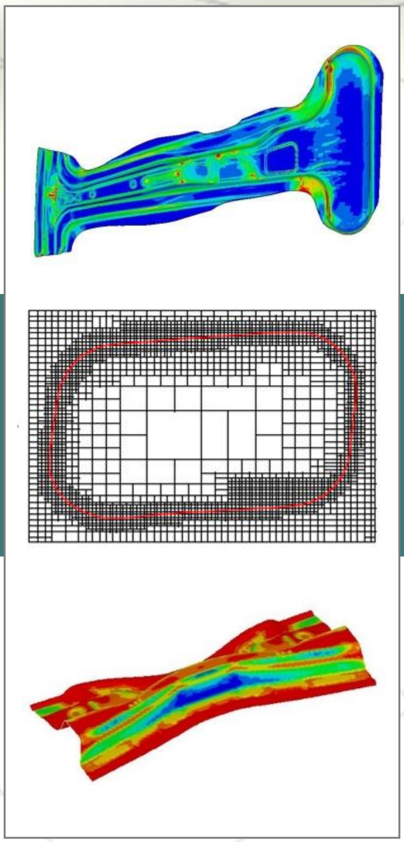

New Features for Metal Forming in LS-DYNA

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- L. Zhang (LSTC)
- B. Hochholdinger (DYNAmore Swiss GmbH)
- David Schröder (DYNAmore Swiss GmbH)

Outline

- Definition of material hardening behavior — **pre**
- Best-fit for comparison of geometrical deviations — **post**
- Improvements for One-Step simulations — **solver**
- Uniform mesh refinement of selected region — **adaptivity**
- Mesh fusion
- Adaptivity and Trimming for sandwich sheets
- Miscellaneous — **misc**

Definition of material hardening behavior

Definition of hardening behavior

- Currently different material models offer different options to define yield curve

`*MAT_037`

HLCID	Load curve ID expressing effective yield stress as a function of effective plastic strain in uniaxial tension.

`*MAT_036`

HR	Hardening rule:
	EQ.1.0: linear (default),
	EQ.2.0: exponential (Swift)

`*MAT_133`

HARD	Hardening law:
	EQ.1.0: Exponential hardening: $\sigma_y = k(\varepsilon_0 + \varepsilon_p)^n$
	EQ.2.0: Voce hardening: $\sigma_y = a - be^{-c\varepsilon_p}$
	EQ.3.0: Hansel hardening
	EQ.4.0: Gosh hardening: $\sigma_y = k(\varepsilon_0 + \varepsilon_p)^n - p$
	EQ.5.0: Hocket-Sherby hardening: $\sigma_y = a - be^{-c\varepsilon_p^q}$
	LT.0.0: Absolute value defines load curve ID or table ID with yield stress as functions of plastic strain and in the latter case also plastic strain rate.

New keyword: *DEFINE_CURVE_STRESS

- Defines yield curve based on commonly used hardening laws.
- Weighted combinations of hardening laws are possible.
- *DEFINE_CURVE_STRESS can be used by any material model that accepts a curve to define the hardening behavior.

Define second card with the same LCID if ITYPE = 11.

Card 1	1	2	3	4	5	6	7	8
Variable	LCID	ITYPE	P1	P2	P3	P4	P5	
Type	I	I	F	F	F	F	F	
Default	none	none	none	ITYPE 1: 0.001	none	none	none	

New keyword: *DEFINE_CURVE_STRESS

Implemented hardening laws:

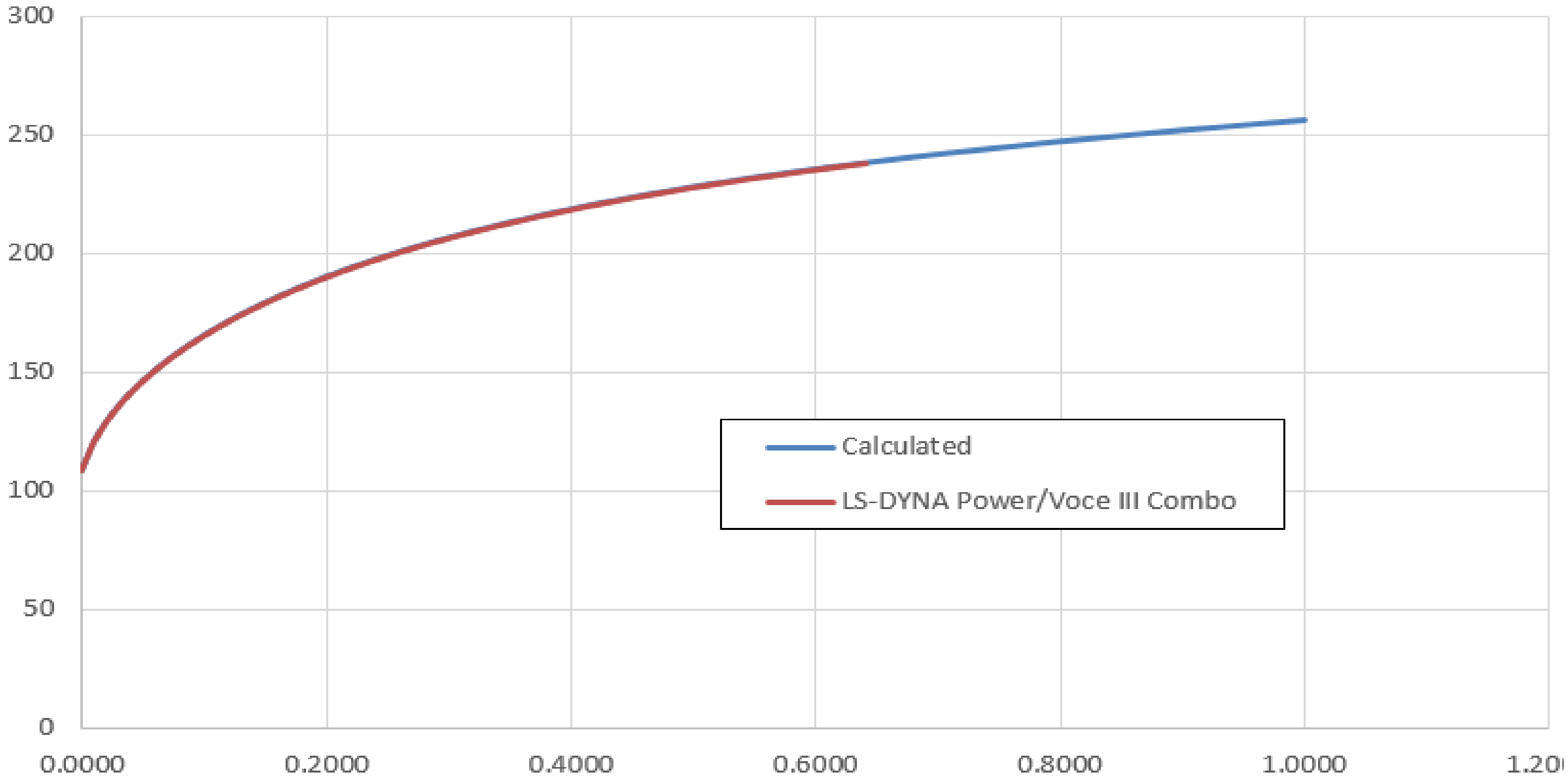
- Swift Power law $\sigma = K\left(\varepsilon_0 + \varepsilon_p\right)^n$
- Voce law $\sigma = \sigma_0 + R_{sat}\left(1.0 - e^{-\zeta \cdot \varepsilon_p}\right)$
- Alt. Voce law $\sigma = A - Be^{-C \cdot \varepsilon_p}$
- Hockett-Sherby law $\sigma = A - Be^{-C \cdot \varepsilon_p{}^H}$
- Stoughton-Yoon law $\sigma = A - Be^{-C \cdot \varepsilon_p{}^m} + D \cdot \varepsilon_p$
- Weighted combination of Swift + Voce or Hockett-Sherby

New keyword: *DEFINE_CURVE_STRESS

- Example: Weighted Combination of Swift Power Law + Voce

$$\sigma = 0.5 \cdot K\left(\varepsilon_0 + \varepsilon_p\right)^n + 0.5 \cdot \left(A - Be^{-C\varepsilon_p}\right)$$

