NUMERICAL AND EXPERIMENTAL INVESTIGATIONS FOR HOT METAL GAS FORMING OF STAINLESS STEEL X2CrTiNb18

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OUTLINE

1 Motivation and objective
2 Process
3 FE modeling
4 FE results
5 Comparison with experimental data
6 Excursus Hot Metal Gas Forming-Press Hardening
7 Conclusion
The presented research work originates from the MANUNET ERA-NET collaboration project “Temperature supported hydroforming of stainless steel tubes” which was funded

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**Consortium**

- **Salzgitter Hydroforming**
- **IK4-TEKNIKER**
- **SW3**
- **SEIDEL WERKZEUGBAU GmbH**
- **Fraunhofer IWU**
- **IWC Engineering GmbH**
- **Grupo TTT**
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1 Motivation and objective

Motivation
- Replacement of austenitic steel grades with ferritic grades for exhaust gas components
  - Price advantage due to alloy composition
  - Significantly lower thermal expansion

Objective
- Increase of the degree of forming at forming temperatures of 850°C
- Avoidance of multi-stage hydroforming process at 20°C and thus annealing steps between

Multi-stage IHU processes require annealing steps between, which leads to the formation of precipitates at the grain boundaries and thus to reduced formability.
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2 Process

**Temperature**
- 1000 °C
- 850 °C

**Pressure**
- $P_{\text{max}} = 70 \text{ MPa}$

**Process time**

### Pre-heating
- Pre-heating in chamber furnace within recrystallization temperature

### Transfer phase
- Transfer of the tube into the tool, press closing until position for resistance heating

### Resistance heating
- 8 s from 740 to 1000 °C
- 30 s from 20 to 1000 °C

### Press closing
- Final press closing and sealing

### HMGF
- Hot Metal Gas Forming by pressure built up (1.4 s to 70 MPa), holding and pressure release

### Part removal
- Part removal, cooling on air

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![Image](image.png)
2 Process

- Technologically challenging geometry with local high plastic strains (65 %) in radius areas and hardly any free forming

- Tube diameter: 55.08 mm
- Wall thickness: 1.84 mm

Component failure with single-stage hydroforming at 20°C
2 Process

Hot Pressure Forming (HPF) bei Salzgitter Hydroforming
3 FE modeling

FE model setup

- Tools: rigid active surfaces
- Tube: elastic-plastic shell, 1 mm element length
- Input from Comsol simulation: axial temperature distribution of tube → result mapping
- Local tube diameter scaled according to local temperature
- Thermal boundary conditions are considered (pressure dependent contact heat transfer, heat radiation and convection, initial tool temperature of 25 °C)

Axial temperature distribution of tube at beginning of pressure build-up

Temperature in °C vs. X-Position in %
3 FE modeling

Material modeling

- Uniaxial tensile tests with specimens milled lengthwise from tubes

Flow curve approximation and transfer into material model (elastic-plastic)

- High strain rate sensitivity \(\rightarrow\) strain rate dependent flow curves

20 °C \(\rightarrow\) 800 °C: increase of elongation at break from 27.6 to 74.8 % (2.7 times)
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4 FE results

Temperature

- First contact between workpiece and tool occurs in the region of point III → earlier cooling
- Significant cooling during pressure build-up when tube gets in contact with die
- Radius areas cool down more slowly than plane areas due to later tool contact
4 FE results

**Plastic strain**

- Different behavior depending on the position of the component area
- Larger, free expansions are initiated already at low pressures and at higher strain rates (point B)
- Forming of radii (points A, C) is only completed at higher pressures and lower strain rates

![Graph showing strain rate behavior and internal pressure over process time.](image)
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- Determination of remaining wall thickness with coordinate measuring machine

Cross section with dome

- Possible causes of larger deviations
  - Inhomogeneous initial circumferential wall thickness distribution not considered
  - Sealing not considered (axial compression / position deviation)
  - Material modeling, e.g. tensile test specimen axially cut from tubes

Need of more information out of experiment for precise verification of simulation
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6 Excursus Hot Metal Gas Forming-Press Hardening

- Demonstrator for chassis and body structure

- Geometric and mechanical properties
  - Bent outlet tube
  - Boron-Steel (1800PHS)
  - Cross sections close to series production

- HMGF-tool
  - Tool with integrated conductive component heating
  - Component and electrode cooling

Different cross sections
6 Excursus Hot Metal Gas Forming-Press Hardening

- **Results**
  - Geometrical properties
    - Wall thickness distribution
    - Shape accuracy
  - Mechanical properties
    - Martensitic structure
    - Ultra-high strengths

### Mechanical properties

- **Martensitic structure**

### Geometrical properties

- **Wall thickness distribution**
- **Shape accuracy**

### Mechanical properties

- **Martensitic structure**
- **Ultra-high strengths**

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**Results Table**

<table>
<thead>
<tr>
<th>sample</th>
<th>part</th>
<th>position / section</th>
<th>hardness in HV0.2 (measuring)</th>
<th>average</th>
<th>tensile strength</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>11</td>
<td>3 outer fiber</td>
<td>594 638 623</td>
<td>618</td>
<td>2040</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>3 inner fiber</td>
<td>660 649 608</td>
<td>639</td>
<td>2140</td>
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<tr>
<td></td>
<td>11</td>
<td>3 neutral area</td>
<td>538 568 522</td>
<td>539</td>
<td>1750</td>
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<tr>
<td></td>
<td>11</td>
<td>7 preformed area</td>
<td>613 576 594</td>
<td>594</td>
<td>1970</td>
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<tr>
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<td>11</td>
<td>7 neutral area</td>
<td>567 576 585</td>
<td>576</td>
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<tr>
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<td>3 neutral area</td>
<td>598 571 576</td>
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<tr>
<td></td>
<td>21</td>
<td>3 neutral area</td>
<td>554 571 542</td>
<td>556</td>
<td>1835</td>
</tr>
</tbody>
</table>
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6 Conclusion

- New HMGF process for the material 1.4509
  - Two-stage heating, 2nd step by tool-integrated conduction
  - Improvement of process stability, dimensional accuracy and thinning

- Simulation of HMGF process
  - Simulation leads to a more critical evaluation of thinning
  - More information needed out of experiment for precise verification of simulation

- Hot Metal Gas Forming - Press Hardening
  - Successful forming of demonstrator for chassis and body structure
  - Martensitic structure with ultra-high strengths
  - Highly developed tool-technology
## 5 Comparison with experimental data

### Possible causes of deviations

<table>
<thead>
<tr>
<th>Material modeling</th>
<th>Semi-finished tube</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile test specimen axially cut from tubes → Radial behavior not measured</td>
<td>Initial circumferential wall thickness distribution not considered (mean wall thickness)</td>
</tr>
<tr>
<td>Flow curve approximation → No experimental points for higher strain rates</td>
<td>Welding seam not considered</td>
</tr>
<tr>
<td>Yield locus approach → Assumption due to missing data</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Process modeling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radial deviations of the tube position in the tool not considered</td>
</tr>
<tr>
<td>Sealing not considered → Possible axial compression and position deviation</td>
</tr>
</tbody>
</table>

### Interactions between influencing variables currently unknown