Center for Precision Forming
(www.cpfomring.org)

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A short Review
March 2014
• The Ohio State University (OSU) has established the Industry/University Cooperative Research Center (I/UCRC) on Precision Forming (CPF) focusing on research needs of metal forming industry

• Funding is provided by National Science Foundation (NSF) and member companies.

• CPF (www.cpforming.org) benefits from research conducted at the Engineering Research Center for Net Shape Manufacturing (ERC/NSM – www.ercnsm.org)
OBJECTIVES

• Improve existing metal forming processes/products and develop new innovative processes, tooling and equipment

• Conduct projects in close collaboration with industry and transfer the results to the member companies

• Train and educate engineers in the fundamentals and practice of metal forming science and technology
CPF is supported by NSF and member companies, interested in metal forming
Project CPF-1.1 – Warm Forming of Al Alloys
Project CPF-1.4 – Forming of AHSS in a Servo Press – Die Design
Project CPF-2.1 – Material Properties and Formability
Project CPF-2.2 – Forming Al in a Servo Press
Project CPF 3.3 – Friction/Lubrication/Wear
Project CPF-5.1 – Bending and Springback in Forming of AHSS and Copper Alloys
Project CPF-5.2 – Blanking / Piercing
Project CPF-5.2 A – Hole Flanging and Edge Cracking
Project CPF-5.5 - Hot Stamping
Project CPF 5.6 Practical Method for Predicting Fracture Using FE Simulation
CPF-1.1 - Warm Forming of Al, Mg, Ti & SS in an Aida Servo Drive Press

<table>
<thead>
<tr>
<th>T(°C)</th>
<th>LDR</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT</td>
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<tr>
<td>250</td>
<td>2.5</td>
</tr>
<tr>
<td>300</td>
<td>2.9</td>
</tr>
</tbody>
</table>

Velocity: 2.5-50mm/sec
Cup diameter: 40 mm

<table>
<thead>
<tr>
<th>T(°C)</th>
<th>LDR</th>
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<tbody>
<tr>
<td>RT</td>
<td>-</td>
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<tr>
<td>275</td>
<td>2.6</td>
</tr>
<tr>
<td>275</td>
<td>3.2</td>
</tr>
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</table>
Can we use servo drive properties to improve formability and reduce springback in forming AHSS?
CPF-1.4 - Forming of AHSS

Forming of AHSS in Servo Press

Materials of interest:
DP 600
DP 980
And others

Die design (manufactured by Shiloh) for testing AHSS.
Forming of AHSS in Servo Press

1) Straight Bending
2) Shrink Flanging
3) Stretch Flanging
4) U-Bending
5) Curved U-Bending
6) Deep Drawing
 CPF-1.4 – Forming of AHSS in a Servopress

CPF/Shiloh die set (for 300 ton servo-press)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Notation</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concave side radius</td>
<td>R₁</td>
<td>601.6 mm</td>
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<tr>
<td>Convex side radius</td>
<td>R₂</td>
<td>598.4 mm</td>
</tr>
<tr>
<td>Cavity corner radii</td>
<td>R₃</td>
<td>51.6 mm</td>
</tr>
<tr>
<td></td>
<td>R₄</td>
<td>56.6 mm</td>
</tr>
<tr>
<td></td>
<td>R₅</td>
<td>61.6 mm</td>
</tr>
<tr>
<td></td>
<td>R₆</td>
<td>66.6 mm</td>
</tr>
</tbody>
</table>
Example: Shrink and Stretch Flanging
Forming of AHSS in Servo Press

Thinning (%)

-12.8
-9.7
-6.6
-3.5
-0.4
2.7
5.8
9.0

Min = -12.8
Max = 9.0

Max. Thinning ~ 9%

Deep drawn sample
DP 600, \( t_0 = 0.83 \) mm
Draw depth = 50 mm
CPF-2.1 Material Characterization

