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Numerical Simulation of a Conical Shape Made by Single Point Incremental Forming

Adaptive Remeshing technique with solid-shell elements

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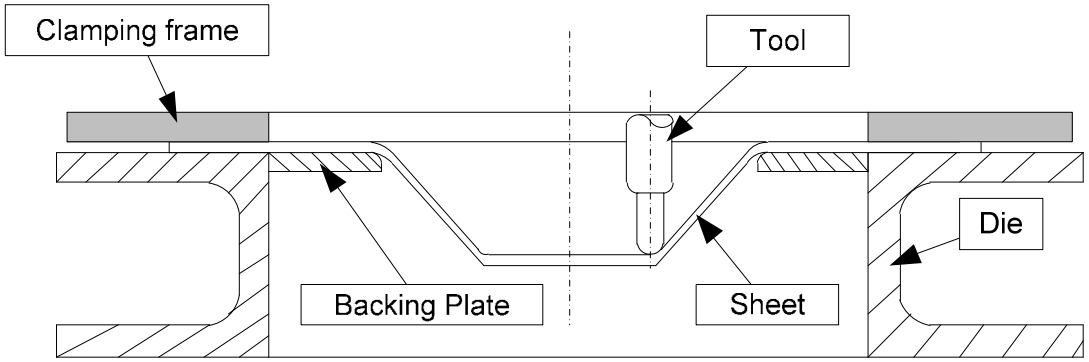
Contents

➢ Single point incremental forming (SPIF) sheet forming process adapted for rapid prototyping. Neither dies nor punches to form a complex shape.



➢ Tool guided by numerical control system, forming tool deforms a clamped sheet into its desired shape

➢ High deformations occur close to the current location of the tool.

Work Scope

- PROBLEM:

  - Moving contact between the tool and the sheet
  - The nonlinearities

  } Refined mesh near the tool

- First Adaptive SPIF Remeshing : only for Shell finite elements*.

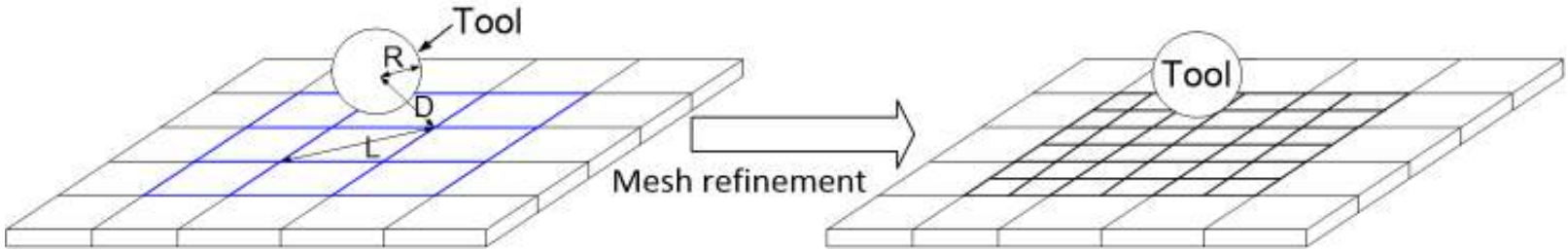
- Now : extension to 8 nodes 3D finite elements= RESS (Reduced Enhanced Solid-Shell).

- RESS + Remeshing ADVANTAGES :
  - Use a 3D constitutive law
  - Prediction of the sheet thickness
  - Decrease the CPU time

*see Cedric Lequesne *et al.*, Numisheet 2008, Switzerland, September 1 - 5, 2008.

Refinement / Unrefinement Criterion

- Selection of a neighborhood around the position of the tool center.
- Mesh dynamically refined on the tool vicinity



- Proximity condition :

$$D^2 \leq \alpha (L^2+R^2)$$

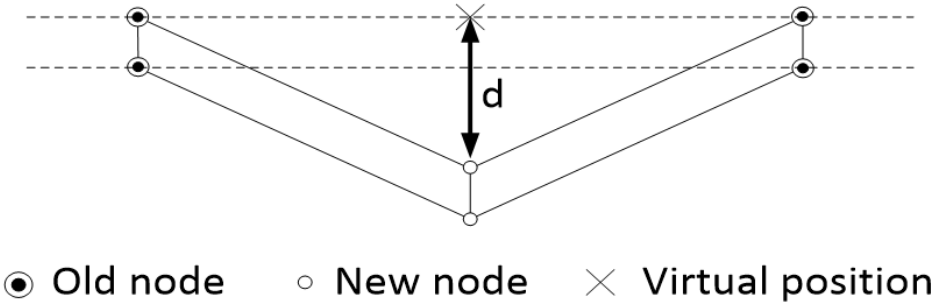
- **D**: minimum distance between the tool center and the four nodes of the contact element
- **L**: length of the longest diagonal of the element
- **R**: radius of the tool
- **α**: coefficient adjusting the size of the neighborhood chosen by the user

Additional Unrefinement Criterion

• To avoid losing geometric accuracy, if the mesh distortion significant keep the refined mesh elements

• Computation of the initial relative position:

$$\underline{X}_v = \sum_{i=1,4} H_i(\xi,\eta)\underline{X}_i$$



• Computation of the distance

$$d = \left|\underline{X}_c - \underline{X}_v\right|$$

• Unrefinement criterion

$$d \leq d_{max}$$

- $\mathbf{H_i}$: interpolation function
- $\mathbf{X_i}$: nodes positions of the coarse element
- $\mathbf{X_c}$: Current position of the node
- $\mathbf{d_{max}}$: maximal admissible distance chosen by the user

