Rapid Simulations of Welding and AM using LS-DYNA and LS-PrePost

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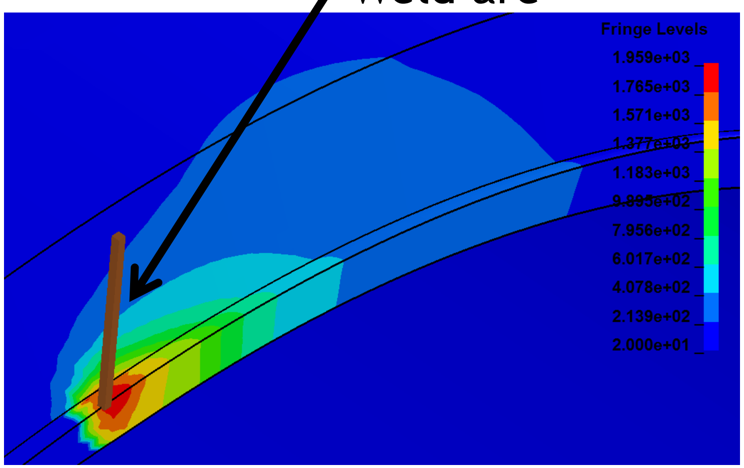
Agenda

- Welding in LS-DYNA
  - Material Models
  - Heat Source
  - LS-PrePost
  - Weld contact
- Thermal Dumping
  - Motivation
  - Methodology
  - LS-PrePost
- Example
  - Incremental vs. Thermal Dumping
  - Results
- Thermal Dumping in Additive Manufacturing simulations
- Conclusions

Material Models - *MAT_CWM

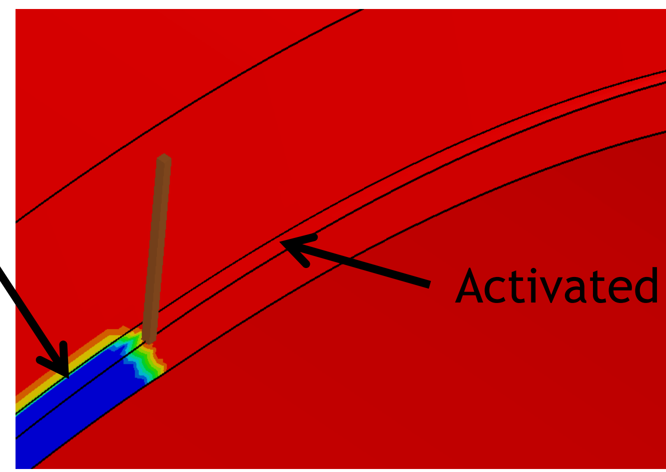
- The element can either be ”Solid”, ”Liquid” or ”Ghost”.
  - Solid: Material is activated in a previous weld pass
  - Liquid: Material will be activated in the current weld pass
  - Ghost: Material will not be activated in the current weld pass
- When the temperature reaches a specified temperature, material is activated and recieves ”material” properties.
- Solid and shell elements
- Load curve/Table hardening input

Weld arc



Temperature

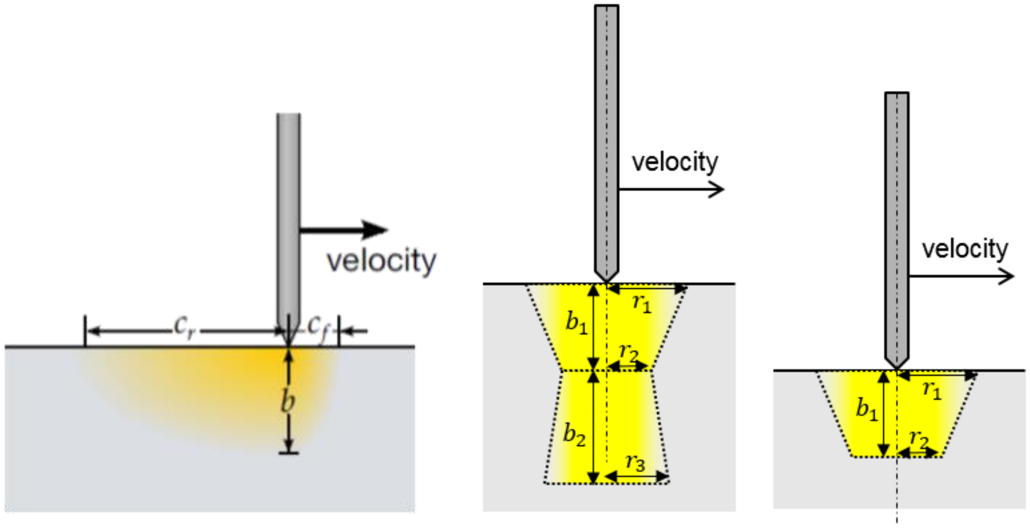
Ghost



Activated material

Heat Source

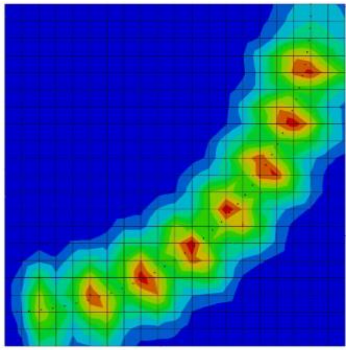
- *BOUNDARY_THERMAL_WELD_TRAJECTORY
- Heat source movement implemented in the thermal solver
- Heat source follows a node string defined in *SET_NODE
- User controlled integration for accurate heat input
- Goldak, cone and double cone heat sources



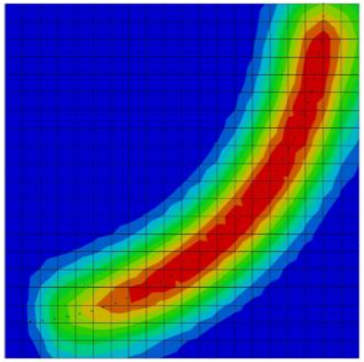
Heat Source

- There is a restriction of how large thermal timesteps that can be used in an incremental welding simulation before loosing accuracy.
- The heat source can only step forward approximately one element/timestep.
- A sub-cycling option is available for the heat source to take larger thermal timesteps, but make sub-cycling timestep between.
- This option can be used to decrease the simulation time.

NCYC=1, one sub-cycle over each thermal timestep

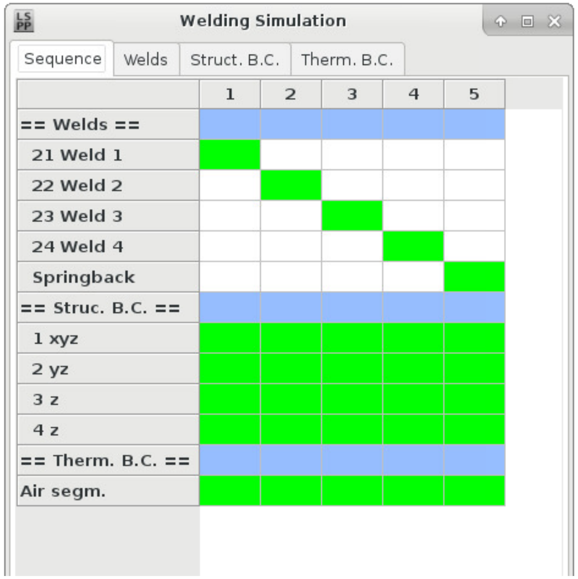


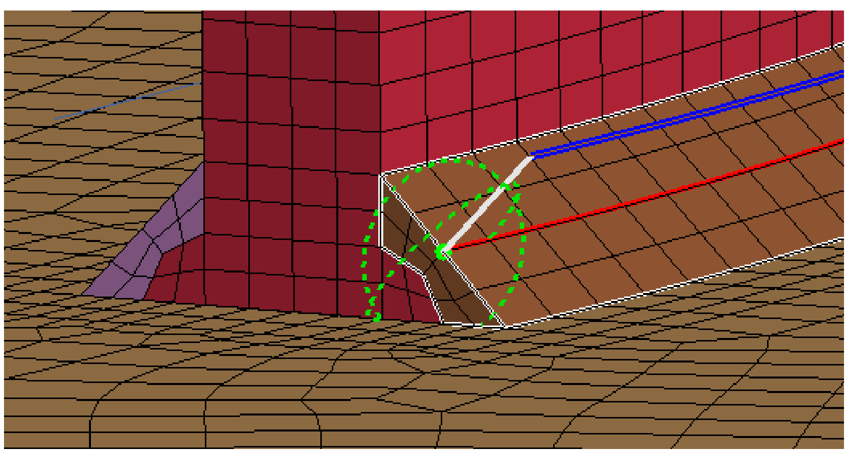
NCYC=10, ten sub-cycles over each thermal timestep

