Towards fracture prediction in single point incremental forming

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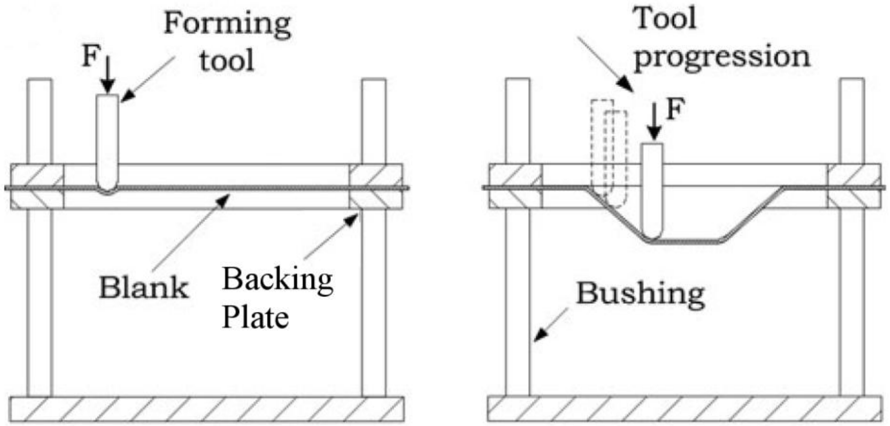
Single point incremental forming - SPIF

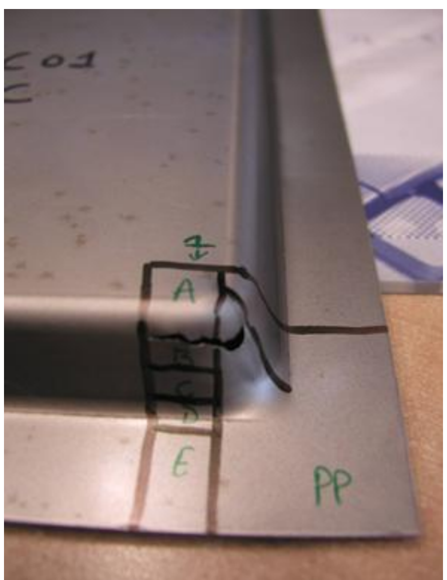
- A sheet metal deformed by a small tool.
- The tool guided by a CNC (milling machine, robot)
- Dieless, with high sheet formability.
- For rapid prototypes, small batch productions



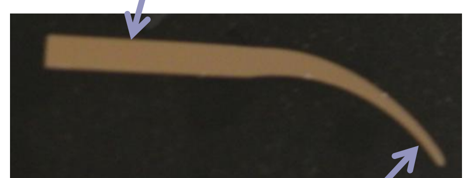
[Henrard et al. 2010]

Fracture in SPIF

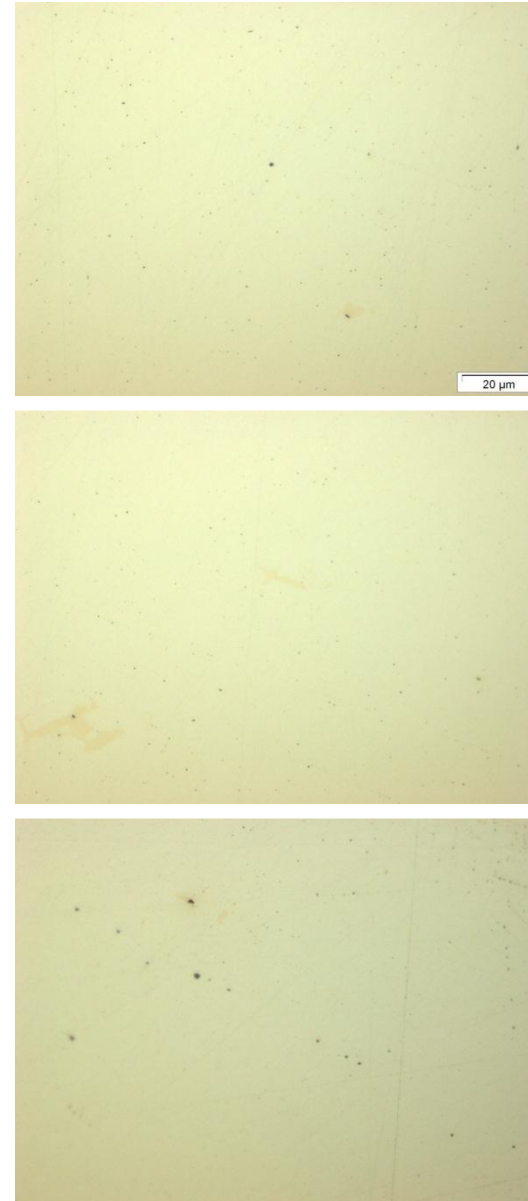
- Damage localised in a **very small** area near the crack.
- DC01 steel pyramid:



Away from the crack,
$A_{porosity}$ = 0,023 %

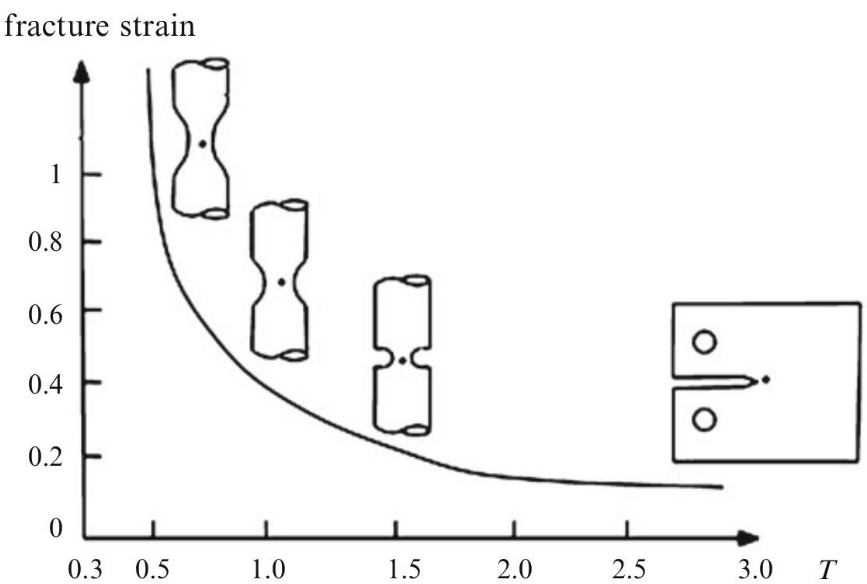


Near the crack
$A_{porosity}$ = 0,042 %



Damage modeling

- Strong influence of stress state on damage.
  → Triaxiality classicaly introduced in damage function



[Pineau and Pardoen 2007]

$$T\left(I_1, J_2\right) = \frac{\sigma_m}{\sigma_{eq}} = \frac{1}{3\sqrt{3}} \frac{I_1}{\sqrt{J_2}}$$

- At low triaxialities (<1/3), void shape evolution more important than void growth.

Damage modeling

- Shape effects related with shearing mechanisms.
- Triaxiality insufficient for low triaxialities

→ use the Lode angle:

$$X\left(J_2, J_3\right) = \cos 3\theta = \frac{27}{2}\frac{J_3}{\sigma_{eq}^3}$$

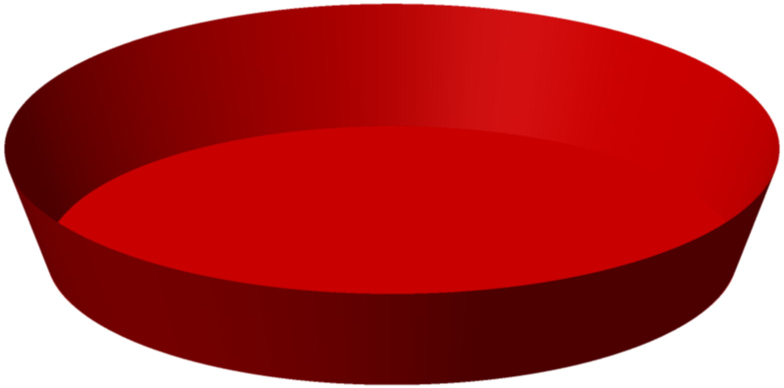
- Shear effects during SPIF → low triaxiality