$K = 350$
$\varepsilon_0 = 0.01$
$n = 0.22$
$A = 162$
$B = 72$
$C = 4.3$



Best-fit for comparison of geometrical deviations

*CONTROL_FORMING_BESTFIT

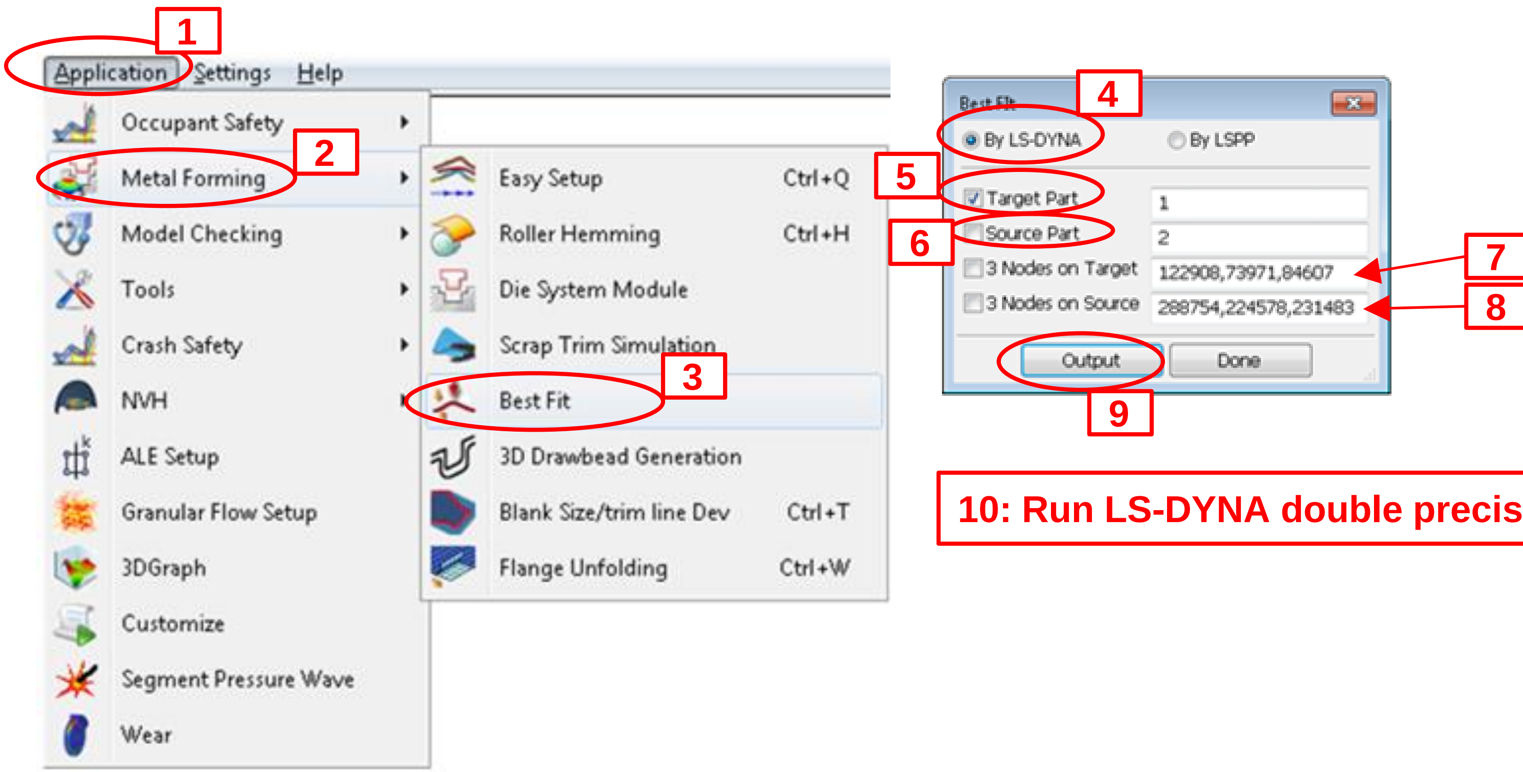
- Comparison of geometries from simulation and scan of real part.

- Rigidly moves a source (mesh) to the target (e.g. STL) so they maximally coincide:
  - Source mesh: predicted springback shape (e.g. dynain file)
  - Target mesh: scan data (e.g. stl file)
  - Result file: bestfit.out (dynain file with shell thickness as normal deviations between the two parts)

- Limitations:
  - shell elements only
  - double precision only.

- Available now in LS-PrePost 4.3 in Metal Forming Application/eZ Setup.

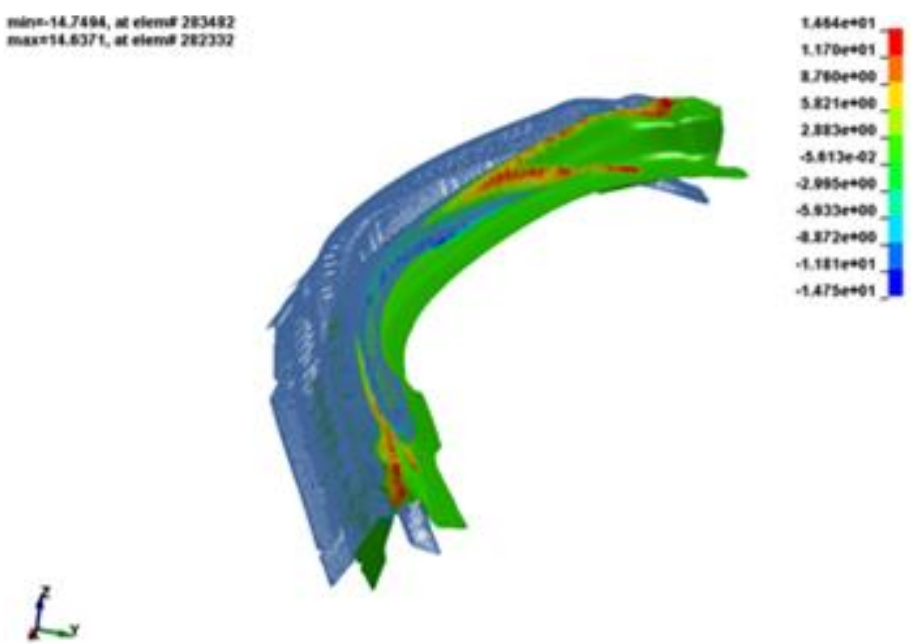
LS-PrePost interface for *CONTROL_FORMING_BESTFIT



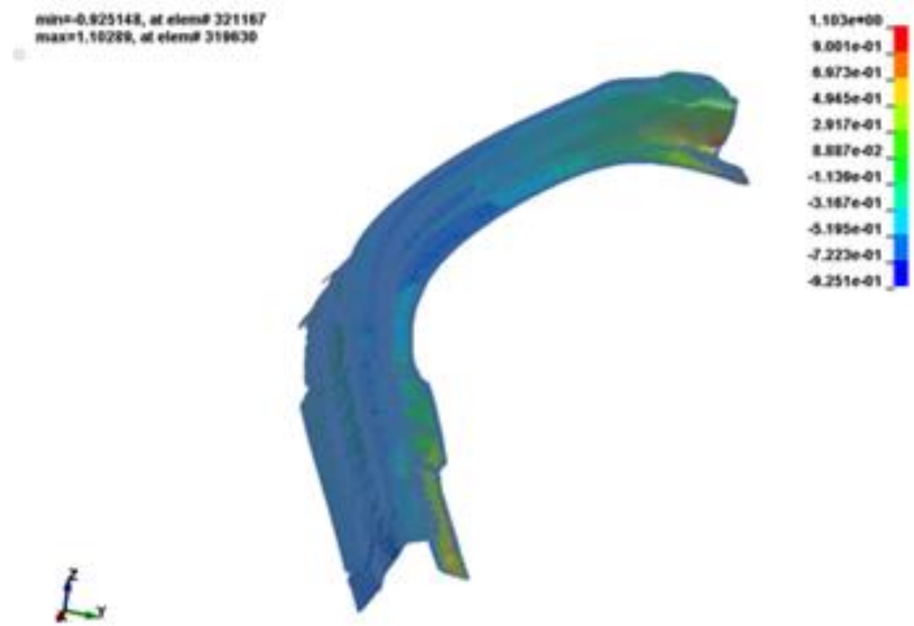
10: Run LS-DYNA double precision.