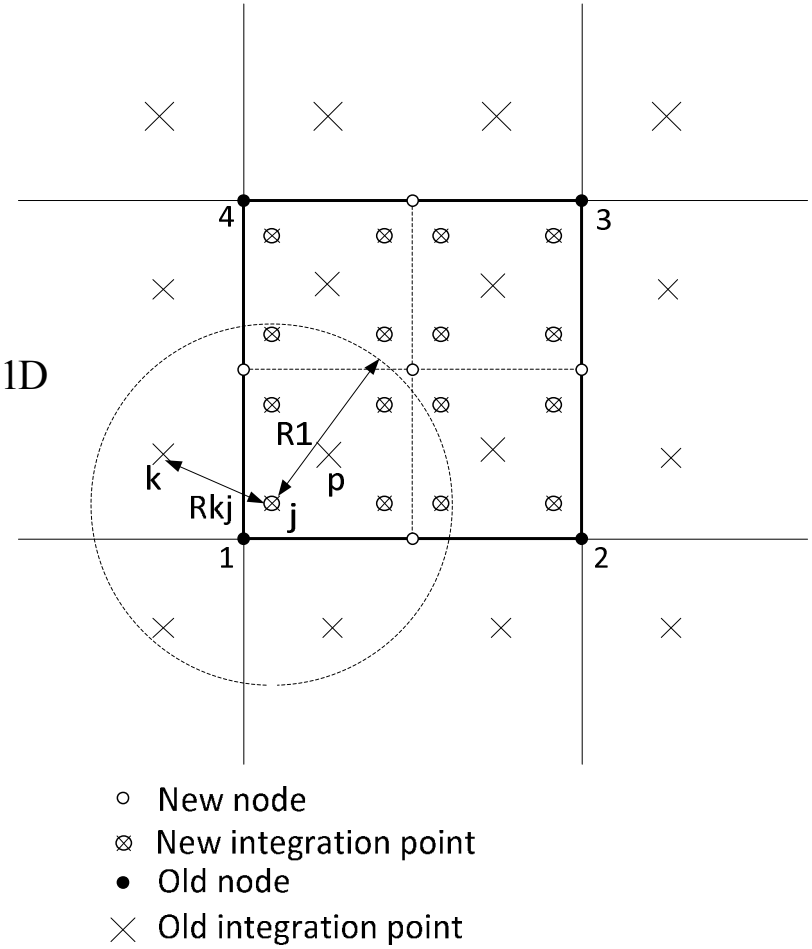
Interpolation of state variables and stress

$$Z_j = \begin{cases} \dfrac{\sum_k \dfrac{Z_k}{R_{kJ}^n} + \dfrac{CZ_p}{R_{pj}^n}}{\sum_k \dfrac{1}{R_{kJ}^n} + \dfrac{C}{R_{pj}^n}} & \text{if } R_{pj} > R_{min} \\ Z_p \text{ if } R_{pj} \le R_{min} \end{cases}$$

With :

