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.

Materials Studied

The materials evaluated in this study were DP600, TRIP590, CP800, and boron steels, as shown in Table 1. For comparison purposes, mild steel was also tested.

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 ($4\sqrt{t}$ rule). The welding parameters were set up to achieve a minimum button sizefor 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.

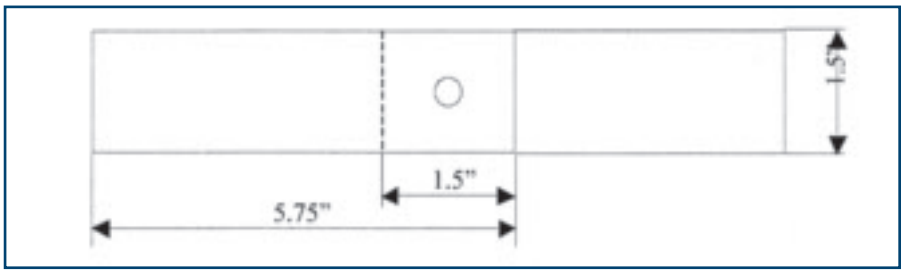

Fig. 1 — Schematic of the resistance spot welding specimen.

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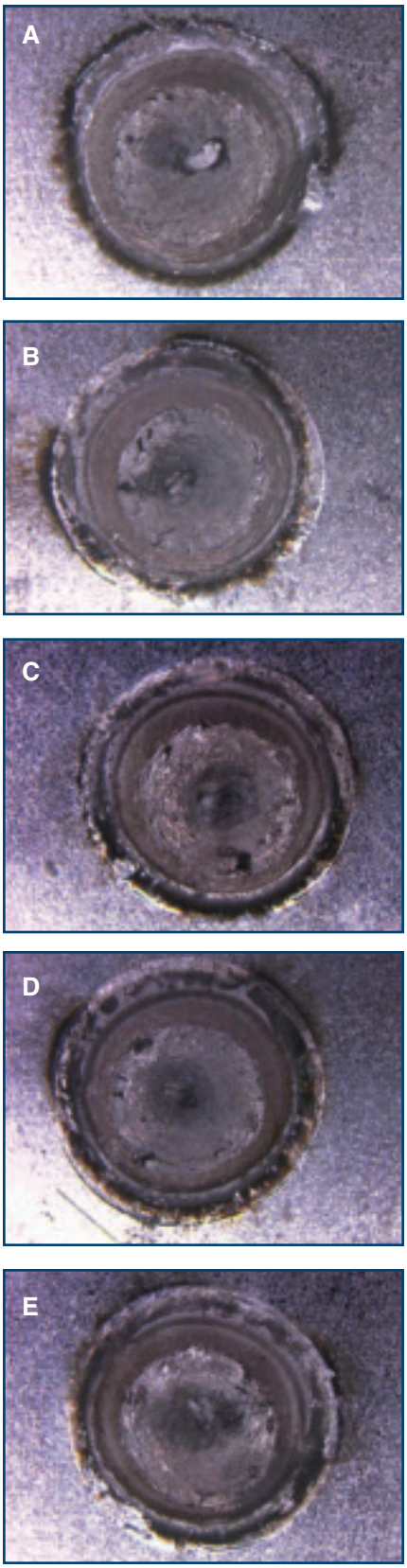

Fig. 2 — Shrinkage voids in 2-mm HDGI DP600, AC, truncated electrode. A — Hold time: 5 cycles; B — hold time: 10 cycles; C — hold time: 15 cycles; D — hold time: 20 cycles; E — hold time: 25 cycles.

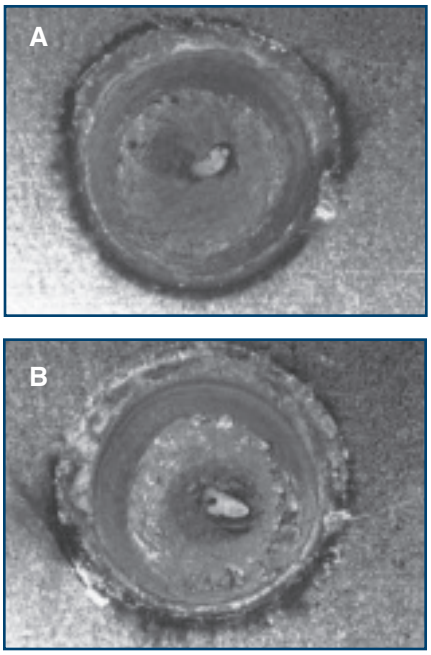

Fig. 3 — Shrinkage voids in 2-mm HDGI DP600, AC, truncated electrode, hold time = 5 cycles. A — Single pulse; B — three pulse.

