15. Deutsches LS-DYNA Forum

Recent Updates to the Structural Conjugate Heat Transfer Solver

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DYNAmore GmbH

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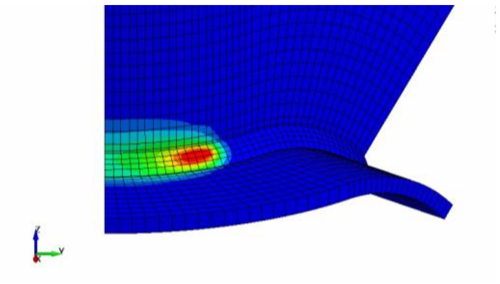
Block 1: New developments for thermal boundary conditions

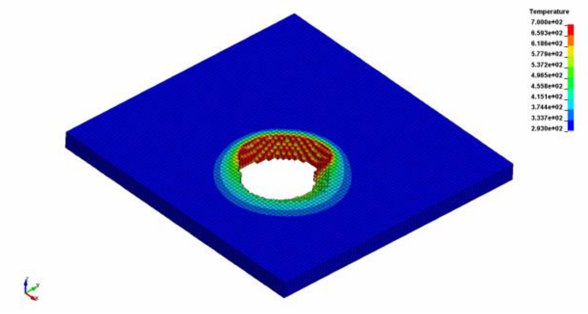
- Motivation
- Brief summary of *BOUNDARY_THERMAL_WELD_TRAJECTORY
- New *BOUNDARY_FLUX_TRAJECTORY
- New *BOUNDARY_TEMPERATURE_RSW
- Summary 1

Motivation: Manufacturing Processes

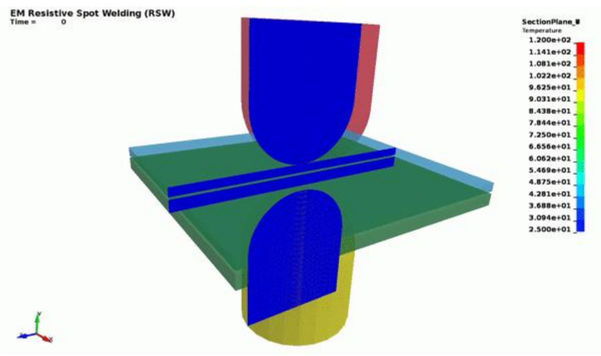
- Line welding processes
  - motion of volumetric heat sources
  - different equivalent sources for different applications
  - welding curved geometries with solids and/or shells



- Laser cutting
  - motion of surface heat sources on curved geometries
  - element erosion due to temperature criterion
  - after element erosion propagation to new segments



- Resistance spot welding
  - complex coupled problem (structure, thermal, EM)
  - for large number of welds in a model a simplified solution technique is requested



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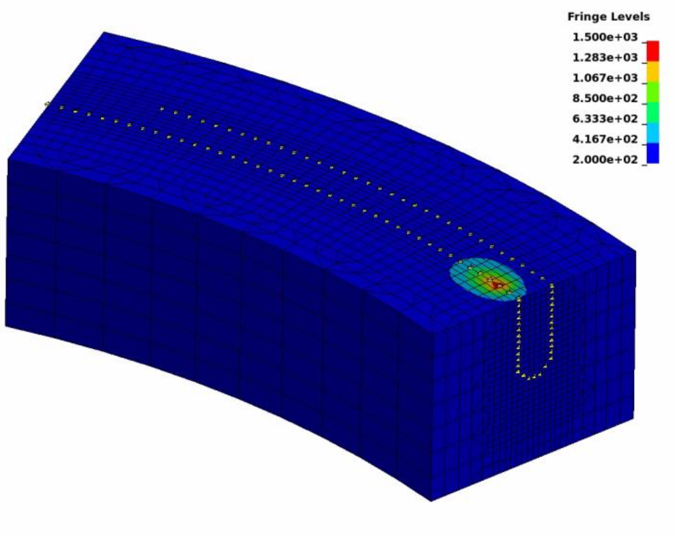
*BOUNDARY_THERMAL_WELD_TRAJECTORY

	1	2	3	4	5	6	7	8
Card 1	PID	PTYP	NSID1	VEL1	SID2	VEL2	NCYC	RELVEL
Card 2	IFORM	LCID	Q	LCROT	LCMOV	LCLAT	DISC	ENFO
Card 3	P1	P2	P3	P4	P5	P6	P7	P8
Opt.	Tx	Ty	Tz					

- Heat source follows a node path with a constant or varying prescribed velocity
- No need to include mechanical solver for motion
- Different possibilities to define aiming direction, for example based on segment normals
- Implemented for solid and thermal thick shells



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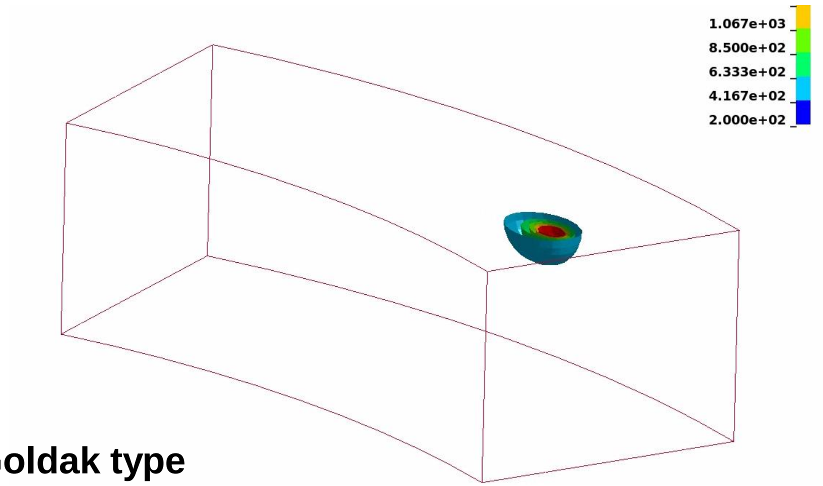
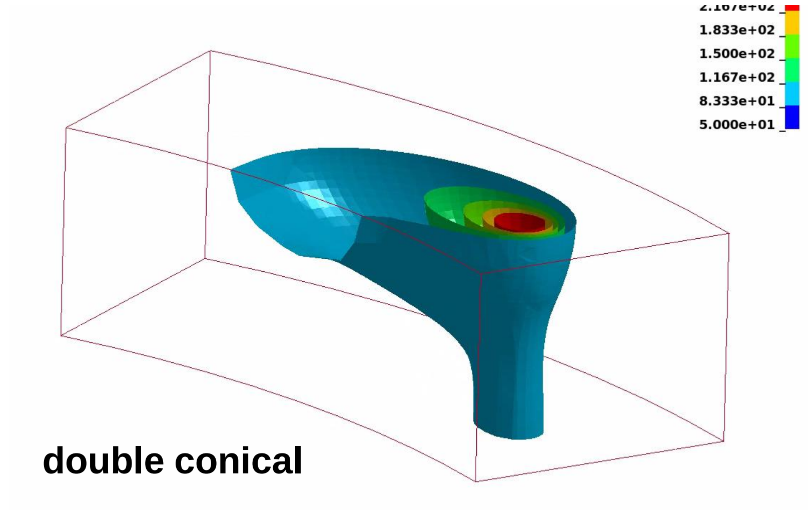
Opt.	Tx	Ty	Tz					

