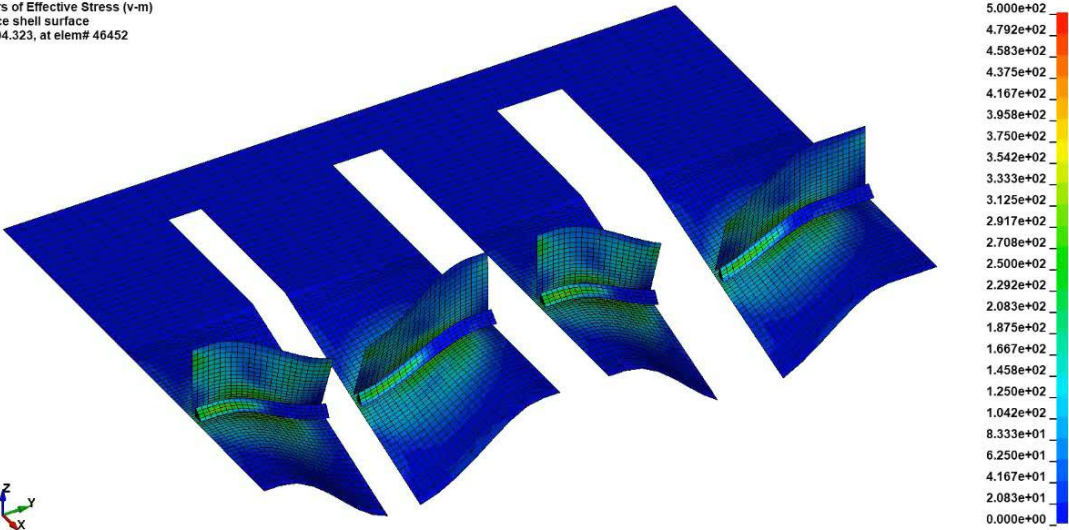
Structure Run:

Time = 24
Contours of Temperature
max=2671.67, at node# 71530

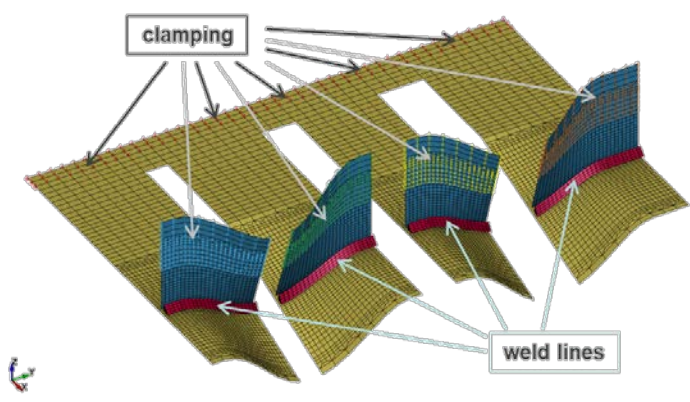


Temperature

Time = 24
Contours of Effective Stress (v-m)
reference shell surface
max=394.323, at elem# 46452