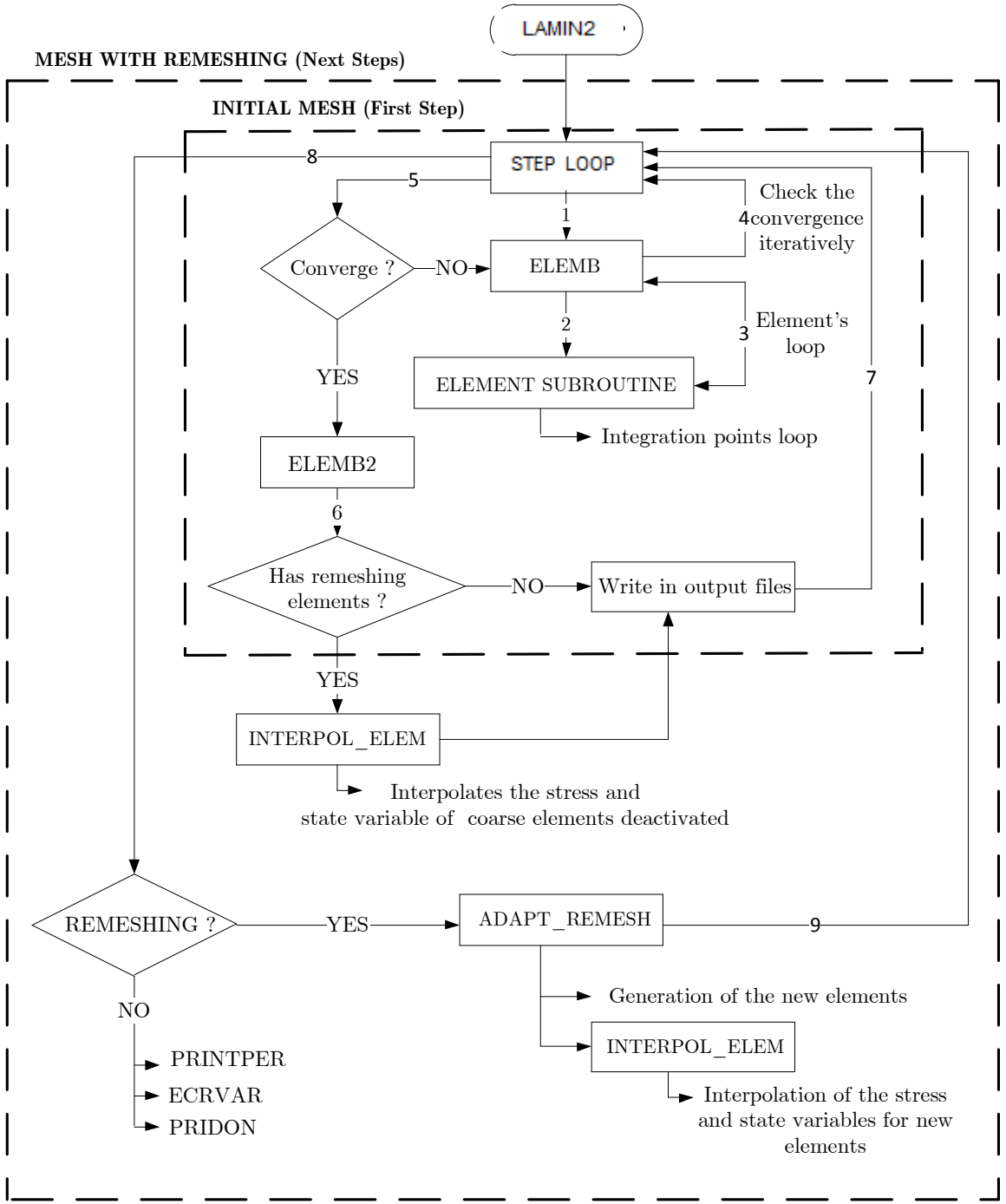
$R_1 = 1.5d$

$R_{min} = 0.0001D$



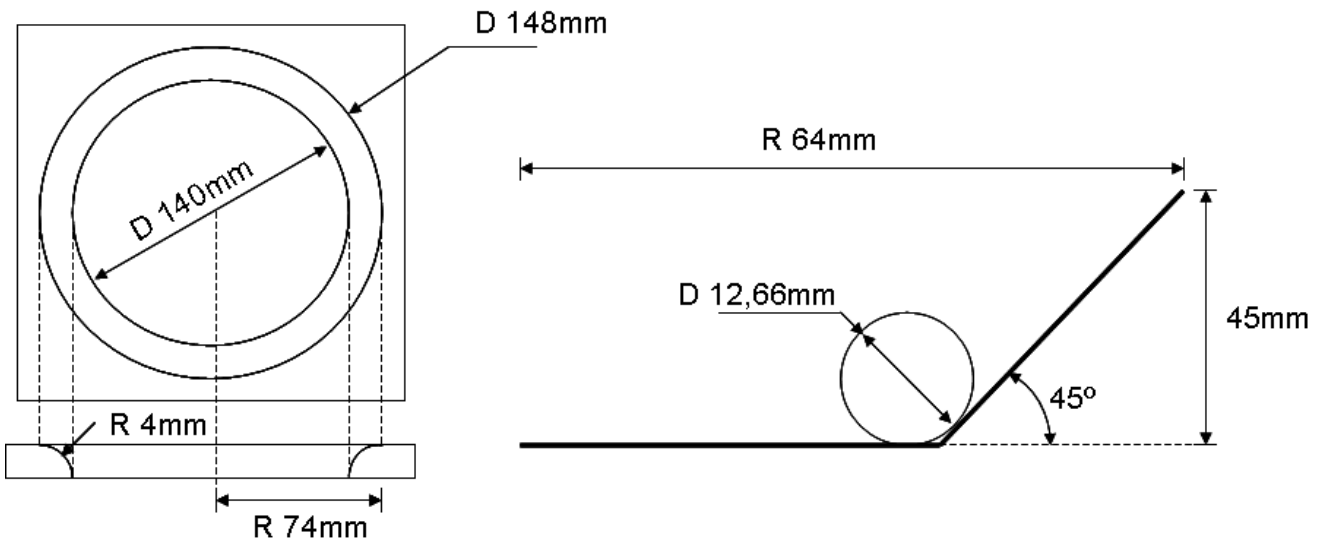
- **j**: the index of the new integration point
- **k**: the index of the integration point of another element in the sphere
- **p**: is the index of the closest integration point
- **Z_i**: stress or state variables components at the integration point j
- **R_{kj}**: distance between the integration point k and j

- **C**: coefficient defined by the user
- **n**: degree of interpolation
- **d**: highest diagonal of the element
- **D**: highest diagonal of the structure


LAMIN2
MESH WITH REMESHING (Next Steps)
INITIAL MESH (First Step)
STEP LOOP
8
5
1
Check the convergence iteratively
4
Converge ?
NO
ELEMB
2
3
Element's loop
YES
ELEMENT SUBROUTINE
7
Integration points loop
ELEMB2
6
Has remeshing elements ?
NO
Write in output files
YES
INTERPOL_ELEM
Interpolates the stress and state variable of coarse elements deactivated
REMESHING ?
YES
ADAPT_REMESH
9
Generation of the new elements
NO
PRINTPER
ECRVAR
PRIDON
INTERPOL_ELEM
Interpolation of the stress and state variables for new elements

Conical shape simulation

- Benchmark proposal from NUMISHEET 2014 conference:



- Setup description:
  - Material : Aluminium alloy AA7075-O
  - thickness: 1.6 mm
  - spherical tool radius: 6.33 mm
  - Vertical step-down of 0.5 mm (90 contours)

Material

- Material : An aluminium alloy AA7075-O

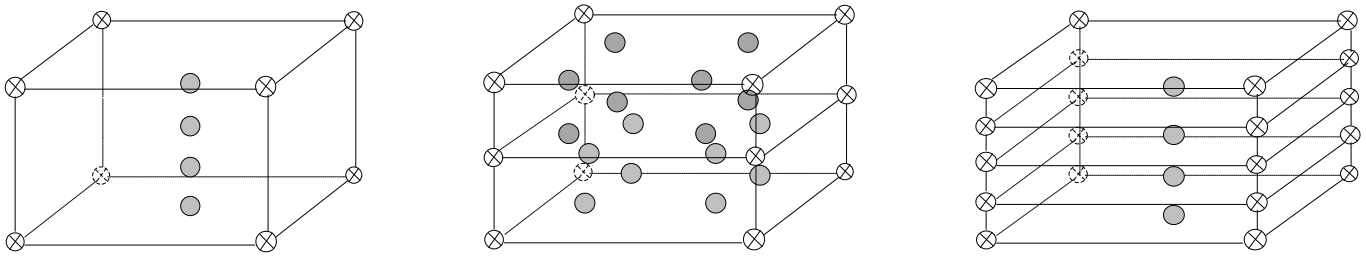
- The constitutive law: Hill (**but** Isotropic behaviour law)

