Thermomechanical Processing for Creating Bi-Metal Bearing Bushings

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Outline

- Introduction and Motivation
- SFB 1153 Tailored Forming
- Forming Process Design
- Results
- Summary and Outlook
Introduction and Motivation

Automobile Engines

- Otto engine (non-charger)
- Otto engine (turbocharger)
- Diesel engine

<table>
<thead>
<tr>
<th>Specific Output, kW/dm³</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1900</td>
</tr>
<tr>
<td>20</td>
<td>1910</td>
</tr>
<tr>
<td>30</td>
<td>1920</td>
</tr>
<tr>
<td>40</td>
<td>1930</td>
</tr>
<tr>
<td>50</td>
<td>1940</td>
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<tr>
<td>60</td>
<td>1950</td>
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<td>70</td>
<td>1960</td>
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<td>80</td>
<td>1970</td>
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<td>90</td>
<td>1980</td>
</tr>
<tr>
<td>100</td>
<td>1990</td>
</tr>
<tr>
<td>110</td>
<td>2000</td>
</tr>
<tr>
<td>120</td>
<td>2010</td>
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</tbody>
</table>

Source: Golloch, 2005

- Rising output density
- Locally varying loads
- Conservation of resources
- Energy efficiency

- Integrate different materials into one single bi-material component
- Take advantage of specific characteristics of different materials

Source: Audi AG 1.8 TFSI Engine
Introduction and Motivation

Appropriate Material at the Appropriate Location

- Extended functionality of components
- Lightweight construction

Automotive Engineering
- Piston: little weight, thermal/mechanical loading
- Drive Shaft Yoke: mechanical loading, tribological loading

Energy Technology
- Generator Shaft: little weight, mechanical/tribological loading

Aerospace Engineering
- Turbine Blade: mechanical loading, thermal loading

Automotive Engineering
- Piston: little weight, thermal/mechanical loading

Medical Engineering
- Dental Implant: biocompatible surface roughness, mechanical loading

Energy Technology
- Generator Shaft: little weight, mechanical/tribological loading

Automotive Engineering
- Drive Shaft Yoke: mechanical loading, tribological loading

Medical Engineering
- Dental Implant: biocompatible surface roughness, mechanical loading
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Use of combined semi-finished workpieces and thermo-mechanical manufacturing processes to produce hybrid components with locally-adapted properties.

- **Joining**
  - Profile extrusion
  - Deposition welding
  - Friction welding

- **Forming**
  - Die forging
  - Impact extrusion
  - Cross wedge rolling

- **Finishing**
  - Machining
  - Heat treatment
  - Finishing

- **High-performance components with locally-adapted properties**
  - Service life evaluation
  - Geometrical inspection
  - Damage prediction
  - Multiscale modelling
Bi-Material Automotive Parts

- Stepped Shaft 1
  Coaxial Arrangement of Materials

- Stepped Shaft 2
  Sequential Arrangement of Materials

- Bearing Bushing

- Bevel Gear
SFB 1153 Tailored Forming

Bi-Material Automotive Parts

- Stepped Shaft 1
  - Coaxial Arrangement of Materials
  - Cross Wedge Rolling
  - Deposition Welding

- Stepped Shaft 2
  - Sequential Arrangement of Materials
  - Impact Extrusion
  - Friction Welding

- Bearing Bushing
  - Profile Extrusion

- Bevel Gear
  - Die Forging
  - Die Forging
  - Deposition Welding
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The bi-metal bearing bushing represents a lightweight concept:

- Combination of steel 20MnCr5 and aluminum 6082
- Coaxially arranged workpieces were designed in accordance with the final geometry
- High performance and wear resistant material on the high loaded bearing surface
- Light aluminum in the structure areas
- Low weight while maintaining high durability and performance
Forming Process Design

Forming Tool System

- Precise positioning of the workpiece by an integrated punch guide
- Near-net-shape forging
- Automatic detaching of the forged parts with disc springs’ force
- Inhomogeneous forming temperature (Steel/Aluminium)
Forming Process Design

Heating Concept – Induction Coil

- Dissimilar thermal, physical and mechanical properties of steel and aluminum
- Reaching of material specific forming temperatures for both material is required
- Targeted presetting of temperature gradients by induction heating in order to increase the formability
- Maximum temperature of steel is limited due to the melting temperature of aluminum
- Improvement of the heating efficiency by magnetic flux controller

![Diagram showing the components of the heating concept including the induction coil, thermocouples, workpiece, and magnetic flux controller.]