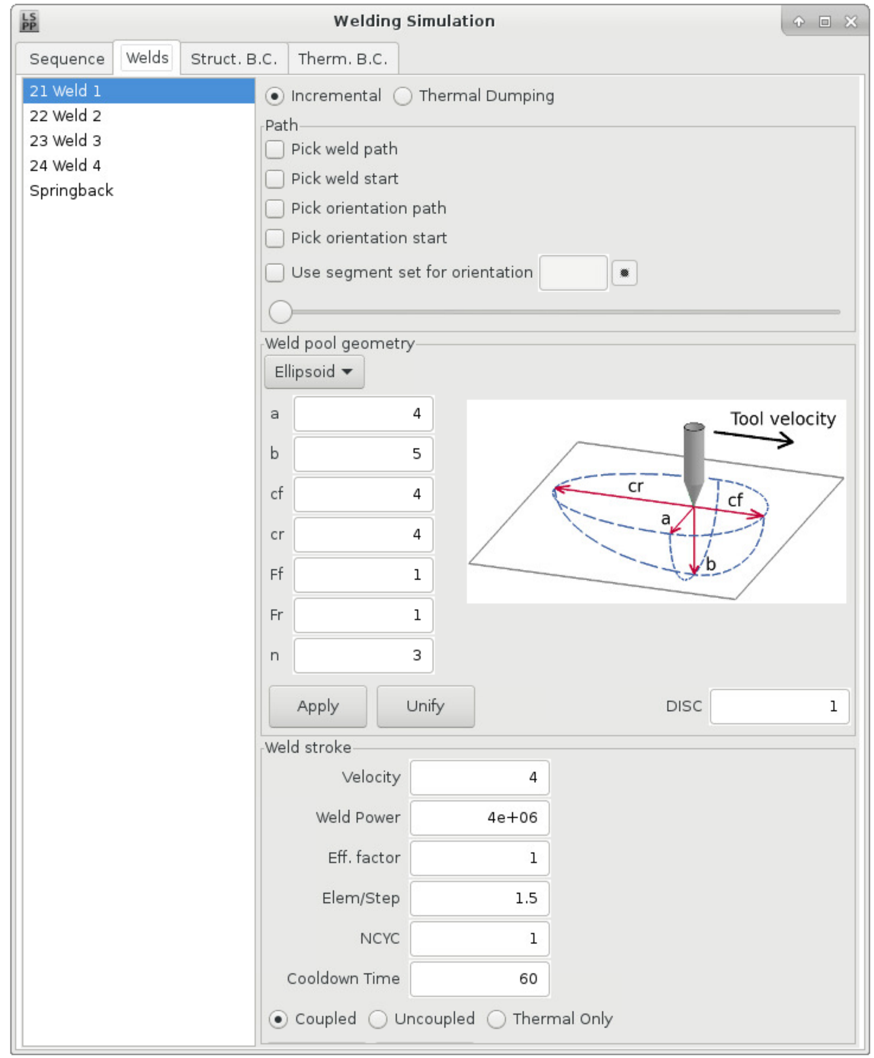


Temperature field

LS-PrePost


Welding Simulation
Sequence
Welds
Struct. B.C.
Therm. B.C.
1
2
3
4
5
== Welds ==
21 Weld 1
22 Weld 2
23 Weld 3
24 Weld 4
Springback
== Struc. B.C. ==
1 xyz
2 yz
3 z
4 z
== Therm. B.C. ==
Air segm.




Welding Simulation
Sequence
Welds
Struct. B.C.
Therm. B.C.
21 Weld 1
22 Weld 2
23 Weld 3
24 Weld 4
Springback
Incremental
Thermal Dumping
Path
Pick weld path
Pick weld start
Pick orientation path
Pick orientation start
Use segment set for orientation
Weld pool geometry
Ellipsoid
a 4
b 5
cf 4
cr 4
Ff 1
Fr 1
n 3
Tool velocity
cr
cf
a
b
Apply
Unify
DISC 1
Weld stroke
Velocity 4
Weld Power 4e+06
Eff. factor 1
Elem/Step 1.5
NCYC 1
Cooldown Time 60
Coupled
Uncoupled
Thermal Only

Weld Contact

- *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_TIED_WELD

- When regions of contact surfaces are heated to the welding temperature and come in contact, the nodes are tied.
- The contact works as a standard sliding contact when the temperature is below the welding temperature
- An MORTAR option is also available

7	TEMP	CLOSE	HCLOSE

- Input for TIED_WELD contact:
  - TEMP: Minimum temperature required on both surfaces for tying
  - CLOSE: Surfaces closer than CLOSE are tied
  - HCLOSE: Thermal contact conductivity for a tied interface

Thermal Dumping - Motivation

- One of the issues with welding simulations is quite long simulation times due to many timesteps, and the number of timesteps is also dependant of the weld lengths

Incremental approach

Weld stage → Cooling stage

- Fixed thermal and implicit timestep
- Auto thermal and implicit timestep

- Hypothesis: The stresses and shrinkage in the weld lines are quite uniform and is not dependant of the incremental approach
- Solution: Heat the full weld lines simultaneously

Thermal dumping approach

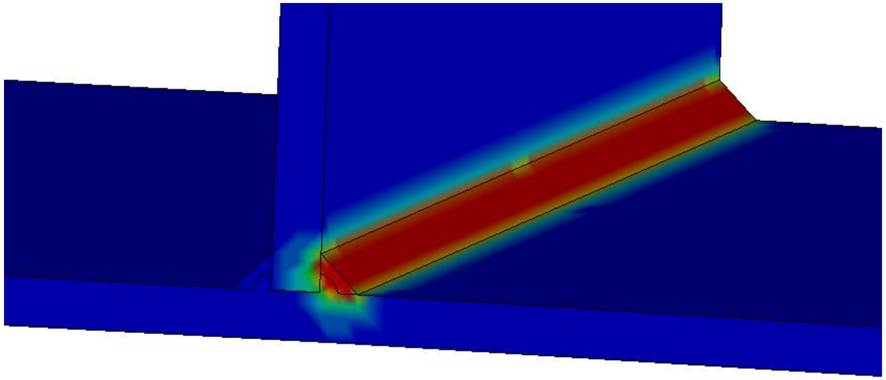
Heating and cooling stage

- Auto thermal and implicit timestep

Methodology

- There are several different thermal dumping techniques that are used when it comes to welding simulations.
- One example is the inherent strain method where a strain field is applied in the weld lines, and the thermal part is completely removed.