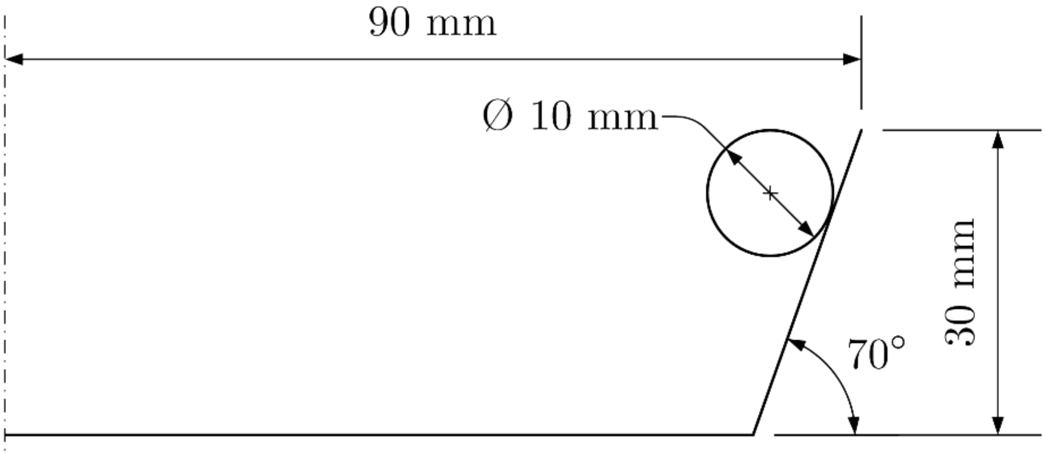
→ use of Lode angle?

- *What happens with the triaxiality and the Lode angle during SPIF near failure?*

Simulations

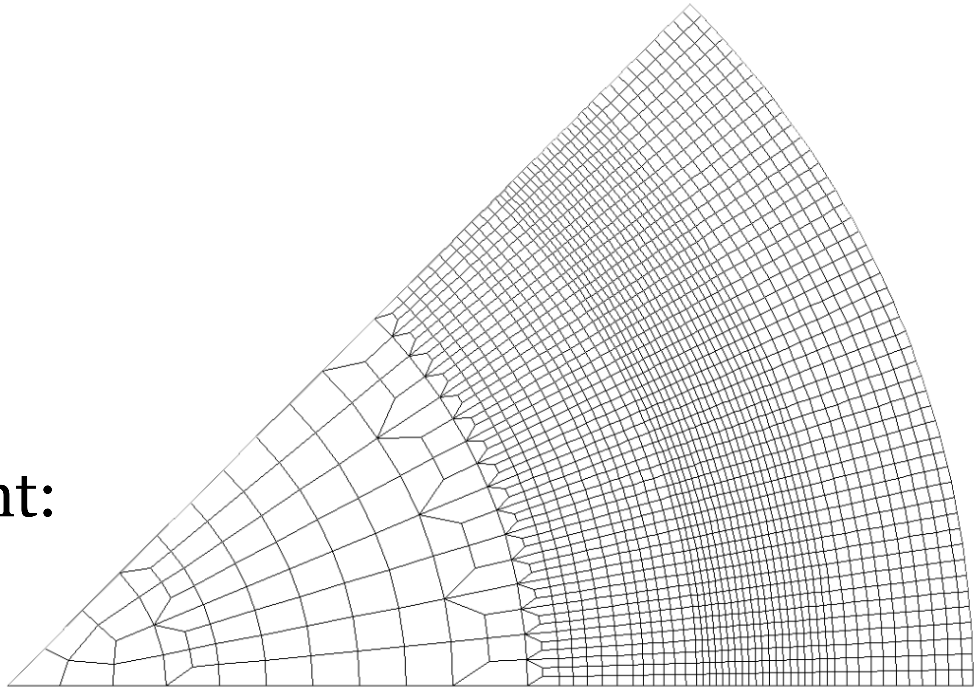
- Material: Aluminum AA3003-O (1.2mm thickness)
- Failure angle: 71°.
- Tool path = circles with a step down of 0,5 mm





Mesh and boundary conditions

- FE code: LAGAMINF
- Implicit simulations.
- One layer with 4492 solid-shell elements.