Example for *CONTROL_FORMING_BESTFIT

Before best fit



After best fit



Deviation
Before: (-14.75, 14.64)
After: (-0.925148, 1.10289)

Improvements for One-Step solver

*CONTROL_FORMING_ONESTEP_***OPTION**

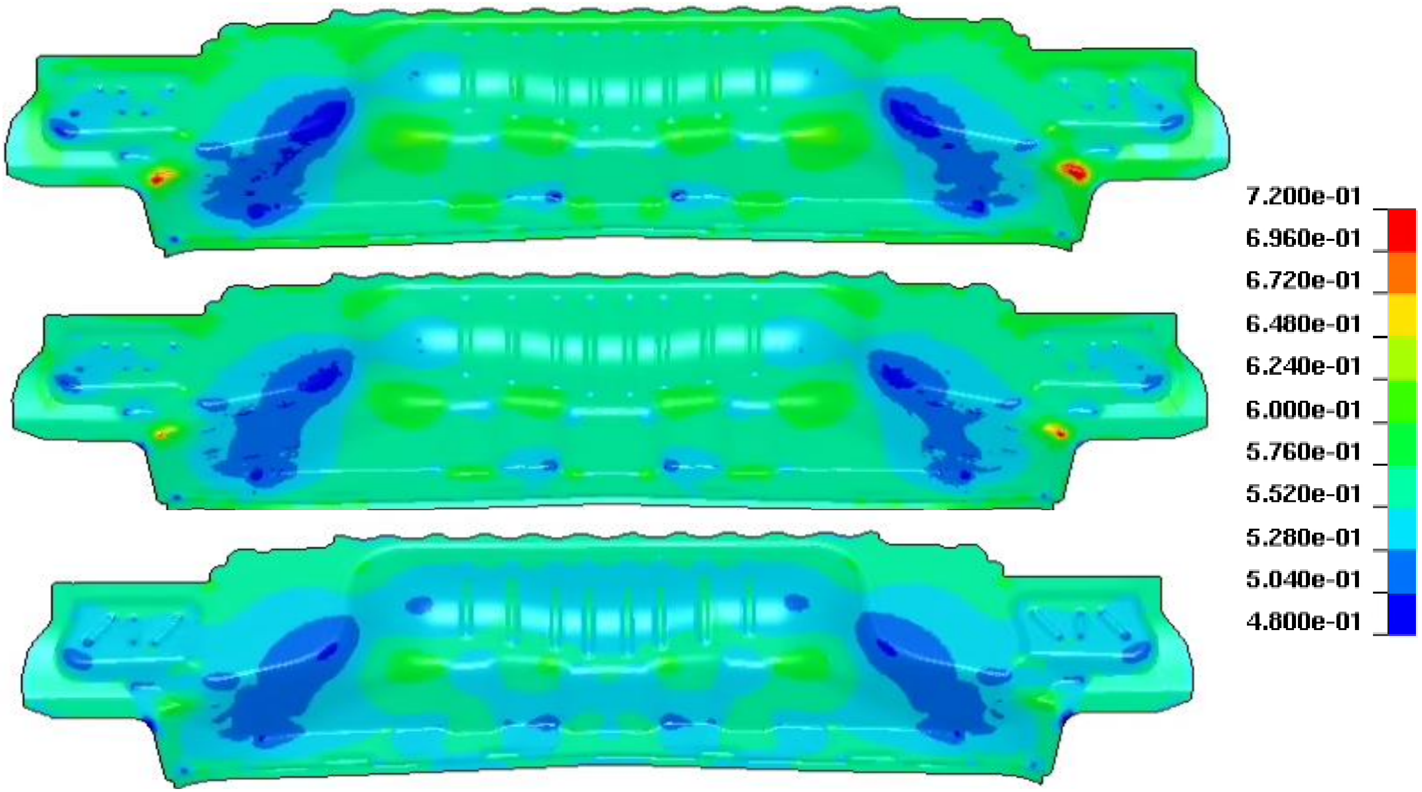
- *CONTROL_FORMING_ONESTEP_**TRIA**
  - activates original implementation from 2011
  - all quadrilateral elements are internally split into 2 triangular elements

- *CONTROL_FORMING_ONESTEP_**QUAD**
  - quadrilateral elements with improved algorithm
  - better results
  - Improved calculation speed on multiple CPUs/Cores (SMP)

- *CONTROL_FORMING_ONESTEP_**QUAD2**
  - Further improved element formulation but slightly longer CPU times than option QUAD
  - Better prediction of thinning and plastic strains
  - New default

*CONTROL_FORMING_ONESTEP_***OPTION***

- **TRIA**
- **QUAD**
- **QUAD2**



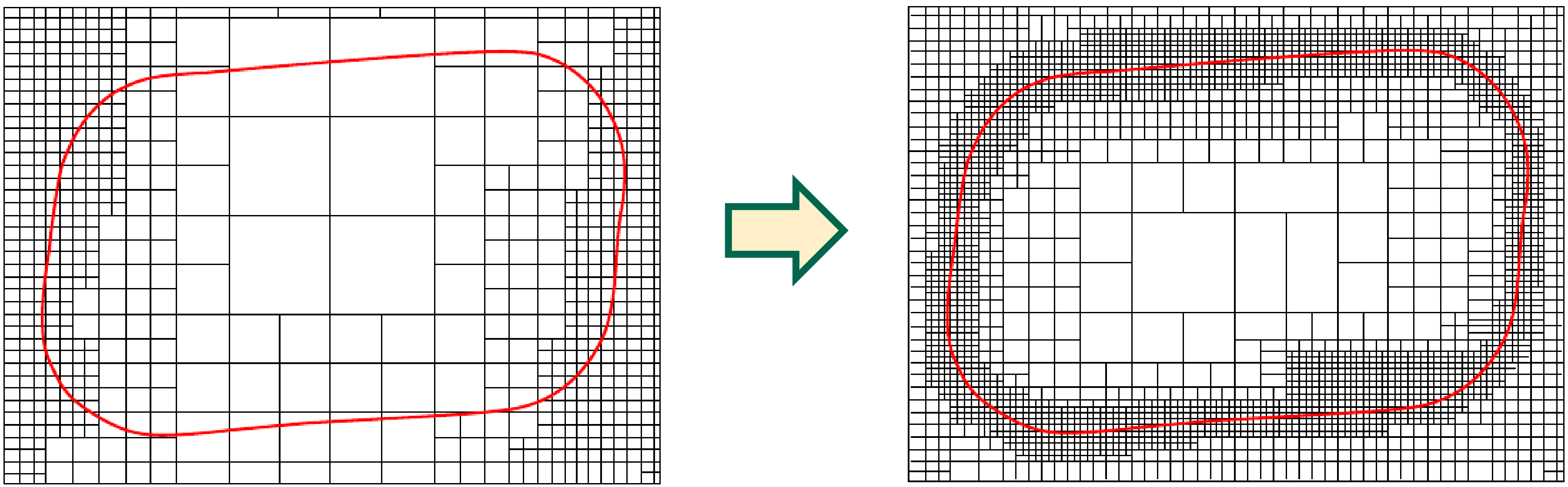
	Number of elements	Calculation speed (D.P. SMP Rev.112720, 8 CPUs)		
		Option TRIA	Option QUAD	Option QUAD2
A hat shape part	71000	21.0 min	14.1 min	16.6 min
A upper dash panel	61700	24.5 min	11.5 min	17.2 min