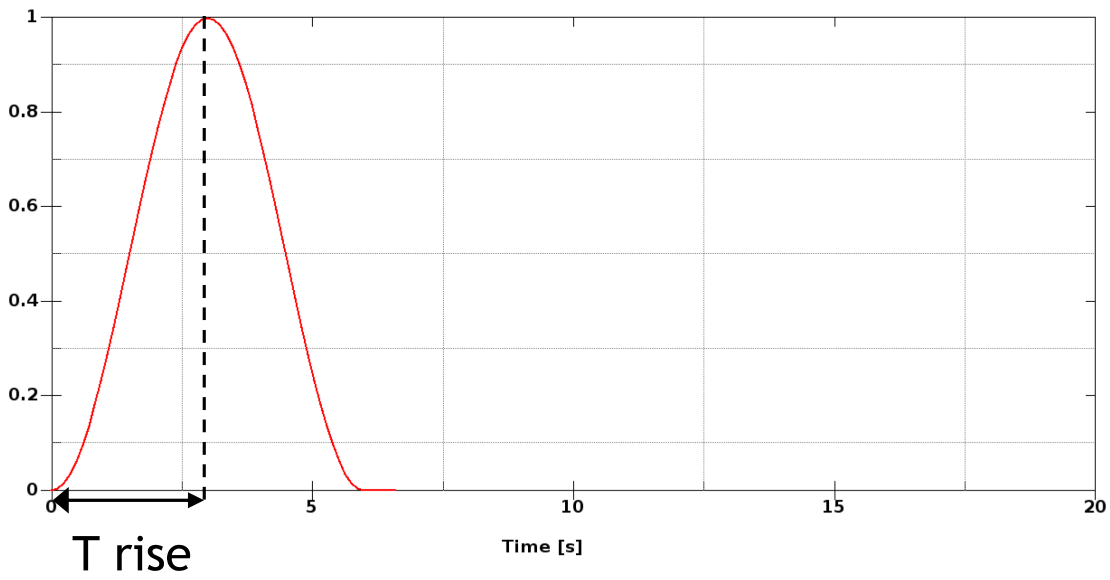
- The method presented here is a thermo-mechanical approach which is based on the physics of welding.
- The intention with this method is to apply the equivalent amount of energy as with an incremental approach, and also to capture the temperature history in the weld.



Load Heat Generation

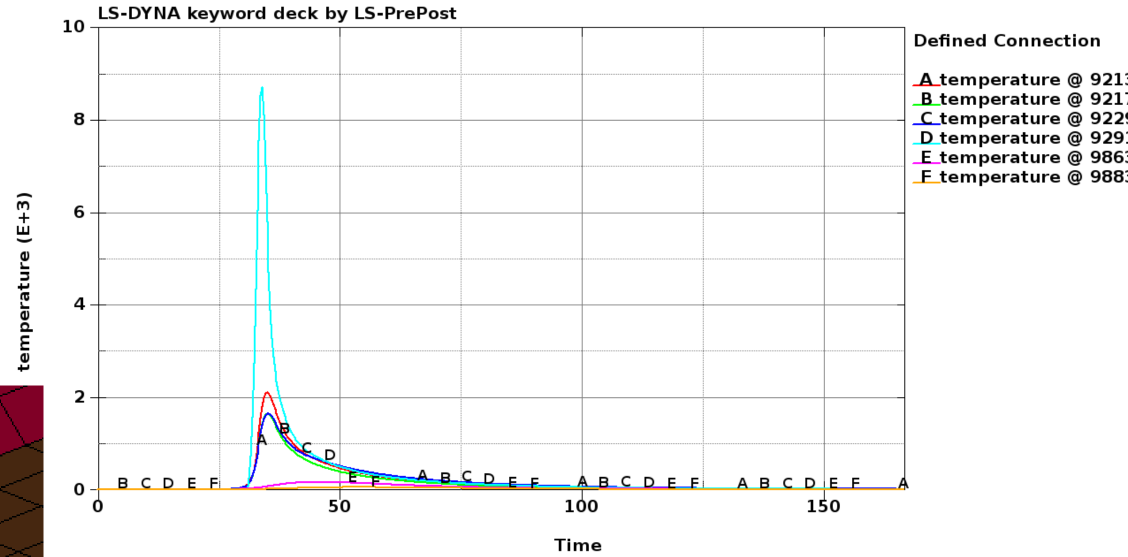
- Volymetric heat generation
- *LOAD_HEAT_GENERATION_SET_SOLID
- A load curve is used for the volumetric heat generation rate.

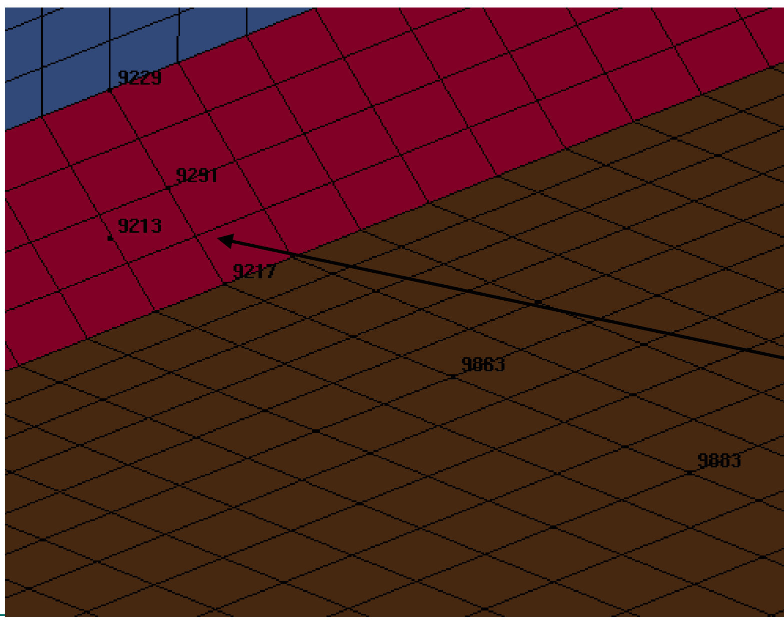
- Energy in for transient analysis : W_{weld} * $Time_{weld}$
- Energy in for thermal dumping: Vol_{weld} * ∫(load curve)

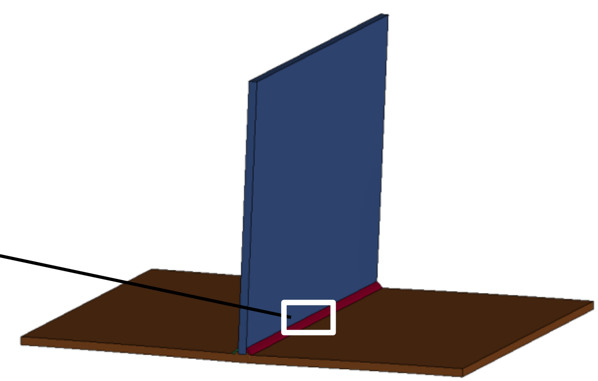


Temperature History

- Incremental thermal only analysis with temperature node output
- See the temperature history to define the rise time.

