C. Generic Issues in Welding Advanced and High Performance Steels

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The steel industry has undergone considerable changes in the past two decades. Emergence of mini mills, opening to global competition, new technologies such as direct steelmaking and mergers and acquisitions of integrated mills have shaken the industry in an unprecedented way. Interestingly enough, this time has also been associated with launching of new products and technologies that have been kept from implementation by a strict price- and trade structure.

In flat rolled steel product sector that mainly serves the automotive industry, Advanced High Strength Steels (AHSS) were introduced. AHSS is a collective term used for dual- and multiphase steels that have yield strengths up to180 ksi. On the plate side of the business, High Performace Steels (HPS) have been developed for 70 and 100 ksi yield strengths and bridge construction applications in 2-to-4 inches in thickness. Weldability of these hardenable grades poses specific challenges such as weld cracking and interfacial brittle failure at the resistance spot weld interface. The presentation will present an overview of these and other welding-related issues in AHSS and HPS, as well as look at future trends in the industry sector.

Selected Results, Sheet Products

1.1.1 Sheet vs. Plate

Typical use of AHSS used in hybrid design is illustrated in Figure 1, Ultra-Light Body Vehicles were designed and manufactured under a joint project between AISI and Porsche

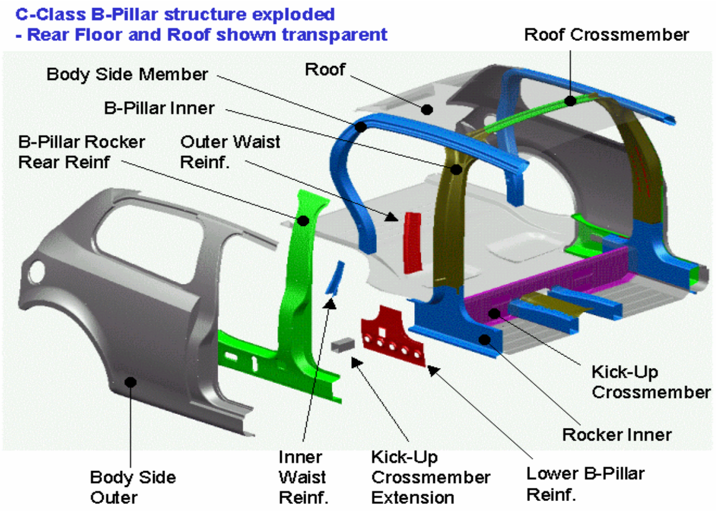

Figure 1: Hybrid Design in Vehicles

However, weldability predictive equations and testing procedures for high strength steels had been developed in during the 1960-1990s for plate and tubular products of strength of up to 130 ksi. However, as a famous saying goes in the industry: “Sheets are not thin plates”, chemistry, processing and coating-related metallurgical reactions are very different in these product lines. Moreover, emergence of direct steel making technology makes modern steel sheet even more different from traditional plate. Nevertheless, people nonchalantly use hardenability equations for sheet (such as Carbon Equivalent or Pcm numbers) that were originally developed using 2-inch diameter end-water-quench Jominy bars. Due to significantly lower cooling rates, we found that these equations are not applicable for welding 0.030-inch thick sheet. New predictive equations need to be developed for sheet steels, as related to most applicable welding processes such as LBW, RSW and GMAW.

1.1.2 Welding vs. Joining

The need for optimization of crash-worthiness, weight and corrosion resistance makes automotive industry use of AHSS more flexible and dynamic. Hybrid joining such as Weld Bonding is commonplace in the industry. Dissimilar joints between different grades of AHSS and traditional steels, joining AHSS to aluminum, as well as plastics becomes very important in this industry. Therefore, emerging joining technologies have already been successfully used – Laser/MIG hybrid welding for Tailor-Welded-Blanks and GMAW and Laser Brazing of roof panels being a few of such applications.

1.1.3 Fracture Mechanics-Based Design

Welds in low strength DQSK and other traditional grades have been known for decades to fail in a ductile mode. Crash tests results could be mostly characterized by “plastic collapse”, i.e. much yielding takes place before failure. In AHSS however, this is not the case. Weld nuggets tend to fail at the interface in what appears as a brittle failure. Micro cracks have often been associated with these welds. These facts seem to indicate the presence of a tri-axial state of stresses that warrants a Fracture Mechanics approach.