Viscous Pressure Bulge (VPB) Test

Downward motion clamps the sheet

Before Forming

After Forming

Laser Sensor

Test Sample

Viscous Medium

Pressure Transducer

Stationary Punch

Continued downward motion forms the bulged sheet
CPF-2.1 Material Characterization – Flow Stress

Viscous Pressure Bulge (VPB) Test

True Stress (MPa)                                      True Stress (ksi)
          1000                                                   145
              800                                                  116
                600                                                87
                  400                                              58
                    200                                            29
                      0

Material, DP600, 1 mm

Uniform Strain from Tensile Test = 0.16

Tensile data with Power Law

(σ = Kεⁿ)

Useful strain from Bulge Test = 0.49
Test sample

Before bursting

After bursting

CPF-2.1 - Material Characterization – VPB Test
CPF-2.1 - Material Characterization – VPB Test

The diagram shows the maximum dome height in millimeters for different materials:
- AZ31B
- AISI 1050
- SS409
- HSS
- AKDQ
- AMS 5504

The Materials are plotted along the x-axis, and the Maximum dome height is shown on the y-axis.
Graph shows dome height comparison for **SS 304** sheet material from eight different batches/coils [10 samples per batch].

Highest formability $\rightarrow$ G , Most consistent $\rightarrow$ F

Lower formability and inconsistent $\rightarrow$ H
CPF-2.1 - Materials Tested with VPB Test at CPF
(data available to CPF members)

<table>
<thead>
<tr>
<th>Steels</th>
<th>Aluminum and Magnesium Alloys</th>
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<tbody>
<tr>
<td>St 14</td>
<td>AA 6111</td>
</tr>
<tr>
<td>St 1403</td>
<td>AA 5754-O</td>
</tr>
<tr>
<td>AISI 1018</td>
<td>X626 -T4P</td>
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<tr>
<td>AKDQ</td>
<td>AZ31B</td>
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<tr>
<td>1050</td>
<td>AZ31B-O</td>
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<tr>
<td>DR 120</td>
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</tr>
<tr>
<td>DDS</td>
<td></td>
</tr>
<tr>
<td>BH 210</td>
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</tr>
<tr>
<td>HSS</td>
<td></td>
</tr>
<tr>
<td>DP500</td>
<td></td>
</tr>
<tr>
<td>DP 590</td>
<td></td>
</tr>
<tr>
<td>DP 600</td>
<td></td>
</tr>
<tr>
<td>DP 780-CR</td>
<td></td>
</tr>
<tr>
<td>DP 780-HY</td>
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</tr>
<tr>
<td>Bare DP 980 Y-type X</td>
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<tr>
<td>Bare DP 780 T-Si type</td>
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<tr>
<td>GA DP 780 T- AI Type</td>
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<tr>
<td>GA DP 780 Y-type U</td>
<td></td>
</tr>
<tr>
<td>GA DP 780 Y-type V</td>
<td></td>
</tr>
<tr>
<td>DQS-270F GA-Phosphate coated</td>
<td></td>
</tr>
<tr>
<td>DQS-270D GA-Phosphate coated</td>
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<tr>
<td>DP 780</td>
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</tr>
<tr>
<td>TRIP 780</td>
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</tr>
<tr>
<td>DP 980</td>
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<tr>
<td>Stainless Steels</td>
<td></td>
</tr>
<tr>
<td>SS 201</td>
<td></td>
</tr>
<tr>
<td>SS 301</td>
<td></td>
</tr>
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<td>SS 304</td>
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</tr>
<tr>
<td>SS 409</td>
<td></td>
</tr>
<tr>
<td>SS 410 (AMS 5504)</td>
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<td>SS 444</td>
<td></td>
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<tr>
<td>LDX 2101</td>
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<tr>
<td>DP 780</td>
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<td>TRIP 780</td>
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When the blank is well lubricated, it fails at the center of the dome. Necking / fracture moves with increased friction.
CPF-2.1 - Formability

Challenge:
This type of fracture cannot be predicted using conventional Forming Limit Curve (FLC).