- List of pre-defined equivalent heat sources (IFORM).



Goldak type



double conical

- The applied total heat rate can be enforced (ENFO)

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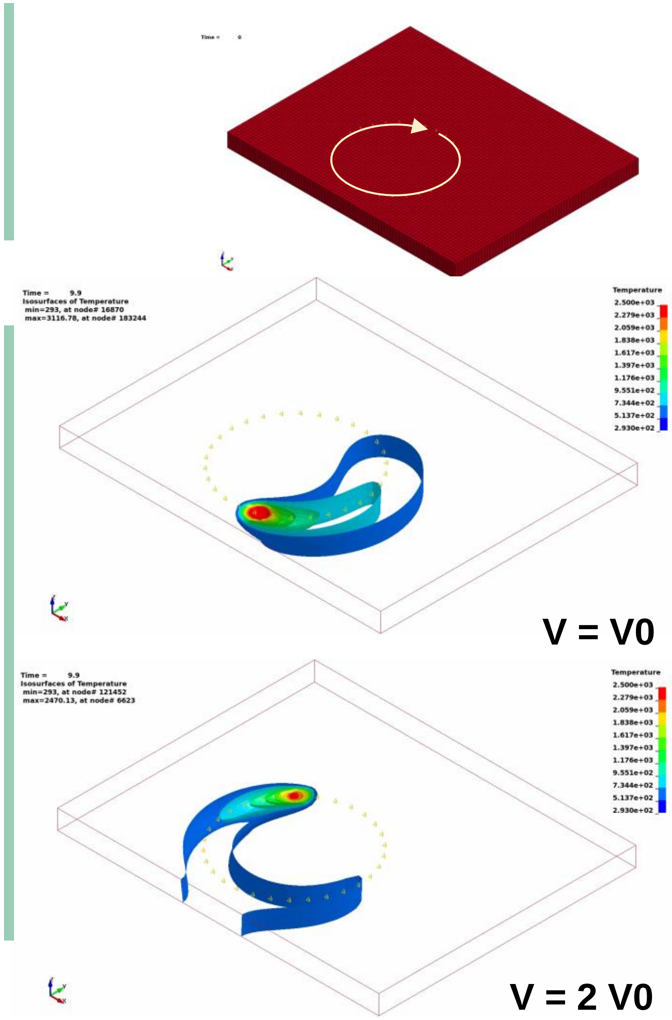
	1	2	3	4	5	6	7	8
Card 1	SSID	PSID	NSID1	VEL1	SID2	VEL2	RELVEL	
Card 2	PROP		LCROT	LCLAT				
Card 3	GEO	LCQ	Q	LCINC	ENFO			
Card 4	P1	P2	P3	P4	P5	P6	P7	P8
Opt.	Tx	Ty	Tz					

- aims and scope
  - surface flux boundary condition that follows a prescribed path
  - tilting of heat source has to be accounted for
  - propagation to newly exposed segments after element erosion is the crucial feature for laser cutting applications
- modified surface version of *BOUNDARY_THERMAL_WELD_TRAJECTORY

*BOUNDARY_FLUX_TRAJECTORY

	1	2	3	4	5	6	7	8
Card 1	SSID	PSID	NSID1	VEL1	SID2	VEL2	RELVEL	
Card 2	PROP		LCROT	LCLAT				
Card 3	GEO	LCQ	Q	LCINC	ENFO			
Card 4	P1	P2	P3	P4	P5	P6	P7	P8
Opt.	Tx	Ty	Tz					

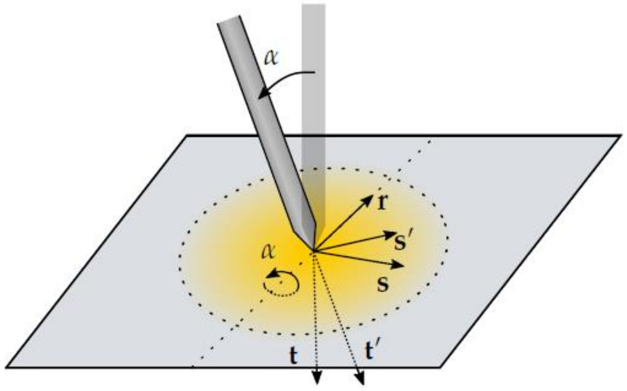
- source defined on a segment set (SSID)
- trajectory defined by nodal path (NSID1)
- motion with prescribed velocity (VEL1), possibly defined as function of time
- base orientation of heat source via second trajectory (SID2, VEL2) or constant (Tx,Ty,Tz)
- can be applied in thermal-only simulations

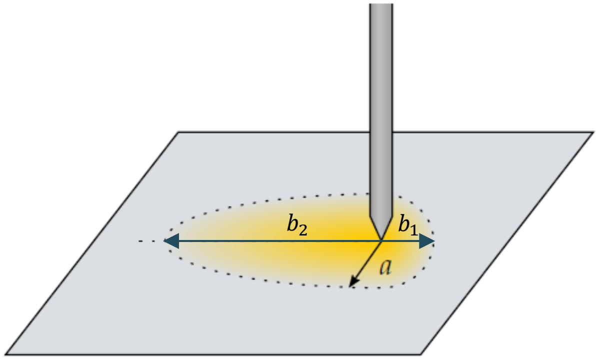


*BOUNDARY_FLUX_TRAJECTORY

	1	2	3	4	5	6	7	8
Card 1	SSID	PSID	NSID1	VEL1	SID2	VEL2	RELVEL	
Card 2	PROP		LCROT	LCLAT				
Card 3	GEO	LCQ	Q	LCINC	ENFO			
Card 4	P1	P2	P3	P4	P5	P6	P7	P8
Opt.	Tx	Ty	Tz					

