The Ohio State University - Welding Engineering Program

Liquid Metal Embrittlement in Resistance Spot Welds of Advanced High Strength Steels: Microstructure and Fracture Characteristic

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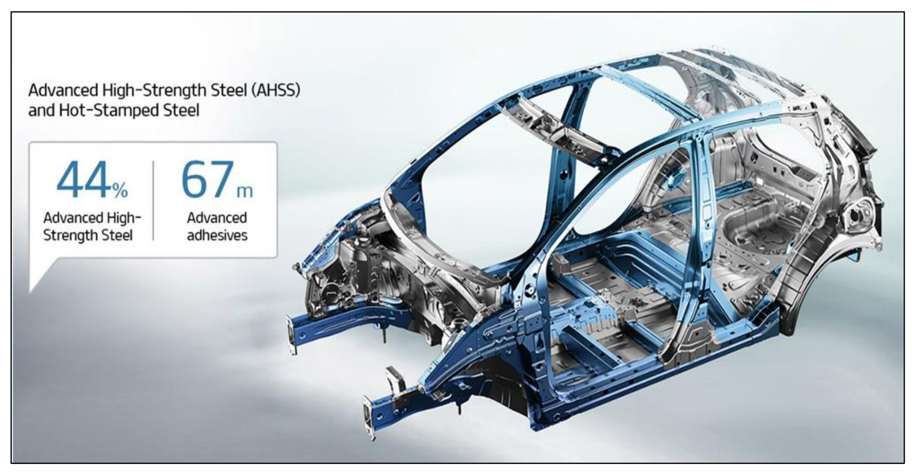
Background

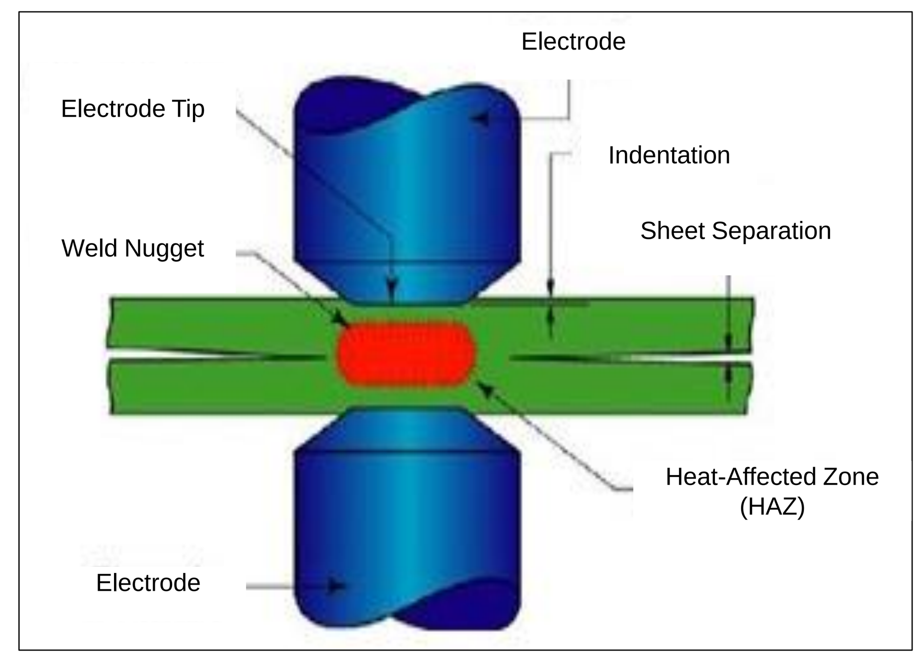
Advanced High Strength Steels (**AHSS**) are being utilized in automotive production in an effort for body in white weight reduction while attaining an increase in strength. During the Resistance Spot Welding (**RSW**) of these AHSS in dissimilar metal combinations such as zinc coated materials, the cracking phenomena known as Liquid Metal Embrittlement (**LME**) can occur.

For LME to occur three factors are necessary: (1) the presence of a liquid material, (2) tensile stresses, and (3) a susceptible microstructure. The presence of a liquid material (zinc) with a considerably lower melting point tends the result in grain boundary penetration of the solid substrate (steel) and subsequent embrittlement and cracking.

The mechanisms behind LME are not well understood. It is widely accepted that LME occurs most often in austenitic microstructures.



3-D model of AHSS material use in frame of Kia Sportage (Source: ArcelorMittal).



Schematic of resistance spot welding (RSW) configuration.

