Edge-fracture-tensile-test
Kantenrissprüfverfahren im Zugversuch

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Motivation and objective

Challenges due to the formation of edge-cracks

- Reduced producibility
- Increased component rework
- Increased mechanical tool wear and damage
- Re-design of tool
- Increased risk of component failure during the lifecycle
- Change in sheet material and thickness

Edge-cracks increase

- auxiliary costs and
- reduce the component reliability

Objective

Identification of process- and material-adjusted shear-cutting parameters to reduce the risk of the edge-crack formation and to increase the edge formability of high-strength steels
State of the art

- Shear cut edges of higher- and high-strength steels (especially dual phase steels) show a high risk of edge-crack formation
  → The material’s forming potential can not be utilized
- Necessity to estimate the edge-crack sensitivity of a given material

Testing methods of edge-cracks

Friction based
- Collar forming experiment
- Diabolo experiment
- Hole-expansion test ISO 16630
- BMW-test

Frictionless
- Strip-tensile-test
- Dog-bone-tensile-test
- Half-a-dog-bone-tensile-test
- Open-hole-tensile-test
- Tensile-test with notched specimen
- Edge-fracture-tensile-test

Unidimensional stress
- Strip-tensile-test
- Dog-bone-tensile-test
- Half-a-dog-bone-tensile-test

Multidimensional stress
- Hole-expansion test
- BMW-test
- Diabolo experiment

Hole-expansion test ISO 16630 [5]

Diabolo experiment [7]

Strip-tensile-test Open-hole-tensile-test Edge-fracture-tensile-test [12]

Tensile-test with notched specimen
**Edge-fracture-tensile-test**

**Development of a new testing procedure**

Evaluation of the edge-crack sensitivity based on the tensile test according to DIN EN ISO 6892-1

- Frictionless procedure
- Shear-cut surfaces are usually subjected to uniaxial stress during the forming process
- Cost-efficient and simple manufacturing of samples, use of
  - reference samples with milled surfaces on both sides
  - edge-crack samples with one shear-cut side
- Logging of the logarithmic elongation upon mechanical failure, local necking and mechanical fracture possible

**Schematic draft of sample geometry**

(a) Closed cutting line

- Locating hole
- Milled edge
- Cutting
- Punch outline
- Shear cut edge
- Cutting

(b) Open cutting line

- Locating hole
- Milled edge
- Cutting
- Punch outline
- Shear cut edge
- Cutting

Edge-fracture-tensile-sample
Experimental process chain for a closed cutting line

Edge-crack-tensile-test shear cutting tool

- Top plate
- Gas valve
- Gas pressure spring
- Base plate
- Punch
- Blank holder
- Die
- Locator

Milled starting blank

Shear-cut sheet metal

One-side shear-cut edge-crack tensile test samples

Tensile test samples with spray pattern Aramis 4 M

Laser Extensometer Array HP
Zwick GmbH & Co. KG

2D-deformation analysis
- Principal strain
- Secondary strain
- Sheet metal thinning

Max. strain

Shear cut edge

Measuring area of the edge-fracture-sample

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Tensile test
Design of experiments

HCT980X, $s_0 = 1.5$ mm

**Process variation**

*edge-fracture-tensile-test*

- Die clearance (2 %, 5 %, 10 %, 15 %, 20 %)
- Cutting outline (*closed, open* (2 mm, 4 mm scrap-width))
- Shear cutting radius (*sharp-edged, rounded*)
- Cutting process (*one-, two-stage*)
- Blank holder pressure (20 bar – 140 bar)

**Process evaluation**

**Reference experiments**

Samples milled on both sides

**Cutting surfaces**

- Tactile surface measurement
- Light microscope recording

**Optical 2D-deformation analysis**

- Principal strain
- Secondary strain
- Sheet metal thinning

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High-speed press
BSTA 1600-181

Laser Extensometer Array HP

2D-deformation system

Aramis 4 M

Universal testing machine
Zwick Typ 1484 / DUPS-M
Design of experiments

**HCT980X, \( s_0 = 1.5 \text{ mm} \)**

**Process variation**

*edge-fracture-tensile-test*

- Die clearance (2 \%, 5 \%, 10 \%, 15 \%, 20 \%)
- Cutting outline (closed, open (2 mm, 4 mm scrap-width))
- Shear cutting radius (sharp-edged, rounded)
- Cutting process (one-, two-stage)
- Blank holder pressure (60 bar)