- local coordinate system based on
  - the base orientation
  - a rotation as function of time
  - a lateral motion as function of time
- constant surface heat density is currently assumed in a double elliptic region
- Gaussian distribution and user-defined function to follow





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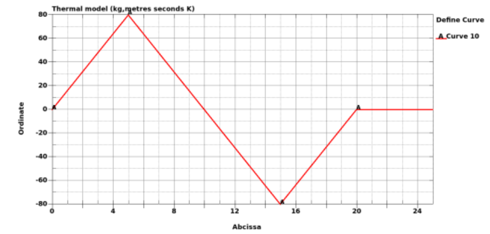
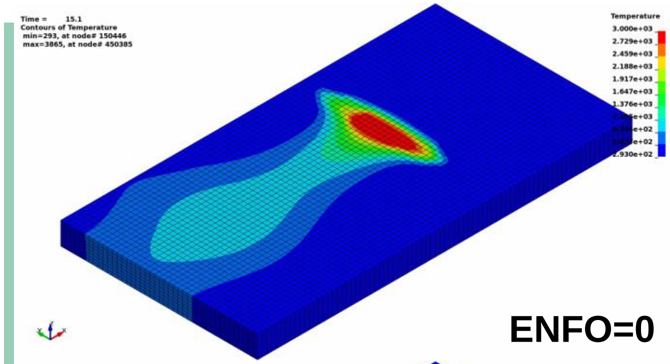
Opt.	Tx	Ty	Tz					

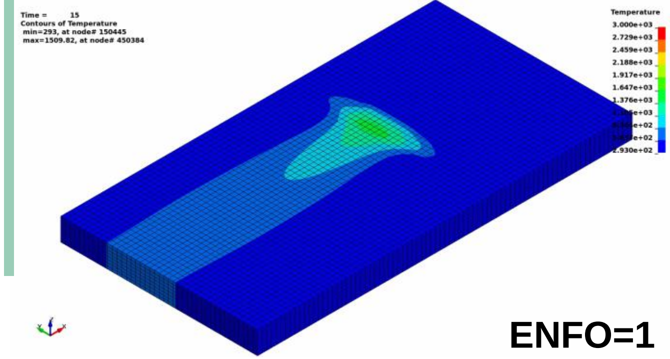
LCROT



- tilting (angle between beam aiming direction t and the surface normal) changes the projection on the surface
- the changes in projected area is counterbalanced by a reduced heat density for ENFO=1
- further tuning with parameter LCINC that defines a heat density scale factor as function of tilt angle



ENFO=0



ENFO=1

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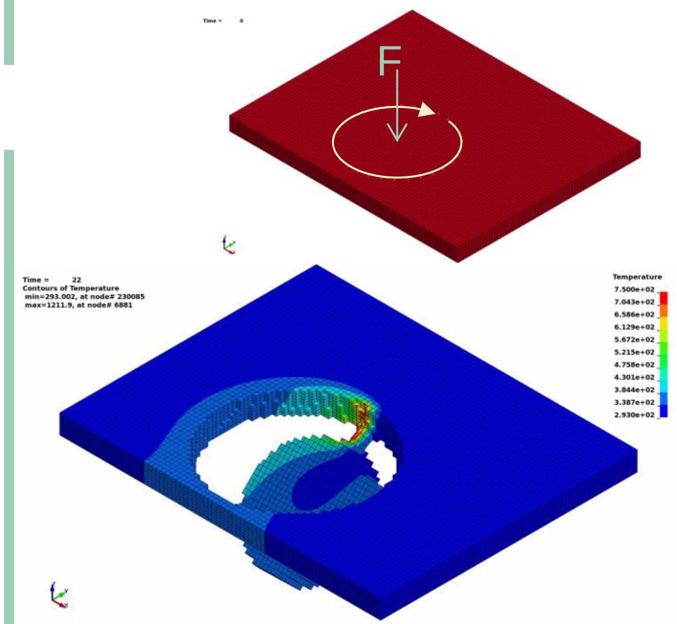
Card 3	GEO	LCQ	Q	LCINC	ENFO			
Card 4	P1	P2	P3	P4	P5	P6	P7	P8
Opt.	Tx	Ty	Tz					

- propagation of boundary condition for eroded elements can be activated with PROP=1
- a part set (PSID) specifies candidates
  - elements in the set are monitored
  - if an element fails the newly exposed segments are communicated to the boundary condition
- element failure due to a temperature criterion can be defined with *MAT_ADD_EROSION



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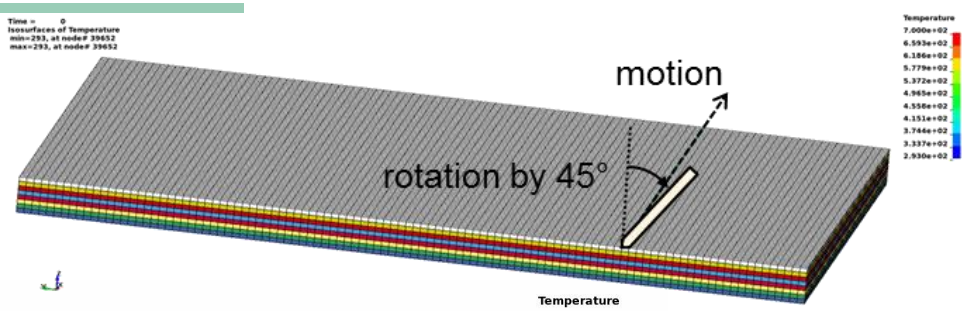