Objectives

- Reproduce LME induced cracking in resistance spot welds in a laboratory environment by varying welding parameters, and the introduction of additional restraint during welding
- Develop metallographic procedures to examine the cracking, and characterize the LME crack location and morphology

Experimental Method

Welding parameters (i.e. current, force, hold time, and electrodes) were varied to facilitate melting of zinc coating, penetration of the AHSS grain boundaries and sufficient tensile stresses during resistance spot welding in a laboratory setting.
In addition, additional restraint (tensile stresses) was applied during the welding process using two methods:

(1) Self-designed and 3D-printed fixture to provide a physical separation between the AHSS and the Zn-coated low alloy steel, and

(2) Modified electrode geometry to create an offset between the two welding partners.

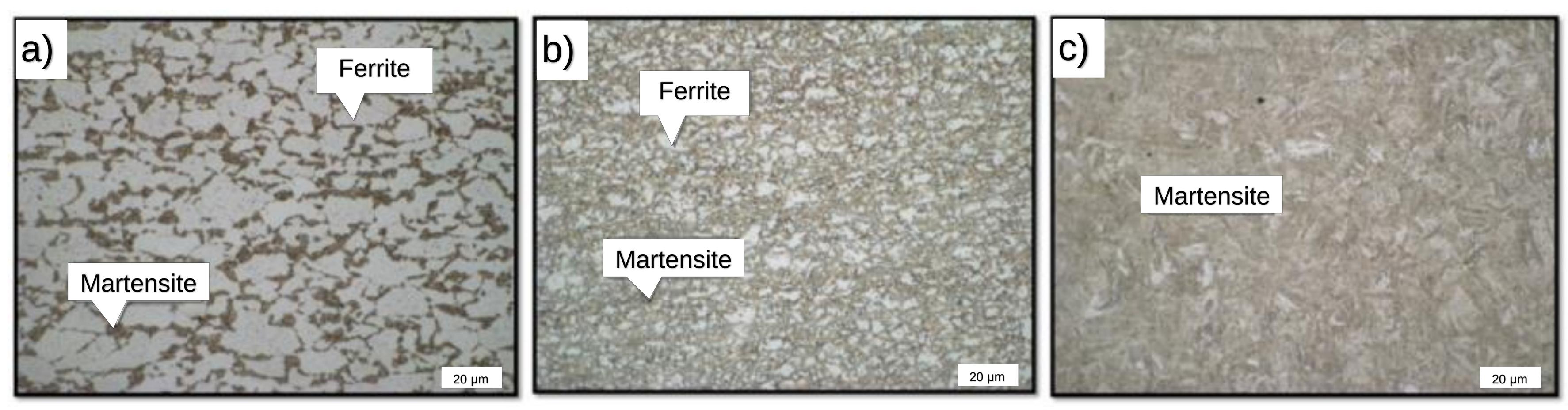
Experiments were performed on three AHSS, including two Dual Phase (**DP**) steels (DP590, DP980) and one Press-Hardened Boron Steel (**PHBS**) in a two-sheet dissimilar metal combination with a galvanized (Zn-coated) low-alloy steel.

Steel Composition (wt.-%)										
	Thickness	C	Mn	Si	B	P	Cr	Mo	S	Fe
PHBS (Usibor-1500)	1.5 mm	0.25	1.40	0.40	0.01	—	—	—	—	Balance
DP590	1.4 mm	0.18	2.20	0.80	—	0.04	—	—	0.03	Balance
DP980	1.4 mm	0.14	1.70	0.08	—	—	0.25	0.16	—	Balance

Results and Discussion

Characterization of different base metal microstructures of experimental AHSS
1) Light Optical Microscopy (LOM)
2) Phase quantification using image analysis

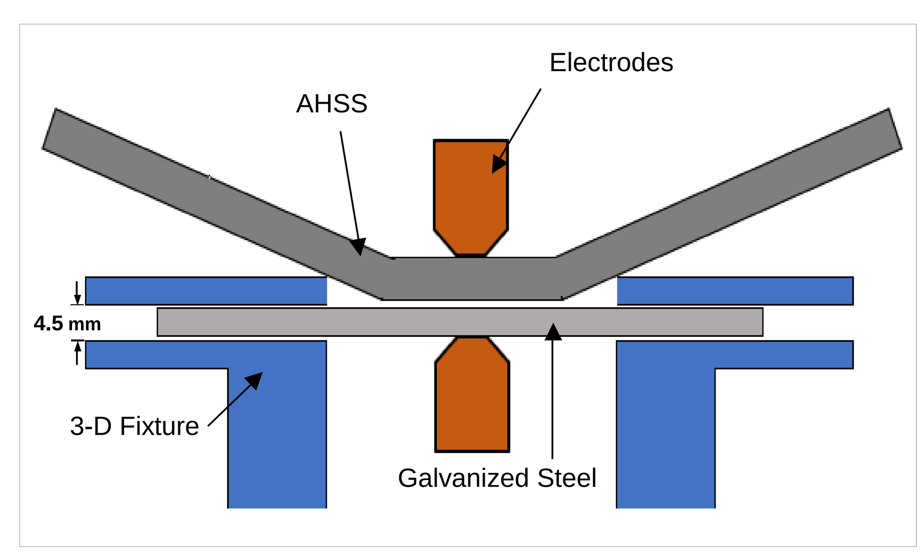
Base Metal	Ferrite Vol. %	Martensite Vol. %
DP590	29	71
DP980	54	46
Usibor-1500	–	100