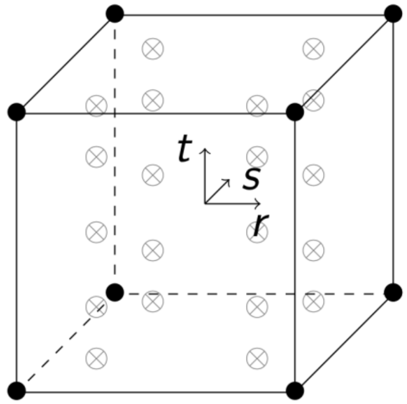


- SSH3D solid-shell element:
- Ben Bettaieb et al. [2011]
- Duchêne et al. [2011]

The solid-shell element

- Brick element designed for thin structures.

Shell element ⟺

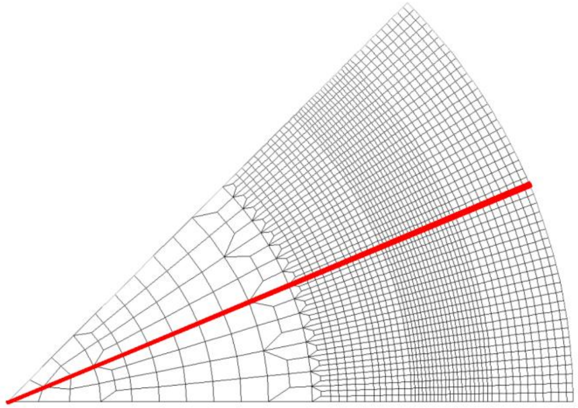


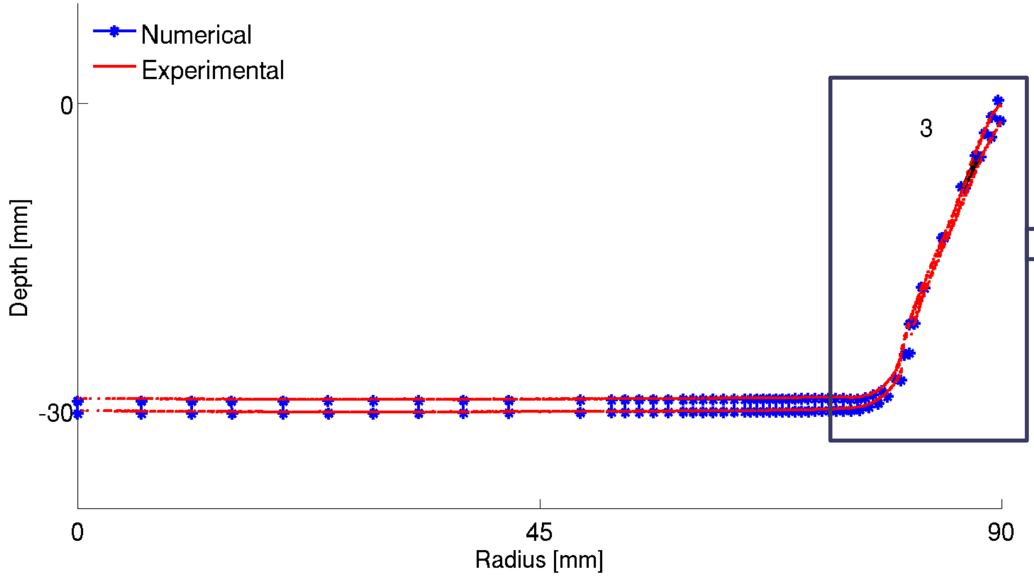
⟺ *Brick element*

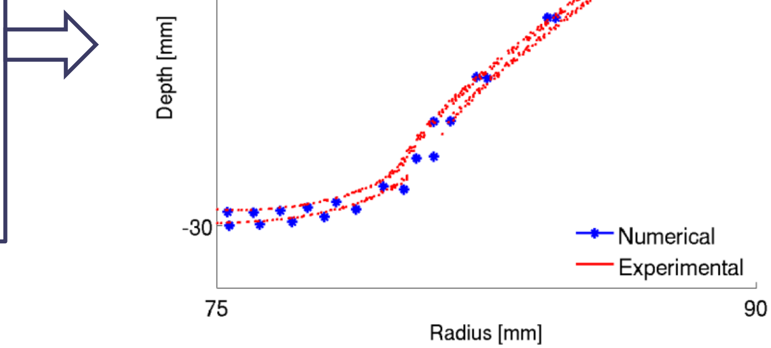
- Enhanced assumed strain (EAS) [Simo and Rifai 1990, Alves de Sousa et al. 2007].
- Assumed natural strain (ANS) [Schwarze and Reese 2009].
- In-plane full integration and 5 IP through the thickness.

Results: Geometry

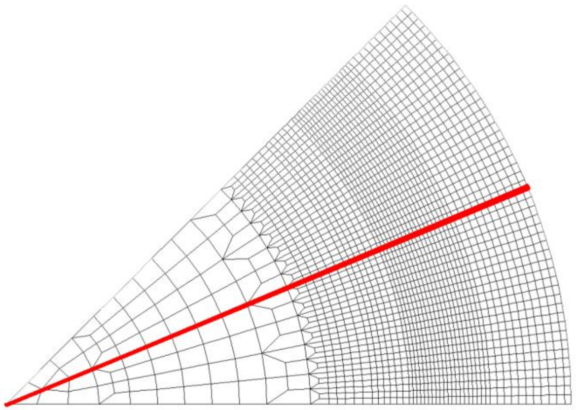
- Results from a transversal cut:
- Good correlation in both the top and the bottom.