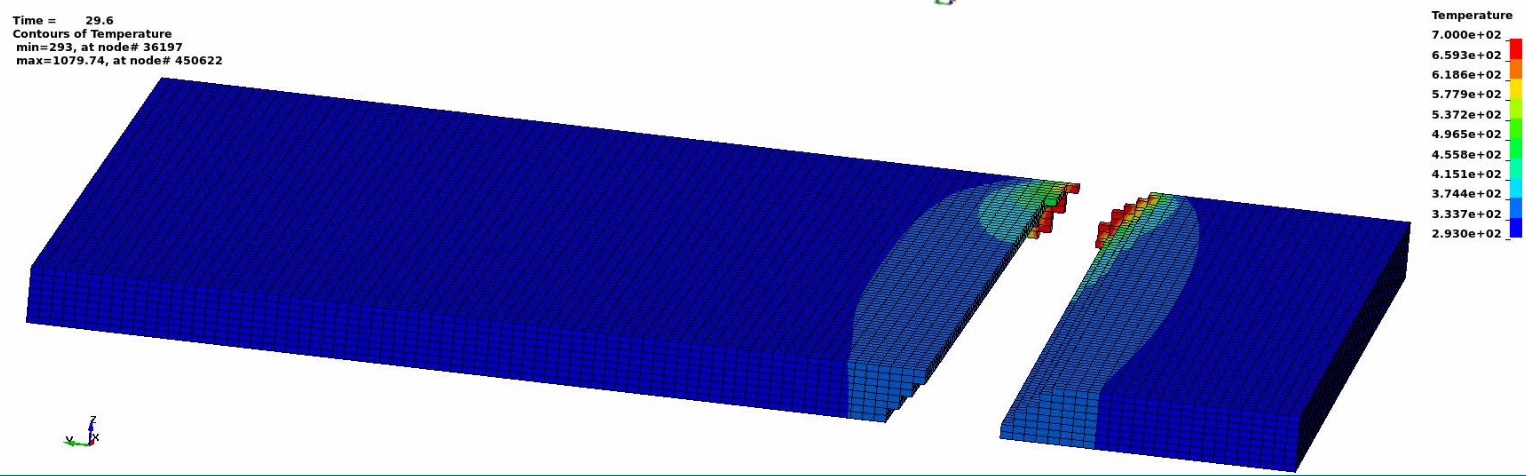

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	1	2	3	4	5	6	7	8
Card 1	SSID	PSID	NSID1	VEL1	SID2	VEL2	RELVEL	
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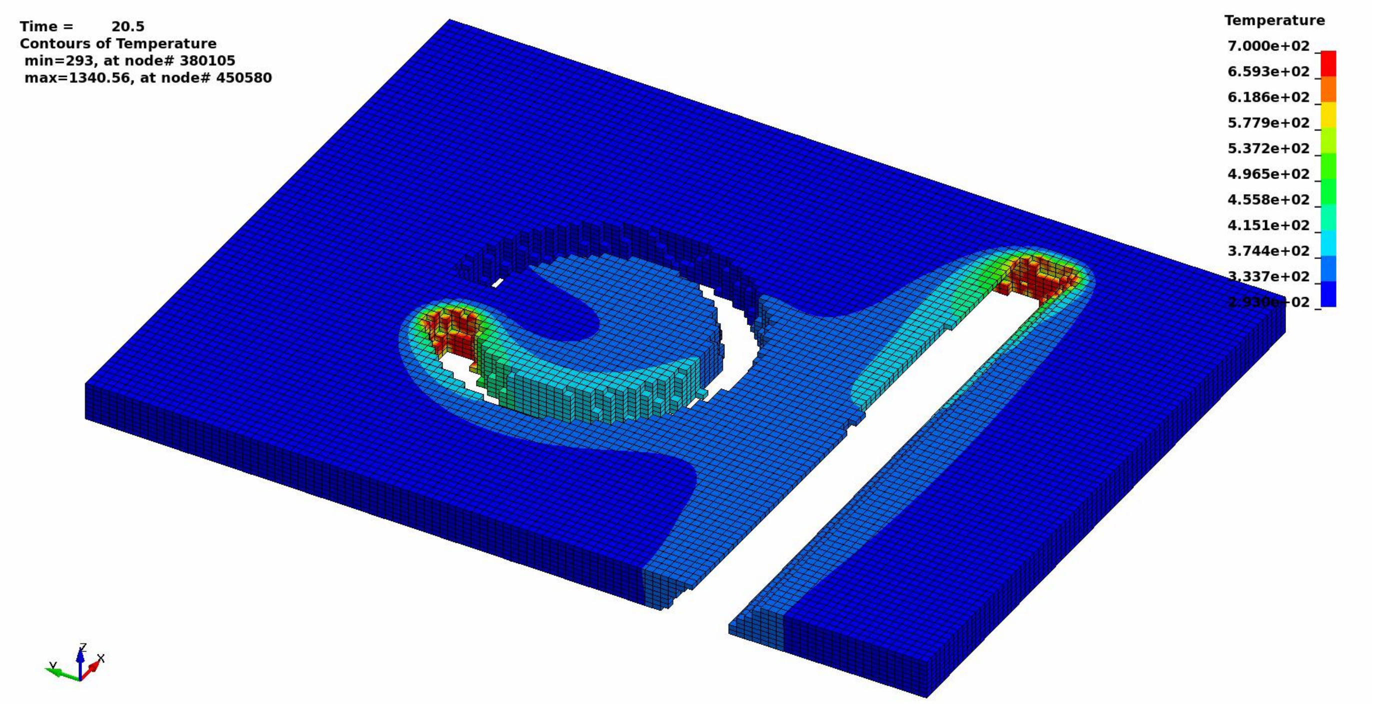

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- Summary of block 1

*BOUNDARY_TEMPERATURE_RSW

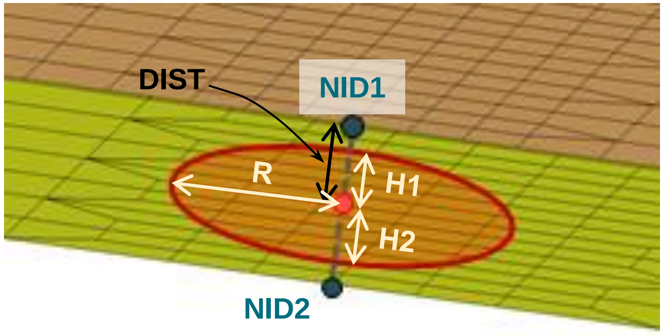
	1	2	3	4	5	6	7	8
Card 1	**NSID**		**NID1**	**NID2**	**DEATH**	**BIRTH**	**LOC**	
Card 2	**DIST**	**H1**	**H2**	**R**	**TEMCTR**	**TEMBND**	**LCID**	