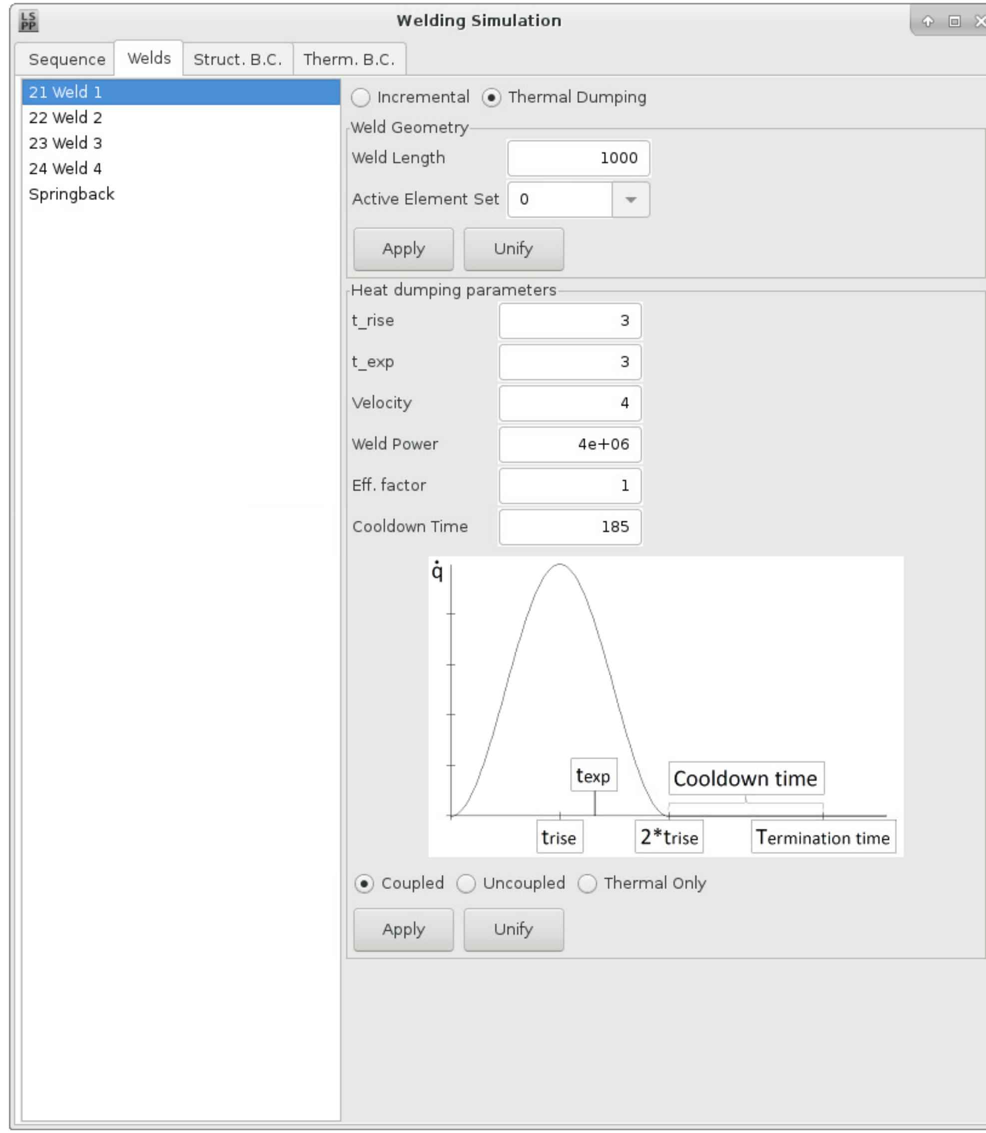






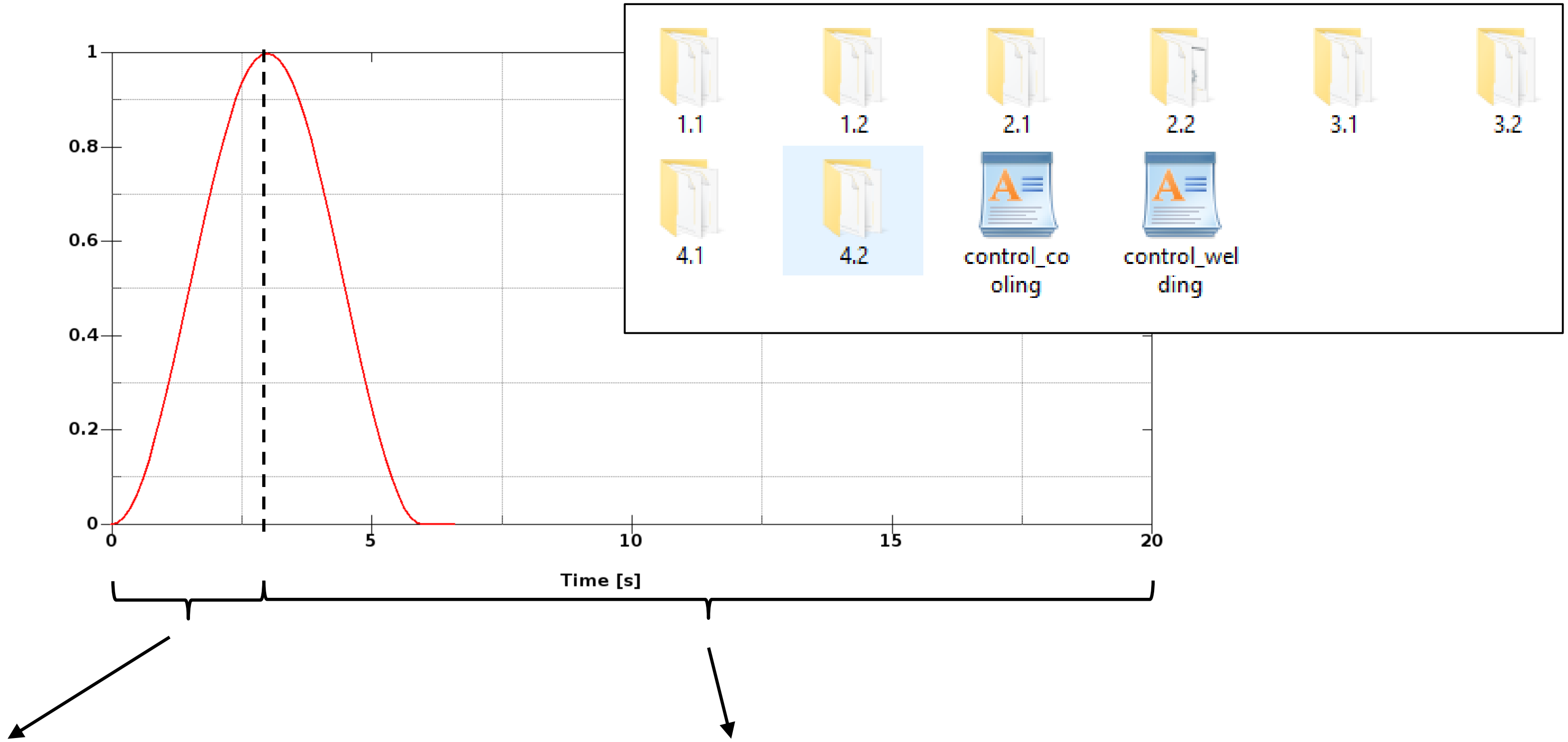
LS-PrePost

- The dumping method is now implemented in the welding GUI in LS-PrePost.
- Input needed for a dumping analysis:
  - **Weld Length** (or defined element sets for the welds)
  - **t_rise** and **t_exp**. Usually set these to the same value
  - **Velocity** and **Weld Power** similar to an incremental analysis



Thermal Dumping Runs

- During the develompment of this method it was found that go get the best accuracy and efficiency the thermal dumping simulation needed to be split in two runs.