Uniform mesh refinement of selected region

*CONTROL_ADAPTIVE_CURVE

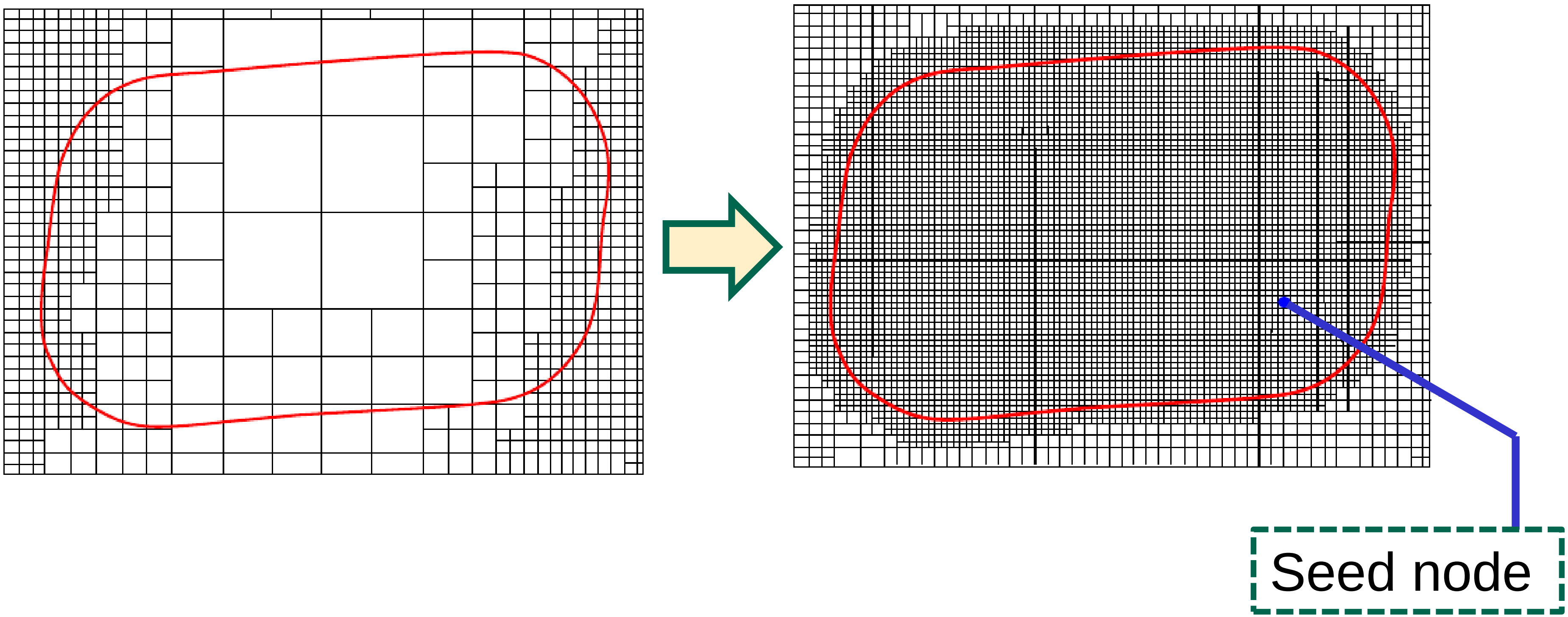
Card 1	1	2	3	4	5	6	7	8
Variable	IDSET	ITYPE	N	SMIN	ITRIOPT			
Type	I	I	I	F	I			

- ITRIOPT=0 ➔ Refine shell elements along a curve



*CONTROL_ADAPTIVE_CURVE

- ITRIOPT=1 ➔ Refine shell elements along and inside a curve loop
  - Seed node has to be defined

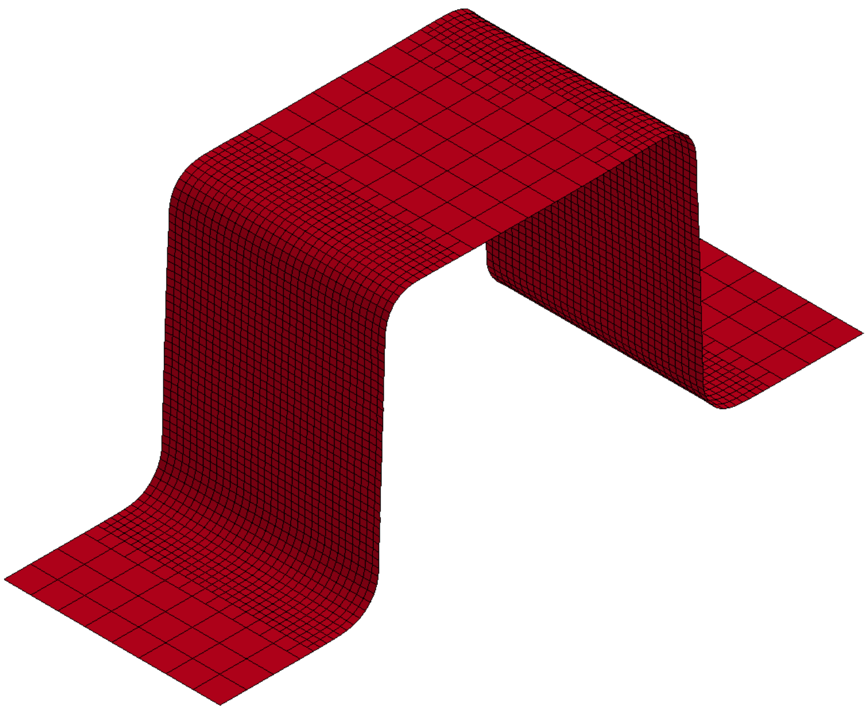


Mesh fusion

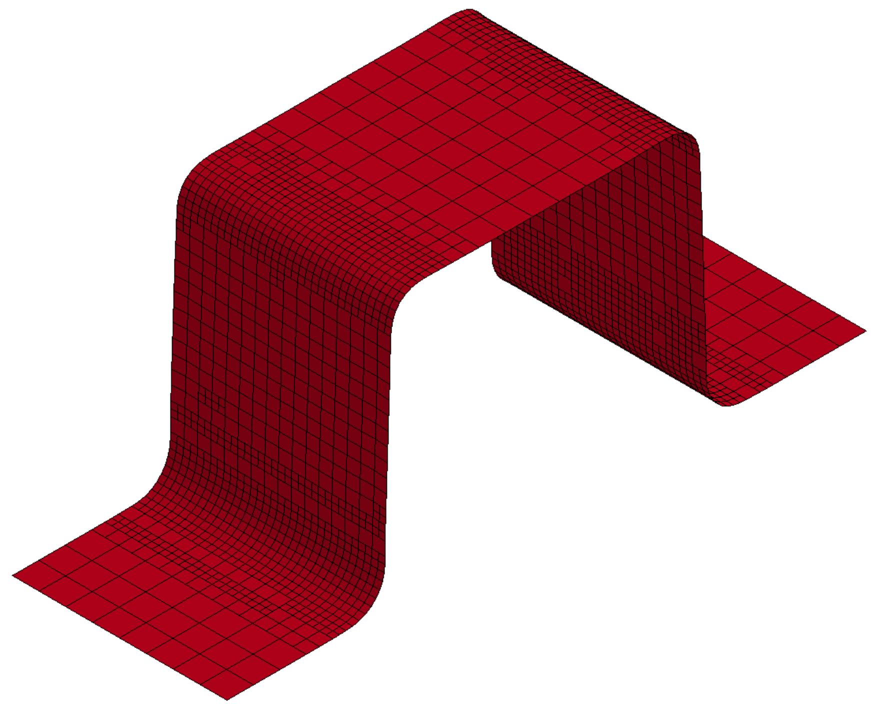
Mesh fusion

- Mesh fusion so far was available for **SMP** only
- Now mesh fusion also is available for **MPP**
- Fusion can be configured via `*CONTROL_ADAPTIVE`

