Hot Hydroforming of Sheets and Tubes: An Overview

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Disclaimer

• The entire presentation is based on published literature. The source of information has been indicated at the bottom of each slide.
Why Hot Hydroforming?

• High strength alloys – High YS at room temperature
  – Greater frictional force (due to greater forming force)
  – Nonuniform strain distribution
  – Need to deform under hot conditions
  – Usual working media like oil & water good until 300 deg C

• Three questions:
  – Means of heating the workpiece to a high working temperature
  – Working media that will work under high temperatures
  – Pressurising working media at high working temperatures
Working Media & Materials

Working Media
• Granular medium
• Hot Gas

Methods of heating
• Resistance heating
• Furnace heating

Materials
• Titanium alloys
• Hot forming steels for autobody components
Issues in hot hydroforming

- Heating of workpiece by heaters embedded in the dies
- Die heating too slow due to large energy requirement
- Hot gas hydroforming: Temperature distribution complex
- Process (formability) is sensitive to temperature
- In service properties are sensitive to temperature
- Uniform temperature distribution for a circular tube
- Larger circumferential temperature variation for a rectangular tube
- Microstructure evolves during forming. Processing maps are important to establish manufacturing parameters
Processing steps in hot hydroforming

A possible manufacturing setup

Min. hydroforming pressure at temperature $T_{a1}$

$P_h = (p_0 + 0.1) \frac{T_{a1} + 273}{T_{a0} + 273} - 0.1$

Compressed air in the sealed tube

Power : 60 kW; 10V & 6000A  
Electrode (Cu) width : 35mm  
Contact area = 32900 mm$^2$  
To prevent overheating : water cooled electrodes by demineralised water at 18 deg C

Electrical insulation : PEEK cylindrical elements (between tube and machine frame)

**Alloy AA6060 Chemical composition**

<table>
<thead>
<tr>
<th>Element</th>
<th>Al</th>
<th>Mg</th>
<th>Si</th>
<th>Fe</th>
<th>Mn</th>
<th>Zn</th>
<th>Cr</th>
<th>V</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>98.9</td>
<td>0.42</td>
<td>0.41</td>
<td>0.19</td>
<td>0.016</td>
<td>0.016</td>
<td>0.012</td>
<td>0.013</td>
<td>0.011</td>
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</table>

Electrical and Thermal parameters

<table>
<thead>
<tr>
<th>Temperature [°C]</th>
<th>Current Intensity [A]</th>
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</thead>
<tbody>
<tr>
<td>100</td>
<td>890</td>
</tr>
<tr>
<td>200</td>
<td>1340</td>
</tr>
<tr>
<td>300</td>
<td>1640</td>
</tr>
<tr>
<td>400</td>
<td>1835</td>
</tr>
<tr>
<td>500</td>
<td>2010</td>
</tr>
<tr>
<td>600</td>
<td>2123</td>
</tr>
<tr>
<td>680</td>
<td>2200</td>
</tr>
</tbody>
</table>

\[ T = 28387 \cdot e^{0.0014 \cdot I} \]

High temperature behaviour of Al 6063 alloy

The Al alloy has practically ZERO strain rate sensitivity

Mechanical Behaviour of AA 6060 alloy

Shows small strain rate sensitivity

Free Bulging

$p_0 = 0.8$ MPa, $J = 76$ A/mm$^2$ and $v = 20$ mm/s.

What may go wrong

Tube melted out due to overheating

Failure due to tensile stresses in hoop & axial directions

NO axial feeding

Expansion ratio

\[ P_0 = 0.8 \text{ MPa} \]

\[ J = 38 \text{ A/mm}^2 \]

\[ J = 76 \text{ A/mm}^2 \]

More Uniform temperature distribution

Axial feed + temperature

Pulsating pressure in hydroforming

\[ p = \Delta p \sin 2\pi \omega (s - 1) + \]

Thickness distribution

Amplitude and Frequency of Pulsation

$\Delta p = 7 \text{ MPa}$

$\omega = 0.33$ cycles/mm of stroke

High Pressure Pneumatic Forming

• Material: Ti-3Al-2.5V alloy
• Strain rate sensitive alloy
• Adopting the lower pressurization rate and filling regenerative materials into the tube are effective methods for decreasing or eliminating the temperature difference.
Pressurisation and Corner filling

Tensile behaviour

Ductility in Uniaxial tension

Corner filling

$T = 700 \text{ deg C}$

Other means of Hydroforming
Granular medium based hydroforming

Formability in hot hydroforming

Hot Hydroforming Stainless Steel

- Ferritic stainless steels
- Better corrosion resistance (esp. SCC)
- Lower coeff. Of thermal expansion
- High thermal conductivity
- Poor formability in warm working; better above 700 deg C
- Quartz / Zirconia beads are safe forming media
- Inherent friction between granules and tube aids axial feeding
### Hot forming stainless steel & Media

<table>
<thead>
<tr>
<th>Chemical composition</th>
<th>C</th>
<th>Cr</th>
<th>Mn</th>
<th>Ni</th>
<th>Ti+Nb</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amount (wt-%)</td>
<td>0.02</td>
<td>18</td>
<td>-</td>
<td>-</td>
<td>0.6</td>
<td>Bal.</td>
</tr>
</tbody>
</table>

- Density (g/cm³) 7.7
- Young’s modulus (GPa) 220
- Heat capacity (J/kg·K) 460
- Coefficient of thermal expansion (°C⁻¹) 10x10⁻⁶
- Thermal conductivity at 20 °C (W/m·K) 25

<table>
<thead>
<tr>
<th>Granular material</th>
<th>Particle size (mm)</th>
<th>Hardness</th>
<th>Melting point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zirconia beads</td>
<td>0.4-0.6</td>
<td>&gt;1180 HV</td>
<td>2715</td>
</tr>
<tr>
<td>Steel balls</td>
<td>1.0</td>
<td>60~66 HRC</td>
<td>1505</td>
</tr>
</tbody>
</table>

Tube OD = 50mm, wall thk = 1.5mm

Forming limits & Fracture Limits

Forming with hot granular media

In Summary

- Hot hydroforming is needed for sheets & tubes of high temperature materials
- The working medium depends upon the temperature capability of each.
- Hot gas forming, granular media are viable options
- Gas and granular media have their own advantages in hot forming
- Pulsating pressure works better than monotonic pressure of the working fluid / media
Thank you