Resistance Spot Welding of Coated High Strength Dual Phase Steels

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Topics

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Types of AHSS

- Advanced High Strength Steels (AHSS)
  - Stretch-Flange (Ferrite-Bainite)
  - Dual Phase (Ferrite-Martensite)
  - Transformation-Induced Plasticity (TRIP) (Ferrite-Bainite-Austenite)
- Dual Phase Steels are commercially available in different strength levels
  - 500 to 980 MPa Min. Tensile Strength
Advantages of Dual Phase Steels

• Advantages often cited of Dual Phase steels:
  – Good Stamping Characteristics – High Ductility
  – Easy Fabricability and Repairability – Weldability
  – Better Occupant Protection – Higher Energy Absorption

• Automotive industry has gone through a learning curve with welding DP steels.
Trends in Commercial Use of DP Steels

- Dual Phase steel 590 MPa found use in many 2004 and 2005 models.
- Several automotive companies are actively investigating the use of 780 MPa Dual Phase steels for 2007 and 2008 models.
- Some companies have already shown interest in exploring 980 MPa Dual Phase steels.
- So, it is a good time to provide an overview of the welding behavior of these steels.
Hot-Dipped Dual Phase Steels

- Strengthening through transformation strengthening.
- Contain 5 to 40 percent martensite in a soft ferrite matrix.
- As strength increases, the amount of martensite in the steel increases.
- Available in galvannealed (zinc-iron alloy) and galvanized (zinc) coated conditions.
- Commercially available at present in strength levels are 500, 590, 780 and 980 MPa (min. tensile strength).
## Hot-Dipped DP Steel Composition

<table>
<thead>
<tr>
<th>Alloying Element (Weight Percent)</th>
<th>Influence and Reason For Adding</th>
</tr>
</thead>
</table>
| **C** (0.06 – 0.15)              | 1. γ-stabilizer  
2. Strengthens martensite  
3. Determines the phase distribution |
| **Mn** (1.5 – 2.5)               | 1. γ-stabilizer  
2. Solid solution strengthener of ferrite  
3. Retards ferrite formation |
| **Cr, Mo** (each up to 0.40)     | 1. α-stabilizer  
2. Retard pearlite and bainite formation |
| **V** (up to 0.060)              | 1. α-stabilizer  
2. Precipitation strengthener  
3. Refines microstructure |
| **Nb** (up to 0.04)              | 1. α-stabilizer  
2. Reduces $M_S$ temperature  
3. Refines microstructure |

Ref: W. Bleck
Base Metal Microstructures

590 MPa

780 MPa

980 MPa
## Typical Tensile Properties

<table>
<thead>
<tr>
<th>DP Steel Grade</th>
<th>Yield Strength, MPa</th>
<th>Ultimate Tensile Strength, MPa</th>
<th>Total Elongation, percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>590</td>
<td>370</td>
<td>620</td>
<td>25</td>
</tr>
<tr>
<td>780</td>
<td>465</td>
<td>835</td>
<td>17</td>
</tr>
<tr>
<td>980</td>
<td>600</td>
<td>1040</td>
<td>14</td>
</tr>
<tr>
<td>DQSK*</td>
<td>170</td>
<td>300</td>
<td>45</td>
</tr>
</tbody>
</table>

* Provided for comparison
Strength and Formability

![Graph showing the relationship between Ultimate Tensile Strength (MPa) and Total Elongation (%). The graph compares Low Carbon, HSLA, TRIP, and Dual Phase steels.](www.autosteel.org)
Purpose of the Study

- To examine the resistance spot welding behavior of hot-dipped 780 and 980 MPa dual phase steels against that of the 590 MPa steel.
- To examine if these higher strength grades can be welded with simple, easy to use welding parameters.
Materials And Welding Conditions

- 590, 780, and 980 MPa steels in the Hot-dipped galvannealed condition.
- Coating weights - 45 g/m² per side.
- Thickness of sheets – different gauges from 1.2 to 2.0 mm.
- Taylor Winfield pedestal-type alternating current welding machine.
- RWMA Class II (Cu-Cr) type (both dome-shaped and truncated cone) electrodes.
- No pre heating or post weld tempering used.
Weld Evaluations

- Current Ranges - Welding currents required to produce minimum button size and expulsion.
- Weld Shear-Tension and Cross-Tension Tests
  - Weld load-bearing ability
  - Peak load
  - fracture mode determined.
- Microhardness Profiles
- Weld Microstructures
  - To check for any weld imperfections (cracks, voids).
Weld Tensile Tests
(Source AWS D8.9)

Spot Weld

Cross-Tension Specimen

Shear-Tension Specimen
780 MPa Grade-Current Range

780 DP - 2mm - Button Diameter vs Welding Current

Min. Button Dia, 5.7 mm

Expulsion

Welding Current, kA

Button Diameter, mm
780 MPa Grade-Current Range

780 DP - 2mm - Button Diameter vs Welding Current

Min. Button Dia, 5.7 mm

Expulsion

Welding Current, kA

Button Diameter, mm
980 MPa Grade – Current Range

![Graph showing the relationship between button size and welding current]

- **Min. Button Size**
- **Interfacial Fractures**
- **Full Button Pull out**
- **Expulsion**

**Button Size, mm** vs. **Welding Current, kAmps**
980 MPa Grade – Weld Strength vs. Size

- Full button pull out fractures
- Interfacial fractures

Diagram showing the relationship between SIT, kNewtons and Button Size, mm.
Weld Hardness Comparison

![Graph showing hardness comparison for different welds.](graph.png)

- **Hardness, HVN**
- **Indentations**

- **590**
- **780**
- **980**
Weld And HAZ Microstructures

Weld

780

HAZ

980

www.autosteel.org
Weld Cooling Rates

- Spot welds in sheets of thickness up to 2 mm typically solidify in less than 3 to 4 cycles.
- Even at 500 °C the cooling rates in spot welds are in excess of 1000°C/sec (Ref. Kimchi et al).
- These cooling rates are much faster than those needed to form martensite (which are around 200 to 250 C/sec) in the weld and the HAZ in DP steels (Ref. Easterling).
- Therefore, the presence of martensite in the weld and the HAZ is expected.
Spot Weld Fractures

- Eight different fracture modes in resistance spot welds have been defined by AWS (and Auto/Steel Partnership of AISI)
- Some of these include full button, partial interfacial, interfacial fractures.
- Work at US Steel has shown dependence of fracture mode on sheet thickness, weld size, and steel tensile strength.
Weld Fracture in DP Steels

- Weld tensile tests on 980 DP showed that full-button pull out fracture mode can be seen in 980 MPa grade when the weld size is big.
- Even when interfacial fractures were seen, the load-bearing ability of the weld was still high.
- Therefore, fracture mode alone is not a good indicator of weld integrity and performance.
Summary and Conclusions

- Welding behavior similar to that of 590 MPa steel can be expected with 780 and 980 MPa DP steels.
- 780 and 980 MPa DP steels possess good weldability and can be welded with simple, easy to use weld schedules.