Ken-ichiro Mori  
Professor  
Department of Mechanical Engineering,  
Toyohashi University of Technology  
CIRP fellow, forming processes

Scopus (from 1995)  
Number of papers: 205, Number of citations: 2516, h-index:28  
Web of Science (from 1993)  
Number of papers: 172, Number of citations: 1419, h-index:19

Numiform 2001,  
Metal Forming 2010,  
ICTP 2014

History of research works

- Software: rapid development of computers
  - 1980: Formulation of rigid-plastic finite element method
  - Application to forging, rolling, extrusion, drawing, sheet metal forming, powder forming, etc.
  - Knowledge engineering: expert system, fuzzy control, neural network, GA

- 1990: Microscopic analysis: microscopic FEM, DEM, Monte Carlo method

- 2000: 1997: Toyohashi University of Technology  
  Hardware: automobile lightweighting  
  Stamping of high strength steel sheets, hot stamping
  Joining by plastic deformation: self-pierce riveting, mechanical clinching

- 2010: Pulsating forging and hydroforming
  Plate forging for thickening and thinning
  Stamping of titanium, magnesium, aluminium sheets

1. Reduction in car weight
2. Hot stamping
3. Material and oxide prevention
4. Heating
5. Stamping
6. Die quenching

Toyohashi University of Technology

National university  
Found in 1976  
Undergraduates: 1,190  
Postgraduates: 989  
Academic staff: 229
5 departments, 1 research institute and 6 research centers  
Area: 355,606 m²

Hot Stamping of Ultra-High Strength Steel Parts

Toyohashi

Population: 380,000  
Area: 630 km²
**Approaches of environmentally friendly automobiles**
- Engine
  - Thermal efficiency
  - Lean burn
  - Direct injection
  - Friction reduction
  - Piston and ring
  - Engine oil
- Power source
  - EV, PHEV, HV, Idling stop
- Powertrain
  - CVT, Multi-speed shift, Friction reduction
- Aerodynamics
  - Body shape improvement
- Body weight reduction
  - Body structure
  - Lightweight material: High strength steel, Aluminum alloy, Magnesium alloy, CFRP
  - 100kg reduction: 1km/l fuel consumption improvement

**Body parts of automobiles**
- Component parts
  - Skin parts
  - Body-in-white
  - Fr Side Member
  - Locker
  - Cneter Pillar
  - Fr Pillar
  - Roof side rail
  - Fender
  - Doors
  - Luggage
  - Hood
  - Roof
  - Beams

**Weight percentage of automobiles parts**
- Body components: 30%
- Engine: 12%
- Powertrain: 7%
- Suspension: 7%
- Fuel tank: 4%
- Wheels, Hubs: 4%
- Seats: 4%
- Tires: 3%
- Window glass: 3%
- Others: 26%

**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>

**Problems in cold stamping of ultra-high strength steel sheets**
- Fracture
- Seizure
- Large springback
- Small ductility

Cold stamping of steel sheets having tensile strength more than 1.2GPa is difficult.
Variations in tensile strength and elongation with temperature for SPFC980Y

Hat-shaped bent sheets of SPFC980Y at different heating temperatures

Hot Stamping of Ultra-High Strength Steel Parts

1. Reduction in car weight
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6. Die quenching

Hot stamping for ultra–high strength steel products

Hot press forming, press hardening

Increase in hardness by die quenching

Hot stamping process for ultra–high strength steel products

Miyazu Malaysia
Hot stamping

Volkswagen Passat
16% of body components

Audi A7 Sportback
Aluminium, cold stamping
Aluminium, cast
Aluminium, extrusion
Steel, hot stamping
Steel, cold stamping

Center pillar in Honda N BOX

Hot stamping in Germany, Benteler
Hot stamping in Canada, Magnum

- Bumper reinforcement member
- Door beam reinforcement
- A pillar reinforcement
- Roof reinforcement
- Dash lowercross member
- Centre pillar
- Roof reinforcement

Hot stamping in Japan, Aisin Takaoka

- Unipres

Number of parts produced by hot stamping

Start from Europa, spreading in Asia and America

- Ref: Hund 2011, Belanger 2011

Ration of hot stamped part in body-in-white

- 45% Limit (Volvo)
- 26% 2012 Ford Focus
- 19% 2008 VW Passat
- 17% 2011 Volvo S60
- 7% 2002 Volvo XC90
- 6% 2007 Fiat 500

Number of hot stamping lines

- Europa (62)
- North America (51)
- China (11)
- Japan (10)
- Korea (4)
- Others (4)

Total: 142

Number of lines (October, 2011)

- Ref: Belanger 2011

Papers for hot stamping

- CHS2: International Conference on Hot Sheet Metal Forming of High-Performance Steel, 193
- General: 229
Advantages of hot stamping

- Decrease in forming load
- Prevention of springback
- Increase in formability
- Formed products having 1.5GPa in tensile strength

Hot Stamping of Ultra-High Strength Steel Parts

1. Reduction in car weight
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Problems in conventional hot stamping

- Expensive equipment
- Low productivity
- Limited applicable range
- Sheet
- Oxide prevention
- Big furnace
- Long heating time
- Heating
- Stamping
- Trimming and punching
- Applicable range