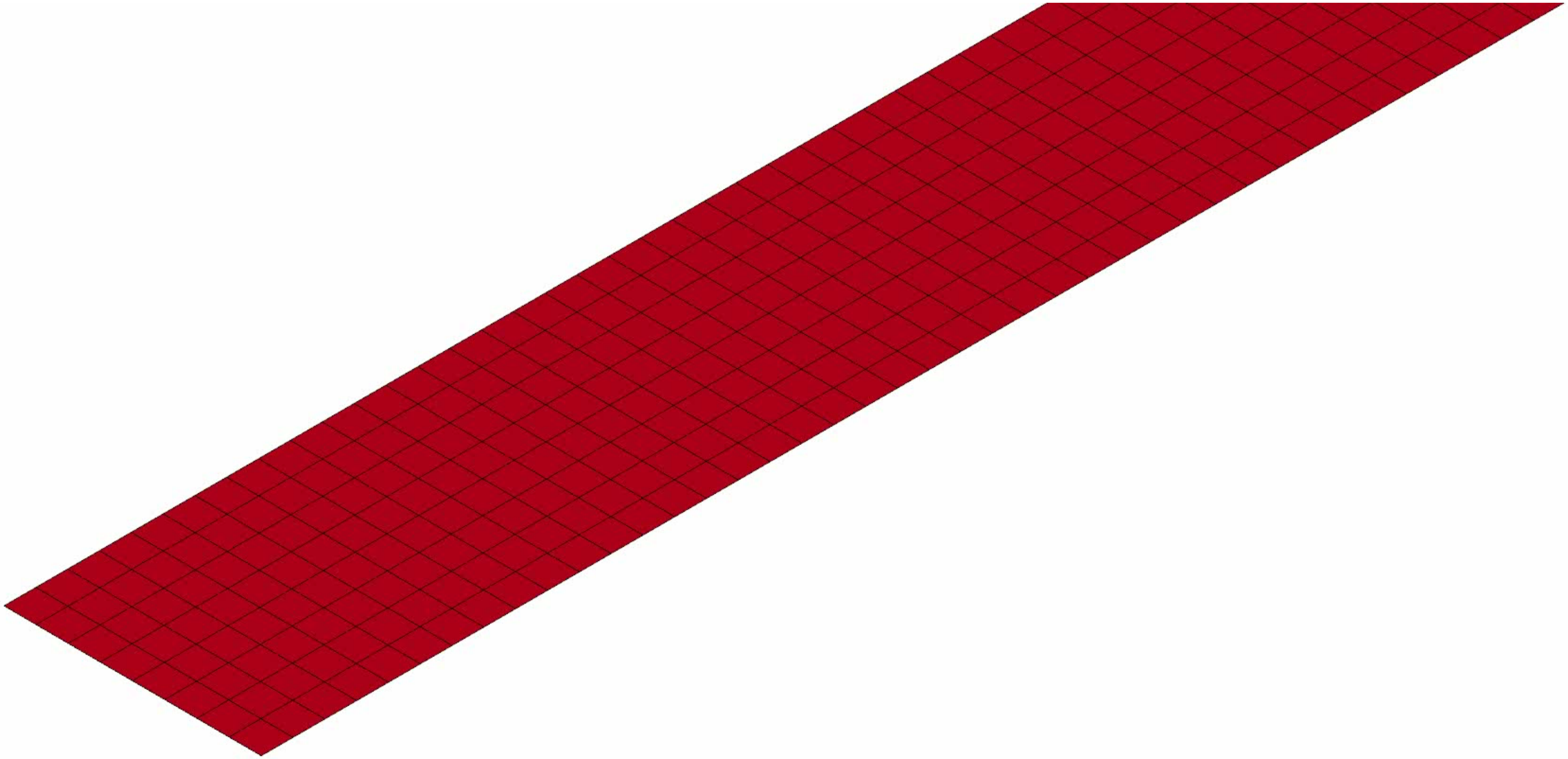
without fusion



with mesh fusion

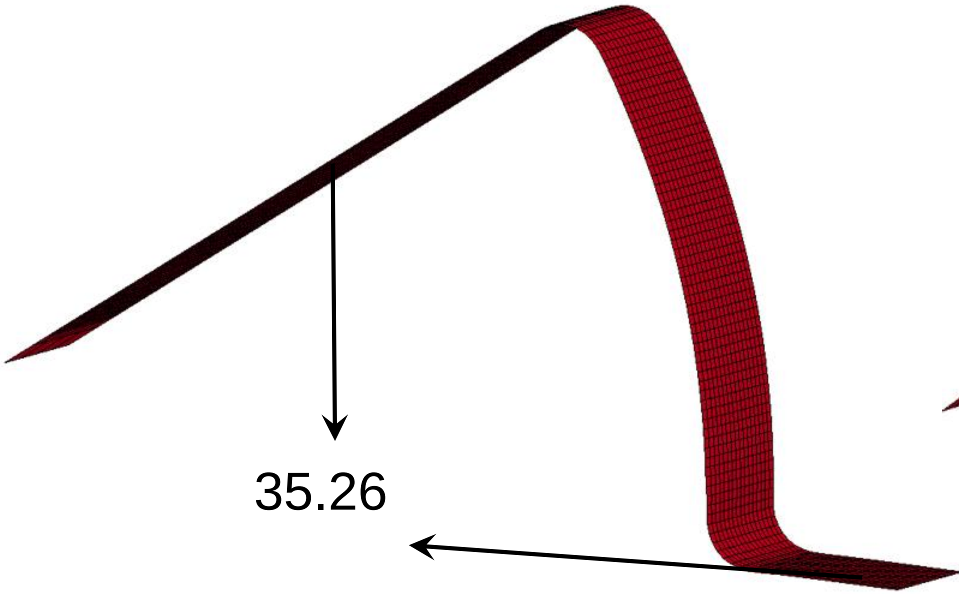


Mesh fusion



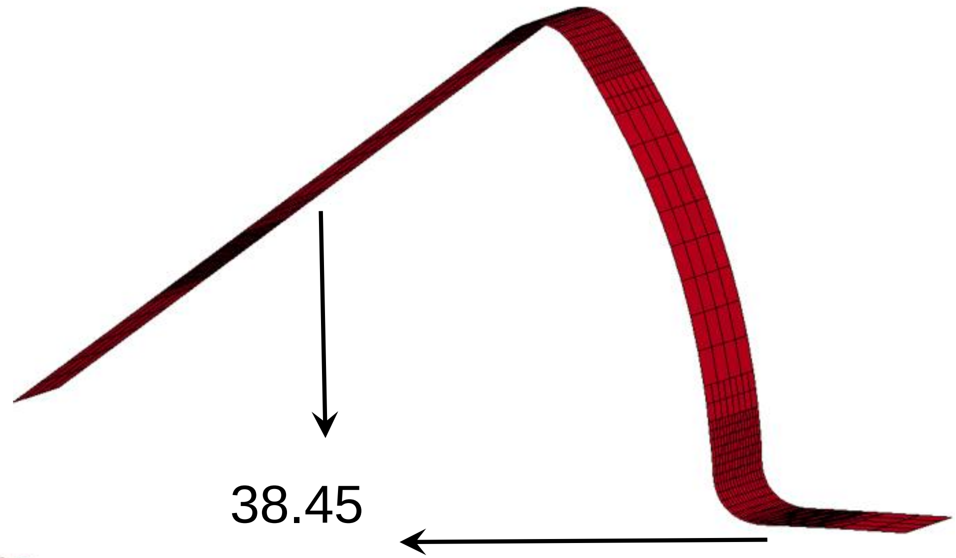
Mesh fusion

Springback **without** fusion



Final number of shell elements = **2476**

Springback **with** mesh fusion

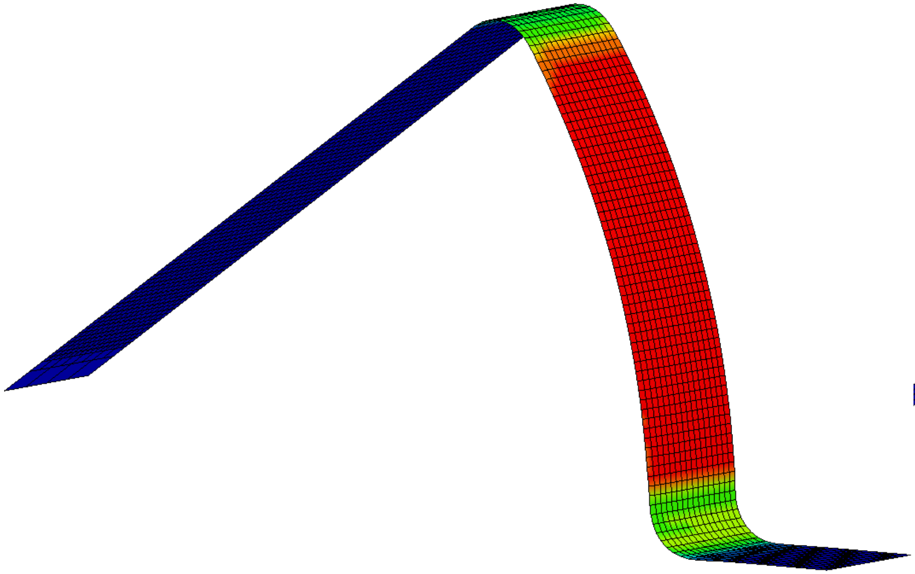


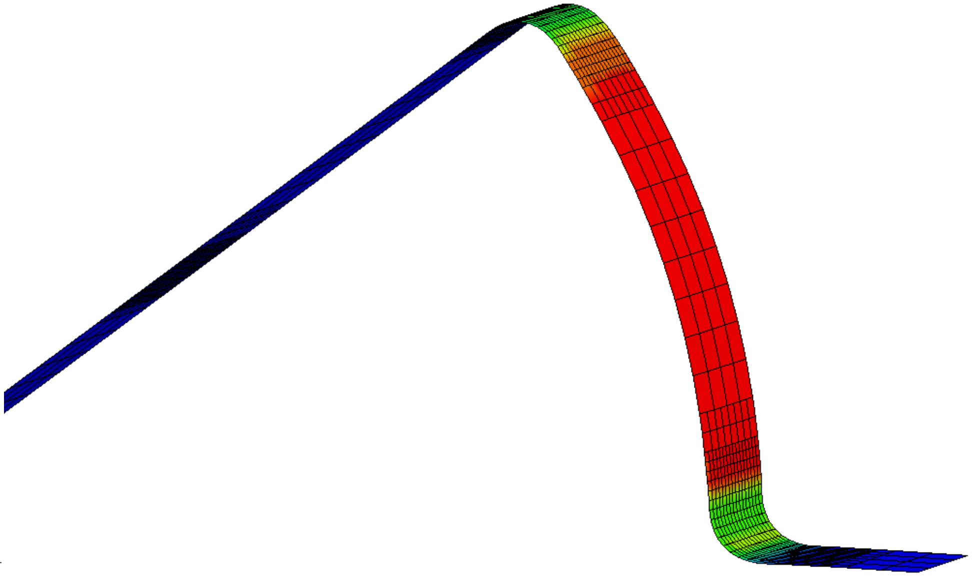
Final number of shell elements = **1000**

