Accurate Single Point Incremental Forming Simulations using Solid-Shell Elements

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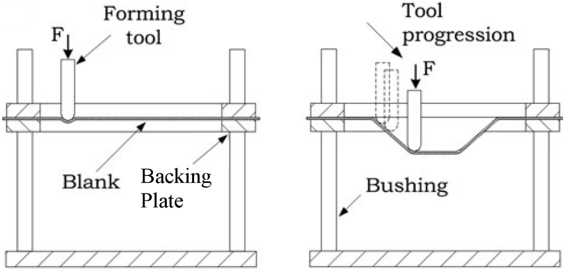
September 11th, 2013

Presentation contents

Contents

Single point incremental forming

- A sheet metal is deformed by a small tool.
- The tool could be guided by a CNC (milling machine, robot).



[Henrard et al., 2010]

Single point incremental forming

- **Dieless**, with high sheet formability.
- Easy shape generation.
- For rapid prototypes, small batch productions, etc.

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- Geometrical inaccuracy.
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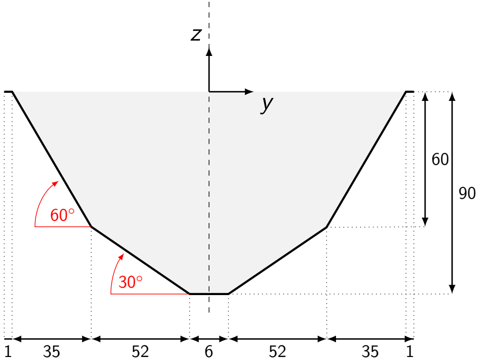
Motivations

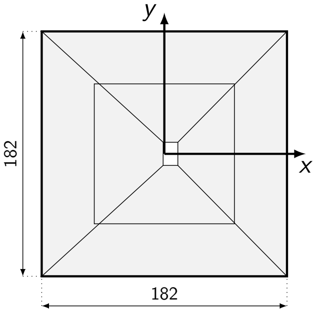
- Through the thickness gradient are important.
- 2D constitutive laws cannot be used.
- New advances on element formulation in FE codes.

Contents

Simulations

- Material: DC01 ferritic steel (1 mm thickness).
- Two slope pyramid:





Constitutive modeling

- Isotropic elasto-plastic constitutive law (`HILL3D_KI.F`).
- Voce and Armstrong-Frederick isotropic/kinematic hardening.

$$\sigma_Y = \sigma_{Y0} + K\left(1 - \exp\left(-n\epsilon^P\right)\right)$$

$$\dot{\mathbf{X}} = C_x\left(X_{sat}\dot{\boldsymbol{\epsilon}}^P - \dot{\epsilon}^P\mathbf{X}\right)$$

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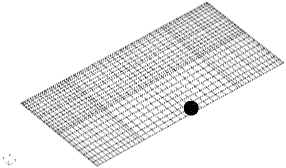
- Material parameters:

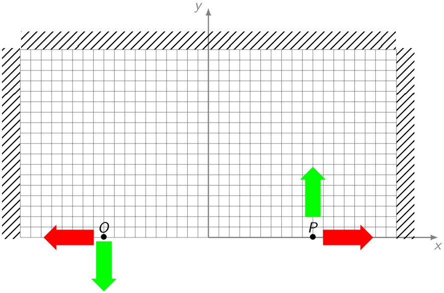
$$\begin{array}{lcl lcl} \sigma_{Y0} & = & 158\,\text{MPa} & C_x & = & 257 \\ K & = & 255\,\text{MPa} & X_{sat} & = & 4\,\text{MPa} \\ n & = & 13 & & & \end{array}$$

- Identification through *classical* (tensile, monotonic/Bauschinger shear) tests (`OPTIM`).

Mesh and boundary conditions

- Displacement-controlled implicit simulation.
- One layer with 2248 elements.
- Symmetry and rotational boundary conditions (`BINDS.F`):

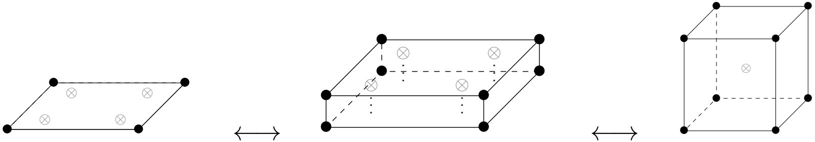




Solid-shell element

Formulation

- Large aspect ratios $\Longrightarrow$ locking
- Enhanced Assumed Strain (EAS)
- Assumed Natural Strain (ANS)



Shell element $\longleftrightarrow$ *Solid-shell* $\longleftrightarrow$ *Brick element*

