Exceeding the Forming Limit Curve with Deep Drawing Followed by Electromagnetic Calibration

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Strains that can be reached by the process chain composed of

- Deep drawing
- Electromagnetic forming
Can the quasi-static FLC be exceeded by the process chain?
Significance of the question

Aim: To understand the increase of process limits in case of such process chains better

We can design and optimize such process chains better

Sources:
Imbert and Worswick; Electromagnetic reduction of a pre-formed radius on AA 5754 sheet, 2011
Liu, Li, and Yu; Numerical modeling and deformation analysis for electromagnetically assisted deep drawing of AA5052 sheet
Content

- Motivation
- Experimental setup
  - Deep drawing
  - Electromagnetic calibration
- Discussion
- Conclusion
The process chain

Material: EN AW-5083

Deep drawn cup

Tooling for electromagnetic calibration

Cup after electromagnetic calibration
The process chain

Deep Drawing

Electromagnetic forming

- Female die
- Sheet
- Blank-holder
- Punch Ø130 mm

- Female die
- Coil windings
- Electromagnetic calibration
Deep drawing

Motivation          Methods          Results          Discussion Conclusion

Encouraged material flow

Good lubrication

Should reach the quasi-static forming limits

No lubrication
Content

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Blankholder force 560 kN
Deep drawing

Blankholder force 540 kN

Necking
Deep drawing

Blankholder force 520 kN

No failure
Deep drawing

- **Blankholder force 560 kN**
  - Rupture

- **Blankholder force 540 kN**
  - Necking

- **Blankholder force 520 kN**
  - Safe
  - To be calibrated
Content

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- Discussion
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Forming limit diagram after calibration

- **Motivation**
- **Methods**
- **Results**
- **Discussion**
- **Conclusion**
Sharpest radius reached
Sharpest radii reached

Process chain
Drawn to R20
Calibrated to R13

Deep drawing with R15
Content

- Motivation
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- Discussion
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Quasi-static FLC can be exceeded.

What is the cause?

- Impulse forming
- Strain rate change
Reason: Impulse forming

Sources:
Balanethiram and Daehn, Enhanced formability of interstitial free iron at high strain rates, 1992
Balanethiram and Daehn, Hyperplasticity: Enhanced formability at high rates, 1994
Reason: Strain rate change

Motivation          Methods          Results          Discussion          Conclusion
Reasons

The factor causing the extension of quasi-static FLC:

- Impulse forming
- Strain rate change

Further research is needed!
Process chain extends the forming limits of deep drawing

Evidences:

- Part at the forming limits can be calibrated
- The calibrated part cannot be produced by deep drawing
Extending limits of deep drawing

Part, which was formed until the process limits can be formed further electromagnetically

**Motivation**

Methods

Results

Discussion

Conclusion

**Part, which was formed until the process limits can be formed further electromagnetically**

- **Blankholder force 520 kN**
- **Blankholder force 540 kN**

**Electromagnetic calibration**

Strains after process

Strains after deep drawing
Extending limits of deep drawing

The calibrated part cannot be produced by deep drawing

**Motivation**

**Methods**

- Punch edge radius 20 mm
- Punch edge radius 15 mm
- Electromagnetic calibration
- Sharpest safe edge radius 13 mm

**Results**

**Discussion**

**Conclusion**
Content

- Motivation
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- Results
  - Deep drawing
  - Electromagnetic calibration
- Discussion
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Quasi-static FLC can be exceeded by the process chain
Quasi-static FLC can be exceeded by the process chain

Further research is needed to determine the factor(s) causing this

The process chain extends the forming limits of deep drawing
THANK YOU FOR YOUR ATTENTION!