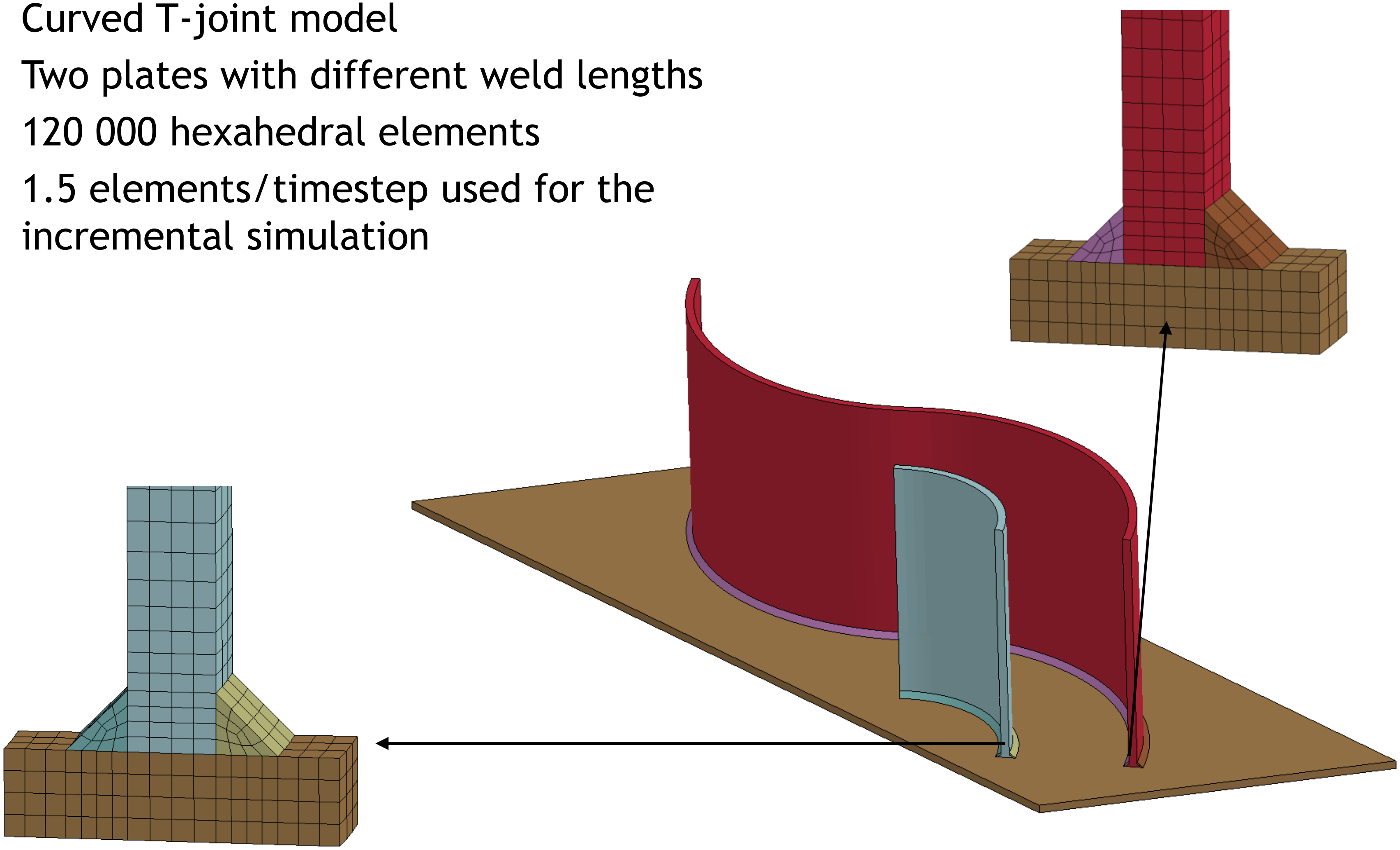


Run 1: Thermal only – Simulate the first half of the heating

Run 2: Thermo-mechanical – Simulate the second half of the heating and the cooling

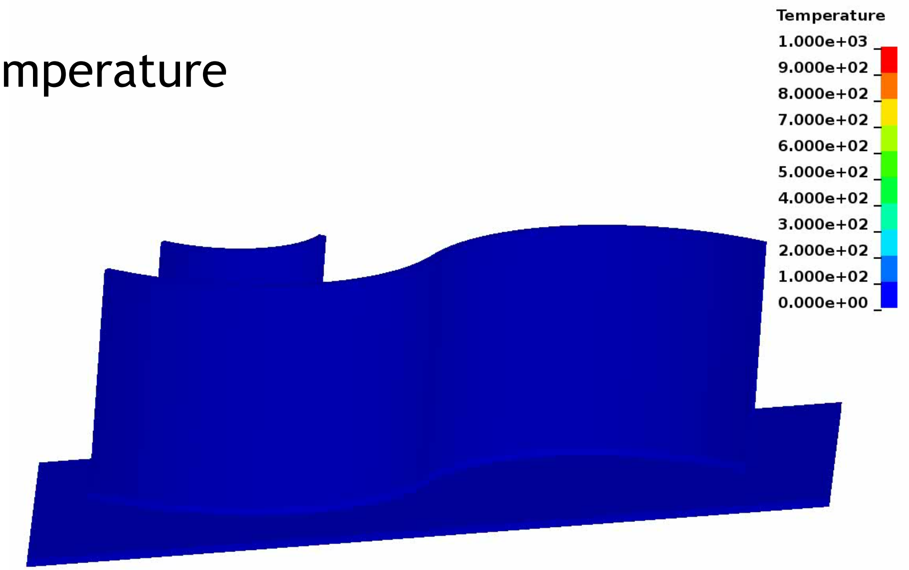
Example

- Curved T-joint model
- Two plates with different weld lengths
- 120 000 hexahedral elements
- 1.5 elements/timestep used for the incremental simulation

