**Stamping of High Strength Steel Sheets**

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Reduction in car weight → Use of high strength steel sheets

**Ultra high strength steel sheet > 1GPa**

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

Cheaper and higher strength

<table>
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<th>Specific gravity</th>
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<tbody>
<tr>
<td>SPFC980Y</td>
<td>0.065/s</td>
<td>0.0002/s</td>
<td></td>
</tr>
<tr>
<td>SPFC780Y</td>
<td>0.091/s</td>
<td>0.0002/s</td>
<td></td>
</tr>
<tr>
<td>SPFC440</td>
<td>0.093/s</td>
<td>0.0002/s</td>
<td></td>
</tr>
<tr>
<td>SPCC</td>
<td>0.096/s</td>
<td>0.0002/s</td>
<td></td>
</tr>
<tr>
<td>A5083</td>
<td>0.0001/s</td>
<td>0.0002/s</td>
<td></td>
</tr>
<tr>
<td>A1050</td>
<td>0.051/s</td>
<td>0.0002/s</td>
<td></td>
</tr>
</tbody>
</table>

**How are the sheets formed?**

- **High strength steel sheets**
  - High strength: large forming load, large springback, small tool life
  - Low formability: fracture

1) Cold stamping: no heating
2) Warm and hot stamping: heating

**Strength of high strength steel sheets**

Remarkable increase in strength

Flow stress curve of sheets at room temperature

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<thead>
<tr>
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<th>Specific gravity</th>
<th>Strength-to-specific gravity ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>IF</td>
<td>Conventional</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRIP</td>
<td>Recently developed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DP</td>
<td>Die quenching</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ultra sheet</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
1) Ultra high strength steel sheets
2) Reduction in springback using servo press
3) Improvement of formability in stretch flanging
4) Resistance heating
5) Warm and hot stamping
6) Warm and hot spline forming
7) Prevention of oxidation in hot stamping using oxidation preventive oil
8) Warm and hot shearing
9) Self pierce riveting of ultra high strength steel and aluminium alloy sheets

Reduction in springback in V-shaped bending

Deformation behaviour in V-shaped bending

Effects of finishing reduction in thickness and holding time at bottom dead centre for SPFC980Y

Distribution of stress in width direction just after unloading for finishing reduction in thickness
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Prediction of fracture at corner of 980MPa sheet using gradual contact punch

(a) Flat punch, $\alpha=180^\circ$
(b) Gradual contact punch, $\alpha=170^\circ$

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Variations in tensile strength and elongation with temperature for SPFC980Y

Forming of ultra high strength steel sheets

Large load, large springback, small formability

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

5.0s

Interval between 5.0s
heating and forming 3.0s

Resistance heating and forming

Warm and hot stamping using rapid resistance heating

Direct heating into dies
Prevention of drop in temperature
Reduction in oxidation
Variations in temperature and input energy in resistance heating of SPFC980

Electrode Resistance heating

SPFC980, thickness: 1.2mm, Power: 85kJ (10V, 2sec)

Energy efficiency of resistance heating

Energy efficiency /%

Heating temperature T/ºC

Variations in temperature and input energy in resistance heating of SPFC980

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Hat-shaped bending using resistance heating

Hat-shaped bending using resistance heating at 980 ºC
Products formed by hat-shaped bending of SPFC980Y at different heating temperatures

Relationships between springback and heating temperature in hat-shaped bending of various sheets

Relationships between bending load and heating temperature

Relationship between hardness of bent sheets and heating temperature

Microstructures in bottom of bent sheets

Deep drawing of SPFC980Y rectangular sheet for 800ºC
Formed products in deep drawing of SPFC980Y rectangular sheet

(a) $T=600^\circ C$

(b) $T=800^\circ C$

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Spline forming of clutch drum

Plate forging

Clutch drum

High strength steel

Uniform resistance heating of cup

Resistance heating

Temperature

Side wall: uniform cross-section

Cup
electrode

Rectangular blank

Trapezoidal electrode

Cup
electrode

Resistance heating of cup

Cupper electrode

Resistance heating

Temperature

Spline forming of clutch drum

Lower electrode

Upper electrode

Die

Air cylinder

Cup

Bolster

Slide

Electrify
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**Oxidation preventive oils used for hot stamping**

<table>
<thead>
<tr>
<th>Target: 900°C, 10s</th>
<th>Quenchable steel sheet for hot stamping</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>Si</td>
</tr>
<tr>
<td>0.21</td>
<td>0.25</td>
</tr>
</tbody>
</table>

**Oxidation preventive oils**

<table>
<thead>
<tr>
<th>Oil</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lubricant</td>
<td>Stainless steel warm stamping</td>
<td>Titanium warm stamping</td>
</tr>
<tr>
<td>Element</td>
<td>K, B, C, Na</td>
<td>K, B, C, Na, P, Ca</td>
</tr>
<tr>
<td>Oxidation prevention</td>
<td>Liquefied film</td>
<td>Liquefied film</td>
</tr>
</tbody>
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**Conventional prevention of oxidation**

- Shot blasting
- Heating
- Stamping
- No oxidation
- High cost
- Increase in processes, accuracy reduction
- Aluminium and zinc coatings

**Coating of sheets with oxidation preventive oil**

1) Ultrasonic cleaning (3 times)
2) Drying
3) Application
4) Drying
Evaluation test of oils under natural cooling

Heating temperature: 800, 825, 850, 875, 900, 925°C
Dimension: L130mm, W20mm, t1.2mm

Oxidation on surface of heated sheet for different coatings

T=800°C
T=850°C
T=900°C
(a) Non-coated (b) Oil A (c) Oil B

Improvement of oxidation prevention by repeating of coating (T=900°C)

Increase in weight /g
Amount of coating /mg

Hat-shaped bending for evaluating oxidation preventive oil

Hat-shaped bending of quenchable steel sheet
Hat-shaped bent sheets

Hardness of bent sheets

Cleaning of layer remaining on surface of formed product by phosphoric acid

Scale on surface of sheet bent at $T=900^\circ C$ and before and after cleaning

Shearing of ultra high strength steel sheet

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Warm and hot shearing using local resistance heating near shearing region

Whole heating: low efficiency and accuracy

- High heating efficiency
- Compact apparatus
- Small oxidation

Contact pin electrodes used for local heating

Uniform heating

Contact pins with spring in holder

Contact pins with spring in knockout

Local heating using contact pins

Servo press

Load cell

Punch, φ19.8

Sheet, SPFC980, 50x50x2.0

Spring

Holder

Knockout

12 contact pins, φ2.6

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 for $T=800$ °C
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Finite element simulation of self piercing riveting of ultra high strength steel and aluminium alloy sheets

Upper: SPFC980, 1.4mm
Lower: A5052-H34, 1.5mm

Self pierce riveting of ultra high strength steel and aluminium alloy sheet using optimised die

Conventional die ➔ Optimised die

Cold stamping
Reduction in springback using servo press
Improvement of formability in stretch flanging
Self pierce riveting of high strength steel and aluminium alloy sheets

Warm and hot stamping
Warm and hot stamping
Warm and hot spline forming
Prevention of oxidation in hot stamping using oxidation preventive oil
Warm and hot shearing