von Mises stress

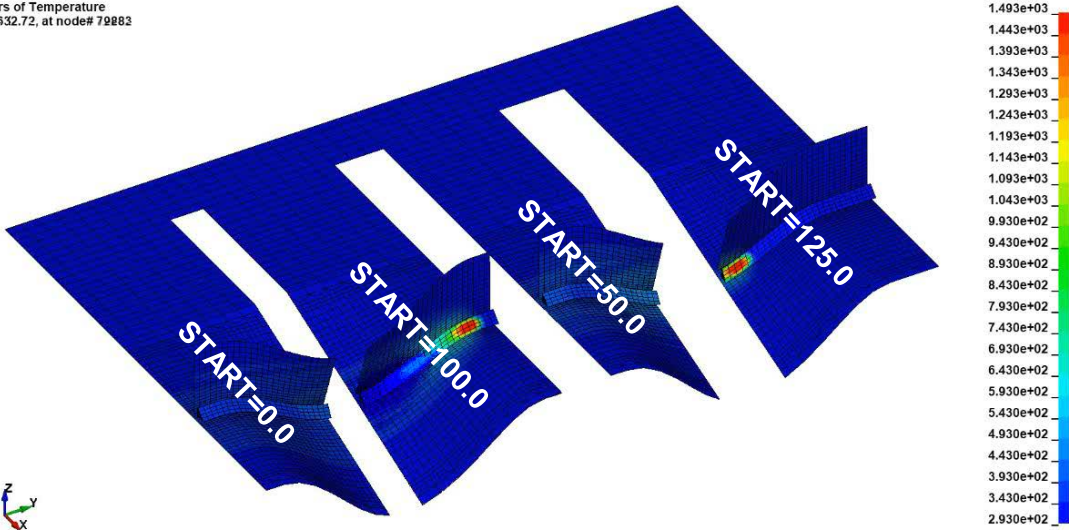


*LOAD_THERMAL_BINOUT

	1	2	3	4	5	6	7	8
Card 1	DEFTEMP							
Card 2	Filename							
Card 3	START	TSF						

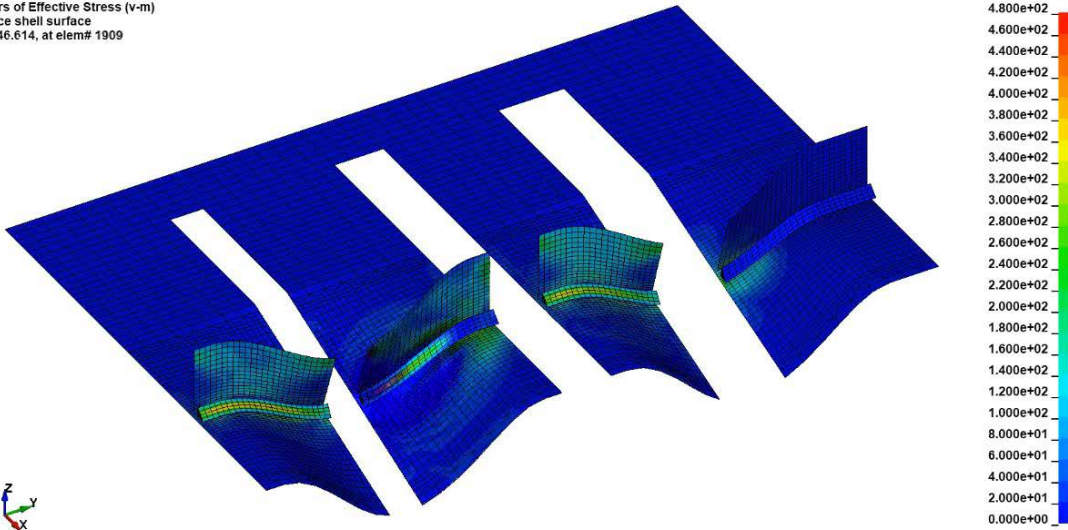
Structure Run:

Time = 130
Contours of Temperature
max=2632.72, at node# 79882

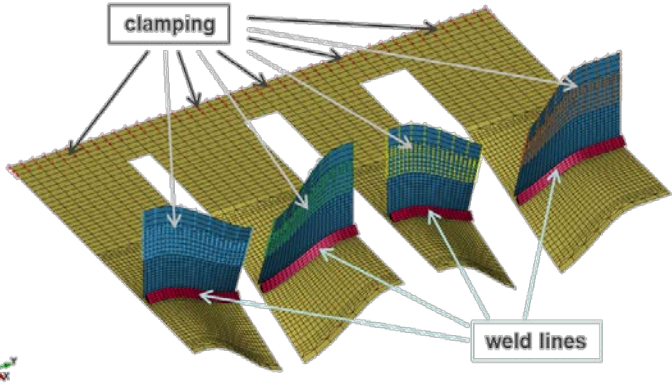


Temperature

Time = 130
Contours of Effective Stress (v-m)
reference shell surface
max=446.614, at elem# 1909



