

Evaluation of Liquid Metal Embrittlement and Spot Weldability in E-Coated, Galvannealed 1.8 GPa Hot-Stamped Steel

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This study comprehensively evaluated the mechanical properties, liquid metal embrittlement (LME), and spot weldability of galvannealed (GA) hot stamping steel (GA 1.8G) in comparison with conventional Al–Si 1.8 GPa hot stamping steel (Al–Si 1.8G). Tensile test results showed that GA 1.8G maintained similar yield and tensile strength while exhibiting higher elongation (7.8% vs. 6.6%) and superior V-bending performance (62° vs. 40°) compared to Al–Si 1.8G. These improvements are attributed to the surface decarburization treatment applied prior to Zn coating, which induces a soft ferrite layer on the surface.

Microstructural analysis of the GA 1.8G coating layer revealed that at short heat treatment holding times (0 and 1 min at 870°C), a high fraction of liquid-state Γ -Fe₃Zn₁₀ phase was present. This Γ phase penetrates grain boundaries under tensile stress, causing LME fracture, as confirmed by high-temperature tensile tests (Gleeble 3500). Early fracture occurred at elongations below 10% for holding times of 0–3 min, while the specimen held for 5 min achieved 28.5% elongation without LME. Cross-sectional BSE imaging confirmed Zn penetration along grain boundaries for the 1 min specimen. Sufficient heat treatment time is therefore essential to transform Γ -Fe₃Zn₁₀ into α -Fe(Zn) and suppress LME.

Resistance spot weldability was evaluated by measuring the weldable current range (minimum nugget diameter $4\sqrt{t}$, without expulsion). Both GA 1.8G and Al–Si 1.8G showed a comparable weldable current range of 1.5 kA. However, GA 1.8G showed interface separation at low current ranges (4–5 kA) and smaller nugget diameters (6.5 mm vs. 7.2 mm) at higher currents, due to increased contact resistance from the Zn-based oxide layer. EDS analysis revealed that the Zn and Mn oxide layer on GA 1.8G surface was approximately 0.3 μ m thick (net-like morphology), which is thicker than the $\sim$ 100 nm Al₂O₃ layer on Al–Si 1.8G. Despite this, tensile shear strength of GA 1.8G (32.3 kN at 8.5 kA) was comparable to Al–Si 1.8G (34.3 kN at 8.0 kA).

In conclusion, GA 1.8G demonstrates superior mechanical properties and LME resistance when adequate heat treatment time is secured, confirming its high potential for automotive component application. Optimization of the oxide layer through coating control remains the key challenge for achieving equivalent spot weldability to Al–Si coated steels in mass production.