Increase in strength

- Increase in carbon: large strength
- 1.5 GPa
  - 0.2%C-B
  - No fracture
  - 1.8 GPa
  - 0.3%C-Mn
  - Partial fracture
  - 2 GPa
  - 0.4%C-B
  - Complete fracture
- 1.8 GPa
- No fracture
- 2 GPa: ArcelorMittal
- Martensitic stainless steel
- Grain refinement
- Mazda CX-5, bumpers

Phase transformation

Manganese boron steel 22MnB5: 1.5 GPa

<table>
<thead>
<tr>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.21</td>
<td>0.25</td>
<td>1.2</td>
<td>0.015</td>
<td>0.0014</td>
</tr>
</tbody>
</table>

Ferrite → austenite → martensite
pearlite, bainite

Conventional treatments for oxidation

- Heating
- Stamping
- Shot blasting

Increase in processes, accuracy reduction

Aluminium and zinc coatings

Intermetallic compound
No oxidation

Coated sheets
Heating
3-5 min.
Stamping
**Oxidation treatment**

- Before shot blasting: Uncoated, shot-blasted
- After shot blasting: Al-Si coated, Zinc coated: high corrosion resistance
- Oxidation preventive oil: Nano-X sol-gel, inert gas
- After stamping: Uncoated, Coated

**Hot Stamping of Ultra-High Strength Steel Parts**

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**Furnace size**

- Furnace length (3 spm): 26.4m
- Heating time: \( \frac{230\text{sec}}{20\text{sec}} \times 1.6m \approx 26.4m \)
- Ref: Eriksson 2010

**New heating processes**

- (a) Furnace heating
- (b) Far-infrared heating
- (c) Induction heating

**Hot stamping using resistance heating**

- Drop in temperature: Oxidation
- Resistance heating: Less temperature drop, Less oxidation, Synchronisation with press, High energy efficiency

**Resistance heating**

SPFC980, thickness: 1.2mm, Power: 85kJ (10V, 2sec)
Linkage of power supply and servo press

Hat-shaped bending using resistance heating

Hat-shaped bent sheet at 980 ℃

Hot stamping using resistance heating

Repeated resistance heating hot stamping
Repeated resistance heating hot stamping

Sheet feeding

Transferring → Resistance heating, stamping + die quenching → Products

Real production using resistance heating

(a) Heating
(b) Taking from
(c) Setting
(d) Forming

Limitation of resistance heating to rectangular sheets

Electrode

Temperature [°C]

(a) Rectangular blank
(b) Trapezoidal blank

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Hydraulic press used for hot stamping

Hydraulic press

Mechanical servo press

Hydraulic cylinder

Crank

Reduction gear

Servo motor

Holding at bottom dead centre

• Low slide speed
• High slide speed
• Flexible slide motion

Hot stamping for different forming speeds

(a) Low speed (26 mm/s)  (b) High speed (149 mm/s)
Effect of forming speed on formability

(a) Cold
(b) Hot, 149 mm/s
(c) Hot, 26 mm/s

Temperature distribution in hot stamping

(a) 149 mm/s
(b) 26 mm/s

High speed stamping by mechanical servo press

Mechanism of improvement of formability for high speed

(a) Low speed: low formability
(b) High speed: high formability

Improvement of formability by delay of sheet holding

(a) Start
(b) Former stage
(c) Latter stage
(d) End

Effect of punch offset on formability

Effect of drawing in hot stamping

(a) Drawing: sheet holder
(b) No drawing: no sheet holder
Seizure in no drawing

(a) Drawing
Perpendicular
Seizure
Inclined
Seizure
(b) No drawing
Perpendicular
Seizure
Inclined
Seizure

Hot Stamping of Ultra-High Strength Steel Parts

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Problems in conventional hot stamping

Expensive equipment
Low productivity
Limited applicable range

Expensive sheet
Oxide prevention
Big furnace
Long heating time
Hydraulic press
Die quenching
Laser cutting
Cabin parts

Productivity of hot stamping operation

Application of servo press and direct water quenching in Honda

Increase in productivity: 8 spm
Conventional: 2 or 3 spm

Water direct quenching

(a) Start
(b) Holding at bottom dead centre
(c) End

Nippon Steel & Sumitomo Metal, Unipres
Direct water quenching and delay of sheet holding

(a) Start | (b) Former stage | (c) Latter stage | (d) End

Direct water quenching in hot stamping

Effect of direct water quenching on Vickers hardness

Effect of prevention of die quenching on shearing load

Hat-shaped bending using bypass local resistance heating
1. Reduction in car weight
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Successive forging of tailored blanks

Increase in production flexibility
Production by forming companies

Tailored blank having two thicknesses
produced by successive forging

22MnB5, Al-Si coated, 1.6 mm

Non-compressed: only feeding
Compressed

Transient region
(a) Tailor forged blank
(b) Cross-section

Roof rail produced by hot stamping

(a) Hot-stamped part
(b) Cross-section

Non-compressed
Compressed

Advices for reachers

1. Generate ideas.
2. Change situation.
3. Write English journal papers.
Citation of papers in scientific database

Scientific paper database: Web of Science, Scopus, Google Scholar, Science Direct

Citations: number cited in references of other papers
Impact factor: number of citations for journal, evaluation of journal and not individual papers

Papers of Mori cited in Scopus

Variation in number of citations in Scopus


Number of citations per one year
K. Mori
Year

Advises for reachers

1. Generate ideas.
2. Change situation.
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Thank you very much