- Modelling approaches for resistance spot welding (RSW)
  - use a detailed and coupled (EM, thermal, structure) simulation
  - use an equivalent heat source and calibrate power to obtain realistic weld nuggets
- for large assemblies and hundreds of spot welds neither approach is feasible

- aims and scope of the new keyword
  - simplified approach with reduced calibration requirements
  - direct temperature definition (Dirichlet condition) for the weld nugget
  - condition only active during the welding, standard degree of freedom otherwise

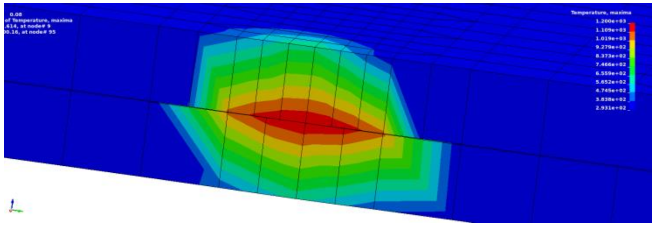
*BOUNDARY_TEMPERATURE_RSW

	1	2	3	4	5	6	7	8
Card 1	NSID		NID1	NID2	DEATH	BIRTH	LOC	
Card 2	DIST	H1	H2	R	TEMCTR	TEMBND	LCID	



- condition defined on a node set (NSID)
- for thermal thick shells surface (LOC) can be chosen

- position between two nodes (NID1, NID2) at a given distance from base node (NID1)



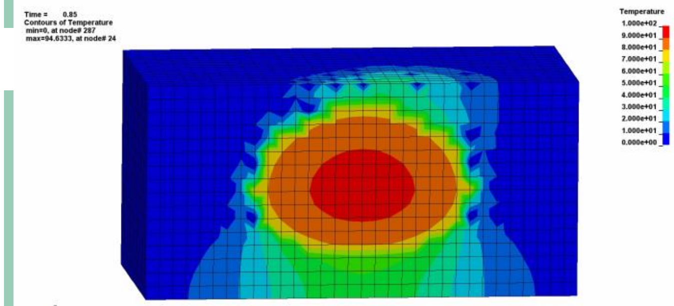
- weld nugget consist of two half ellipsoid
- axis of symmetry of nugget is line between nodes

*BOUNDARY_TEMPERATURE_RSW

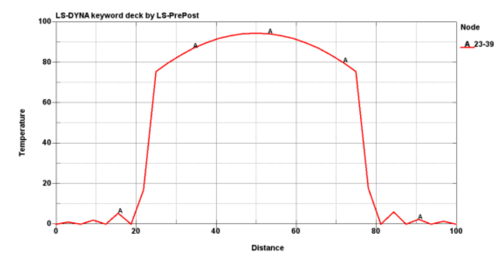
	1	2	3	4	5	6	7	8
Card 1	NSID		NID1	NID2	DEATH	BIRTH	LOC	
Card 2	DIST	H1	H2	R	TEMCTR	TEMBND	LCID	

- temperature in the weld nugget
  - prescribed at the center
  - prescribed at the boundary
  - quadratic approximation
- boundary condition active between BIRTH and DEATH times
- load curve input (LCID)
  - temperature as function of time
  - abscissa normalized to active time period

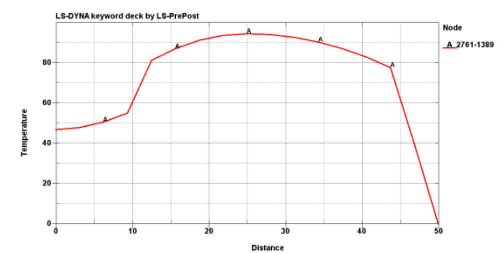
linear temp increase, DEATH=0.9



temp. profile horizontal



temp. profile vertical



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Summary 1

- *BOUNDARY_THERMAL_WELD_TRAJECTORY
  - Realistic heat source description for all fusion welding processes
  - Easy and flexible input also for curved and deforming structures
  - Readily applicable as tool in the virtual process chain even with mixed discretizations
- *BOUNDARY_FLUX_TRAJECTORY
  - Easy and flexible input for flux boundary also for curved and deforming structures
  - Tilting of heat source is accounted for
  - Applicable to laser cutting simulations due to propagation after element erosion
- *BOUNDARY_TEMPERATURE_RSW
  - Simplified simulation method for spot welds in assembly simulations
  - Applicable to shells and solids
  - Reduced calibration effort

Block 2: Thermal Composite TSHELL

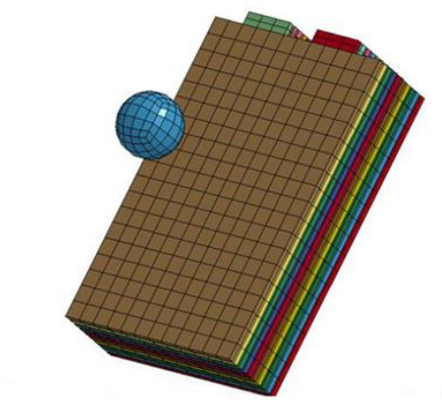
- Motivation
- Element formulation and mesh reconstruction
- Contact functionalities
- Summary and Outlook

Motivation 2: Battery Abuse Simulation

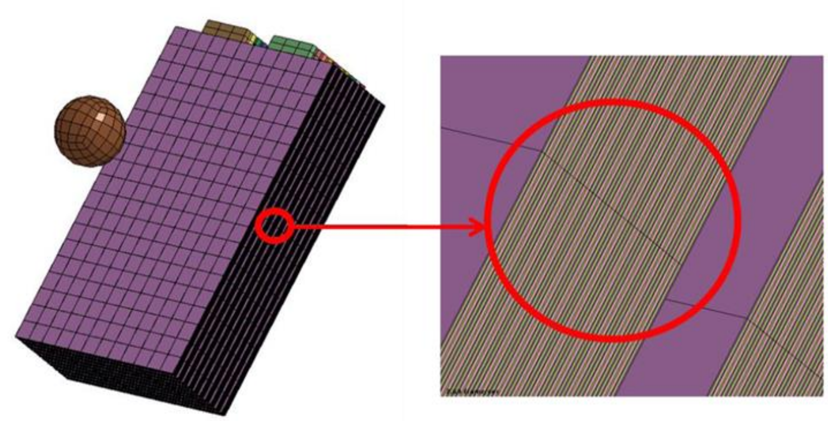
- lithium-ion batteries have gained importance in various applications
- prediction of response to abusive conditions is of particular importance
- customers request LS-DYNA to support the development phase by predictive simulations
- this kind of simulation poses a strongly coupled multi-physics problem:
  - structure mechanics
  - electromagnetics
  - heat transfer