- Parameters:
  Young modulus: $E_1 = E_2 = E_3 = 72000$ MPa
  Poisson ratio: $\nu_1 = \nu_2 = \nu_3 = 0.33$
  Coulomb modulus: $G_1 = G_2 = G_3 = 27067.669$ MPa

- Hardening Swift law: $\sigma_{eq} = K (\varepsilon_0 + \varepsilon_{pl})^n$ with K= 335.1 MPa,
  $\varepsilon_0 = 0.004$,
  n= 0.157

RESS (Reduced Enhanced Solid Shell)*

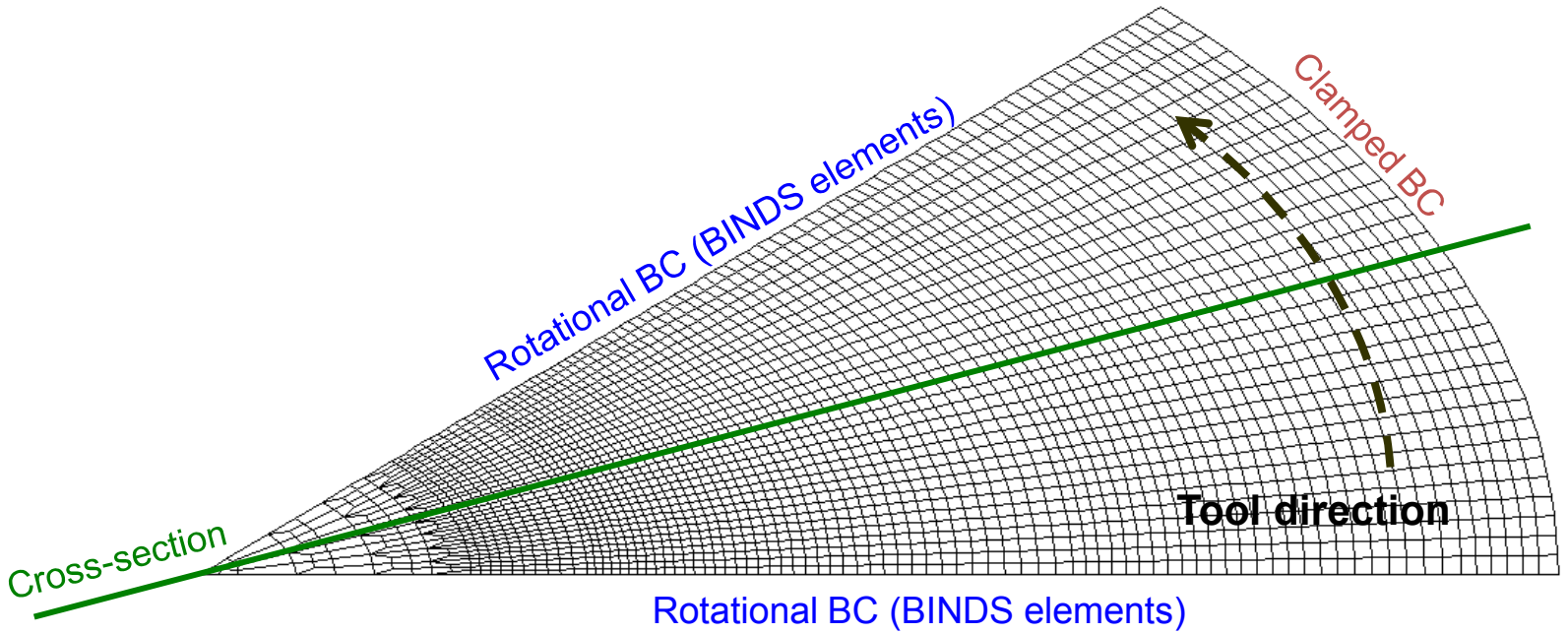
- Solid-Shell Element specially designed for metal forming applications
- Implemented in LAGAMINE code
- Integration scheme (a) advantages:
  - Reduced integration in plane
  - Arbitrary number of integration points in one single layer in thickness direction



- Combination Enhanced Assumed Strain of Simo and Rifai (1990)
- Stabilization technique

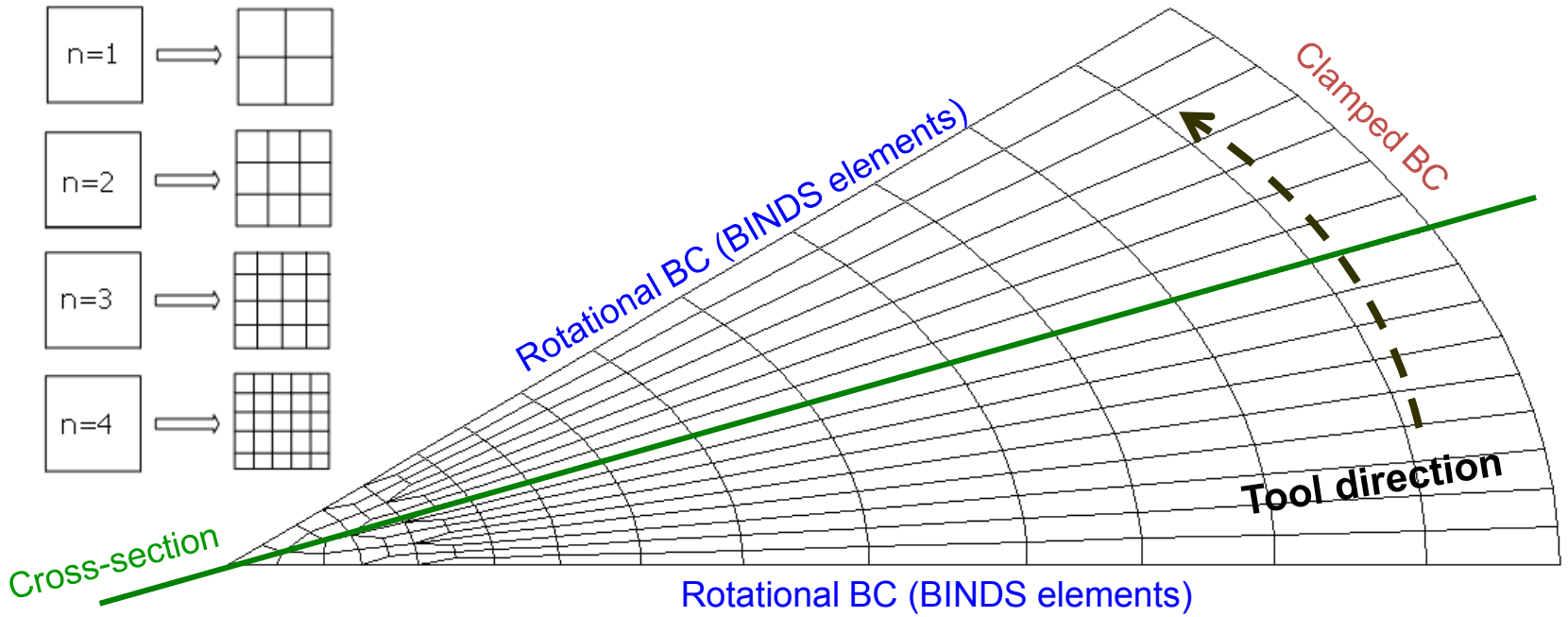
*See in Alves de Sousa R.J. *et al.* (2007), I. J. P., Vol. 23, pp. 490-515.