von Mises stress

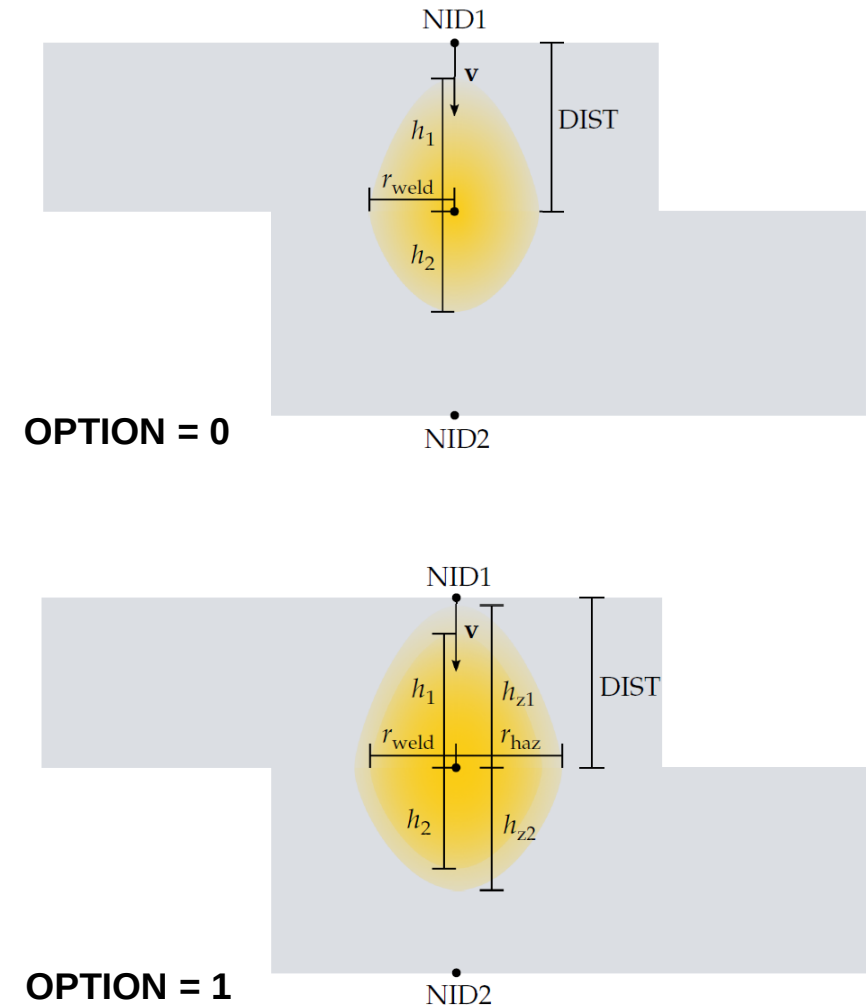


Content

- 2-way coupled approaches
 - Data transfer and simulation principles
 - Application example: laser cutting
- Interlude: Hot forming and press-hardening simulations
- 1-way coupled approaches
 - Motivation and data transfer
 - New keyword *LOAD_THERMAL_BINOUT
 - Application example
- Prescribed thermal loading conditions for resistance spot welding
 - Motivation
 - New keyword *LOAD_THERMAL_RSW

Motivation

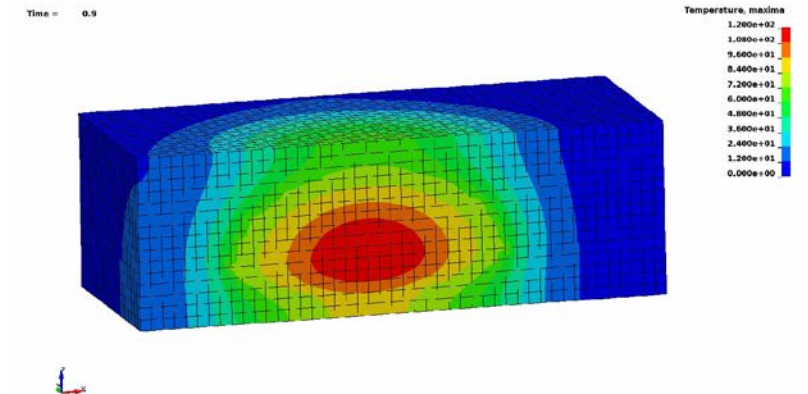
- Modelling approaches for resistance spot welding (RSW)
 - Use a detailed and coupled (EM, thermal, structure) simulation
 - Use an equivalent heat source and calibrate power
- For large assemblies and hundreds of spot welds neither approach is feasible
- *BOUNDARY_TEMPERATURE_RSW
 - Direct temperature definition (Dirichlet condition) for the weld nugget and the heat affected zone for the **thermal** solver
 - Constraint condition only active during the welding
 - Very good prediction of deflections in large assemblies
 - A HAZ can be additionally accounted for