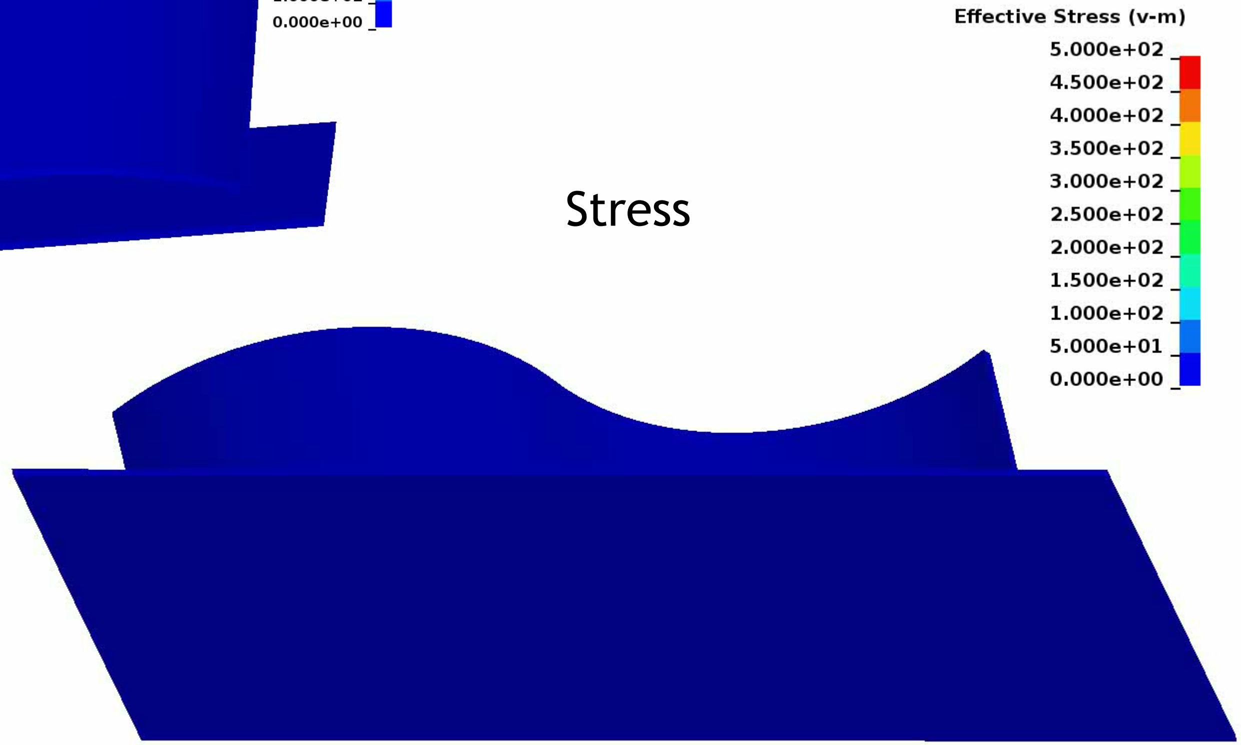


Results

Temperature

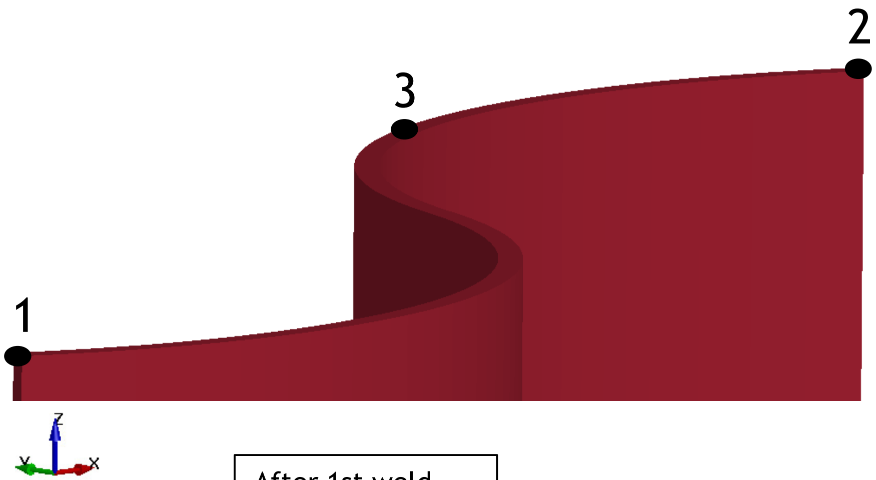


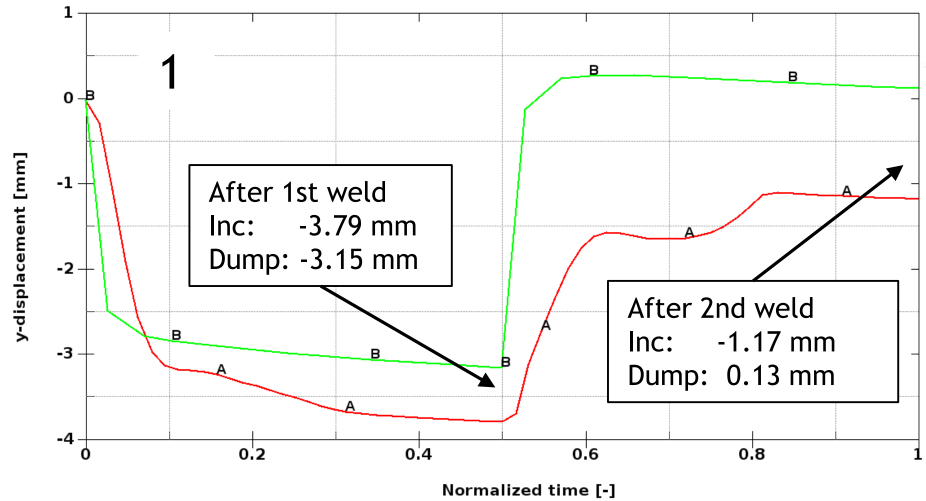
Stress

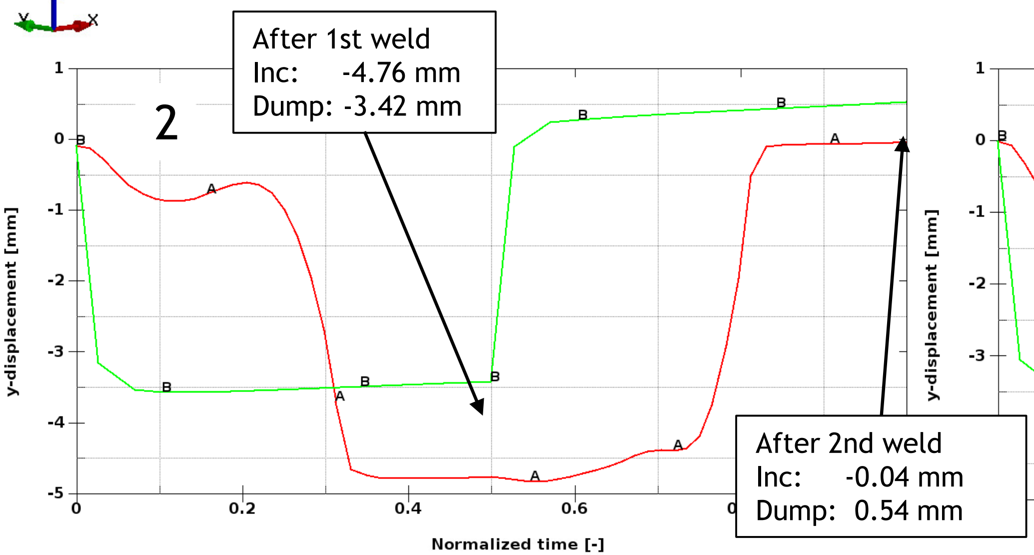


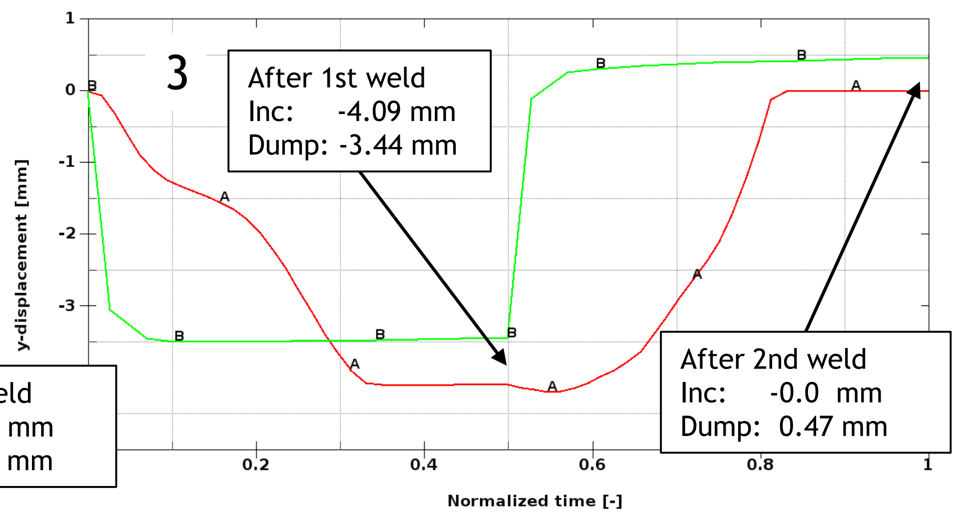
Results - Distortion

Incremental   Dumping

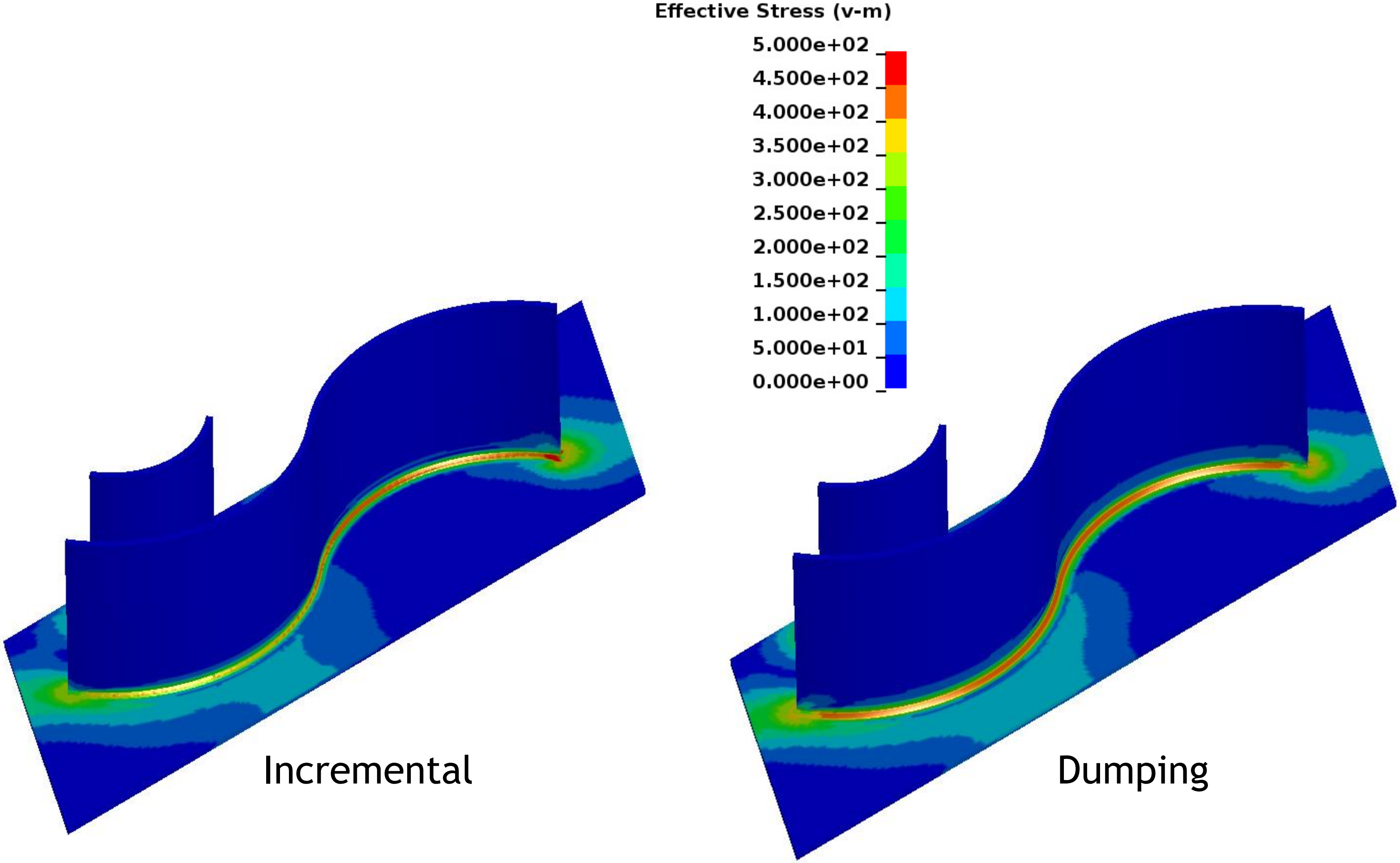




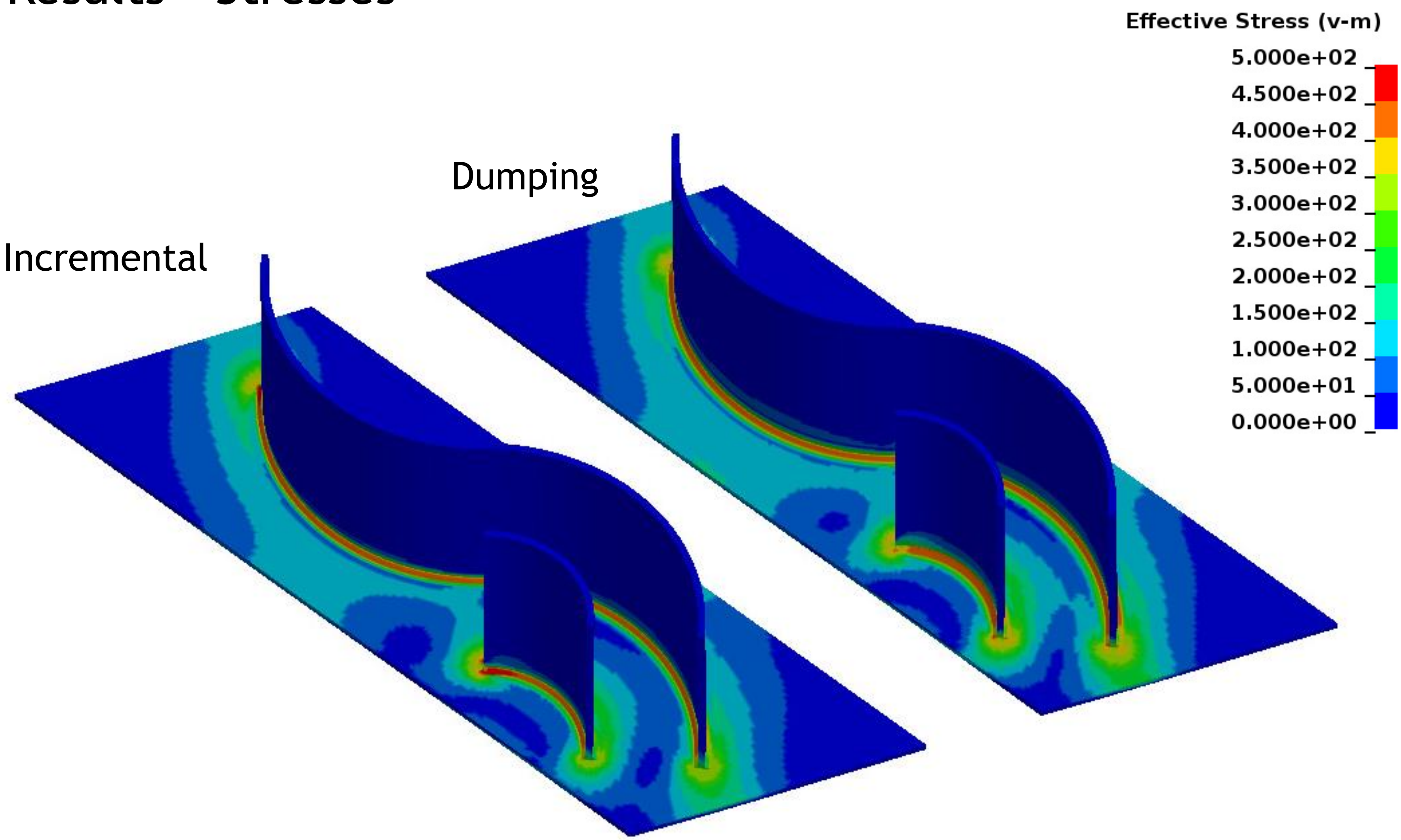




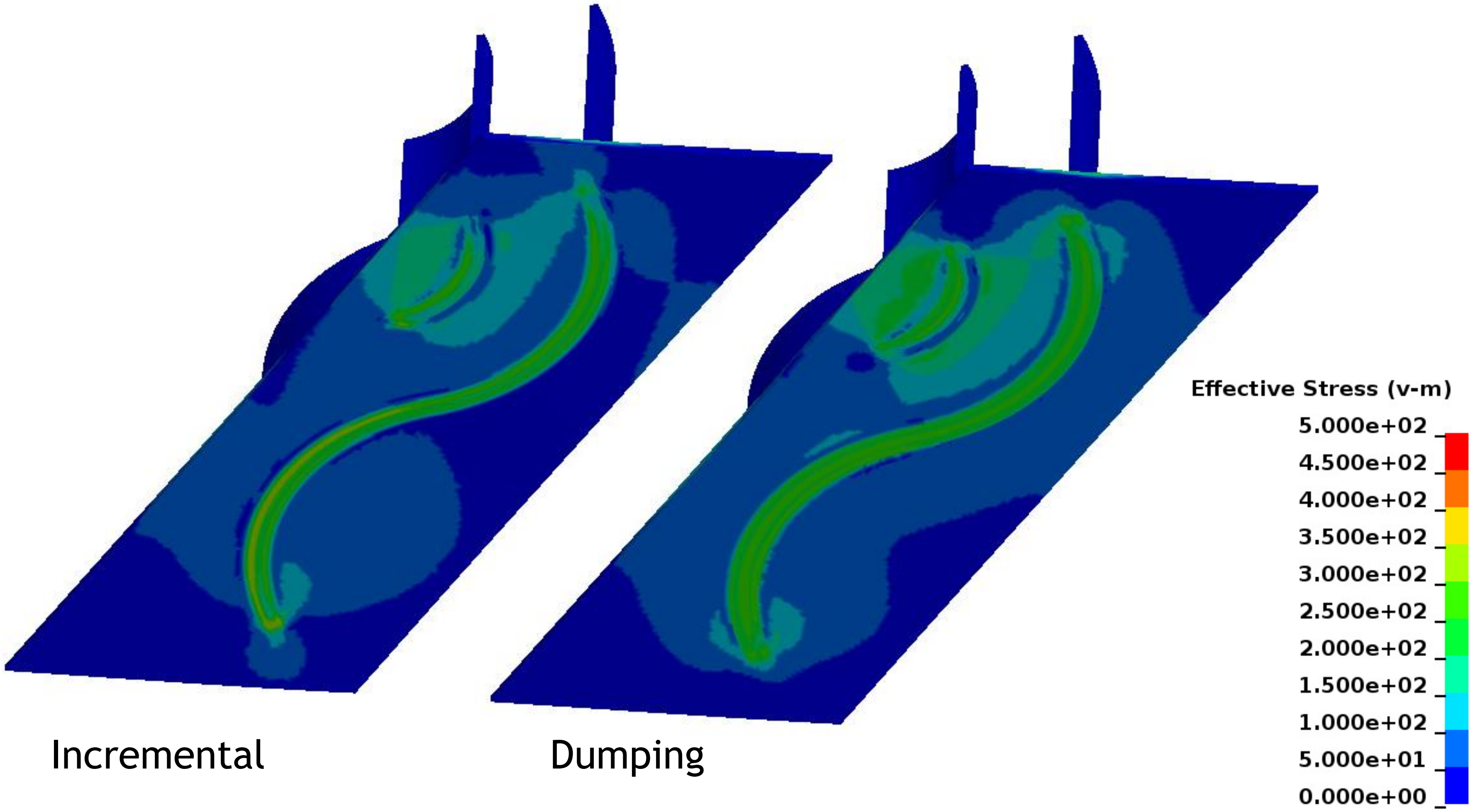
Results - Stresses



Results - Stresses



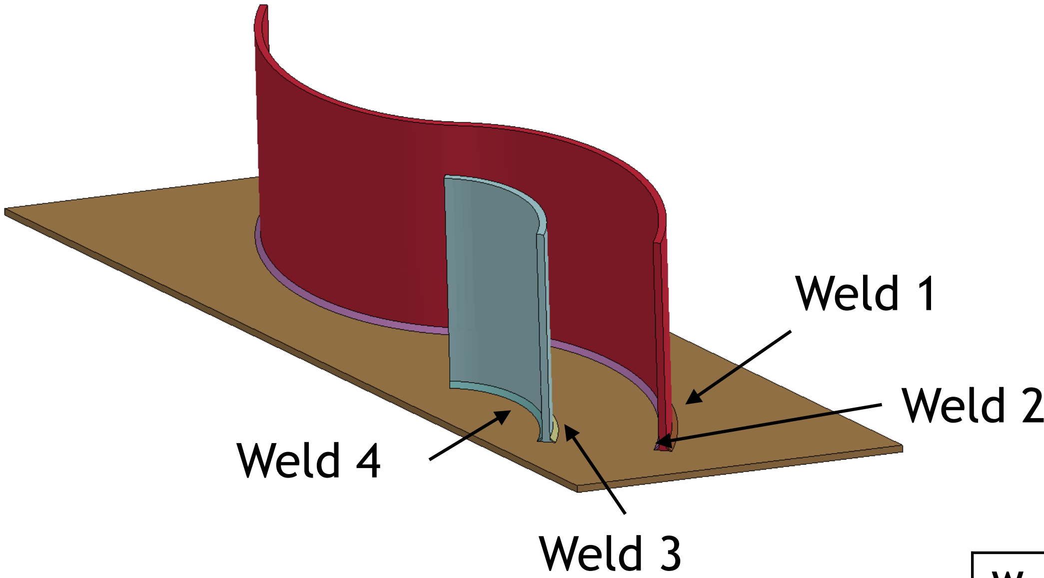
Results - Stresses



Incremental

Dumping

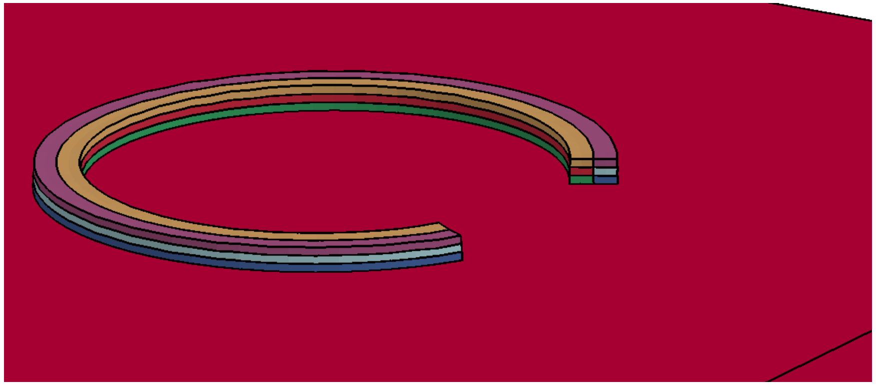
Computing Time



Weld (Heating and cooling)	Inc	Dump
