Reducing Shrinkage Voids in Resistance Spot Welds

Key factors that contribute to the formation of shrinkage voids in resistance spot welds of advanced high-strength steels were investigated.

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Advanced high-strength steels (AHSS) continue to play an increasing role in vehicle body design. In general, resistance spot welding remains the primary process for joining body sheet metal in the automotive industry. Understanding and managing the resistance spot weld characteristics of AHSS is critical to successful application. Shrinkage voids are one of the main causes of interfacial fracture (Refs. 1, 2). The objective of this study was to develop practical techniques to reduce shrinkage voids in order to decrease the potential or eliminate interfacial fracture in resistance spot welds of AHSS. In this study, the effect of the welding power source, electrode tip shape, welding current input, material type and thickness, and hold time on shrinkage voids were investigated for seven steels.

Welding Procedure

The welding equipment used in this experiment involved two types of power sources, midfrequency direct current (MFDC), and alternating current (AC). General welding parameters for this study are shown in Table 1. Dimensions of the weld specimens are shown in Fig. 1. Previous AHSS resistance spot welding studies show that shrinkage voids play a significant role in formation of interfacial fracture of spot welds when the button size is close to minimum button size (4√t rule). The welding parameters were set up to achieve a minimum button size for the test materials.

Shrinkage Voids Examination

The welded specimens were separated through a method that involved rotation of one piece of the specimen relative to the other, which was clamped in a vice, in order to shear the weld and reveal the interfacial area. Visual examination for the presence of shrinkage voids was then conducted.

Fig. 1 — Schematic of the resistance spot welding specimen.
Typical shrinkage voids in this study are shown in Figs. 2–8. The severity of weld shrinkage voids for different steels are compared in Figs. 9, 10. The effects of material-related and welding-related factors on shrinkage voids are discussed below.

**Effect of Weld Power Source on Shrinkage Voids**

No significant impact of welding power source (AC vs. MFDC) on shrinkage voids was observed on the 2.0-mm HDGI DP600. Based on this result, all subsequent experiments, except for mild steel only, used the MFDC power source. It is believed that the welding power source can only affect the weld nugget formation and growth, not solidification.

**Effect of Coating Condition on Shrinkage Voids**

It was observed that coating condition for materials in this study. It is thought that shrinkage voids could only form during the solidification of the molten nugget, and by that time, it is not likely for any...
coating material to exist in the nugget (aluminized coating may be an exception).

**Effect of Steel Grade and Thickness on Shrinkage Voids**

No shrinkage voids were found for both 1.5-mm HDGI DP600 and 1.5-mm EG DP600. For 2-mm HDGI DP600, shrinkage voids were observed under different welding conditions, as shown in Figs. 2, 3. For 2-mm HDGI mild steel, no visible shrinkage voids were found even when the hold time was 5 cycles, as shown in Fig. 4. Similar to 2-mm HDGI DP600,

![Fig. 7 — Shrinkage voids in 2-mm shot blasted boron steel (heat treated), MFDC, truncated electrode, single pulse. A — Hold time: 5 cycles; B — hold time: 10 cycles.](image)

![Fig. 8 — Shrinkage voids in 1.5-mm TRIP590, MFDC, truncated electrode, single pulse. A — Hold time: 5 cycles; B — hold time: 15 cycles; C — hold time: 30 cycles.](image)

<table>
<thead>
<tr>
<th>Materials</th>
<th>Power Source</th>
<th>Electrode Type</th>
<th>Electrode Force (lb)</th>
<th>Squeeze Time (cycle)</th>
<th>Welding Current Input</th>
<th>Weld Time (cycles)</th>
<th>Hold Time (cycles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DP600, 1.5 mm, HDGI</td>
<td>MFDC</td>
<td>Truncated (45 deg, 6.4-mm face diameter)</td>
<td>1100</td>
<td>90</td>
<td>Single pulse</td>
<td>17</td>
<td>5</td>
</tr>
<tr>
<td>DP600, 1.5 mm, EG</td>
<td>MFDC</td>
<td>Truncated (45 deg, 6.4-mm face diameter)</td>
<td>1100</td>
<td>90</td>
<td>Single pulse</td>
<td>17</td>
<td>5</td>
</tr>
<tr>
<td>DP600, 2.00 mm, HDGI</td>
<td>AC, MFDC</td>
<td>Truncated (45 deg, 7.9-mm face diameter); dome (6.4-mm face diameter)</td>
<td>1300</td>
<td>90</td>
<td>Single pulse</td>
<td>23</td>
<td>5, 10, 15, 20, 30</td>
</tr>
<tr>
<td>TRIP590, Bare</td>
<td>MFDC</td>
<td>Truncated (45 deg, 6.4-mm face diameter)</td>
<td>1100</td>
<td>90</td>
<td>Single pulse</td>
<td>15</td>
<td>5, 15, 20</td>
</tr>
<tr>
<td>CP800, 1.9 mm, EG</td>
<td>MFDC</td>
<td>Truncated (45 deg, 7.9-mm face diameter)</td>
<td>1300</td>
<td>90</td>
<td>Single pulse</td>
<td>17</td>
<td>5, 10, 15</td>
</tr>
<tr>
<td>Boron Steel (a)</td>
<td>MFDC</td>
<td>Truncated (45 deg, 7.9-mm face diameter)</td>
<td>1300</td>
<td>90</td>
<td>Single pulse</td>
<td>21</td>
<td>5, 10, 15</td>
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<tr>
<td>Mild Steel, 2.0-mm, HDGI</td>
<td>AC</td>
<td>Dome (6.4-mm face diameter)</td>
<td>1300</td>
<td>23</td>
<td>Single pulse</td>
<td>23</td>
<td>5</td>
</tr>
</tbody>
</table>

(a) The length of the coupon for boron steel is 4.0 in. instead of 5.75 in. due to the limited amount of this material.
welds of both 1.9-mm EG CP800 and 2-mm shot-blasted boron steel also had shrinkage voids under different welding conditions, as shown in Figs. 5–7. Different from the 1.5-mm DP600, welds of 1.5-mm TRIP590 showed significant shrinkage voids, as shown in Fig. 8.

It appears that steel grade and thickness have an impact on molten nugget solidification characteristics resulting in different severities in shrinkage voids — Figs. 9, 10.

**Effect of Hold Time on Shrinkage Voids**

As shown in Figs. 2–8, it is clear that hold time is the most important welding parameter that affects the severity of shrinkage voids. Relative longer hold time for steels that have higher tendency in formation of shrinkage voids (either have richer chemistry, or heavier gauge, or both) at least helps reduce the tensile thermal stress in the weld nugget when the nugget is not totally solidified.

Held times longer than 15 cycles do not seem to be effective in shrinkage voids reduction.

**Conclusions**

The following conclusions can be drawn from this study:

- The tendency to form shrinkage voids increases as the steels become thicker.
- Materials with richer chemistry also promote the formation of shrinkage voids.
- Formation of shrinkage voids is independent of coating conditions of steels.
- Hold time is the most important welding parameter affecting shrinkage voids in the weld. Longer hold times help to reduce shrinkage voids. However, for most steels in this study, hold times needed to be no longer than 15 cycles.

**References**