Assumed natural strain

$$\begin{tikzcd}
\mathbf{U} \arrow[r, "\mathbf{B}"] \arrow[dr, bend right, "\mathbf{B}^{ANS}"'] & \epsilon^{com} \arrow[d, "\text{linear interpolation}"] \\
& \epsilon^{ANS}
\end{tikzcd}$$

Assumed natural strain

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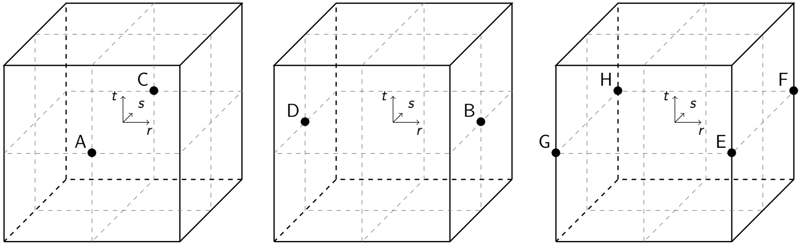
$$

Sampling points (transverse shear and transverse normal strains):



Enhanced assumed strain

Enhanced strain field

$$\boldsymbol{\epsilon} = \boldsymbol{\epsilon}^{com} + \boldsymbol{\epsilon}^{EAS}$$

$$\boldsymbol{\epsilon}^{com} = \Delta^s \mathbf{u} = \mathbf{B}(r, s, t)\mathbf{U}$$

$$\boldsymbol{\epsilon}^{EAS} = \mathbf{G}(r, s, t)\boldsymbol{\alpha} = \frac{|\mathrm{J}_0|}{|J(r, s, t)|}\mathbf{F}_0^{-T}\mathbf{M}(r, s, t)\boldsymbol{\alpha}$$

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$$[\mathbf{M}] =$$

$$\begin{bmatrix}
r & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & rs & rt & 0 & 0 & 0 & 0 & 0 & 0 & 0 & rst & 0 & 0 & 0 & 0 & 0 \\
0 & s & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & rs & st & 0 & 0 & 0 & 0 & 0 & 0 & rst & 0 & 0 & 0 & 0 \\
0 & 0 & t & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & rt & st & 0 & 0 & 0 & 0 & 0 & rst & 0 & 0 & 0 \\
0 & 0 & 0 & r & s & 0 & 0 & 0 & 0 & rt & st & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & rs & 0 & 0 & 0 & 0 & 0 & rst & 0 & 0 \\
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03 EAS modes

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11 EAS modes

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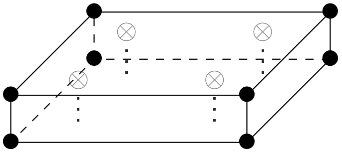
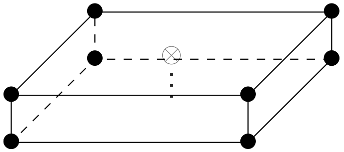
\end{bmatrix}$$

24 EAS modes

	SSH3D	**RESS**
Enhanced Assumed Strain (EAS) modes	24	1
Assumed Natural Strain (ANS) version	4	-
In-plane integration	full	reduced*
Stabilization technique	-	Yes



SSH3D.F



RESS3.F

Running simulations

Not easy...

- Complex toolpath and small contact zone.
- Several time increments.
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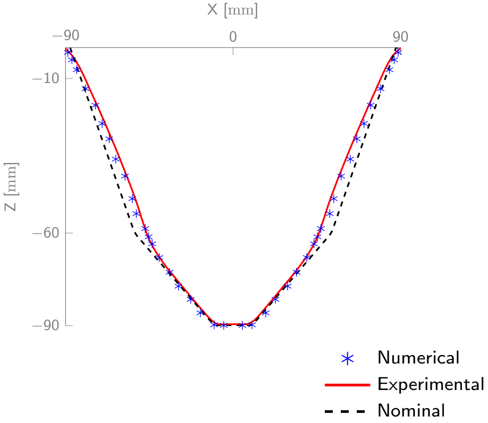
NIC machine

- Near 1000 cores and 5 Tb memory.
- LAGAMINE (and PREPRO) compiled in `Linux`.
- Possibility of using other machines (Lemaître-UCL,...)