Meshes



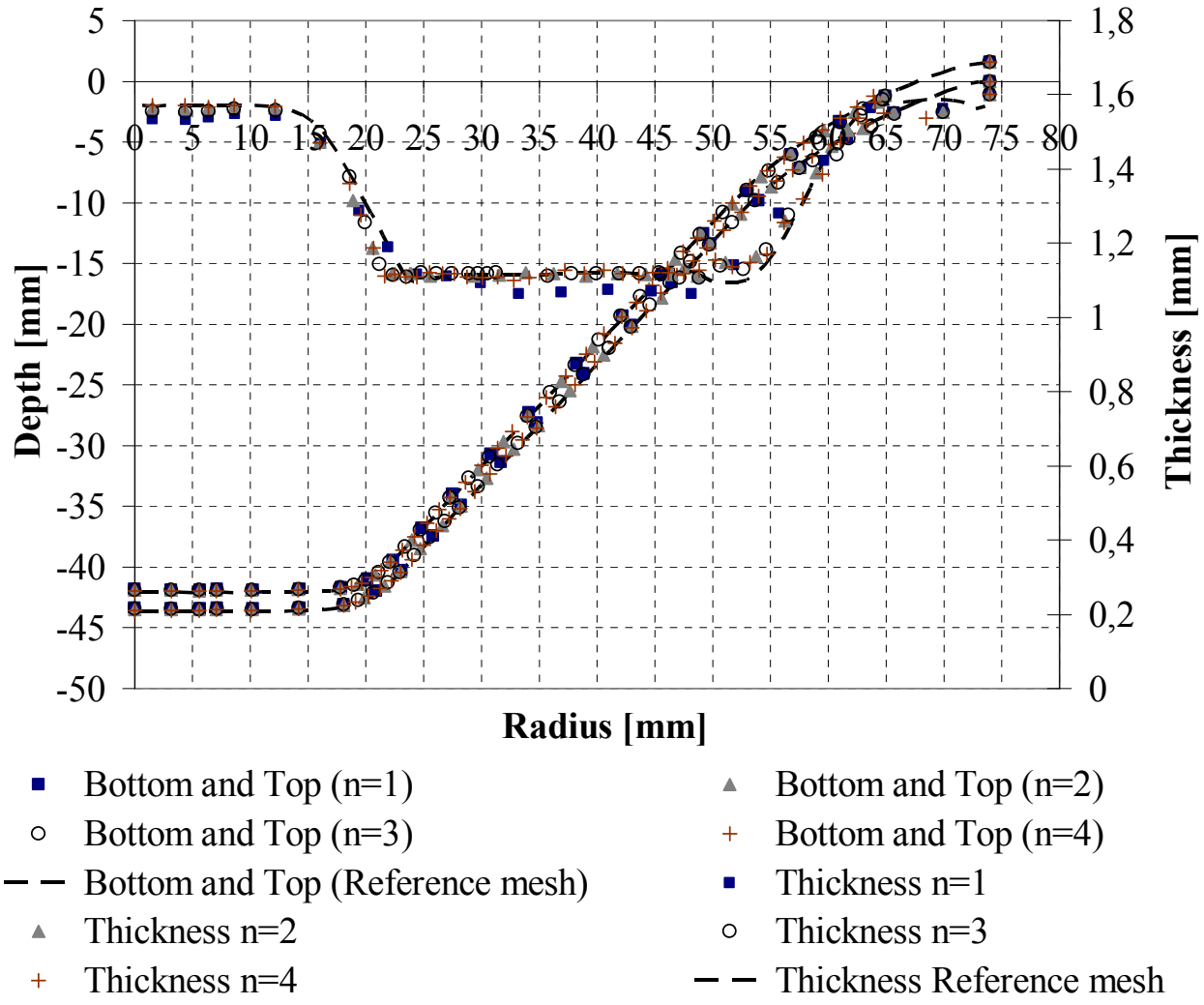
- **Reference mesh** without remeshing 5828 elements (RESS+CFI3D)
- One element in thickness direction
- 3 types of Elements :
  - 8 node solid-shell finite element RESS with 5IP
  - Contact element CFI3D with 4IP
  - Symmetric and rotational boundary conditions (BINDS elements)

Meshes (continuation)