Ref: Shi and Chen 2007
CPF-2.2 - Forming of Al Alloys in a Servo Drive Press (AIDA)

Die set built by Honda

Thinning (%)
Min = -26.3
Max = 28.4

-26.3
-18.5
-10.7
-2.9
4.9
12.7
20.5
28.4

Material draw-in

Maximum thinning ~28%
Draw depth = 155 mm
Evaluation of Lubricants

Performance evaluation criteria (cups drawn to same depth):

i. Higher the Blank Holder Force (BHF) that can be applied without fracture in the drawn cup, better the lubrication condition

ii. Smaller the flange perimeter, better the lubrication condition (lower coefficient of friction)
CPF-3.3 - Friction – Cup Draw Test

Cup Draw Test

Lubrication performance:

- Higher BHF before fracture

Successfully Formed Cup

Fractured Cup

Shorter Perimeter
Temperatures in Cup Draw Test – DP 600

Challenges:
1) Higher contact pressure and higher temperature are detrimental for lubricants,
2) Temperature and pressure additives are needed

Ref: Kim et al 2009
Evaluation of Lubricants for Forming Al 5182-0 (1.5 mm)
CPF-3.3 - Forming of AHSS / Die Wear

Die Wear in Forming of AHSS

Currently with DP590
In future, Stainless Steel
CPF-5.1 – Bending and springback in Forming AHSS and Copper Alloys

Schematic of 3 point bending tooling at OSU

Dimensions are in mm.
Blanking / Piercing

Schematic of piercing

\[ v_p = \text{punch velocity} \]
\[ d_p = \text{punch diameter} \]
\[ r_p = \text{punch corner radius} \]
\[ d_b = \text{blank holder diameter} \]
\[ t = \text{sheet thickness} \]

Blank holder force

\[ f_b = \text{blank holder force} \]

Roll over zone (Z_r)
Shear zone (Z_s)
Fracture zone (Z_f)
Burr zone (Z_b)

Blanked edge (obtained from FE simulations)

Punch-die clearance (% of sheet thickness) = \( \frac{d_d - d_p}{2t} \times 100 \)
Reduction of strains at blanked surface

- Single shear
- Conical with flat tip
- Conical with spherical tip
- Humped

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Graph showing effective strain versus distance from the top surface of the sheet (mm). The graph compares different shapes: Flat, Humped, and Conical.
Hole Expansion Test

Schematic of hole expansion test

Before and After Hole Expansion (conical punch)

Hole expansion ratio
\[ \lambda = \frac{d - d_0}{d_0} \times 100\% \]

- \( v_p \): punch velocity
- \( f_b \): blankholder force
- \( \theta \): punch angle (conical)
- \( d_d \): diameter of the die
- \( d_b \): diameter of blankholder
- \( r_d \): die radius
- \( d_h \): diameter of pierced hole in the blank
- \( d_p \): punch diameter (hemispherical)
CPF-5.5 - Hot Stamping


At ~950°C (1750°F)
_Austenite_

3-5 min.s in Furnace

Mn-B alloyed steel (As delivered)
_Ferrite-Pearlite_

Quenched in the die
>27°C/s (~49°F/s)

Quenched _Martensite_

Less force and springback
FE Simulation of parts with uniform properties

Colors other than gray: Thinning >20%.

Part stamped at the participating company
FE Simulation of cooling channel analysis

Nodal temperature - Membrane

1.3 mm roof rail die, After 10 stampings.
CPF-5.5 - Hot Stamping

FE Simulation of cooling channel analysis

After 10 stampings.
CPF-5.5 - Hot Stamping

FE Simulation of parts with tailored properties

**Hardened zone:**
485 – 515 HV
1500 – 1590 MPa
(~220 – 230 ksi)

**Soft zone:**
310 – 330 HV
920 – 1020 MPa
(~135 – 150 ksi)

Literature:
[George 2011], 400°C dies = 790-840 MPa
[Feuser 2011], 450°C dies = ~850 MPa
Prediction of fracture/necking from strain or thickness variations (tensile data from Jim Dykeman-Honda HRA)
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www.ercnsm.org