1.1.4 Interstitial Gases

Low ductility and micro cracks in the weld HAZ have been initial indications that dissolved hydrogen and nitrogen might be involved in failures. Recent work has confirmed the above hypothesis. Hence, the initial amount of dissolved gases will have to be carefully controlled. It is unclear, however, what are the upper limits of base metal gases, as H and N can often result from poor shielding

Selected Results, Plate Products

In the plate and tubular steel sections of the market, the term “High Performance Steels” or HPS has emerged during the same past two decades. The term HPS is commonly used to describe steels with increased yield strength to 100-130 ksi, improved toughness and lower susceptibility to hydrogen induced cracking have been the driving forces in this area. Figure 2 shows one HPS bridge overpass where both roadside supports could be eliminated by using higher strength steel.

Figure 2. Increases span bridge by using lighter-weight and stronger steels.

Elimination of costly preheat has been another target for cost reduction in the ship- and bridge-building industries. Development of consumables that produced high strength and toughness, as well as low-hydrogen weld deposits has been a major related effort. One of the problems created was narrowing of the operational windows due to need for strict heat input control. Another example of a problem that needed mitigation was the apparent contradiction between hydrogen induced cracking in the Fusion Zone (FZ) versus the Heat Affected Zone (HAZ), Table I

Table I - Minimum predicted preheat temperatures for two diffusible hydrogen levels, HPS 100W, as compared with preheat predictions from the open literature.

Weld Zone Assessed	No.	Test Type	Diffusible Hydrogen Levels,	
		Minimum Preheat	4 ml/100g	8 ml/100g
Fusion Zone (FZ)	1.	GBOP Test, LeTourneau	70°F	150°F
Heat Affected Zone (HAZ)	1.	Tekken Test, LeTourneau	70°F	N/A
	2.	British Standard [4]	325°F	361°F
	3.	Suzuki [7]	161°F	167°F
	4.	Inagaki [8]	348°F	447°F
	5.	Ito/Bessyo [9]	327°F	426°F
	6.	Dueren [10]	181°F	240°F

Following performance of hundreds of Gapped-Bead-on-Plate (G-BOP) and Tekken (Y-groove) tests, it was concluded that:

- Factors affecting delayed cracking still were: 1) - weld deposit strength; 2) - heat input; 3) - level of diffusible hydrogen.
- Hydrogen-induced cracking susceptibility of the heat affected zone (HAZ) was lower than in the weld Fusion Zone (FZ) for the same deposit strength and diffusible hydrogen level.
- Normal ambient conditions (or preheat to 70°F in case the outside temperature is lower) would be sufficient to avoid cold cracking in SAW welding of HPS 100W steels up to 2-inch-thickness provided that:
    1. fabrication practices are employed which maintain diffusible hydrogen below 5 ml/100g, and
    2. undermatching weld metal is used (deposit having 70-80 ksi tensile strength),
    3. the heat input is greater than 40 kJ/in.

Note that all the above conditions have to be simultaneously present in order to avoid weld metal cracking. A summary of recommended preheats is shown in Table II.

Table II. Recommended Minimum and Maximum Preheat / Interpass Temperatures for up to 2-inch-thick Plate, 40 - 80 kJ/in heat input SAW Welds.

	Diffusible Hydrogen Level	
	H4	H8
Conventional A 709 Grade 100W (Table 12.5, D1.5)	250°/ 400°F	250°/ 400°F
High-Performance HP 100W	70°/ 250°F	150°/ 400°F

Conclusions

This overview will serve as an introduction to the special session on modern steel weldability. Sheet and plate weldability have been treated separately and main problems and some solutions presented in more detail. The presentation was prepared from a unique perspective of a former steel company association, as well as from an academic research on steel weldability performed in the past sixteen years. The talk could motivate other researchers to get involved in this area of steel weldability, still considered by many well-understood, unimaginative and where funding is relatively scarce.