Mesh fusion

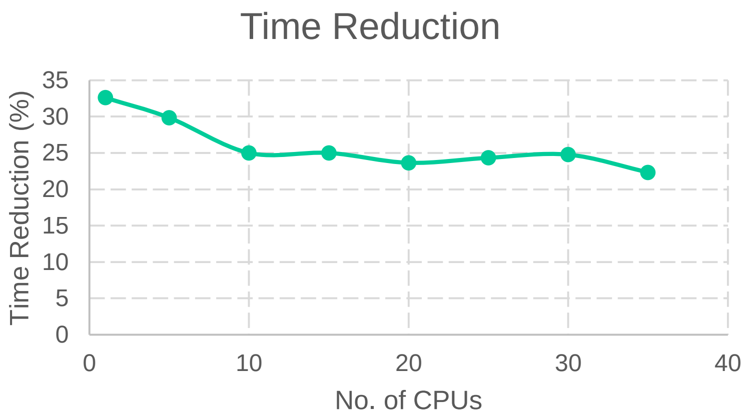
effective plastic strain
without fusion

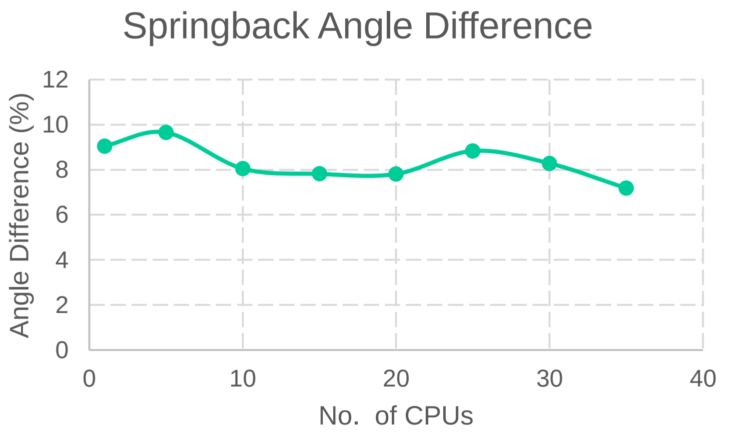
effective plastic strain
with mesh fusion

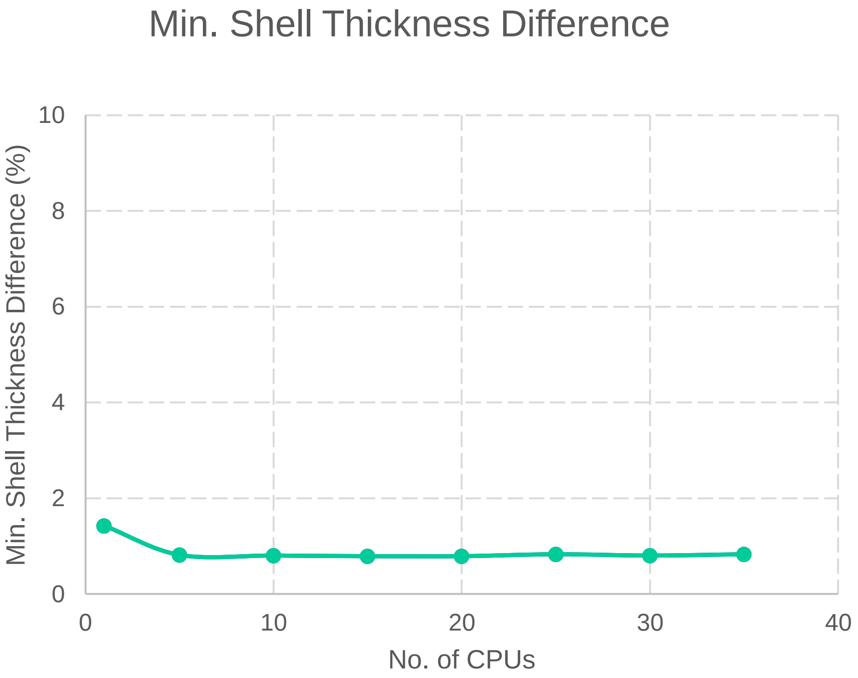




Mesh fusion





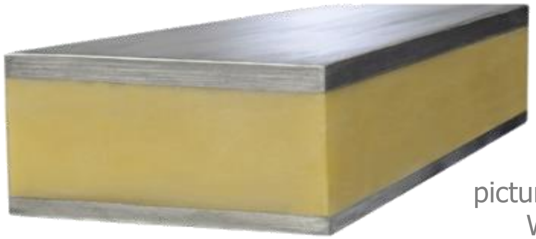


- Significant reduction in CPU cost
- No obvious difference in thinning and plastic strain prediction

Adaptivity and Trimming for sandwich sheets

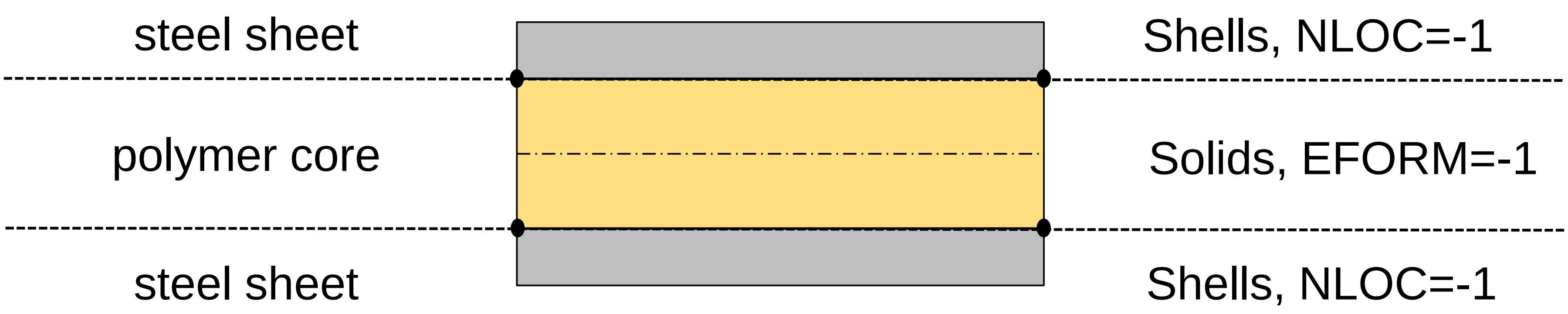
Sandwich sheets

- Sandwich: top and bottom steel sheets and a polymer core



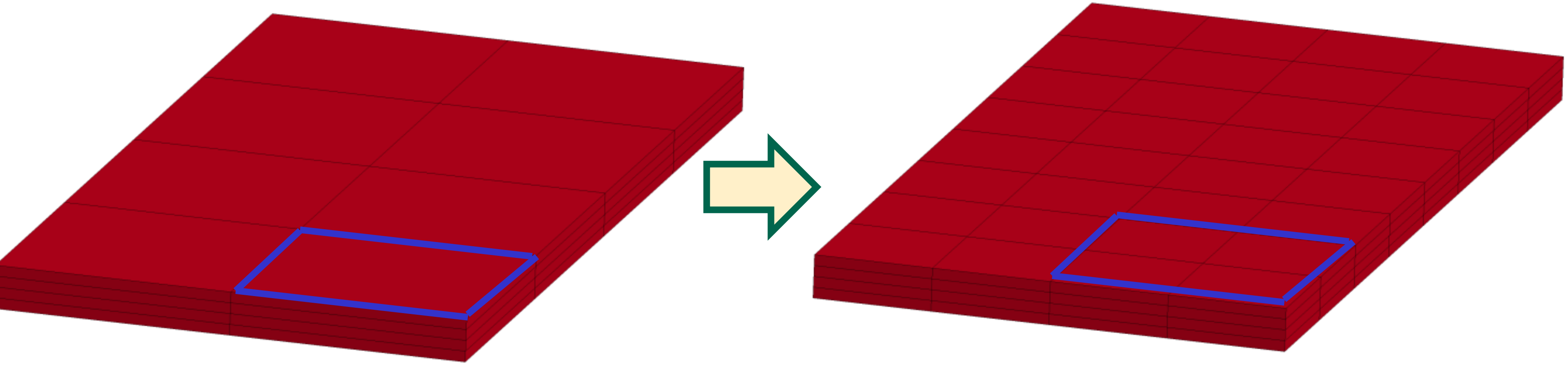
picture credit:
Wikipedia

- Modeling of sandwich sheets:
  - Top and bottom steel sheets: shell elements
  - Polymer core: solid elements