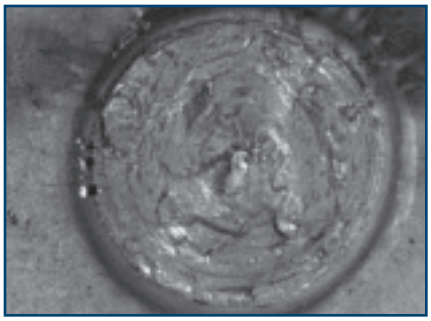

Fig. 4 — No visible shrinkage voids in 2-mm HDGI mild steel, AC, dome, hold time = 5 cycles.

Experiment Results

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.

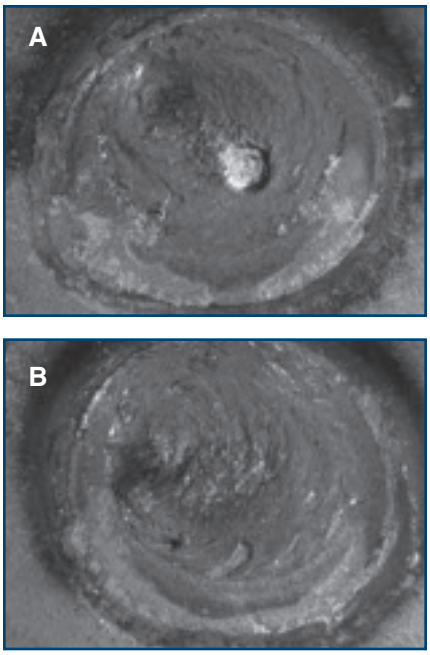

Fig. 5 — Shrinkage voids in 1.9-mm EG CP800, MFDC, truncated electrode, single pulse. A — Hold time: 5 cycles; B — hold time: 10 cycles

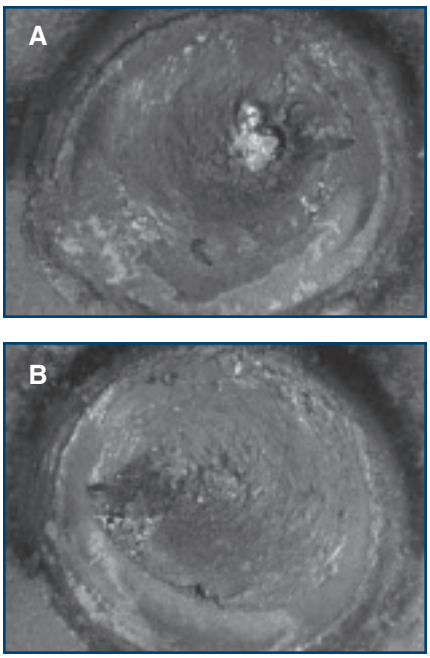

Fig. 6 — Shrinkage voids in 1.9-mm EG CP800, MFDC, truncated electrode, single pulse. A — Hold time: 5 cycles; B — hold time: 10 cycles.

Effect of Coating Condition on Shrinkage Voids

It was observed that coating condition did not have an impact on shrinkage voids 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

Table 1 — Welding Schedule

Materials	Power Source	Electrode Type	Electrode Force (lb)	Squeeze Time (cycle)	Welding Current Input	Weld Time (cycles)	Hold Time (cycles)
DP600, 1.5 mm, HDGI	MFDC	Truncated (45 deg, 6.4-mm face diameter)	1100	90	Single pulse	17	5
DP600, 1.5 mm, EG	MFDC	Truncated (45 deg, 6.4-mm face diameter)	1100	90	Single pulse	17	5
DP600, 2.00 mm, HDGI	AC, MFDC	Truncated (45 deg, 7.9-mm face diameter); dome (6.4-mm face diameter)	1300	90	Single pulse 3-pulse	23 21	5, 10, 15, 20, 30
TRIP590, Bare	MFDC	Truncated (45 deg, 6.4-mm face diameter)	1100	90	Single pulse 2-pulse	15 16	5, 15, 20, 30
CP800, 1.9 mm, EG	MFDC	Truncated (45 deg, 7.9-mm face diameter)	1300	90	Single pulse 3-pulse	17 21	5, 10, 15
Boron Steel [(a)] 2.0 mm, shot-blasted (heat-treated)	MFDC	Truncated (45 deg, 7.9-mm face diameter)	1300	90	Single pulse	21	5, 10, 15, 20
Mild Steel, 2.0-mm, HDGI	AC	Dome (6.4-mm face diameter)	1300	23	Single pulse	23	5

(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.

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,

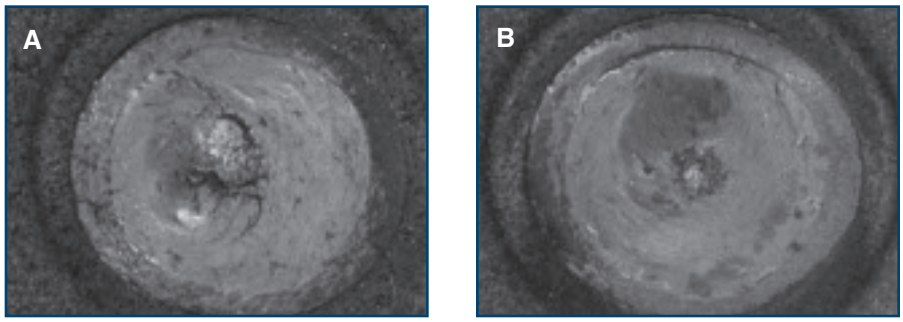

Fig. 7 — Shrinkage voids in 2-mm shot blasted boron steel (heat treated), MFDC, truncated electrode, single pulse. A — Hold time: 5 cycles; B — hold time: 10 cycles.