Motivation 2: Battery Abuse Simulation

- Contradicting requirements on modelling strategy
  - structure mechanics: coarse resolution of layers to obtain a feasible time step size
  - EM and thermal solver: fine resolution of layers to capture all physical effects



optimal mechanical resolution



optimal resolution for EM and thermal

[source: L'Eplattenier et al., Salzburg, 2017]

- Possible Solution: composite Tshell elements:
  - good and relatively fast mechanical resolution
  - reconstruction of the finely resolved model for EM (already implemented) and thermal

Block 2: Thermal Composite TSHELL

- Motivation

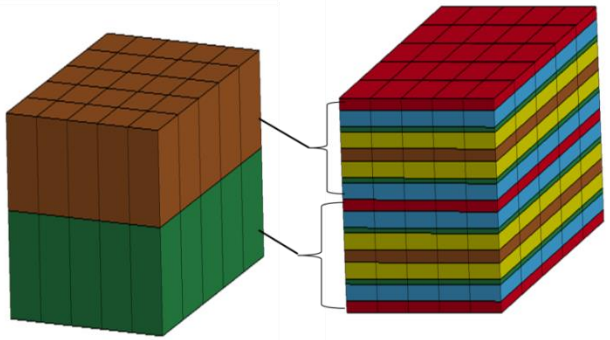
- Element formulation and mesh reconstruction

- Contact functionalities

- Summary and Outlook

Thermal Composite Thick Shell Elements

- starting point is lay-up in a user-defined mesh
  - virtual elements and nodes are created automatically
  - temperature degrees of freedom associated with new nodes
  - internal lists links virtual nodes to “standard” nodes



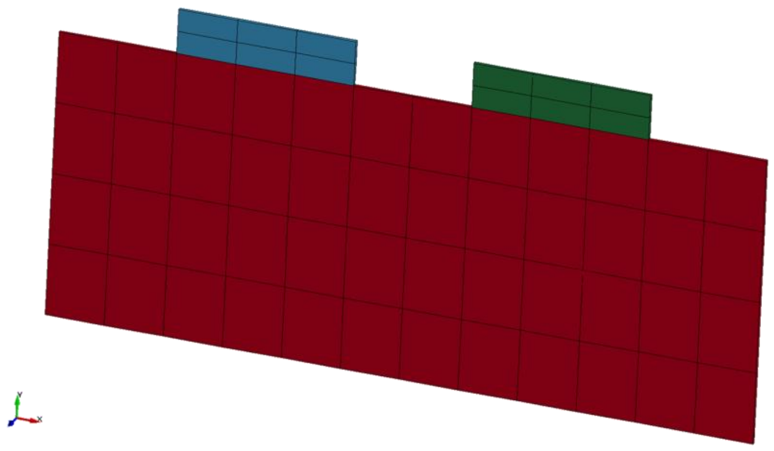
- a potentially largely increased number of degrees of freedom is to be solved for in the thermal solver

- the thick shell element of the thermal solver itself does not need any specific element technology as the structural counterpart

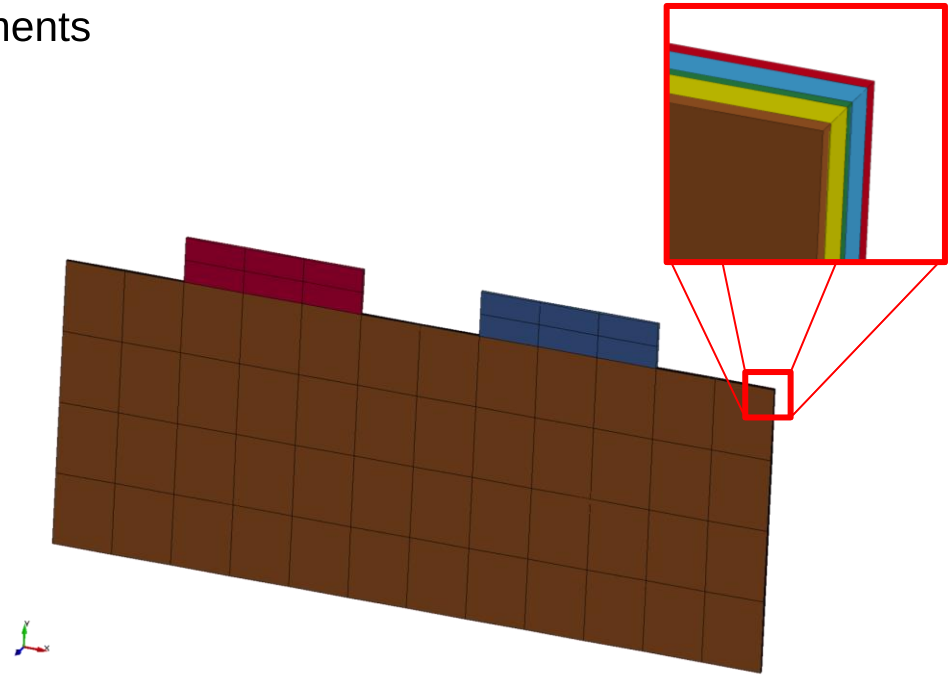
- information of each (virtual) layer can easily be shared between EM and thermal solver