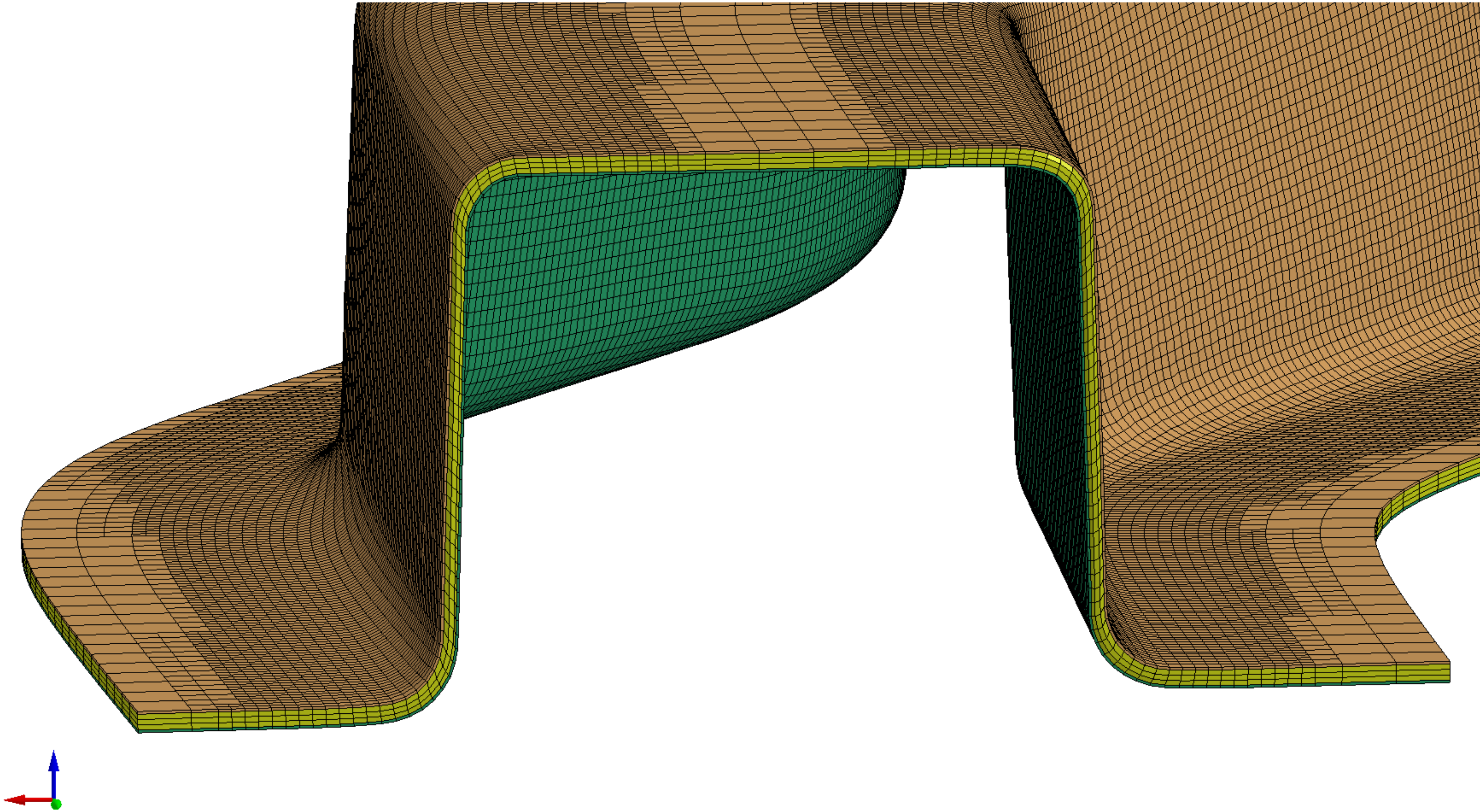


Adaptivity for sandwich sheets

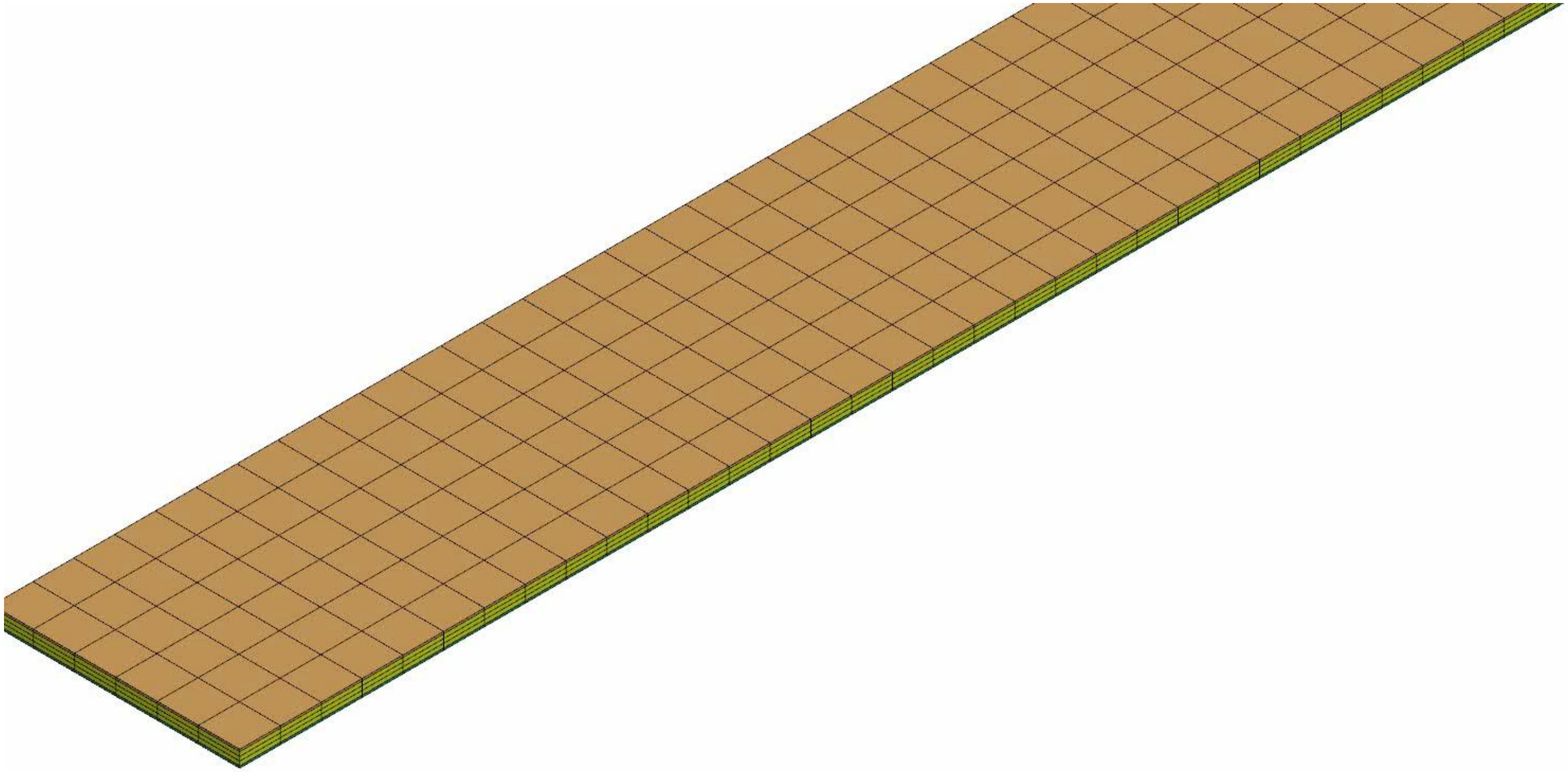
- Option **IFSAND**=1 on `*CONTROL_ADAPTIVE` for adaptive refinement
- Mesh refinement only can happen in the plane of the sheet
- No refinement in the thickness direction
- One solid element is split into 4 solid elements
- Recent improvements:
  - Adaptivity so far was only possible for one solid element over thickness of core
  - Recently adaptivity was extended to multi-layer of solid elements
- Works for both SMP and MPP



