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:

  - Near the crack: $A_{\text{porosity}} = 0.042\%$
  - Away from the crack, $A_{\text{porosity}} = 0.023\%$
Damage modeling

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

\[
T \ I_1, J_2 = \frac{\sigma_m}{\sigma_{eq}} = \frac{1}{3\sqrt{3}} \frac{I_1}{\sqrt{J_2}}
\]

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

[Pineau and Pardoen 2007]
Damage modeling

- Shape effects related with shearing mechanisms.
- Triaxiality insufficient for low triaxialities
  \[ \Rightarrow \text{use the Lode angle:} \]

\[ X \, J_2, J_3 = \cos 3\theta = \frac{27}{2} \frac{J_3}{\sigma_{eq}^3} \]

- Shear effects during SPIF \(\Rightarrow\) low triaxiality
  \(\Rightarrow\) use of Lode angle?

- \textit{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.

- 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:

\[ t_{\text{FEA}} = 0.27 \text{ [mm]} \]
\[ t_{\text{NUM}} = 0.28 \text{ [mm]} \]
Results: Axial force

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

\[ F_{\text{exp}} \approx 500\text{[N]} \]
Triaxiality

Tool contact

Triaxiality peak

Element, IP 5 (top)

Triaxiality

Biaxial tens. 2/3
Uniaxial tens. 1/3
Pure shear 0

Plasticity

Elasticity
Normalized third invariant

Plane stress:

\[ \xi = -\frac{27}{2} T \left( T^2 - \frac{1}{3} \right) \]
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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References