Drop Tower Crash Testing of Advanced High Strength Steel Tubes

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Introduction

- Advanced high strength steels (AHSS) offer very high strength levels and good formability
  - Dual phase (DP)
  - Transformation-induced plasticity (TRIP)
- AHSS can be utilized to absorb crash energy and minimize intrusion in the occupant zone

- Objective: to examine the crash energy absorption characteristics of steel tubes with different strengths and thicknesses
## 70-mm Outer Diameter Steel Tubes

<table>
<thead>
<tr>
<th>Material</th>
<th>Welding Process</th>
<th>Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FS-CR</td>
<td>ERW</td>
<td>1.83</td>
</tr>
<tr>
<td>C-Mn 440-CR</td>
<td>LW</td>
<td>1.59</td>
</tr>
<tr>
<td>DP 590-GA</td>
<td>ERW</td>
<td>1.61</td>
</tr>
<tr>
<td>DP 590-GI</td>
<td>LW</td>
<td>1.59</td>
</tr>
<tr>
<td>TRIP 590-GA</td>
<td>ERW</td>
<td>1.60</td>
</tr>
<tr>
<td>TRIP 590-GA</td>
<td>LW</td>
<td>1.61</td>
</tr>
<tr>
<td>DP 780-GA</td>
<td>LW</td>
<td>1.58</td>
</tr>
<tr>
<td>TRIP 780-GA</td>
<td>LW</td>
<td>1.62</td>
</tr>
<tr>
<td>AKDQ-HR</td>
<td>ERW</td>
<td>3.08</td>
</tr>
<tr>
<td>C-Mn 340-HR</td>
<td>ERW</td>
<td>3.02</td>
</tr>
<tr>
<td>C-Mn 440-HR</td>
<td>ERW</td>
<td>3.05</td>
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<tr>
<td>DP 780-HR</td>
<td>ERW</td>
<td>2.84</td>
</tr>
</tbody>
</table>
# Axial Mechanical Properties

<table>
<thead>
<tr>
<th>Material</th>
<th>YSₐ₀.₂% (MPa)</th>
<th>UTS (MPa)</th>
<th>UE (%)</th>
<th>TE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FS-CR (ERW)</td>
<td>206</td>
<td>294</td>
<td>27.5</td>
<td>52.1</td>
</tr>
<tr>
<td>C-Mn 440-CR (LW)</td>
<td>358</td>
<td>475</td>
<td>17.9</td>
<td>32.1</td>
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<tr>
<td>DP 590-GA (ERW)</td>
<td>480</td>
<td>639</td>
<td>15.8</td>
<td>26.4</td>
</tr>
<tr>
<td>DP 590-GI (LW)</td>
<td>433</td>
<td>593</td>
<td>16.2</td>
<td>27.9</td>
</tr>
<tr>
<td>TRIP 590-GA (ERW)</td>
<td>486</td>
<td>664</td>
<td>23.1</td>
<td>33.0</td>
</tr>
<tr>
<td>TRIP 590-GA (LW)</td>
<td>431</td>
<td>667</td>
<td>23.0</td>
<td>32.7</td>
</tr>
<tr>
<td>DP 780-GA (LW)</td>
<td>462</td>
<td>753</td>
<td>12.9</td>
<td>20.1</td>
</tr>
<tr>
<td>TRIP 780-GA (LW)</td>
<td>517</td>
<td>842</td>
<td>20.7</td>
<td>27.4</td>
</tr>
<tr>
<td>AKDQ-HR (ERW)</td>
<td>280</td>
<td>338</td>
<td>22.8</td>
<td>44.9</td>
</tr>
<tr>
<td>C-Mn 340-HR (ERW)</td>
<td>340</td>
<td>431</td>
<td>5.5</td>
<td>24.4</td>
</tr>
<tr>
<td>C-Mn 440-HR (ERW)</td>
<td>386</td>
<td>513</td>
<td>11.7</td>
<td>28.3</td>
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<td>DP 780-HR (ERW)</td>
<td>674</td>
<td>793</td>
<td>9.5</td>
<td>20.0</td>
</tr>
</tbody>
</table>
Drop Tower Testing