Adaptivity for sandwich sheets

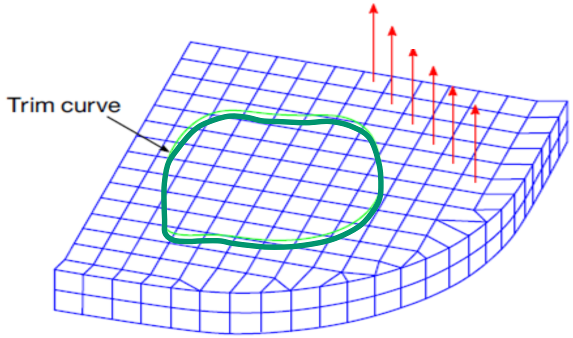


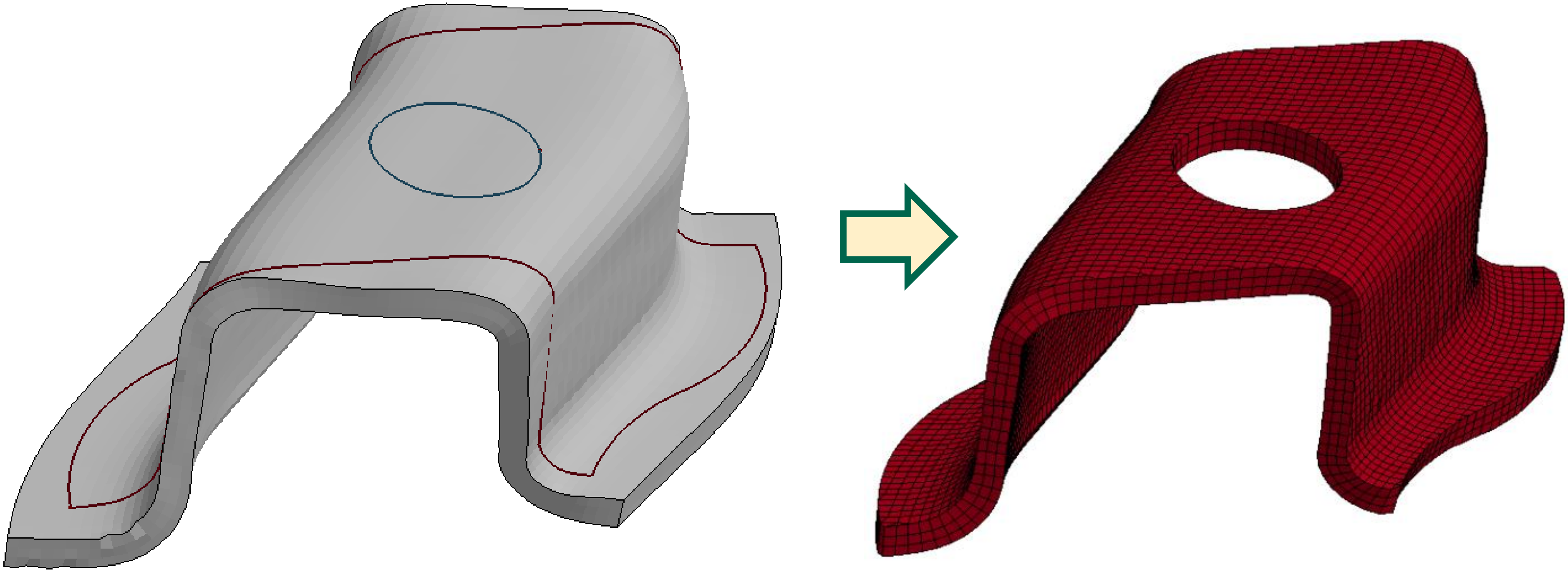
Adaptivity for sandwich sheets



Trimming of sandwich sheets

- 2D and 3D trimming of sandwich sheet and solids
- Definition is similar as for trimming of shell elements
- Additional input to indicate solid normals: TDIR on `*DEFINE_CURVE_TRIM_3D`

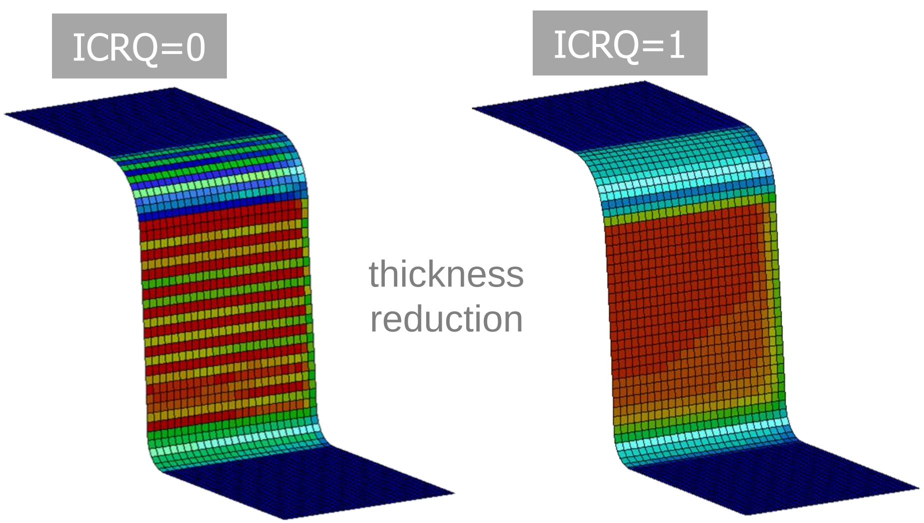


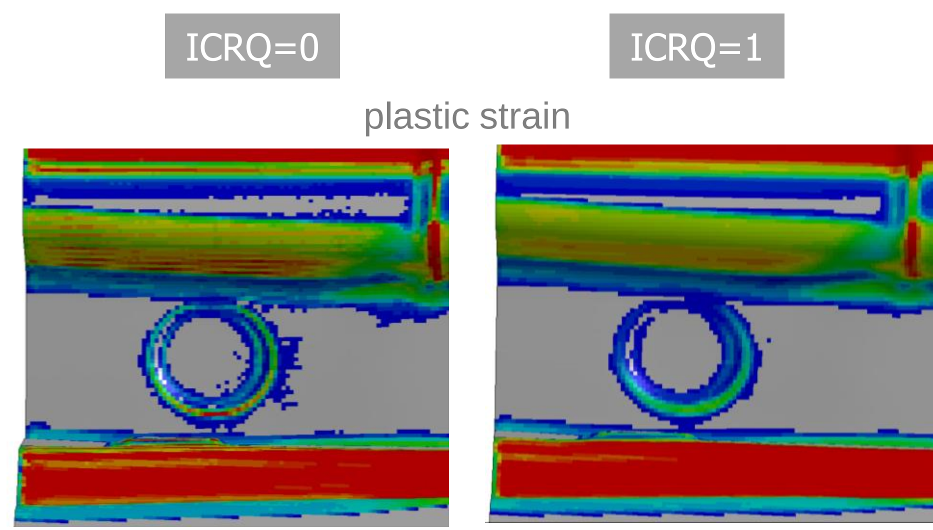


Miscellaneous

Continuous result quantities

- New option ICRQ on *CONTROL_SHELL
  - Continuous treatment of thickness and plastic strain across element edges for shell element formulations 2, 4, and 16 with max. 9 integration points through the thickness
  - Reduces alternating weak localizations sometimes observed in <u>metal forming applications</u> when shell elements get stretch-bended over small radii
  - Similar to MAT_NONLOCAL





Miscellaneous

- Improvements to *CONTROL_FORMING_AUTOCHECK
  - E.g. output rigid tool mesh in offset position
- *BOUNDARY_SPC_SYMMETRY_PLANE_SET
  - Possibility to define symmetry constraints for part set, e.g. tailor welded blanks
- *CONTROL_FORMING_SHELL_TO_TSHELL
  - Automatically change from shell to thick shell elements
- New option *INTERFACE_SPRINGBACK_EXCLUDE to exclude selected portions from the generated dynain file

Thank you for your attention!