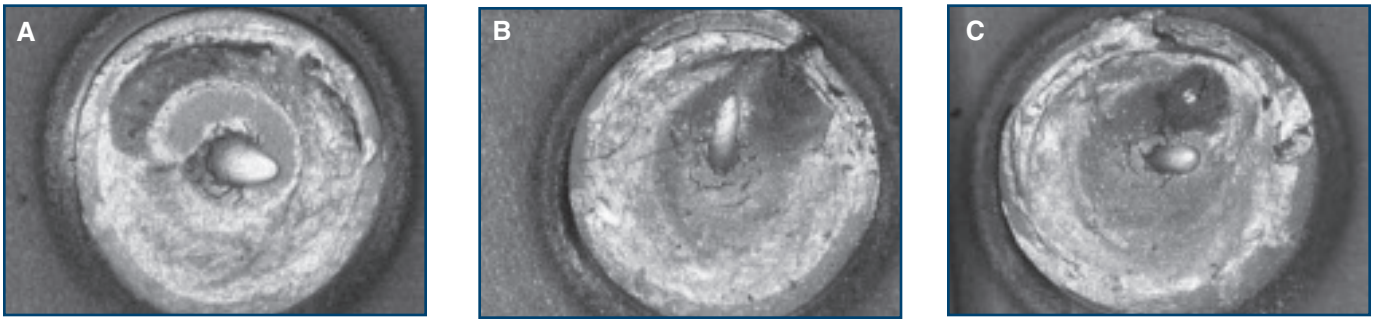

Fig. 8 — Shrinkage voids in 1.5-mm TRIP590, MFDC, truncated electrode, single pulse. A — Hold time: 5 cycles; B — hold time: 15 cycles; C — hold time: 30 cycles.

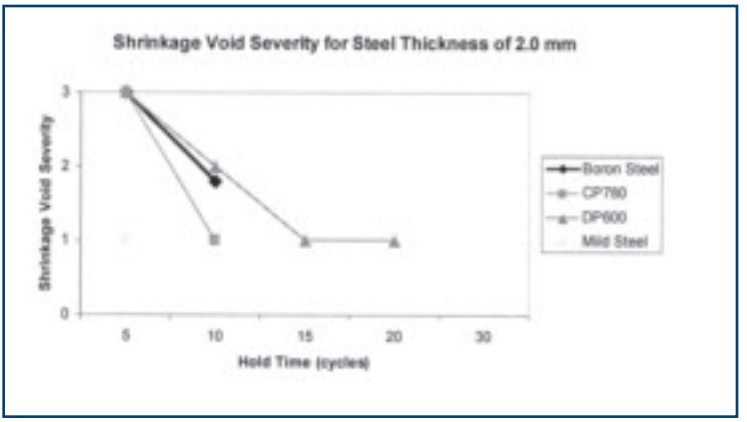

Fig. 9 — Shrinkage voids severity for steel thickness of 2 mm.

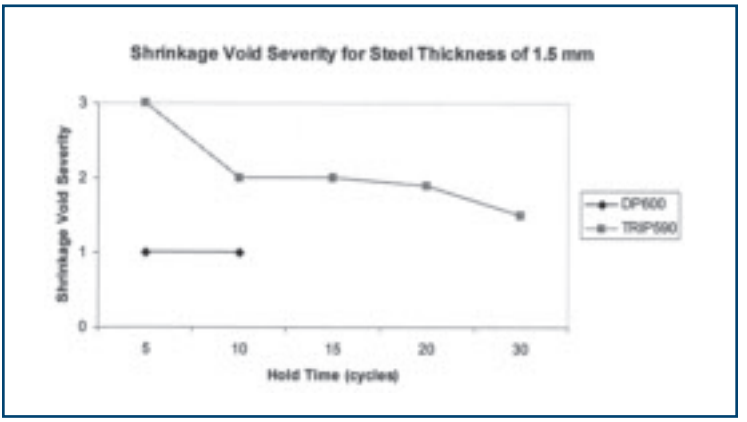

Fig. 10 — Shrinkage voids severity for steel thickness of 1.5 mm.

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.

Hold 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

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2. Tong, W., et al. 2005. Deformation and fracture of miniature tensile bars with resistance-spot-weld microstructures. *Metallurgical and Materials Transactions A: Physical Metallurgy and Materials Science* 36(10): 2651–2669.