**Process evaluation**

**Reference experiments**
Samples milled on both sides

**Cutting surfaces**
- Tactile surface measurement
- Light microscope recording

**Optical 2D-deformation analysis**
- Principal strain
- Secondary strain
- Sheet metal thinning

**High-speed press**
BSTA 1600-181

**2D-deformation system**

**Laser Extensometer Array HP**
Aramis 4 M

**Universal testing machine**
Zwick Typ 1484 / DUPS-M
Distribution of strain before mechanical failure as function of the manufacturing technique

Reference sample

Aramis-Image principal strain

Milled sample edge

Milled sample edge

Position of ductile fracture initiation at later time

Distribution of the principal strain before mechanical failure for milled samples

Metallographic microscope image

Mechanical failure initiated by ductile fracture in the sample's center

Edge-crack tensile sample

Aramis-Image principal strain

Milled sample edge

Shear-cut sample edge

Position of edge crack initiation at later time

Distribution of the principal strain before mechanical failure for one-side shear-cut samples

Metallographic microscope image

Mechanical failure due to edge-crack with characteristic horizontal path
Results

Influence of the cutting strategy on the principal strain at lokal necking

- Punching reduces the principal strain
- Increase of the principal strain with an increase in the die clearance at $u = 2\% - 20\%$
- Tool displacement reduces the principal strain by up to 63%

- HTC980X
- Open and closed cutting line
- Sharp edged cutting edges
- Blank holder pressure 60 bar
- One stage cutting process
Results
Influence of the cutting strategy on the principal strain at localized necking

- Punching reduces the principal strain
- Increase of the principal strain with an increase in the die clearance at $u = 2\% - 20\%$
- Tool displacement reduces the principal strain by up to 63\%

- Cutting off increases the principal strain compared to the punching process
- Increase of the principal strain is dependent on the die clearance

Values for a closed cutting outline

HTC980X
- Open and closed cutting line
- Sharp edged cutting edges
- Blank holder pressure 60 bar
- One stage cutting process
Results

Cut-face parameters as function of the cutting parameters

Measuring station – MarSurf PCV

According to VDI 2906-2 [18]

$\begin{align*}
  h_E &: \text{ Total rollover height} \\
  h_S &: \text{ Clean-shear height} \\
  h_B &: \text{ Total fracture height} \\
  h_G &: \text{ Burr height} \\
  s_0 &: \text{ Sheet thickness} \\
  \beta &: \text{ Fracture angle}
\end{align*}$
Results

Cut-face parameters as function of the cutting parameters

- The cut surface parameters according to [18] are influenced by the stiffness of the scrap due to a change in stress during the cutting process.
- Closed cutting line yields the highest values for rollover and clean-shear height.
- Rollover height increases when using a higher die clearance.

\[ h_E: \text{Total rollover height} \]
\[ h_S: \text{Clean-shear height} \]
\[ h_B: \text{Total fracture height} \]
\[ h_G: \text{Burr height} \]
\[ s_0: \text{Sheet thickness} \]
\[ \beta: \text{Fracture angle} \]

According to VDI 2906-2 [18]
Conclusion and Outlook

Conclusion

- The *edge-fracture-tensile-test* offers advantages which allow to evaluate the edge-fracture-sensitivity
  - Frictionless procedure
  - Cost-efficient and simple manufacturing of samples
  - Modular tool design allows easy variation of the shear-cutting parameters
  - Cut-face is usually subjected to uniaxial strain

- Higher residual formability can be maintained by using a
  - material specific die clearance and an
  - open cutting line with small scrap-width

- Advantages by using a *Laser Extensometer Array HP*
  - No sample preparation
  - No system calibration for each test series
  - Easy handling and flexible positioning of the measuring points

Outlook

Validation of the *edge-fracture-tensile-test* using standard edge-crack testing methods, e.g.
- Collar-forming experiment
- Diabolo experiment
- Open-Hole-Tensile-Test
Thank you for your attention!
References


[17] N.N. Salzgitter Flachstahl GmbH: Werkstoffblatt Dualphasenstahl HCT980XD, Nummer 11-980, Ausgabe Nr. 03;2014

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