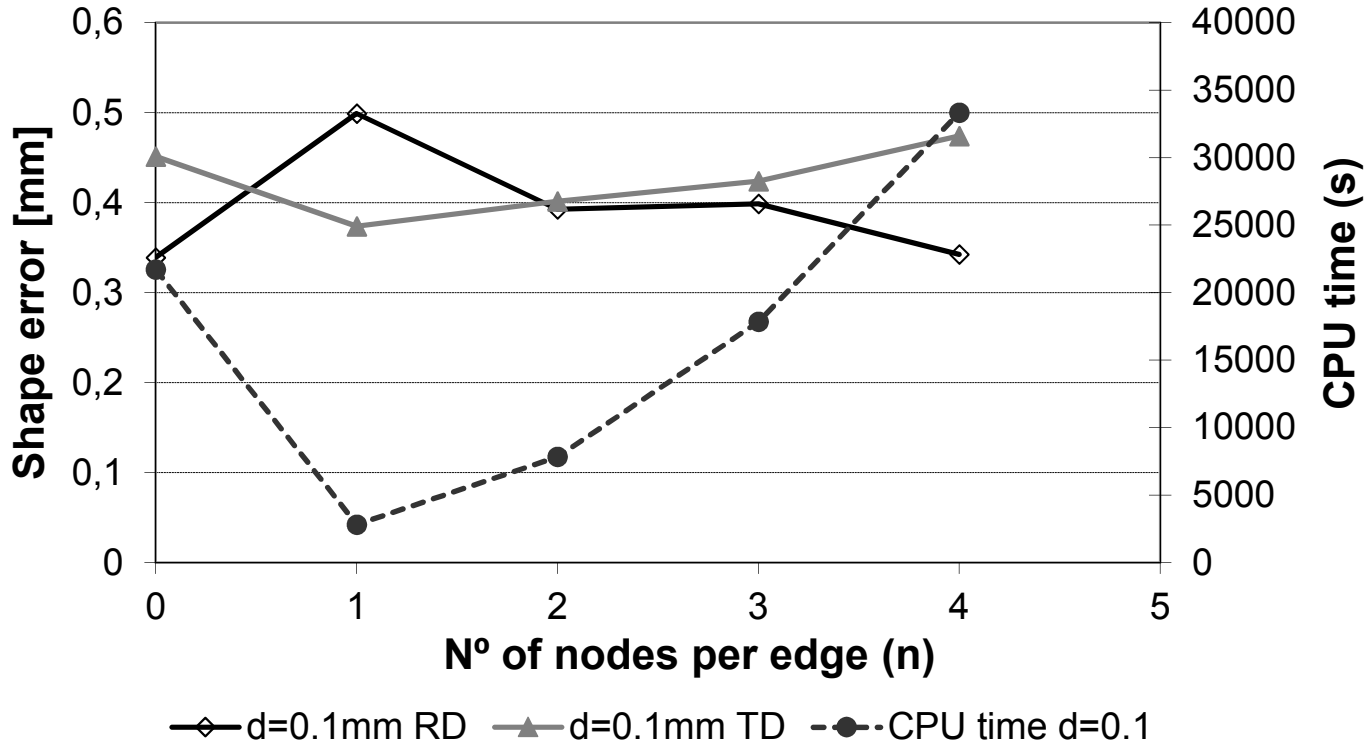
- Coarse mesh with adaptive remeshing, 410 elements (RESS+CFI3D)
- One element in thickness direction
- 3 types of Elements :
  - 8 node solid-shell finite element RESS with 5IP
  - Contact element CFI3D with 4IP
  - Binds elements
- Adaptive remeshing parameters used: n=1,2,3,4; α=1.0; d=0.1mm

Shape and thickness in a cross-section



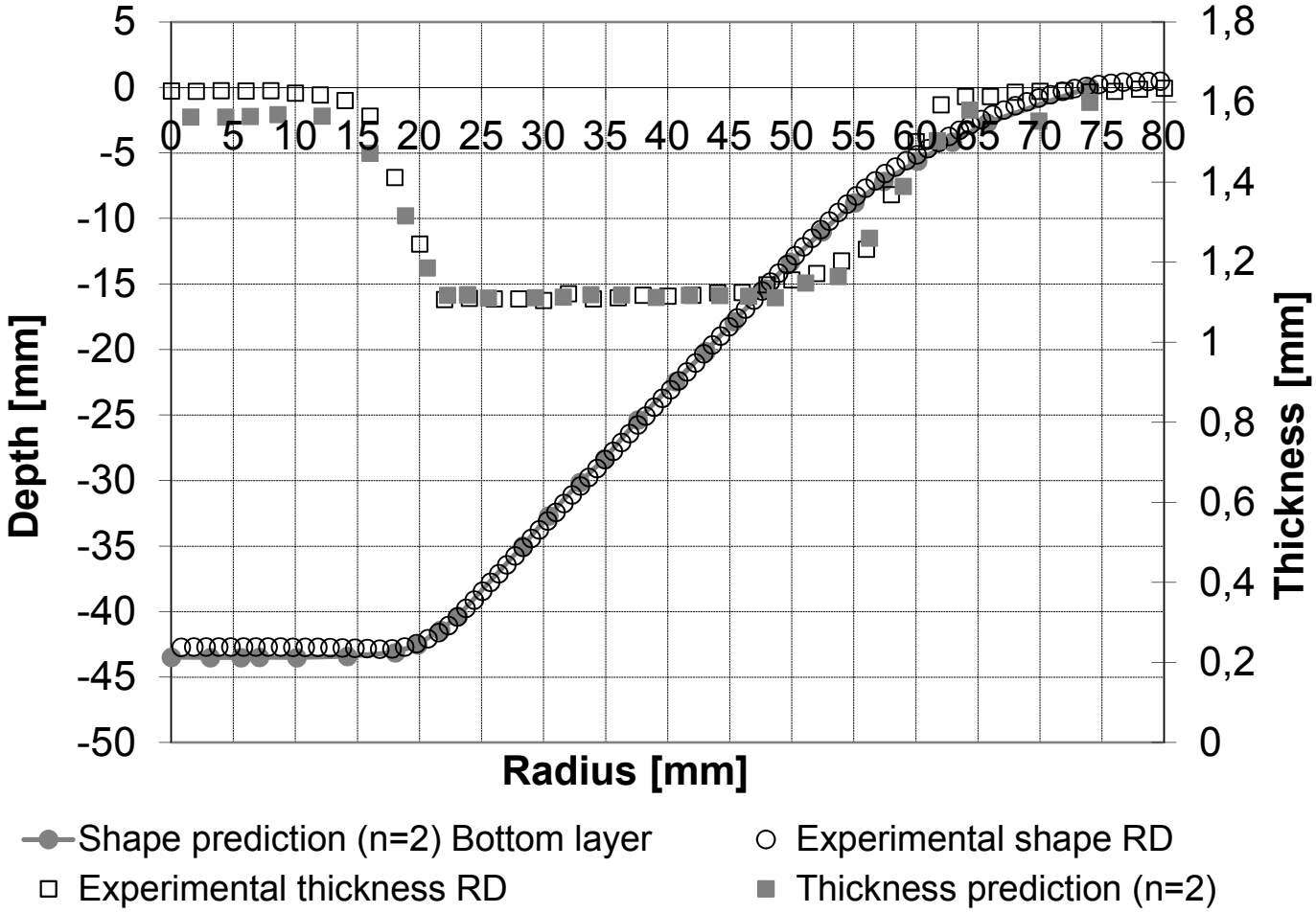
- Numerical shape at the middle section of the pie mesh to avoid boundary condition effect

