Advanced High Strength Steels

Formability

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Great Designs in Steel Seminar
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Formability Introduction

- Formability
- Experimental Forming Limit Diagrams
- Bendability Test
- Other Forming Tests

Comparison of Yield Strength, Tested As Delivered, L-dir.

- DP800
- HSLA340
- DDS
- HSLA550
- DP1000
- DP600
- T600

True Stress vs. True Strain graph.
# Typical Mechanical Properties

## Example of Typical Mechanical Properties

<table>
<thead>
<tr>
<th>GRADE</th>
<th>YS (MPa)</th>
<th>UTS (MPa)</th>
<th>El (%)</th>
<th>YPE (%)</th>
<th>n-value (10%-UE)</th>
<th>n-value (4-6%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IF</td>
<td>163</td>
<td>282</td>
<td>49.0</td>
<td>-</td>
<td>0.240</td>
<td>-</td>
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<tr>
<td>DDS</td>
<td>183</td>
<td>314</td>
<td>42.9</td>
<td>-</td>
<td>0.230</td>
<td>-</td>
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<td>CMn440</td>
<td>354</td>
<td>455</td>
<td>39.0</td>
<td>3.6</td>
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<td>377</td>
<td>443</td>
<td>28.4</td>
<td>2.8</td>
<td>0.170</td>
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<tr>
<td>SF600</td>
<td>490</td>
<td>615</td>
<td>28.6</td>
<td>3.2</td>
<td>0.148</td>
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<td>604</td>
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<td>2.2</td>
<td>0.128</td>
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<tr>
<td>HSLA550</td>
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<td>672</td>
<td>13.5</td>
<td>3.3</td>
<td>0.040*</td>
<td>-</td>
</tr>
<tr>
<td>DP600</td>
<td>340</td>
<td>602</td>
<td>29.0</td>
<td>-</td>
<td>0.170</td>
<td>0.208</td>
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<tr>
<td>T600</td>
<td>393</td>
<td>631</td>
<td>34.0</td>
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<td>-</td>
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<td>822</td>
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<tr>
<td>DP1000</td>
<td>726</td>
<td>1003</td>
<td>10.8</td>
<td>-</td>
<td>0.060*</td>
<td>0.08</td>
</tr>
</tbody>
</table>
True Stress – Strain Curves

Workhardening of selected materials

- T600
- HSLA340
- DP600
Work Hardening Index

Instantaneous $n$ - value

- **T600**
- **DP600**
- **HSLA340**

Engineering Strain [%]
Strain Distribution Ability

Comparison of Thinning

Instantaneous n-value

Engineering Strain [%]

Thinning (%)
Experimental FLDs for Dual Phase Steel

Forming Limit Diagram for DP600
1.2 mm

Forming Limit Diagram for DP800
1.2 mm
Experimental FLD for T600

Forming Limit Diagram for TRIP T600 1.2 mm

- Major Strain [%]
- Minor Strain [%]

- Experiment
- Calculated
- Failed
- Marginal
- Safe

Minor Strain [%]
• The FLC of T600 is comparable to DDS steel in draw forming area, and exceeds DDS steel formability up to 10% in balanced biaxial forming.

• Influence of strain rate, temperature and stress state on TRIP steels formability is different than for other steels.
Bendability is needed for dimensional accuracy control in stamping
Cup Drawing Test

Material Limit Drawing Ratio

- Rp = 2mm
- Rp = 6mm
- Rp = 25mm

Materials:
- IF
- CMn440
- HSLA 340/440
- SF600
- HSLA 440/600
- DP600
- DP800
- T800
- DP1000

Graph showing the limit drawing ratio for different materials and Rp values.
Stretch Forming Test

![Graph showing dome height for different materials and Rp values.]

- **Material**: IF, CMn440, HSLA340/440, SF600, HSLA440/600, DP600, DP800, T600, DP1000
- **Dome Height [mm]**
- **Rp** values: 2mm, 6mm, 25mm
Hole Expansion Test

Hole Expansion Ratio [%]

Material

C Mn440  HSLA 340/440  SF600  HSLA 440/600  DP600  DP800  T800  DP1000
Plane Strain Drawing Test

Springback

- Rd=3mm
- Rd=7mm
- Rd=10mm

Delta W = W - Wo

<table>
<thead>
<tr>
<th>Material</th>
<th>Rd=3mm</th>
<th>Rd=7mm</th>
<th>Rd=10mm</th>
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<tbody>
<tr>
<td>IF</td>
<td></td>
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<tr>
<td>Co440</td>
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<tr>
<td>HSLA 340/440</td>
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<tr>
<td>SF800</td>
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<td></td>
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<tr>
<td>HSLA 440/600</td>
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<tr>
<td>DP800</td>
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<tr>
<td>DP800</td>
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<td></td>
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<tr>
<td>T800</td>
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<td></td>
</tr>
<tr>
<td>DP1000</td>
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</tbody>
</table>

Delta W [mm]

Rd

Wo=48mm

W

UTS [MPa]

200 400 600 800 1000

IF

CMn4 40 HS

LA 340/440

SF600

HSLA 440/600

DP800

DP800

T800

DP1000

Material

R=3mm

R =7mm

R=10mm

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Conclusions

• DP and TRIP steels display excellent formability as compared to conventional HSS and better capacity to distribute strain over the part surface
• AHSS display very good bendability
• ASM FLC approximation (Keeler-Brazier) is applicable for DP and TRIP steels
• Due to excellent combination of strength with formability, TRIP steel has potential for economic application (possibility for reduction of the number of parts in the car)
• A need to understand AHSS unique characteristics to successfully make parts
  - One-for-one direct substitution with other HSS may cause issues
4. Konieczny A. A., On Formability Assessment of the Automotive Dual Phase Steels, IBEC, 2001-01-3075