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Editorial

Welding and Joining of Advanced High-Strength Steels (2nd Edition)

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1. Introduction and Scope

The welding and joining of Advanced High-Strength Steels (AHSSs) have recently evolved in several interconnected directions, including low-heat-input joining, dissimilar material joining (AHSS–Al, AHSS–composites, etc.), solid-state welding, AI-assisted intelligent welding, and hybrid or high-speed laser-based processes. The field is no longer focused solely on achieving acceptable weld strength; instead, increasing emphasis is placed on preserving the AHSS microstructure, minimizing HAZ softening, improving fatigue and crash performance, enabling lightweight electric vehicle (EV) structures, and integrating real-time process monitoring and control. In parallel, finite element analysis (FEA) continues to play a traditional and essential role in understanding thermal cycles, residual stresses, phase transformations, and mechanical performance during AHSS joining. More recently, emerging AI–FEA integrated approaches have attracted growing attention for process optimization, predictive modeling, defect prevention, and real-time adaptive control, thereby enhancing the efficiency and reliability of AHSS welding technologies.

Modern publications indicate that fusion welding processes, particularly GMAW (Gas Metal Arc Welding) and GTAW (Gas Tungsten Arc Welding), remain highly relevant for joining Advanced High-Strength Steels (AHSSs). Recent research shows that GMAW research is strongly focused on reducing HAZ softening, minimizing distortion, residual stresses, martensite over-tempering, improving fatigue/crash behavior, and increasing productivity.

In this Special Issue, Welding and Joining of Advanced High-Strength Steels (2nd Edition), various contributions have been presented to address important research gaps related to the aforementioned topics, with particular emphasis on AI-assisted intelligent welding, finite element analysis (FEA), Gleeble-based physical simulation, and the diverse aspects associated with arc welding processes, especially GTAW and GMAW.

2. Contributions

2.1. AI-Assisted Intelligent Welding

Park S. et al. (contribution 1) applied conventional multiple regression and machine learning (ML) models to predict the yield strength of austenitic stainless steel weld metals using chemical composition and thermal history as input variables. Molybdenum (Mo) showed the strongest correlation with yield strength, while carbon contributed through solid-solution strengthening. In contrast, higher heat input reduced strength by promoting larger dendrite arm spacing. The models successfully predicted strength variations caused by dilution during dissimilar welding, particularly between high-manganese steels and stainless steel consumables. Combined with Schaeffler-diagram analysis, the approach enables optimization of filler-metal composition, cost reduction, and compliance with engineering requirements. The study also highlighted that excessive weld strength may

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increase cracking susceptibility, emphasizing the need to balance mechanical performance and weld integrity through data-driven predictive methods.

2.2. Simulation (Finite Element Analysis (FEA) and Physical Simulation by Gleeble™)

Ji-Ho Eom et al. (Contribution 2) investigated the failure behavior of tailor-welded blanks (TWBs) produced from hot-press-formed 22MnB5 steel. The study combined experimental testing with finite element (FE) simulations to evaluate the effects of welding heat input on mechanical performance and fracture behavior. Results showed that optimized heat input produced the highest strength and ductility, whereas excessive heat input caused heat-affected zone (HAZ) softening and reduced joint performance. The authors demonstrated that 3D FE models predicted failure more accurately than conventional 2D approaches because they captured weld geometry, thickness variations, and stress-concentration effects. Fracture in optimized welds occurred in the base metal, while high-heat-input welds failed in the HAZ, indicating inferior joint quality.

dos Santos, F.M. et al. (Contribution 3) analyzed the influence of welding thermal cycles on the microstructure and corrosion resistance of super-duplex stainless steel (SDSS). Simulated heat-affected zones exhibited increased ferrite content and Widmanstätten austenite compared with the as-received material. Although no detrimental intermetallic phases were detected, all thermal cycles reduced pitting corrosion resistance. The study identified ferrite enrichment as the main factor responsible for lowering the critical pitting temperature (CPT), with higher heat input promoting greater ferrite fractions and increased susceptibility to localized corrosion. The authors established a direct relationship between welding heat input, microstructural imbalance, and corrosion performance, emphasizing the need for careful control of welding parameters, filler-metal selection, and shielding conditions to preserve SDSS integrity in aggressive environments.