Comparisons between time performance



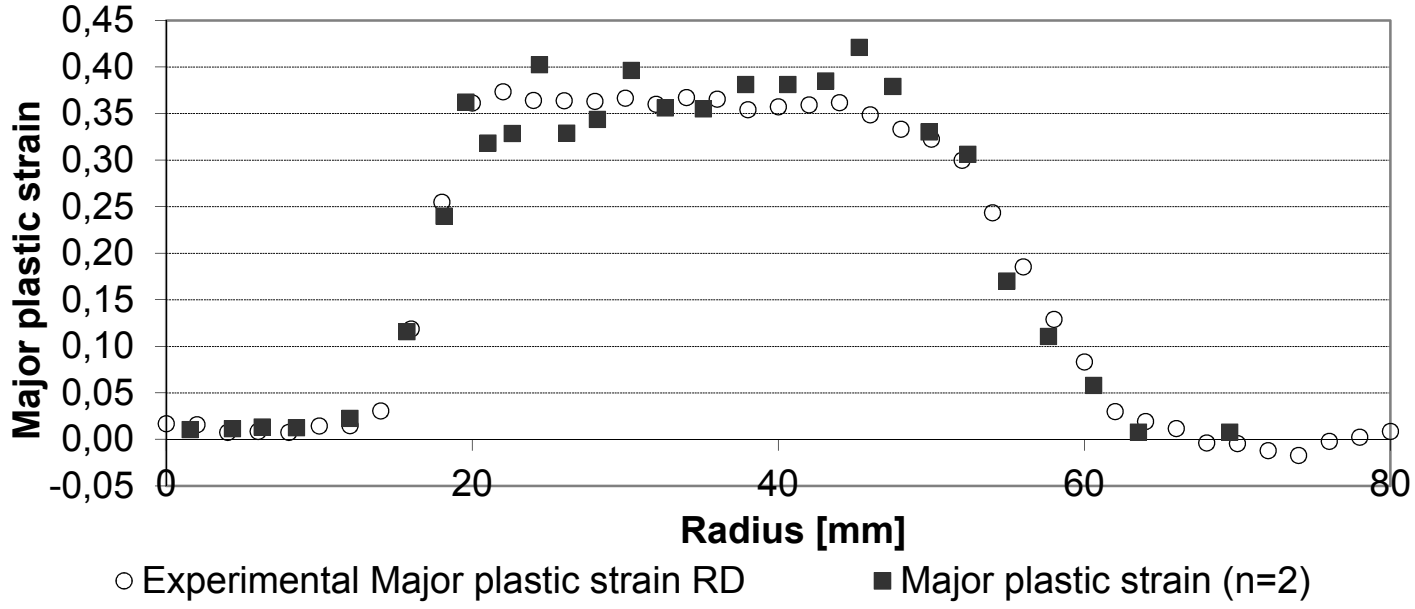
- n=0 indicates the reference mesh (initial refined mesh)
- The shape accuracy for different levels of refinement is analysed in different directions, transverse direction (TD) and rolling direction (RD)
- The refinement level which has a good agreement between the CPU time and accuracy in both directions is n=2

