Warm and Hot Stamping of Ultra High Strength Steel Sheets Using Rapid Resistance Heating

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Reduction in car weight ➔ Use of high strength steel sheets

Ultra high strength steel sheet > 1GPa

Specific strength for various sheet metals

<table>
<thead>
<tr>
<th>Sheet</th>
<th>Tensile strength</th>
<th>Specific gravity</th>
<th>Strength-to-specific gravity ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultra high strength steel</td>
<td>980 - 1470MPa</td>
<td>7.8</td>
<td>126 - 188MPa</td>
</tr>
<tr>
<td>High strength steel</td>
<td>490 - 790MPa</td>
<td>7.8</td>
<td>63 - 101MPa</td>
</tr>
<tr>
<td>Mild steel SPCC</td>
<td>340MPa</td>
<td>7.8</td>
<td>44MPa</td>
</tr>
<tr>
<td>Aluminium alloy A6061(T6)</td>
<td>310MPa</td>
<td>2.7</td>
<td>115MPa</td>
</tr>
</tbody>
</table>

Strength of high strength steel sheets

Remarkable increase in strength

Flow stress curve of sheets at room temperature

Large springback

1) Ultra high strength steel sheets
2) Resistance heating
3) Warm and hot stamping
4) Quenching in hot stamping
5) Prevention of oxidation in hot stamping using oxidation preventive oil
6) Warm and hot shearing
7) Warm and hot spline forming
Variations in tensile strength and elongation with temperature for SPFC980Y

- Thickness 1.2mm, strain-rate 0.4/s
- Heating temperature $T/°C$
- Tensile strength /MPa
- Elongation/%

<table>
<thead>
<tr>
<th>Heating temperature T/°C</th>
<th>Tensile strength MPa</th>
<th>Elongation %</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>200</td>
<td>100</td>
</tr>
<tr>
<td>400</td>
<td>400</td>
<td>40</td>
</tr>
<tr>
<td>600</td>
<td>600</td>
<td>20</td>
</tr>
<tr>
<td>800</td>
<td>800</td>
<td>0</td>
</tr>
</tbody>
</table>

Forming of ultra high strength steel sheets

- Springback: large
- Formability: small

Warm and hot stamping
- Reduction in forming load
- Increase in formability

Heating of sheet?
- Al, Mg, stainless steel: low temperature
- Steel: high temperature (>500°C)

Conventional warm and hot stamping

Very big

- Furnace
- Heating
- Decrease in temperature
- Oxidation
- Setting
- Forming
- Interval between heating and forming

Warm and hot stamping using rapid resistance heating

Direct heating into dies
- Prevention of drop in temperature
- Reduction in oxidation

Resistance heating and forming

Measurement of temperature distribution in sheet in resistance heating

- DC, E=10V
- Control by input energy
- L130 □ W80 □ t1.2
- Thermography
- 7.4MPa
- Sheet holder
- Copper electrode
- 600mm

Resistance heating

SPFC980, thickness: 1.2mm, Power: 85kJ (10V, 2sec)
Distribution of temperature in resistance heating of rectangular sheet measured by infrared thermography for SPFC980Y

Variations in temperature and input energy in resistance heating of SPFC980

Relationship between measured heating temperature and input energy

Energy efficiency of resistance heating

Inhomogeneous contact of sheet with electrode

Distribution of temperature measured by infrared thermography for inhomogeneous contact with electrode
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Quenching test of ultra high tensile strength sheet without deformation

SPFC980Y

Heating temperature and holding time

Cooling curve of sheet at $T=980$ °C for different holding times

Microstructures at $T=980$ °C for two holding times

Comparison between hardnesses obtained from resistance heating and furnace heating for $t=7.0s$

Variations in tensile strength and elongation with heating temperature
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Oxidation preventive oils used for hot stamping

<table>
<thead>
<tr>
<th>Oxidation preventive oil</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Element</td>
<td>K, B, C, Na</td>
<td>Si, Na</td>
<td>Ca</td>
<td>C</td>
</tr>
<tr>
<td>Oxidation prevention</td>
<td>Liquefied film</td>
<td>Sacrificial oxidation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Resistance heating of sheet for evaluation of oxidation preventive oils

Relationships between scale thickness and heating temperature for different oxidation preventive oils

- A
- B
- C
- D
- Non-coated
1) Ultra high strength steel sheets  
2) Resistance heating  
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5) Prevention of oxidation in hot stamping using oxidation preventive oil  
6) Warm and hot shearing  
7) Warm and hot spline forming
**Conditions of warm and hot punching process**

- **Sheet**
  SPFC980, L130 □ W50 □ t2.0

- **Punch**
  SKH51 (TiCN coating), φ10mm

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<tr>
<td>Heating temperature $T , ^\circ C$</td>
<td>650, 700, 830, 970, 1070</td>
</tr>
<tr>
<td>Clearance ratio $c / %$</td>
<td>5, 10, 15</td>
</tr>
<tr>
<td>Punching speed /mm·s$^{-1}$</td>
<td>150</td>
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**Warm and hot punching**

- Servo press
- Load cell
- Sheet holder
- Punch (φ10)
- Die

**Hot punching of SPFC980Y using resistance heating**

- (a) Room temperature
- (b) 650 °C
- (c) 830 °C
- (d) 1070 °C

**Surface and cross-section of punched edge of SPFC980Y**

- Burnishing
- Fracture

**Relationship between percentage of depths of burnished surface, fracture surface and rollover on sheared edge and heating temperature**

**Relationship between ratio of burr height on sheared edge to thickness and heating temperature for different clearance ratios**
**Relationship between roughness of burnished and fracture surfaces on sheared edge and heating temperature for \( c=5\% \)**

![Graph showing roughness vs. heating temperature]

**Relationship between maximum punching load and heating temperature**

![Graph showing punching load vs. heating temperature]

**Problem for heating in warm and hot shearing**

- 1) Low heating efficiency
- 2) Low dimensional accuracy
- 3) Long heating time

**Local heating near shearing region**

- 1) High heating efficiency
- 2) Compact apparatus
- 3) Small oxidation

**Contact pin electrodes used for local heating**

![Diagram showing contact pins in holder and knockout]

**Local heating using contact pins**

![Diagram showing local heating setup]
FEM simulation of temperature distribution in local heating

(a) Diameter: 2.6mm, both 12 pins
(b) Diameter: 1.6mm, both 12 pins
(c) Diameter: 2.6mm, both 8 pins
(d) Diameter: 2.6mm, inside: 12 pins, outside: 24 pins

Local heating using contact pins

\[ T=800 \, ^\circ C, \, v=150\, mm/s \]

Punched sheet for \( c=10\% \) and \( v=150mm/s \)

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