Contents

Shape results

Numerical/experimental (DIC) comparison $Y = 0$



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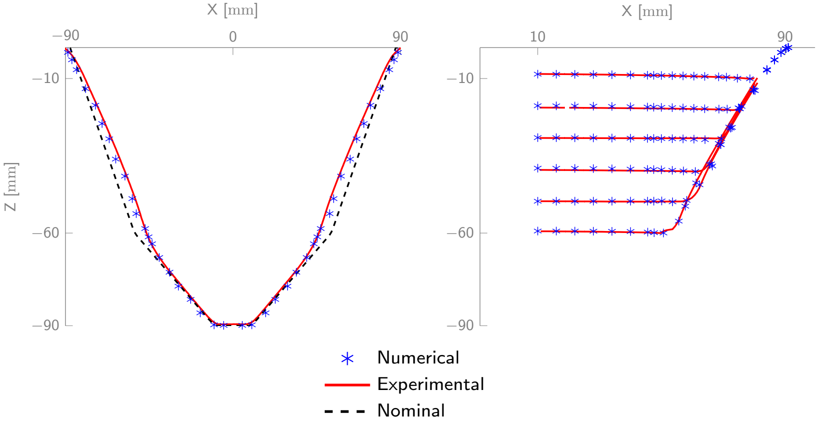

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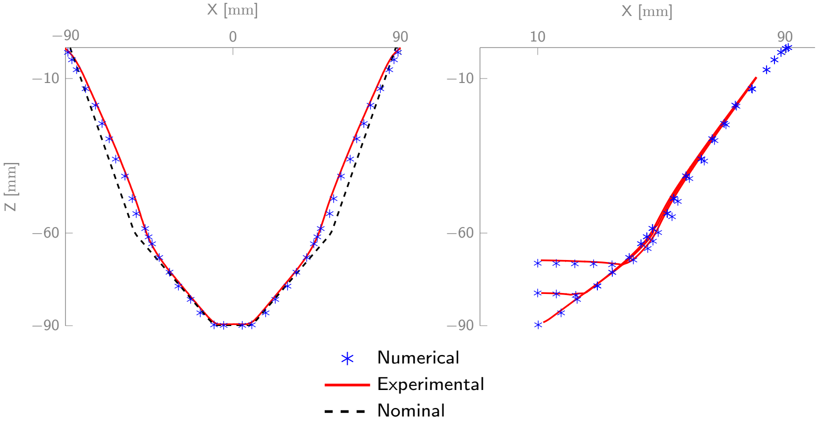
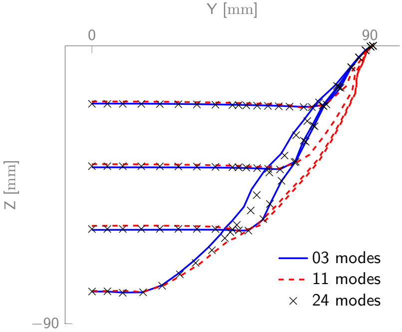
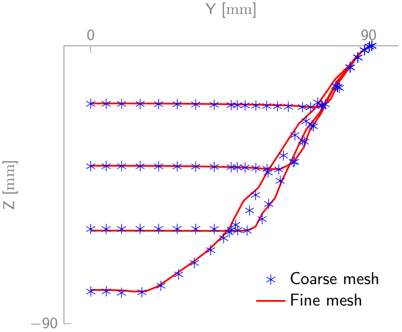


EAS and mesh influence

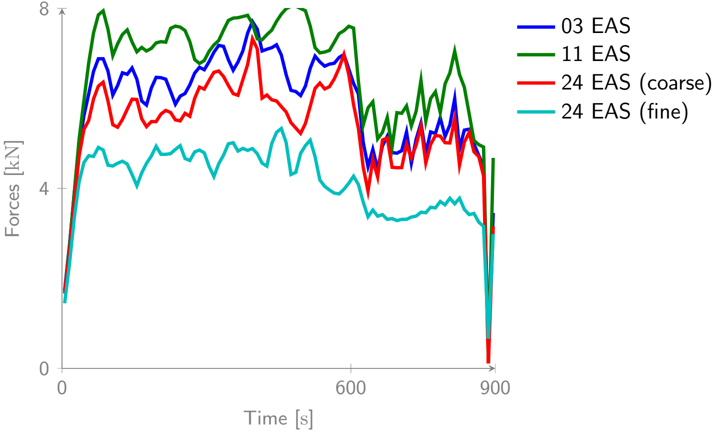
- Strong EAS mode influence.
- Small mesh influence.





Force evolution

- Both EAS modes and mesh influence.



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Conclusions

- EAS modes influence the accuracy of the results.
- The elements are subjected to deformation modes reproduced only using the EAS technique.
- ANS version has no effect on both the shape and the force.
- Material identification procedure important.

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- Material identification procedure important.

Future work

- Identify the most important EAS modes.
- Improve identification procedure to consider out-of-plane stresses.

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References

Henrard, C., Bouffioux, C., Eyckens, P., Sol, H., Duflou, J., van Houtte, P., Van Bael, A., Duchêne, L., Habraken, A. M., Dec. 2010. Forming forces in single point incremental forming: prediction by finite element simulations, validation and sensitivity. Computational Mechanics 47 (5), 573–590.