Thermal Composite Thick Shell Elements - Validation

- study of temperature field evolving in a battery cell due to Joule heating
- comparison of different modeling strategies:
  - one layer of thick shell elements
  - layers resolved with layers of solid elements



tshell



solid

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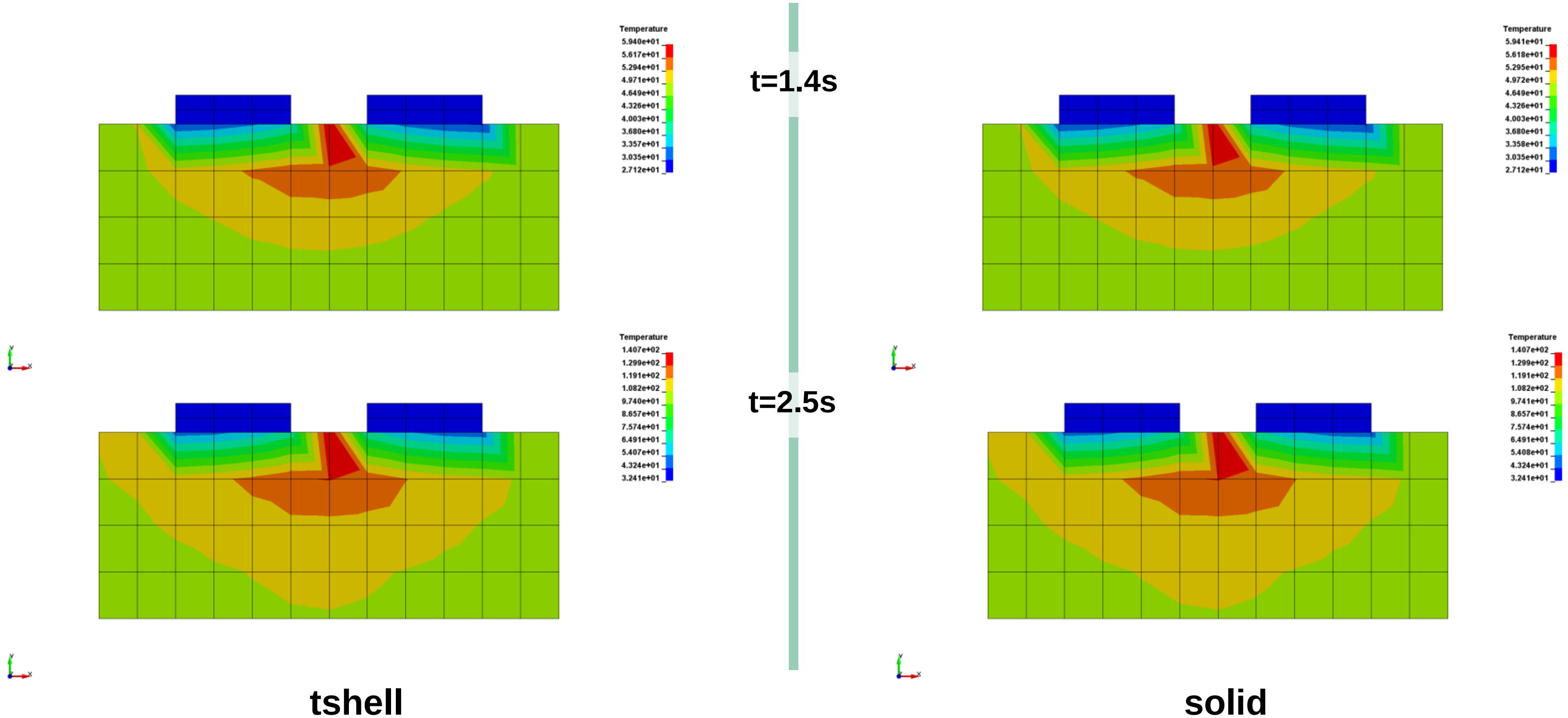
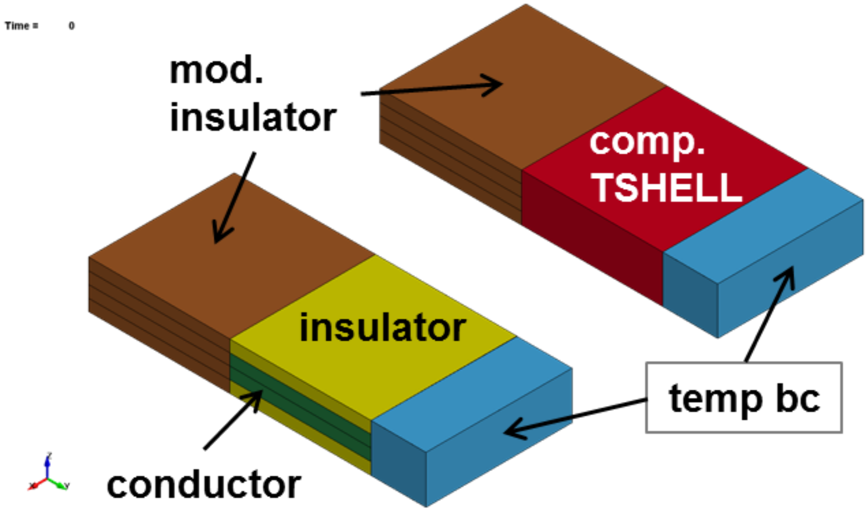


Contact Functionality of Thermal Composite Thick Shell Elements

- reconstructed mesh can also be used for heat transfer through contact

- Example contact of a composite structure with to homogenous blocks
  - strategy 1: one layer of thick shell elements for composite structure
  - strategy 2: 4 different layers resolved with layers of solid elements



