Development of a numerical method for analyzing the robustness of clinching in versatile process chains

In many areas of product manufacturing individual components are usually joined together to form complex structures with numerous joints. Using mechanical joining technologies offers the possibility of joining structures with a wide range of material-geometry combinations. In order to realize the increasing number of varying products using different materials and designs within a process chain, they need to be versatile.

Due to changing properties of the materials to be joined, tool geometries and process variables in mechanical joining processes, especially clinching, must be continuously adapted which results in a limited versatility of the process. Out of this reason, it is necessary to examine the robustness of the clinching process in versatile process chains. Therefore, a method is developed which describes the joint characteristics based on the material properties in order to enable the investigation of the clinching process regarding the robustness concerning continuously changing process and material conditions.

The predictive accuracy of numerical simulations for mechanical joining processes depends on the implemented material model, especially the plasticity of the joining parts. Therefore, experimental material characterization processes are used to determine material properties. Furthermore, clinched joints in different material combinations are experimentally generated and examined. Based on these investigations a simulation model of the joining process is developed as 2D-Clinching FEM model in LS-Dyna. The Validation of the developed simulation model is ensured by comparing the geometric formation of the joint and force-displacement curves of the joining process with experimental generated joints. By combining the simulation model with an optimization tool (LS-OPT) the influence of different parameters on the joint characteristics is determined and the robustness of the joining process in versatile process chains is investigated.
Development of a numerical method for analyzing the robustness of clinching in versatile process chains

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1. Clinching process
2. Material characterization
3. Simulation model and method
4. Results and discussion
5. Conclusion
Clinching process

**Fundamentals**
- Mechanical joining without auxiliary element by cold forming the material
- Form fit and force fit joint
- Joining of different materials possible
- High quasistatic and dynamic load capacities
- Both sides accessibility required

**Process sequence**
1. Blank holder
2. Punch
3. Punch sided sheet
4. Die sided sheet
5. Die

Positioning and Fixation → Forming in die → Forming of interlock → Backstroke

Symbols:
- $d_i$ Joint diameters
- $t_{1,2}$ Sheet thicknesses
- $t_b$ Bottom thickness
- $f$ Interlock
- $t_n$ Neck thickness

[DVS/EFB 3420]
Experimental investigation of different material combinations
Determination of process parameters due to optimized geometric characteristics

Materials
- HCT590X, t = 0.8/1.5 mm
- EN AW-6014 T4, t = 1.0/2.0 mm

Joining technology
- Clinching with rigid die

Joining speed
- 2 mm/s

Blank holder force
- 785 N

Type: TOX® TZ-VSN
Engine: EPMR 100.113
Max. joining force: 90 kN
Stroke: 190 mm
**Material characterization**

**Tensile tests and extrapolation**

- Quasistatic tensile tests according to SEP1230 standard
- Flow curves generated by accordingly extrapolation with different hardening laws

<table>
<thead>
<tr>
<th>Testing method</th>
<th>Quasistatic tensile test</th>
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<tbody>
<tr>
<td>Strainrate</td>
<td>0.01 s⁻¹</td>
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<tr>
<td>Material</td>
<td>HCT590X, t=1.5 mm, 0°</td>
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<tr>
<td></td>
<td>EN AW-6014 T4, t = 2.0 mm, 0°</td>
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<tr>
<td>Testing standard</td>
<td>SEP 1230</td>
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<tr>
<td>Strain measurement</td>
<td>GOM ARAMIS</td>
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**Hardening law**

- **VOCE**
  \[ \sigma = A - B \cdot e^{(-C \cdot \varepsilon)} \]
- **HOCKETT-SHERBY**
  \[ \sigma = A - B \cdot e^{(-C \cdot \varepsilon^D)} \]
- **LUDWIK**
  \[ \sigma = \sigma_0 + A \cdot \varepsilon^B \]

**Legend**

- **Experimental**
- **VOCE**
- **LUDWIK**
- **HOCKETT-SHERBY**
**Material characterization**

**Simulated tensile tests**

- Flow curves implemented in numerical model for simulating tensile test
- Determining flow curves for further investigation by best fitting of the experimental data
  - HCT590X → LUDWIK
  - EN AW-6014 → HOCKETT-SHERBY

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<td>LS Dyna</td>
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Legend:
- Experimental
- VOCE
- LUDWIK
- HOCKETT-SHERBY

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**Technical stress** $\sigma$ (Mpa)

**Technical strain** $\varepsilon$ (-)
Simulation model and method

2D rotation symmetry
LS-Dyna specific setting

Punch
elastic

Blank holder spring
linear elastic stiffness

Blank holder
elastic preload

Contact setting
static friction coefficients

Pre-forming
S1: top-sheet
S2: bottom-sheet

Materials
HCT590x
EN AW6014-T4

Tool geometries depending on the combination

Validation without pre-straining

Force [kN] vs. Displacement [mm]

Sim. vs. Exp.
Simulation model and method

1. Sampler
   Sampling (Point selection)

2. Pre-processing
   Modell Setup

3. FEM
   Pre-deformation (S1; S2)

4. Post-processing
   Geometrical evaluation (P1; P2; P3)

5. Metamodel
   Metamodel

6. Evaluation
   Constrains / Objects (P1_min < P1 < P1_max)

Start

Finish

Sampling type

Sampling type

MAT Lab script

LS-Dyna 2D FEM Simulation

LS-Dyna 2D FEM Simulation

MATLAB

LS-OPT

LS-OPT

Parameter Setup

LS-Dyna 2D FEM Simulation

LS-Dyna 2D FEM Simulation

Contraints / Objects (P1_min < P1 < P1_max)

 feasable

 infeasible

S1

S2

K1

K2

K3
Results and discussion

EN AW 6014 - T4 t = 2.0 mm

HCT590x t = 1,5 mm

Δl = 0 %
Δl = 5 %
Δl = 10 %
Δl = 15 %
Δl = 20 %

Δl = 0 %
Δl = 5 %
Δl = 10 %
Δl = 15 %
Δl = 20 %

Sheet Thickness [mm]

Pre-forming [mm]

Strain [-]

Sheet Thickness [mm]

Pre-forming [mm]

Strain [-]

2D-Rot. FEM Modell

Isotropic stain

axis of rotation

S2

axis of rotation

S2

axis of rotation

S2
Results and Discussion

P1

$R^2 = 96.9\%$

P2

$R^2 = 98.5\%$

P3

$R^2 = 97.0\%$

Feasible

Infeasible

> 0.15 mm Neck thickness

> 0.10 mm Interlock

Top-sheet

$\text{Al 2.0}$

Base-sheet

$\text{St 1.5}$

P1: Bottom thickness

P2: Neck thickness

P3: Interlock

S1: Pre-strain top-sheet

S2: Pre-strain bottom-sheet
Summary

- Basic material characterization and flow curve identification were carried out.
- 2D clinching simulation model was built up and validated.
- Automatic method for analyzing the influence of pre-forming the sheet metal in clinching processes was developed.
- Functionality demonstrated by investigating the influence of preforming sheet metal in clinching process on the geometric characteristics of the joint.

Future Research

- Further investigation of material behavior concerning temperature- and strain rate-dependency.
- Development of a 3D simulation model for clinching processes.
- Expansion of the developed method on other process parameters.
Development of a numerical method for analyzing the robustness of clinching in versatile process chains

Thank you for your attention!

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