Fatigue Performance of Conventional and Advanced High-Strength Steel Spot Welds

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- A.K. Khosravaneh  General Motors

**Staff Members**
- Gene Cowie  A/SP
- Bart Clark  A/SP
## Grades & Gauges

<table>
<thead>
<tr>
<th>Gage mm</th>
<th>IF GI</th>
<th>DQSK GI</th>
<th>CQSK Bare</th>
<th>HSLA 340 GI</th>
<th>DP 600 GI</th>
<th>DP 800 GI</th>
<th>DP 980 Bare</th>
<th>TRIP 600 Bare</th>
<th>TRIP 800 EG</th>
<th>RA 830 GI</th>
<th>MS 1300 Bare</th>
<th>Boron Bare</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>1.60</td>
<td>1.59</td>
<td>1.83</td>
<td>1.78</td>
<td>1.53</td>
<td>1.61</td>
<td>1.55</td>
<td>1.64</td>
<td>1.53</td>
<td>1.39</td>
<td>1.60</td>
<td>1.74-1.47</td>
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<tr>
<td>YS, MPa</td>
<td>178</td>
<td>170</td>
<td>156</td>
<td>370</td>
<td>432</td>
<td>414</td>
<td>702</td>
<td>421</td>
<td>510</td>
<td>901</td>
<td>1156</td>
<td>1237</td>
</tr>
<tr>
<td>UTS MPa</td>
<td>306</td>
<td>308</td>
<td>350</td>
<td>448</td>
<td>671</td>
<td>782</td>
<td>1057</td>
<td>672</td>
<td>839</td>
<td>895</td>
<td>1355</td>
<td>1382</td>
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<tr>
<td>UE, %</td>
<td>21.7</td>
<td>20.5</td>
<td>14.5</td>
<td>15.9</td>
<td>13.6</td>
<td>12.7</td>
<td>7.1</td>
<td>20.6</td>
<td>22.3</td>
<td>0.8</td>
<td>3.2</td>
<td>5.55</td>
</tr>
<tr>
<td>TE, %</td>
<td>32.2</td>
<td>32.5</td>
<td>22.7</td>
<td>31.7</td>
<td>22.1</td>
<td>19.5</td>
<td>11.4</td>
<td>29.3</td>
<td>27.2</td>
<td>6.7</td>
<td>5.1</td>
<td>5.55</td>
</tr>
</tbody>
</table>
### Spot Welding Parameters for All Steels

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Squeeze time</td>
<td>99 cycles</td>
</tr>
<tr>
<td>Weld time</td>
<td>22 cycles</td>
</tr>
<tr>
<td>Hold time</td>
<td>90 cycles</td>
</tr>
<tr>
<td>Electrode force</td>
<td>1500 lb (DQSK, IF ~1100lb)</td>
</tr>
<tr>
<td>Cap size, truncated</td>
<td>7.9mm</td>
</tr>
</tbody>
</table>

**Target Button Size:** 7.0mm

Weld Current Adjusted for Each Material
Fatigue Specimen Designs

Tensile Shear

Coach Peel

$R = 2.5t$
All Spot Weld Results (1.6mm)
1.78mm HSLA-340Y-GI sheet.

Location of Crack Initiation and Growth

Untested Nugget

Typical Fatigue fracture
Fatigue Crack Growth Rates in Steel  (Barsom, et al.)

Fracture and Fatigue Control in Structures: Applications of Fracture Mechanics, Barsom, et al., 2000
Thickness Effects

Cycles to Failure

Load Amplitude (N)

Tensile Shear
Coach Peel

HSLA340TS01 1.78mm
HSLA340TS03 1.78mm
HSLA340CP01 1.78mm
HSLA340CP03 1.78mm
HSLA340TS01 1.00mm
HSLA340TS03 1.00mm
HSLA340CP01 1.00mm
HSLA340CP03 1.00mm
HSLA340TS01 1.53mm
HSLA340TS03 1.53mm
HSLA340CP01 1.53mm
HSLA340CP03 1.53mm
DP600TS01 1.53mm
DP600TS03 1.53mm
DP600CP01 1.53mm
DP600CP03 1.53mm
DP600TS01 0.83mm
DP600TS03 0.83mm
DP600CP01 0.83mm
DP600CP03 0.83mm
Effects of Prestrain

Raw Fatigue Data


Normalized using Rupp parameter
Mean Stress Effects

Tensile Shear

Load Amplitude, N

Cycles to Failure, Cycle

DP600TS01 (R=0.1)
DP600TS03 (R=0.3)
DP600TS01 Wide (R=0.1)
DP600TS-1 Wide (R=-1)

125
38
Spot Weld, Bond-Only, & Weld Bonded

Cycles to Failure

Load Amplitude (N)

SW = Spot Weld
Bond = Bond Only
WB = Weld Bond

Spot Weld, Bond-Only, & Weld Bonded
Multiparameter Study: Hold Time, Spot Size, Heat Treatment, Spot / Weld-bond