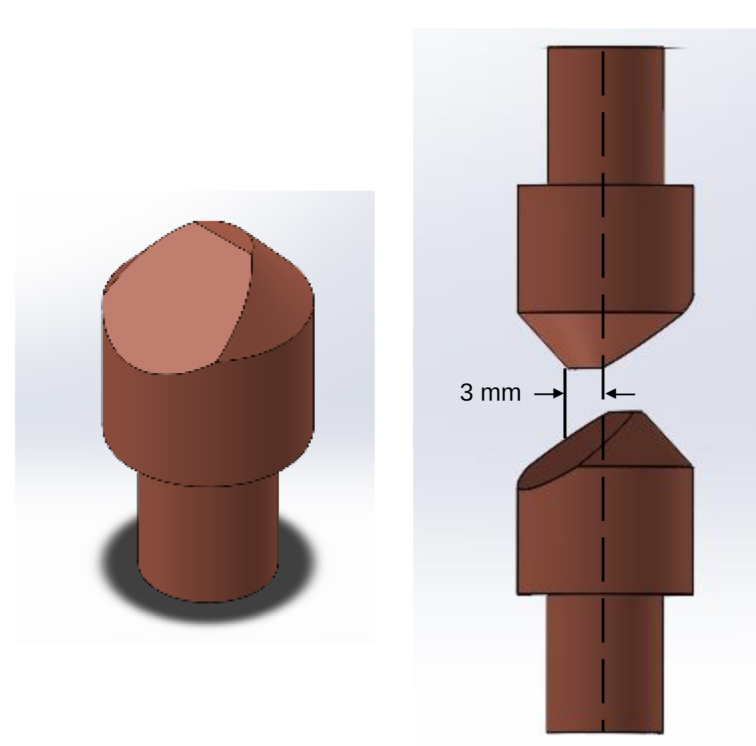
LOM evaluation of a) DP590, b) DP980, and c) Usibor-1500 base metal microstructures at 1000x magnification. Nital etchant.

Introducing additional restraint during RSW process:

***Method 1**:* Use of 3D-printed fixture to induce additional tensile stresses in the weld was successful at deforming both the DP590 and DP980 steels during welding, but was unable to deform the PHS. No LME cracking was located in the LOM cross-sections taken from these welds.



Schematic of 3-D printed fixture (blue) to induce tensile stresses during welding and AHSS/Zn-coated low alloy steel RSW weld set-up.