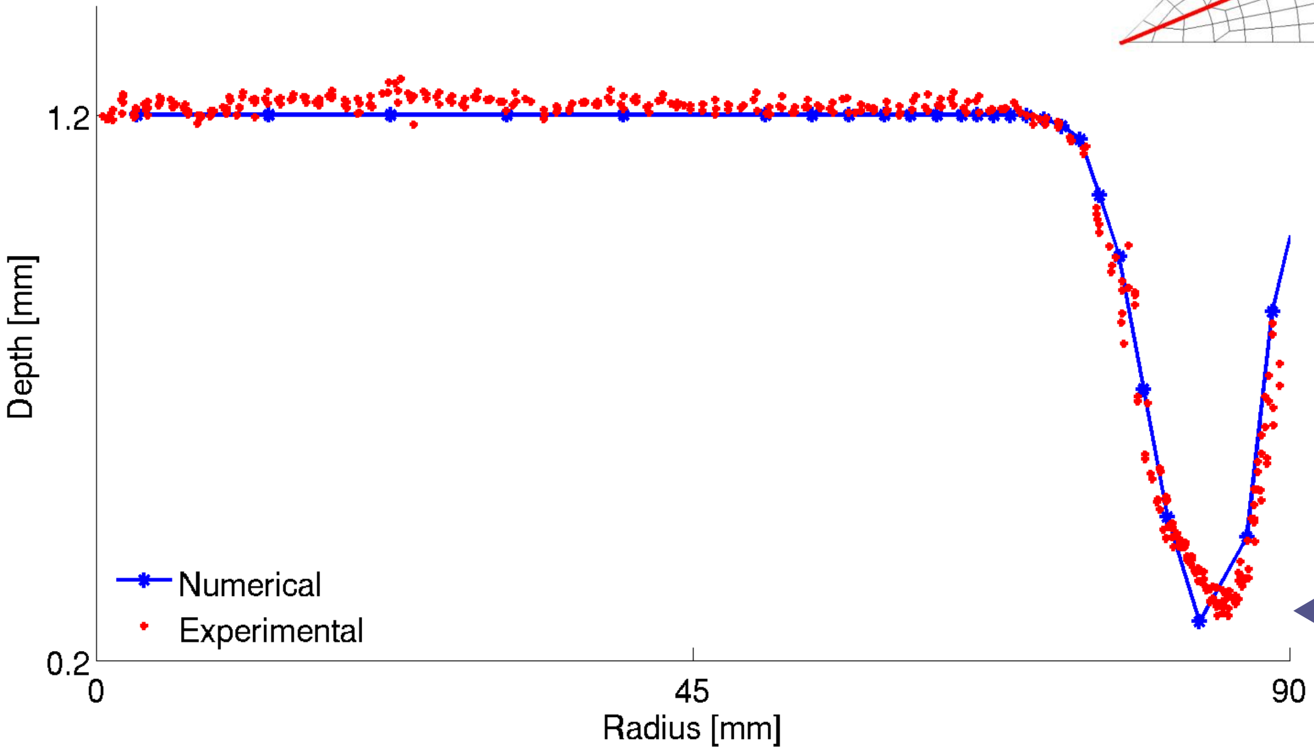






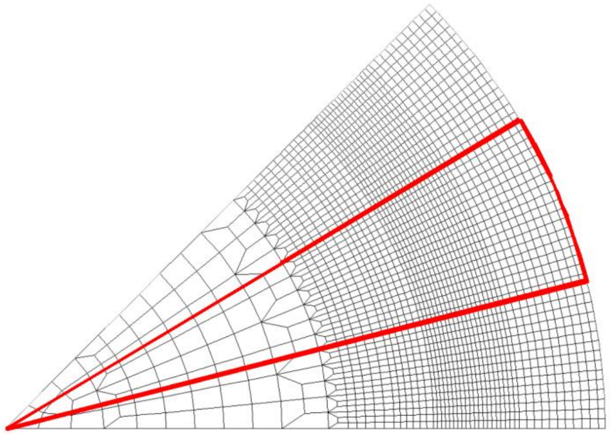
Results: Thickness

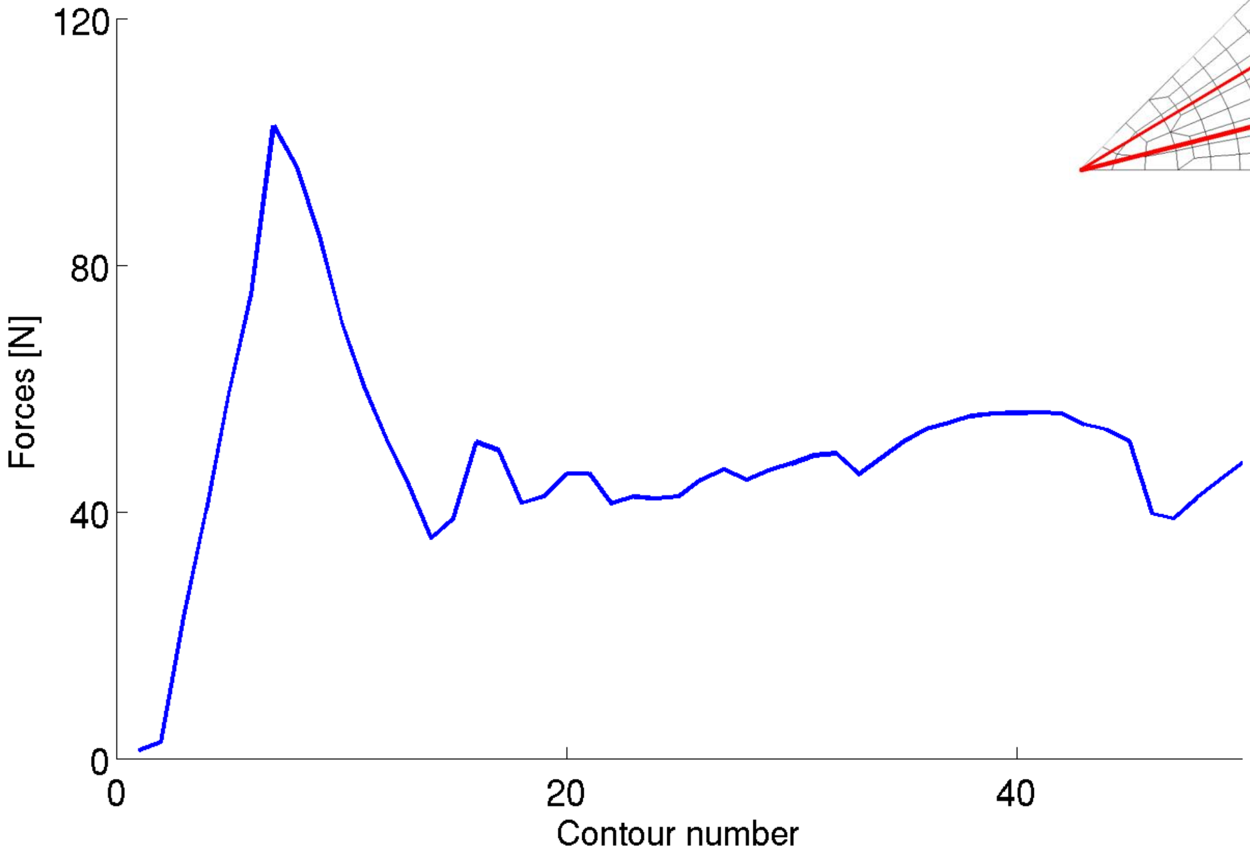




Minimal thickness:
t_FEA = 0.27 [mm]
t_NUM = 0.28 [mm]

Results: Axial force



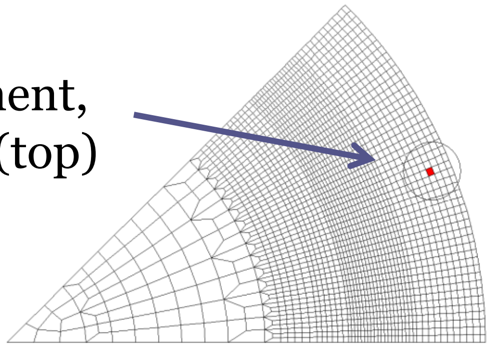


- Average Tool reaction in the Z direction.
- Curve shape oK
- Far below the experimental level:

$$F_{exp} =\approx 500[N]$$

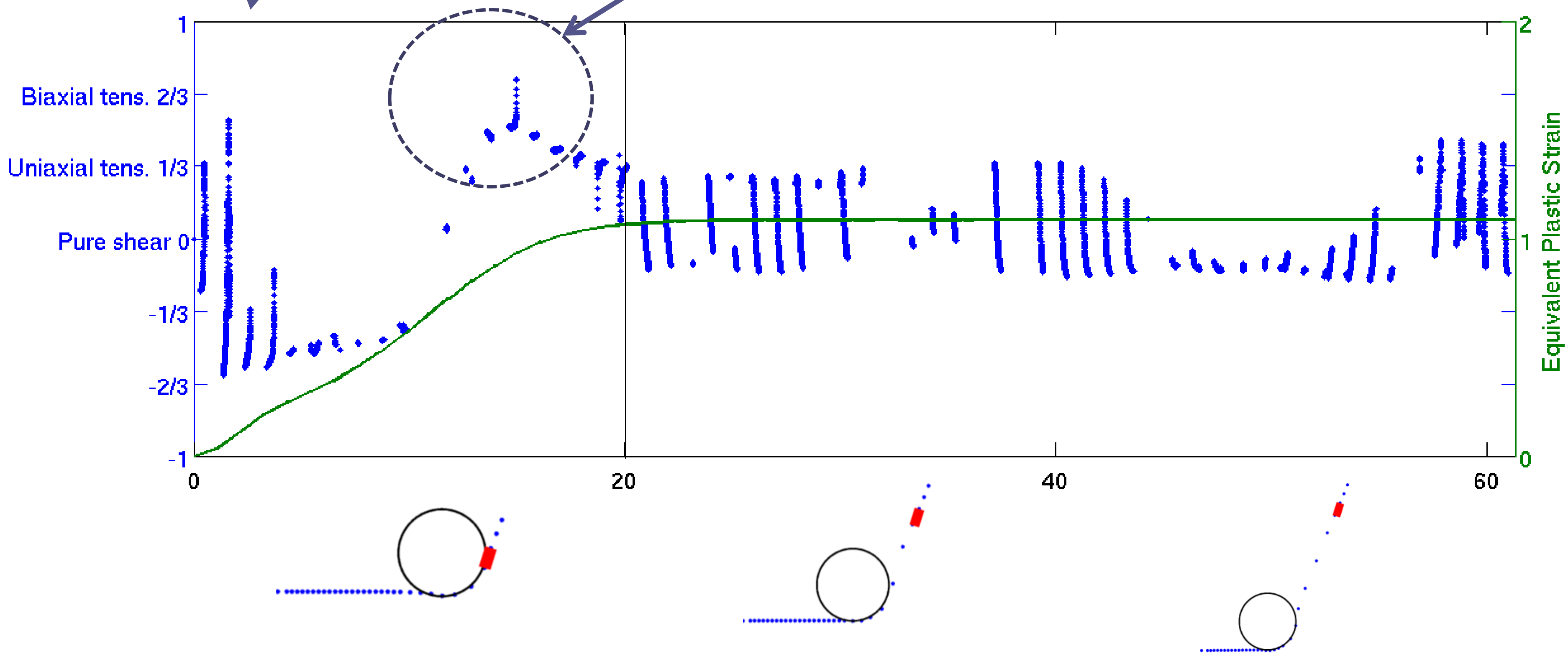
Triaxiality

Element, IP 5 (top)



Tool contact

Triaxiality peak

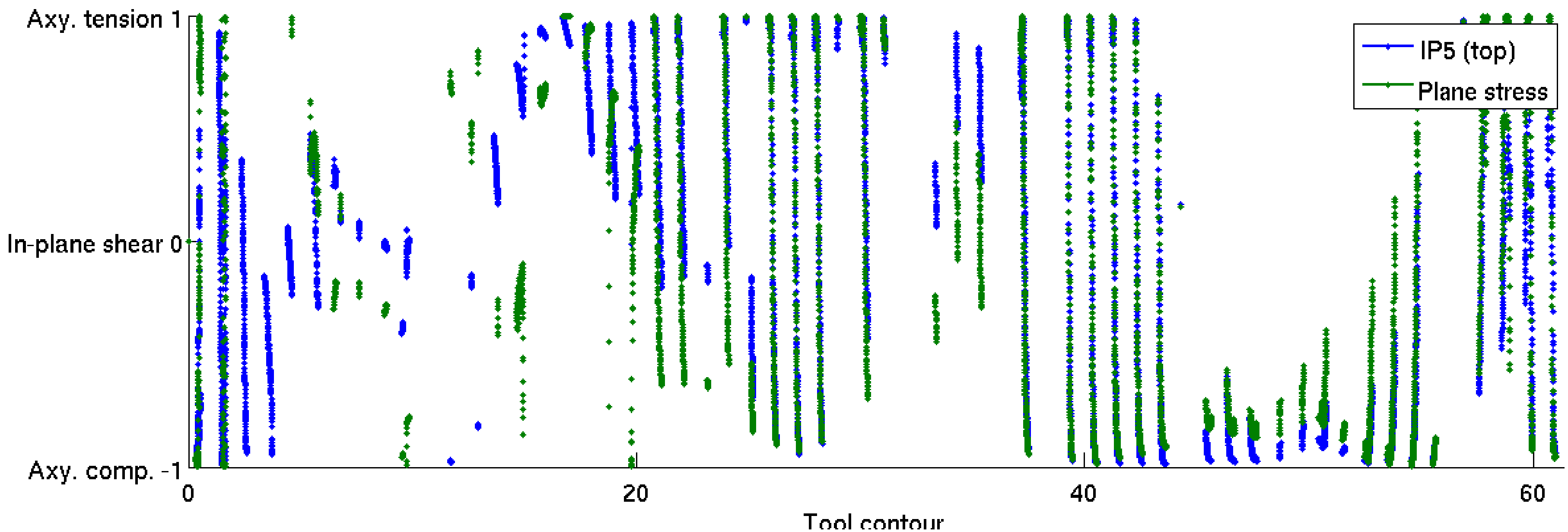


Plasticity

Elasticity

Normalized third invariant

Plane stress: $$\xi = -\frac{27}{2} T \left(T^{2} - \frac{1}{3} \right)$$



Plasticity

Elasticity

Conclusions

- Experimental evidence proves that the damage is very localized in SPIF.
- Low Triaxiality (<1/3) during the whole process, however triaxiality peak after the contact zone
  →a porosity increase?
- In plasticity, the triaxiality remains more or less constant during one contour, while the normalized third invariant changes more.
- Damage modeling should consider the variation of the Lode angle during one contour.

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