- 24-cm (9.5-in) specimen
- 6.1-6.7 m/s (14-15 mph) impact velocity
  - Adiabatic heating
- 11.1 kJ impact energy
- Two temperatures
  - 5-7 tests at 24°C
  - 1-4 tests at –43°C
- 200 kHz data acquisition
Load/Temperature Data

TRIP 590-GA (LW)

Load (kN) vs. Temp (°C) over Time (s)

- Load (kN)
- Temp (°C)

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Acceleration Data

TRIP 590-GA (LW)

Acceleration (g) vs Time (s)
Velocity Curve

TRIP 590-GA (LW)

Velocity (m/s)

Time (s)
Displacement Curve

TRIP 590-GA (LW)

Displacement (cm)

Time (s)
Sample Load-Displacement Curve

Load (kN) vs. Displacement (cm) for TRIP 590-GA (LW)

- Peak Load
- Average Crush Load
Weight Reduction Example

- 1.8-mm FS-CR (ERW)
- 1.6-mm C-Mn 440-CR (LW)
Displacement Reduction Example

- 1.6-mm C-Mn 440-CR (LW)
- 1.6-mm DP 590-GI (LW)
- 1.6-mm DP 780-GA (LW)
Peak Impact Loads

Peak Load (kN) vs. UTS * t² (N)

- 24°C
- -43°C

R² = 0.934
R² = 0.981
Average Crush Loads

- $R^2 = 0.942$
- $R^2 = 0.970$

Average Crush Load (kN) vs. $UTS * t^2$ (N)

- $24^\circ C$
- $-43^\circ C$
Total Crush Distances

Crush Distance = 11.1 kJ/Average Load
Crushed Tube Examples

Room Temperature Tests
1.6-mm thickness

DP 590-GA (ERW)  DP 590-GI (LW)  TRIP 590-GA (ERW)  TRIP 590-GA (LW)
Crushed Tube Examples

Room Temperature Tests
1.6-mm thickness

C-Mn 440-CR (LW)  DP 590-GI (LW)  DP 780-GA (LW)  TRIP 780-GA (LW)
Implications

• DP and TRIP steels at the same UTS level have similar crash performance for a given impact energy
  – TRIP steels have formability advantage over DP steels (TRIP 780 similar to DP 590)
  – TRIP 780 will have superior crash performance to DP 590 (higher loads, lower displacement)

• Similar performance at the two test temperatures
  – Temperature sensitivity of flow stress
  – No catastrophic failures observed
Implications

- AHSS can be effectively utilized to decrease crash deformation with no weight penalty (same gage)
  - Crash performance proportional to UTS

- Downgaging is possible with AHSS while maintaining crash behavior, but weight reduction is not directly proportional to strength increase
  - Crash performance proportional to $t^2$
## Theoretical Downgaging Scenario

<table>
<thead>
<tr>
<th>Material</th>
<th>UTS</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Raw (MPa)</td>
<td>Norm.</td>
</tr>
<tr>
<td>C-Mn 440</td>
<td>480</td>
<td>1.00</td>
</tr>
<tr>
<td>DP/TRIP 590</td>
<td>630</td>
<td>1.31</td>
</tr>
<tr>
<td>DP/TRIP 780</td>
<td>820</td>
<td>1.71</td>
</tr>
</tbody>
</table>

UTS \times t^2 = 1.92 \text{ kN} \text{ for each case}
Conclusions

• Axial steel tube crash performance correlates to $\text{UTS} \times t^2$
  – AHSS can be used effectively to reduce crash displacement without weight penalty
  – Can downgauge with AHSS and maintain existing crash performance

• DP and TRIP steels have similar crash performance at same UTS level
  – TRIP steel formability advantage over DP can yield crash advantage

• Decreasing test temperature from 24°C to –43°C results in increased crush loads, decreased total displacements, and similar deformation modes