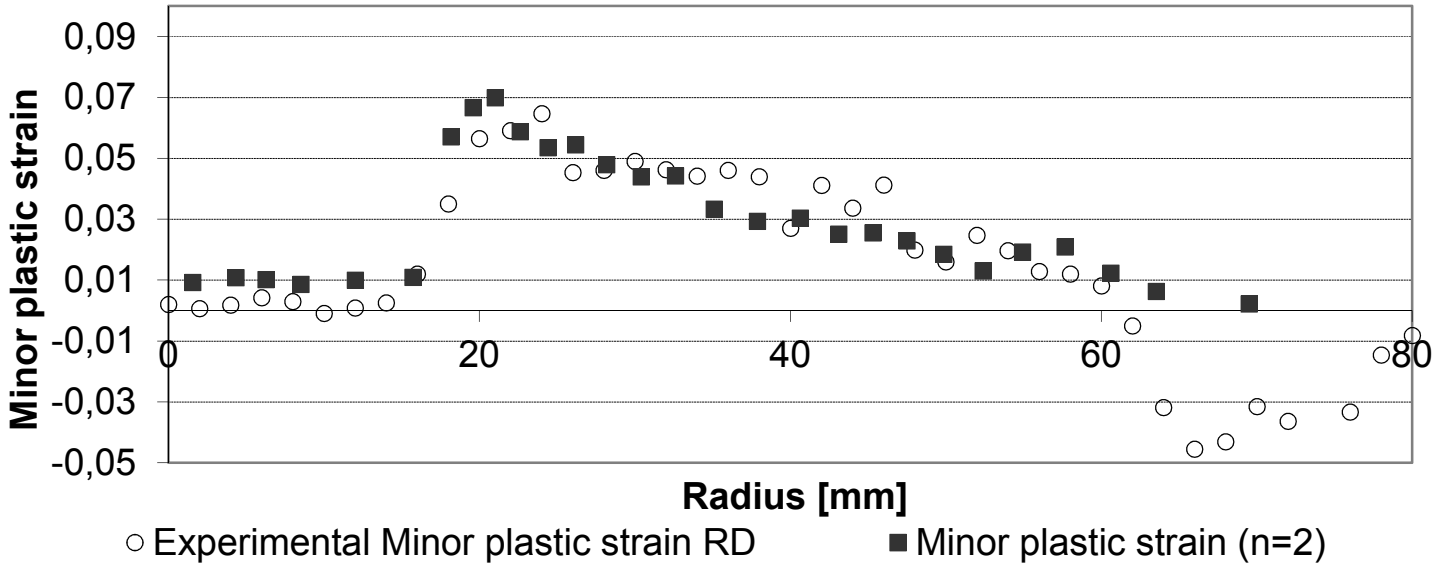
Numerical vs Experimental



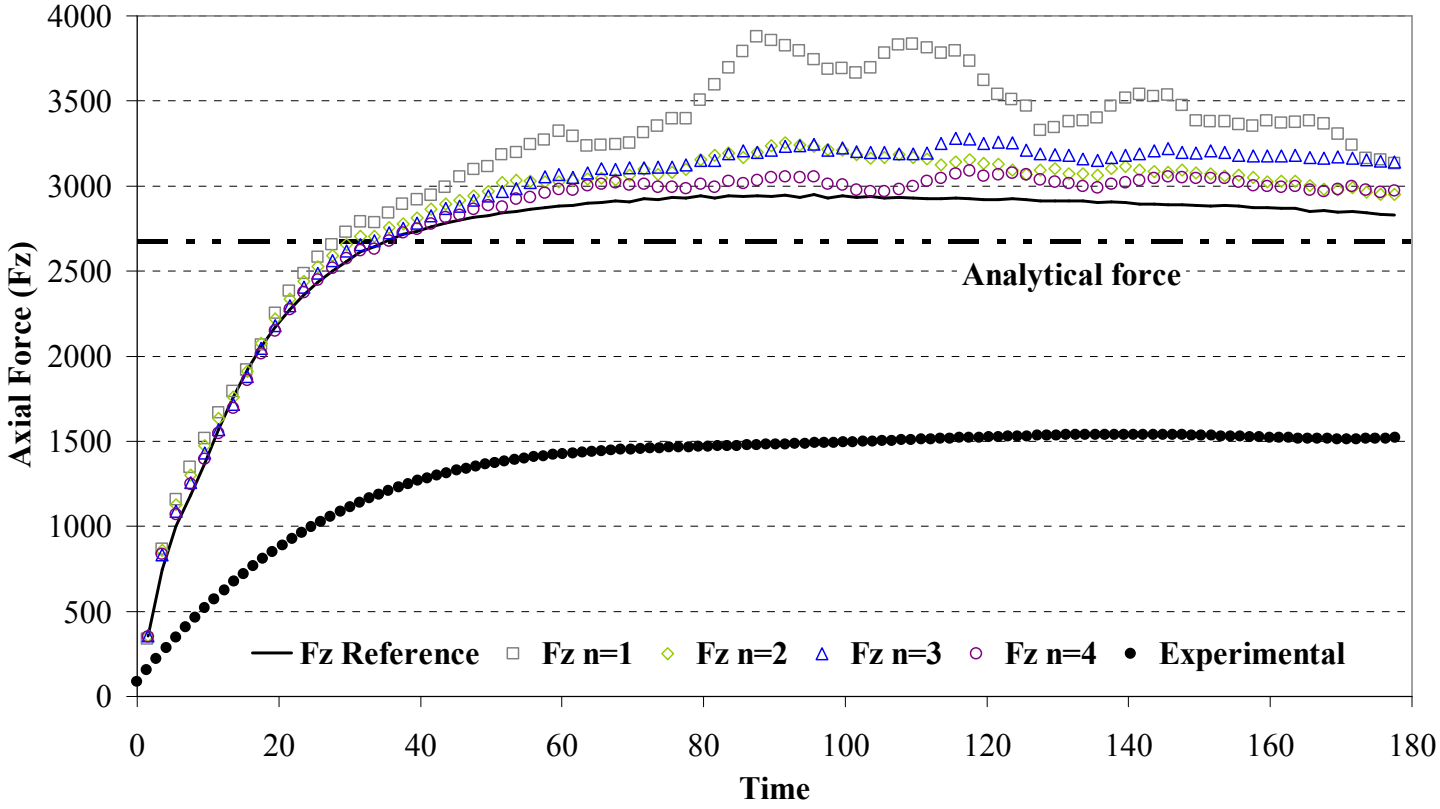
- The accuracy of shape and thickness obtained with adaptive remeshing is acceptable

Major and minor plastic strain





Evolution of force prediction



- N = 1 → 4 different levels of refinement
- Analytical force by Aerens* (team of Duflou KUL)

*See in Aerens R. *et al.* (2010), I. J. A.M. T., Vol. 46, pp. 969-982.

Final Considerations

• 3D analysis of single point incremental forming process.

• This adaptive remeshing method induces CPU time reduction due to the decrease of the number of elements of the mesh

• Interest of 3D finite elements,
  - more accurate thickness computation
  - full 3D constitutive laws

  → all components of the stress field necessary for damage approach.

Thank you for your attention

ACKNOWLEDGMENTS

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