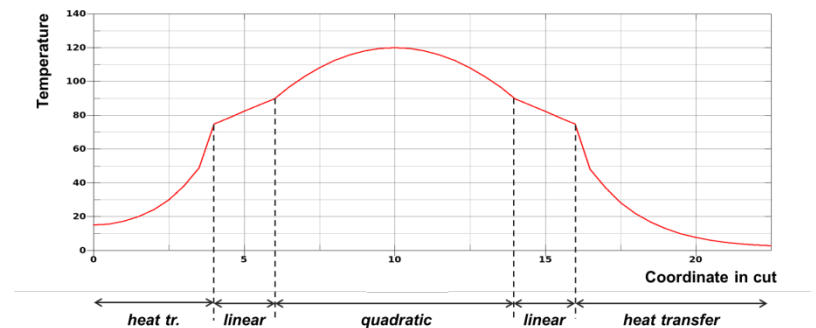
Motivation

- temperature in the weld nugget
 - prescribed at the center, boundary of nugget, and boundary of HAZ
 - quadratic approximation inside the nugget
 - linear approximation in the HAZ
- boundary condition active between BIRTH and DEATH times
- load curve input (LCIDT) for temperature scaling factor as function of normalized time
- To further increase the efficiency, customers want to imprint the temperature field in the weld nugget directly as thermal load in the **structure** solver

linear temp increase,
BIRTH=0.1, DEATH=0.9



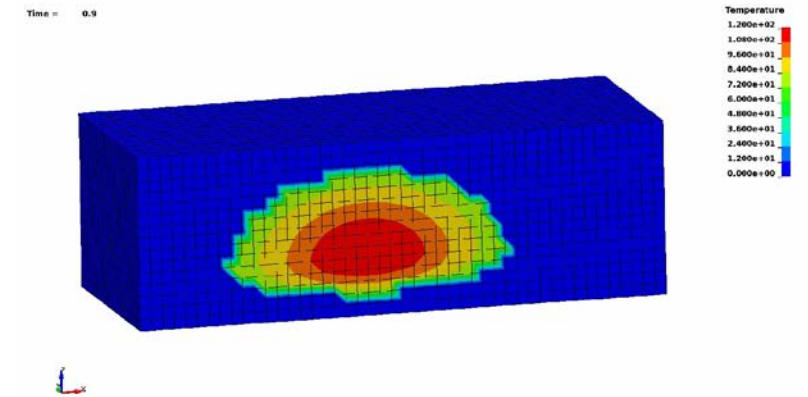
peak temp. profile, horizontal



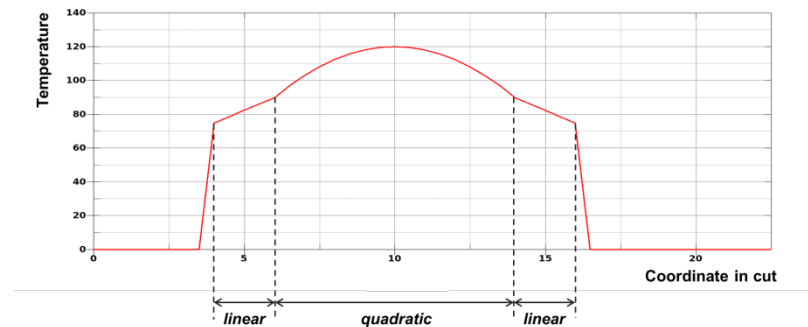
*LOAD_THERMAL_RSW

- Thermal loading condition for the structure solver, i.e. no thermal calculation required
- Temperature profile in the weld nugget same as in the temperature boundary condition
 - Prescribed at the center, boundary of nugget, and boundary of HAZ
 - Quadratic approximation inside the nugget
 - Linear approximation in the HAZ
- Outside the HAZ a default temperature is assumed

linear temp increase,
BIRTH=0.1, DEATH=0.9



peak temp. profile, horizontal



Summary and Outlook

- Presented thermal-mechanical coupling schemes realized within LS-DYNA for assembly simulations
- Discussed new functionality *LOAD_THERMAL_BINOUT for 1-way coupled simulation
 - Uses the flexible and open LSDA data format for data transfer
 - Mapping of temperatures based on user node ID requires only partial overlap of meshes
 - Time offset and scaling functionality for easy modification of weld ordering
- Future work
 - Provide a tailored LSDA output file to reduce memory consumption
 - Implement thermal loading conditions for further line welding process simulations in early design phases

FIN

