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www.cpforming.org
www.ercnsm.org

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CPF is supported by NSF and 16 member companies, interested in metal forming.
CPF – Current Projects

- Material Characterization
- Friction / Lubrication
- Process Simulation / Forming Al & AHSS-Software:
  - DEFORM-forging, PAMSTAMP/LS-DYNA-stamping
- Edge Quality in Blanking / Shearing
- Hot Stamping of UHSS
- Servo Drive Presses and Hydraulic Cushions
  - Project experiments are conducted in cooperation with CPF members
Material Characterization

Viscous Pressure Bulge (VPB) Test

Downward motion clamps the sheet

Before Forming

After Forming

Stationary Punch
Pressure Transducer
Viscous Medium
Test Sample
Laser Sensor

Continued downward motion forms the bulged sheet
Viscous Pressure Bulge (VPB) Test

Material, DP600, 1 mm

Uniform Strain from Tensile Test = 0.16

Tensile data with Power Law ($\sigma = K\varepsilon^n$)

Useful strain from Bulge Test = 0.49

Tensile data with Power Law

0 0.1 0.2 0.3 0.4 0.5
0
200
400
600
800
1000
1200
1400
True Stress (MPa)

0
200
400
600
800
1000
1200
1400
1600
True Stress (ksi)

0 0.1 0.2 0.3 0.4 0.5
Material Characterization – Flow Stress

Viscous Pressure Bulge (VPB) Test

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Tensile data with Power Law ($\sigma = K\varepsilon^n$)

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Material, DP600, 1 mm

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1800
True Stress (ksi)
Material Characterization – VPB Test

Test sample

Before bursting

After bursting
Material Characterization – VPB Test

Maximum dome height (mm)

<table>
<thead>
<tr>
<th>Materials</th>
<th>Maximum Dome Height (mm)</th>
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<tbody>
<tr>
<td>AZ31B</td>
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<tr>
<td>AISI 1050</td>
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<td>AKDQ</td>
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<td>AMS 5504</td>
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Determination of Sheet Formability Using VPB Test

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
### Materials Tested with VPB Test at CPF
(data available to CPF members)

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<thead>
<tr>
<th>Steels</th>
<th>Aluminum and Magnesium Alloys</th>
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Dome Test (Frictionless)

When the blank is well lubricated, it fails at the center of the dome.

Necking / fracture moves with increased friction.
Example Flow Stress data obtained from VPB test, Tensile test, and Frictionless dome test.

**POSCO-TRIP1180, t=1.2mm**

The diagram shows the true stress-strain curve for POSCO-TRIP1180 steel with a thickness of 1.2mm. The data is extrapolated from tensile test, dome test, and bulge test results. The true stress is plotted on the y-axis in units of MPa, and the true strain is plotted on the x-axis.

- **Dome test**
- **Bulge test**
- **Extrapolation of tensile data**

**Tensile test**
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)
Friction – Cup Draw Test

Cup Draw Test

Lubrication performance:

Shorter Perimeter

Higher BHF before fracture
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)
Servo press characteristics

Crank or Link press
Fixed Motion

Cycle time of mechanical press

Free motion press

(1) Variable stroke length

(2) Best speed for materials

(3) Improve accuracy by dwelling at BDC

(4) Other Process at BDC (Multi Process)

(5) Prevention of noise and shock at contact or breakaway of tools

(6) Synchronize with feeder

(a) Holding
(b) Bottoming
(c) Re-striking
Die Cushion Force (kN)
Elimination of Pressure Surge in the Die Cushion

Servo-Hydraulic Cushion (Courtesy-Aida)
Capabilities of the Self-Driven Hydraulic Servo Cushion

• Pre-acceleration to reduce the impact speed between the die and blank holder

• Variable pressure / force capability to control blank holder force/pressure during stroke

• Prevention of momentary return of the cushion after BDC to avoid pressure on the top of the part
Forming of AHSS and Al5182-O in servo press

The Die is designed and manufactured by Shiloh
Forming of AHSS in a Servo press

1-Wipe bending

2-Shrink flanging

3-Stretch flanging

4-Hat and U-channel drawing

5-U-Flanging

6-Deep drawing
Forming of AHSS in a Servo press

**DP980 with 1.4mm thickness**

**Shiloh Die**

Flange length at different locations is measure from experimental samples and compared with simulation results.
Forming of Al Alloys in a Servo Drive Press

Material draw-in

Honda Die

Maximum thinning ~28%

Draw depth = 155 mm
Non-isothermal simulation of deep drawing for Al 5182-O

Deep drawing of Al5182-O shows the maximum temperature observed on blank is about 77 °C for 60mm stroke.