2.3. Fusion Welding Processes (GTAW and GMAW)

Moinuddin, S.Q. et al. (Contribution 4) studied the Gas Tungsten Arc Welding (GTAW) of 0.3% C-Cr-Mo-V steel, evaluating air cooling (AC) and oil cooling (OC) during post-weld heat treatment. Results demonstrate that OC produces a fine martensitic-bainitic microstructure, yielding significantly higher tensile strength and hardness than AC. Increasing weld passes refined the grains, enhancing impact toughness. AC samples showed ductile fractures, whereas OC weldments exhibited mixed ductile–brittle failure. The study concludes that oil cooling offers the superior trade-off between strength and toughness for high-integrity applications. This cooling strategy effectively manages microstructural stability and mitigates cracking risks in steels with high-carbon equivalents.

Kim, D.-Y. et al. (Contribution 5) examined how chemical plating versus electroplating of copper on solid welding wires influences the performance of Gas Metal Arc Welding (GMAW). The research highlights that electroplated wires (E-wires) offer superior surface homogeneity and coating adhesion, leading to significantly better arc stability and reduced spatter generation during hour-long operations. However, the study also reveals that E-wires cause faster contact tip wear due to greater variations in their physical shape, specifically their cast and helix properties. By comparing these two coating techniques, the authors provide a critical framework for optimizing automated welding and wire-arc additive manufacturing (WAAM). Ultimately, the findings suggest that while electroplating enhances weld quality, the mechanical morphology of the wire is the primary driver of consumable part longevity.

Ko, H. et al. (Contribution 6) found that Al-4.8Mg-0.7Sc-0.3Zr filler wire significantly improves MIG welding for aluminum automotive components. Sc and Zr additions precipitate stable Al_3Sc and Al_3Zr compounds, acting as nucleation sites that refine grain

structures and enhance microstructural stability. In butt joints, this refinement yields higher tensile strength (up to 305 MPa) than conventional wires, though strength decreases with increased heat input due to grain coarsening. Conversely, in lap joints, tensile-shear strength (up to 199 MPa) increases with higher wire feed rates, as larger weld geometry offsets the adverse effects of a coarser microstructure. The researchers conclude that Sc/Zr-enhanced wires offer superior joint efficiency. Achieving optimal performance requires balancing heat input for butt joints and maximizing deposited metal for lap joints.

Molina-Castillo, A.E. et al. (Contribution 7) investigated that GMAW of PHS and DP steels causes significant hardness reduction in the sub-critical heat-affected zone (SC-HAZ) due to martensite tempering. PHS showed a 262 HV drop, while DP dropped 118 HV. Consequently, tensile failure systematically occurred at the softened SC-HAZ across all specimens. In dissimilar PHS-DP joints, the ultimate tensile strength (699 MPa) matched the weaker DP-DP weldment, while elongation (7.9%) mirrored the PHS-PHS joint. Compressive residual stresses were consistently measured, being most accentuated in PHS due to its higher martensite content. Furthermore, negative stresses in the fusion zone resulted from weld restraint during anchoring, despite ferrite-pearlite microstructures. These findings highlight that localized SC-HAZ softening governs global tensile resistance, while martensite volume and joint restraint dictate the final residual stress profile.

3. Conclusions and Outlook

The contributions presented in this Special Issue reflect the growing complexity and interdisciplinarity of AHSS welding research. Key advances span AI-assisted strength prediction, FEA-based failure modeling, microstructural control in HAZ, and process-specific optimization in GTAW and GMAW. HAZ softening remains a central challenge, particularly in press-hardening steels. Looking ahead, the integration of machine learning with real-time process monitoring and hybrid joining strategies will be decisive in enabling lightweight, high-performance structures for next-generation electric vehicles and safety-critical applications.

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Conflicts of Interest: The author declares no conflicts of interest.

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