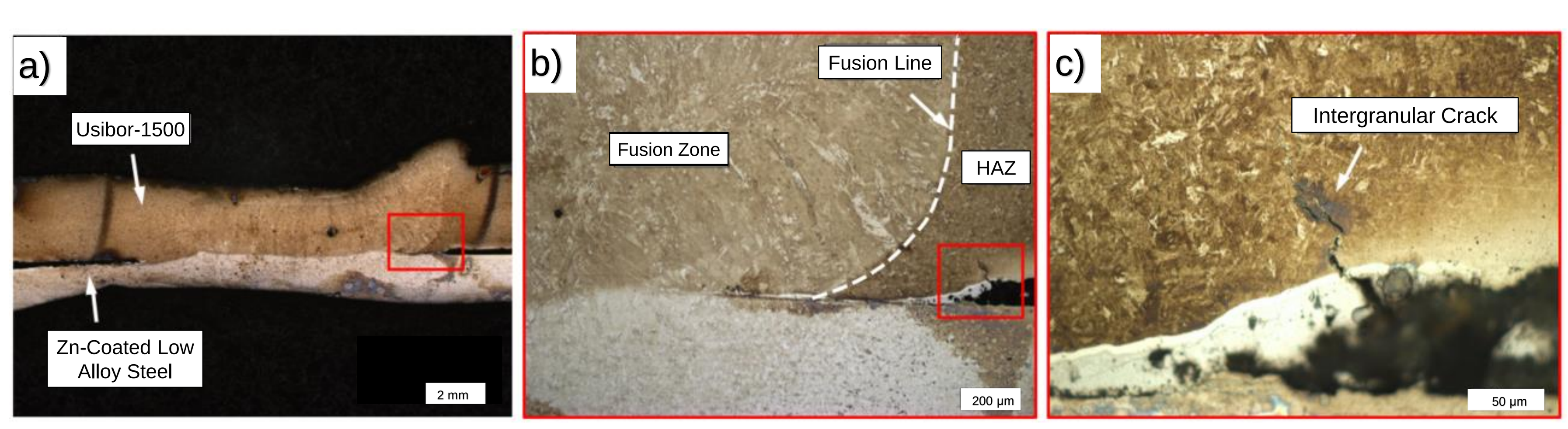


3-D modeling of machined Type-E electrodes and weld parameters used in weld sequence #5.

***Method 2**:* Use of an offset between modified electrodes to induce additional tensile stresses in the weld. LME cracking was observed in the LOM cross-sections of all three AHSS/Zn-coated low alloy steel welds. Cracking is located in the Heat Affected Zone (**HAZ**) at a distance from the fusion boundary. Crack lengths are quite short (50-100 µm). The crack path is intergranular.

Material	Force (lbs)	Weld Cycles	Current (kA)
DP590	700	16	12
DP980	700	16	12
Usibor	700	16	12

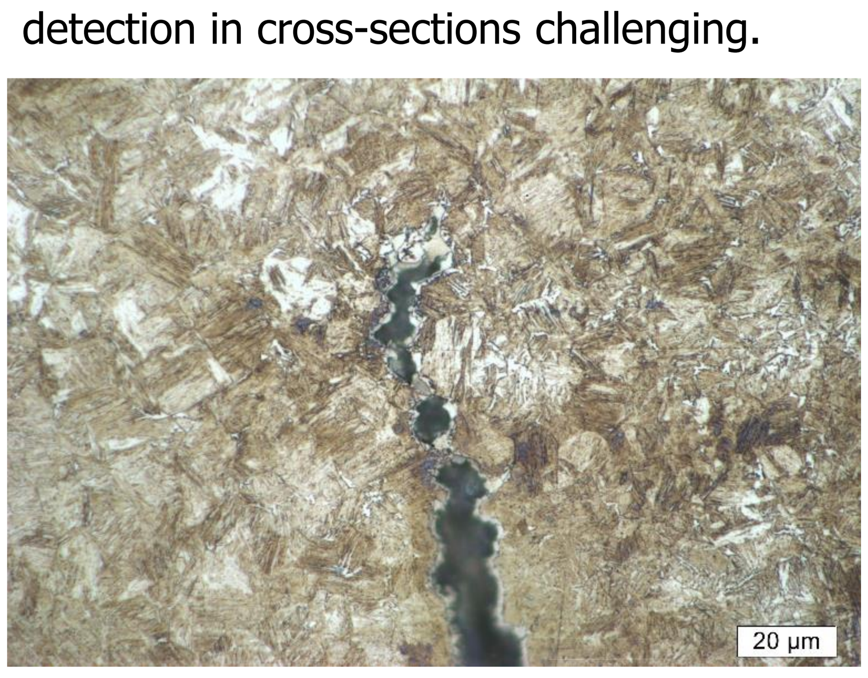
Weld Parameters used during off-set electrode series.



RSW weld on Usibor/Zn-coated low alloy steel with offset electrodes: at a) 10x , b) at 100x, and c) at 1000x magnification showing LME cracking in the HAZ of the AHSS.

Conclusions

- Variation of welding parameters alone did not lead to LME induced cracking that was detected via LOM evaluation on cross-sections.
- The 3-D printed fixture was able to deform the DP steels during RSW, but not the PHS due to its high strength (1500 MPa). No cracking was observed.
- Without the introduction of external tensile stresses LME induced cracking was unable to be attained.
- Welding with electrode offset results in LME induced cracking in the HAZ of all three AHSS. The crack path was intragranular, and cracks were quite short (50-100 µm), which made sample preparation and detection in cross-sections challenging.



LOM micrograph of the intergranular crack path of LME induced cracking in a DP590/Zn-coated low alloy steel weld.

Future Work

- Additional testing using electrode offset to determine the effect of varying welding parameters under additional restraint conditions.
- Characterization of cracking using Scanning Electron Microscopy (SEM) to determine the presence of Zn along cracking.
- Detailed microstructural analysis and micro-hardness traverse across HAZ to determine the region where LME induced cracking occurs.

Acknowledgments

- Dr. Carolin Fink as research advisor for her knowledge, patience, and constant encouragement throughout this research project.
- Dr. Menachem Kimchi for providing the materials.
- The Ohio State University College of Engineering Research Scholarship Program for selecting this project for my undergraduate research distinction and funding.