Surface heat transfer is between blank and tooling is not considered. Room temperature is 20 °C.
Deep drawing of DP980 shows the maximum temperature observed on blank is about 97 °C for 25mm stroke and 219 °C for 55mm stroke.

Surface heat transfer is between blank and tooling is not considered. Room temperature is 20 °C.
Ram speed and blank holder force profiles used in tryouts (Aida servo press)

Different ram speed and BHF profiles were used in the tryouts.

Note: 1) These speed vs stroke curves were obtained from press.

2) These blank holder force curves are input to the press.
Deep drawn part using AIDA servo press (Al5182-O)

Blank holder force: 250KN

Draw depth: 75.8mm
Blanking / Piercing

Schematic of piercing

Blank Holder

DIE

Slug

Sheet

Punch

Die

Slab

Blanked edge

(obtained from FE simulations)

Roll over zone ($Z_r$)

Shear zone ($Z_s$)

Fracture zone ($Z_f$)

Burr zone ($Z_b$)

$v_p$ = punch velocity
$f_b$ = blank holder force
$d_p$ = punch diameter
$d_d$ = die diameter
$r_p$ = punch corner radius
$r_d$ = die corner radius
$d_b$ = blank holder diameter
$t$ = sheet thickness

Punch-die clearance (% of sheet thickness) = $(d_d - d_p) / 2t \times 100$
Blanking/Piercing of AHSS

Hole Expansion Test

Schematic of hole expansion test

Before and After Hole Expansion (conical punch)

- $v_p =$ 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)

Hole expansion ratio

$$\lambda = \frac{d-d_0}{d_0} \times 100[\%]$$

- $d_0 =$ Initial diameter of hole
- $d =$ Final diameter of hole
Blanking/Piercing of AHSS

Reduction of strains at blanked surface

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

![Graph showing reduction of strains](image)

**Effective strain**

Distance from the top surface of the sheet (mm)

- Flat
- Humped
- Conical
Hot Stamping

At ~950°C (1750°F)

Austenite

Mn-B alloyed steel (As delivered)

Ferrite-Pearlite

Quenched in the die

>27°C/s (~49°F/s)

Less force and springback

3-5 min.s in Furnace

Hot Stamping

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

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

FE Simulation of cooling channel analysis

After 10 stampings.
Hot Stamping

FE Simulation of parts with tailored properties

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

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

Literature:
[George 2011], 400°C dies = 790-840 MPa
[Feuser 2011], 450°C dies = ~850 MPa
1. Major Challenges in Forming AHSS (DP, TRIP, TWIP) include:

- lower formability (ductility) and higher probability of fracture
- variations in mechanical properties form batch to batch
- higher forming forces and high sheet/die interface pressures & temperatures
- Excessive tool wear, rapid increase in forming force and large reverse tonnage
- large springback due to large tensile strength
2. Forming of Al Alloys

- Becoming popular because of considerable weight savings
- Presents challenges in formability and tendency to fracture
- Presents opportunities for weight savings by using high strength Al alloys (thru warm forming)

3. Use of Servo Presses

- Increase productivity
- Offers flexibility in improving formability and effectiveness of lubricant by changing forming speed
- Have the potential to improve formability of AHSS and high strength Al alloys (possible competition to Hot Stamping Technology)
Summary/ ongoing work at CPF (in cooperation with CPF members)

- Determination of flow stress (Biaxial/Bulge test/ Frictionless Dome test)/ Formability
- Evaluation of lubricants (Cup draw test)
- FE Simulations (AHSS, Al Alloys, Warm Forming/ Hot Stamping)
- Stamping of AHSS and Al 5182-0 in a 300 ton servo press with CNC hydraulic cushion-effects of ram speed, dwell, BHP
- Bending and Springback (Thin Copper alloys and 1-1.5mm thick AHSS)
- Prediction of Thinning and Fracture/ Edge cracking/ Determination of FLD with 3 points
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Non-proprietary information can be found at web site:

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