1	2.00 h	9 min
2	1.57 h	10 min
3	37 min	9 min
4	40 min	10 min
Tot	**5.14 h**	**38 min**

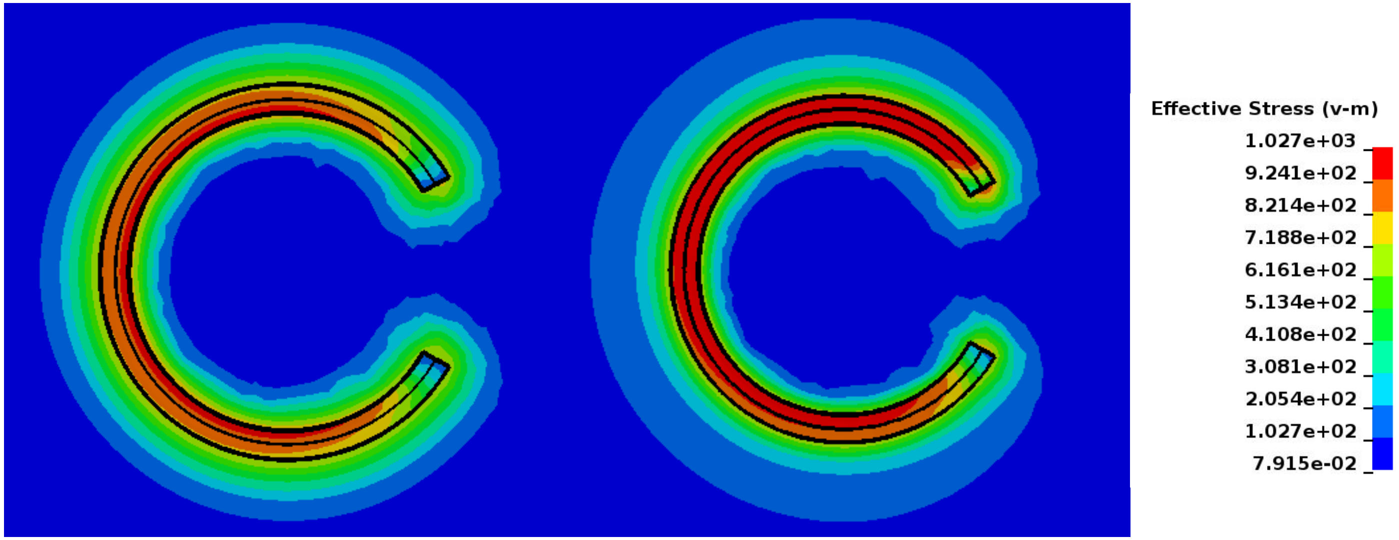
Thermal Dumping in AM simulations

- The welding capabilities in LS-DYNA can be used to simulate additive manufacturing processes also.
- Some AM processes are very similar to welding where liquid material is added and the cooling results in residual stresses and distortion of the geometry.
- Thermal Dumping could be a suitable choice for the AM procsesses as these usually have long weld paths and many layers to simulate.



Thermal Dumping in AM simulations

- The methodology for setting up an AM thermal dumping simulation is the same as for a weld simulation.
- Each layer (or part of a layer) is defined as a weld part and the heat energy is dumped in the layer in different runs.



Incremental Dumping

Conclusions

- A thermal dumping method has been tested as an alternative to incremental heating in welding and AM simulations.
- This method can capture the distortions and residual stresses with an significantly decreased computing time.
- This feature is added in the welding GUI in LS-Prepost and the only extra step needed is an calibration analysis for the temperature history in the weld.

Thank you!

Your LS-DYNA distributor and more