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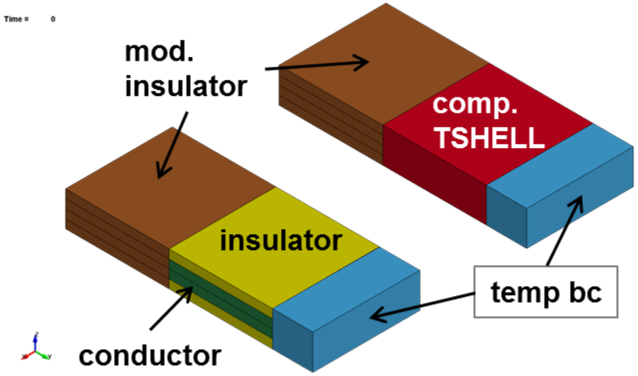
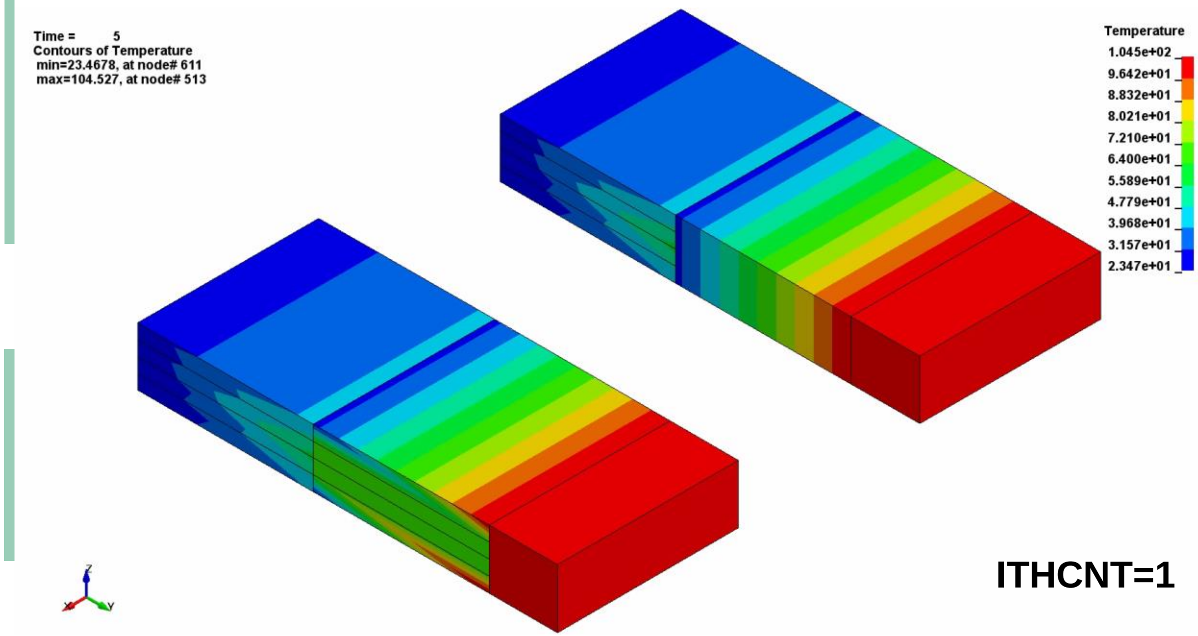


- perfect match
- smoothed solution



ITHCNT=1

Contact Functionality of Thermal Composite Thick Shell Elements

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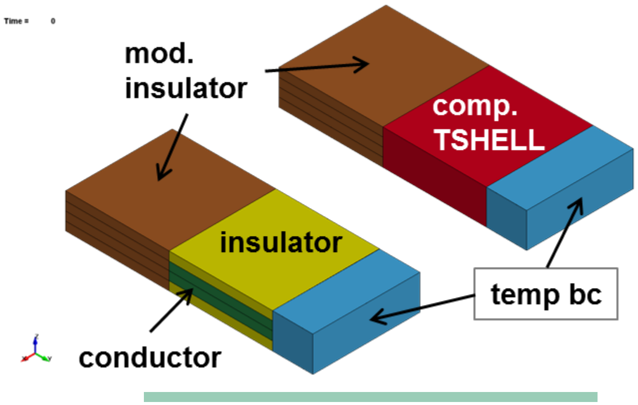

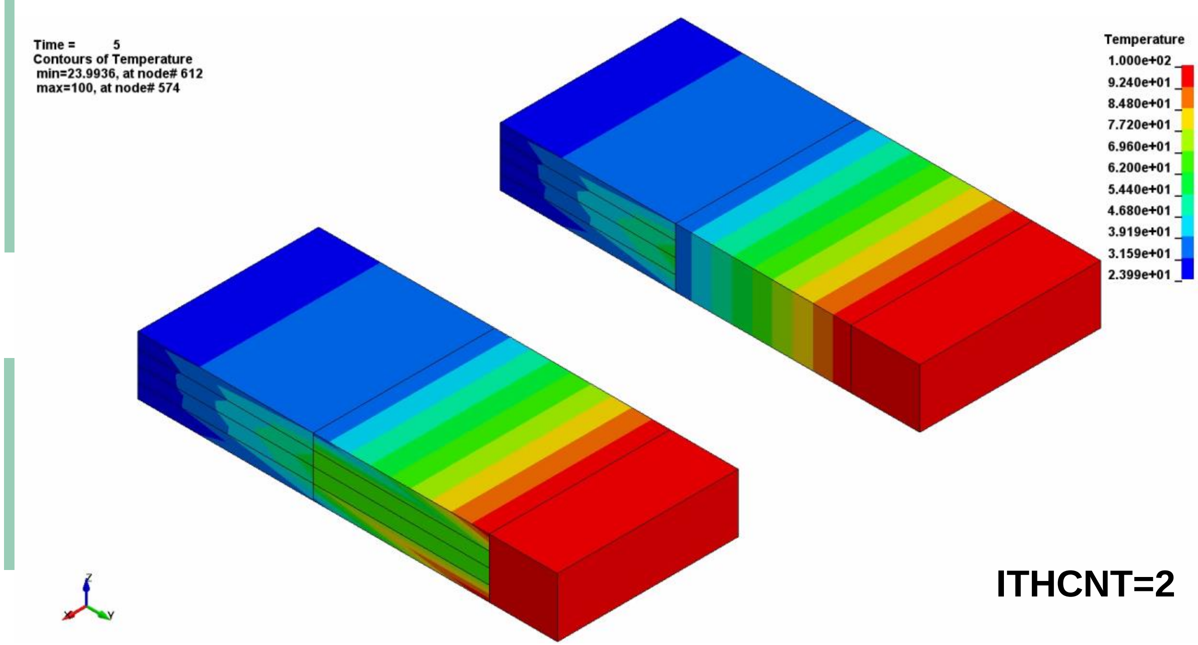

- perfect match
- resolved solution

ITHCNT=2

Block 2: Thermal Composite TSHELL

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Summary 2

- thick shell functionality has been implemented into thermal solver of LS-DYNA
  - finely resolved mesh is reconstructed automatically
  - virtual elements and nodes are generated internally
  - new degrees of freedom are added to the system
  - information is shared with EM and structure solver
  - results in agreement with solution from finely resolved solid meshes
  - heat transfer across contact surfaces

- work in progress
  - provide temperature information at virtual nodes for post-processing

Your questions, please