Position of Thermocouples:
1 - T_{Aluminum}
2 - T_{Steel}
Forming Process Design

Heating Concept – Effect of Magnetic Flux Controller

- Using of magnetic flux controller lead to shorter heating time with less power

Measurement Points

Temperature Curves

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>mm</th>
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<tbody>
<tr>
<td>Outer Diameter Aluminum</td>
<td>62</td>
</tr>
<tr>
<td>Outer Diameter Steel</td>
<td>44</td>
</tr>
<tr>
<td>Inner Diameter Steel</td>
<td>32</td>
</tr>
</tbody>
</table>

Heating Parameter

<table>
<thead>
<tr>
<th></th>
<th>Without Alphaform®</th>
<th>With Alphaform®</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Voltage, V</td>
<td>600</td>
<td>300</td>
</tr>
<tr>
<td>Set Voltage, %</td>
<td>60</td>
<td>100</td>
</tr>
<tr>
<td>Heating Time, s</td>
<td>60</td>
<td>10</td>
</tr>
</tbody>
</table>
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Results

Numerical Modelling of the Heating Process

Comparison between Experiment and Simulation with ideal contact

- Both curves equalize at the same temperature
- The total energy input was the same for both cases
- The shrink-fitted workpieces have not perfect contact → higher temperature gradients possible
The aluminum has a higher thermal expansion coefficient compared with steel

The gap between steel and aluminum grows with increasing temperature

The heat exchange decreases due to less contact
Results

Numerical Modelling of the Heating Process

Comparison between Experiment and Simulation with variable power and conductivity of the gap

- Integration of a thin layer with temperature dependent conduction properties between steel and aluminum in simulation model
- Slight deviations at the beginning and the end of the heating process are caused by thermal lag of the thermocouples
Numerical Modelling of the Heating Process

Radial temperature distribution in bi-metal workpieces

a) Heating time 11 s
b) Heating time 13 s
c) Heating time 14 s

Used for the Forming Tests
Results

Experimental Forming Tests
Results

Experimental Forming Tests

### Heating strategy 1

<table>
<thead>
<tr>
<th></th>
<th>EN AW-6082</th>
<th>20MnCr5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Heating time</strong></td>
<td>13 seconds</td>
<td></td>
</tr>
<tr>
<td><strong>Transportation time</strong></td>
<td>6 seconds</td>
<td></td>
</tr>
<tr>
<td><strong>$T_{Steel}$</strong></td>
<td>Approx. 717 °C</td>
<td></td>
</tr>
<tr>
<td><strong>$T_{Aluminum}$</strong></td>
<td>Approx. 458 °C</td>
<td></td>
</tr>
<tr>
<td><strong>Bonding quality</strong></td>
<td>Form-/ Force- closed joint</td>
<td></td>
</tr>
</tbody>
</table>

### Heating strategy 2

<table>
<thead>
<tr>
<th></th>
<th>EN AW-6082</th>
<th>20MnCr5</th>
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</thead>
<tbody>
<tr>
<td><strong>Heating time</strong></td>
<td>14 seconds</td>
<td></td>
</tr>
<tr>
<td><strong>Transportation time</strong></td>
<td>6 seconds</td>
<td></td>
</tr>
<tr>
<td><strong>$T_{Steel}$</strong></td>
<td>Approx. 719 °C</td>
<td></td>
</tr>
<tr>
<td><strong>$T_{Aluminum}$</strong></td>
<td>Approx. 492 °C</td>
<td></td>
</tr>
<tr>
<td><strong>Bonding quality</strong></td>
<td>Partially metallurgical bonding</td>
<td></td>
</tr>
</tbody>
</table>
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Summary and outlook

Summary

- Forming of dissimilar materials is challenging due to their different material-specific properties
- By using of tailored heating, high forming strains can be achieved in steel-aluminum workpieces
- The forming temperature have the most influence on the resulting bonding quality

Outlook

Mechanical characterization of the bonding quality by push-out test

For further improving of bonding quality, an optimization of the heating process is required:

- Targeted cooling of aluminum surface during the induction heating (water spray field, water-cooled robot gripper)
- Reduction of the transportation time
- Application of the induction generator with higher power
Thank you for your attention!

Contact us!
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