### HSLA 340 1.78mm

![Graph](image)

- 7.0 mm Dia, 1 cycle HT
- 7.0 mm Dia, 90 cycle HT
- 7.0 mm Dia, 1 cycle HT, heat treated
- 7.0 mm Dia, 90 cycle HT, heat treated
- 7.0 mm Dia, 1 cycle HT, weld bonded
- 7.0 mm Dia, 90 cycle HT, weld bonded

### HSLA 340/DP600

![Graph](image)

- 1.78 mm HSLA 340, 7.0 mm Dia
- 1.78 mm HSLA 340, 4.9 mm Dia
- 1.78 mm HSLA 340, 7.0 mm Dia, weld bonded
- 1.78 mm HSLA 340, 4.9 mm Dia, weld bonded
- 1.53 mm DP 600, 7.0 mm Dia
- 1.53 mm DP 600, 4.9 mm Dia
- 1.53 mm DP 600, 7.0 mm Dia, weld bonded
- 1.53 mm DP 600, 4.9 mm Dia, weld bonded

### Tensile Shear Specimens, 1.78 mm HSLA 340-GI, R = 0.1

![Graph](image)

- 4.9 mm Dia, 1 cycle HT
- 4.9 mm Dia, 90 cycle HT
- 4.9 mm Dia, 1 cycle HT, heat treated
- 4.9 mm Dia, 90 cycle HT, heat treated
- 4.9 mm Dia, 1 cycle HT, weld bonded
- 4.9 mm Dia, 90 cycle HT, weld bonded

### Tensile Shear Specimens, 90 Cycle Hold Time, R = 0.1

![Graph](image)

- 1.78 mm HSLA 340, 7.0 mm Dia
- 1.78 mm HSLA 340, 4.9 mm Dia
- 1.78 mm HSLA 340, 7.0 mm Dia, weld bonded
- 1.78 mm HSLA 340, 4.9 mm Dia, weld bonded
- 1.53 mm DP 600, 7.0 mm Dia
- 1.53 mm DP 600, 4.9 mm Dia
- 1.53 mm DP 600, 7.0 mm Dia, weld bonded
- 1.53 mm DP 600, 4.9 mm Dia, weld bonded
Variable Amplitude (Spectrum) Fatigue Testing

- R>0

- Tensile Shear
- Coach Peel

- DQSK-GI 1.59mm TS
- IF-GI 1.60mm TS
- IF-GI 1.60mm CP
- HSLA340Y-GI 1.78mm TS
- HSLA340Y-GI 1.78mm CP
- DP600-GI 1.53mm TS
- DP600-GI 1.53mm CP

- Maximum Load (N)
- Blocks to Failure
Evaluation of Fatigue Damage Parameters

- Tensile Shear
- Coach Peel

Rupp

Tensile Shear Coach Peel

Dong

Kang

Experimental Fatigue Life (Nf)

Predicted Fatigue Life (Nf)
Evaluation of Fatigue Damage Parameters
Conclusions

1. Spot weld fatigue performance of studied steels (AHSS, HSLA, low carbon) appears to be insensitive to base metal composition, microstructure, and strength.

2. Spot weld fatigue behavior is mainly controlled by geometric factors such as sheet thickness and weld diameter.

3. Spot weld fatigue behavior is largely mean stress insensitive, for the mean stresses examined.

4. No effect of weld hold time (between 1 and a 90 cycles).
Conclusions

5. No effect of paint bake cycle.
6. Adhesive bonding and weld bonding significantly improve fatigue behavior over spot welding alone, although this improvement is in keeping with the actual increase in joint area gained by the addition of the adhesive layer.
7. Prestraining or stretch-forming the parent metal before spot welding has no impact on the fatigue performance of spot welded joints.
8. Principal spot weld damage parameters (Rupp, Dong, Swellam, Kang, & Sheppard) predict A/SP data equally well.
Next Steps

- Review as-tested spot weld coupon geometries for nugget size, sheet thicknesses, hardness, etc.

- Develop three dimensional solid spot weld model to determine stress state in the vicinity of the spot weld.
Future Work

- MIG/Laser Fusion Welding Project
  - Frame materials (3.5mm):
    SAE1008, HSLA420, DP590, Boron
  - Body materials (1.6mm)
    DQSK, HSLA350, DP590, DP780, TRIP780

Specimens under construction, testing to begin soon
Acknowledgements

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• Ken Citrin    DaimlerChrysler
• Ron Soldaat Dofasco

Thanks to the Department of Energy for their support of this program.
A/S-P spot weld fatigue knowledge base (including detailed fatigue data, report, microstructure, tensile data, etc.)

*freely available at:*

http://www.a-sp.org

http://www.a-sp.org/database/custom/ASP%20Spot%20Weld%20Fatigue%20Project%202-7-06v1c.exe