GREAT DESIGNS IN STEEL

TWENTY YEARS

WELDABILITY INVESTIGATION OF 3RD GEN AHSS FOR AUTOMOTIVE MANUFACTURING

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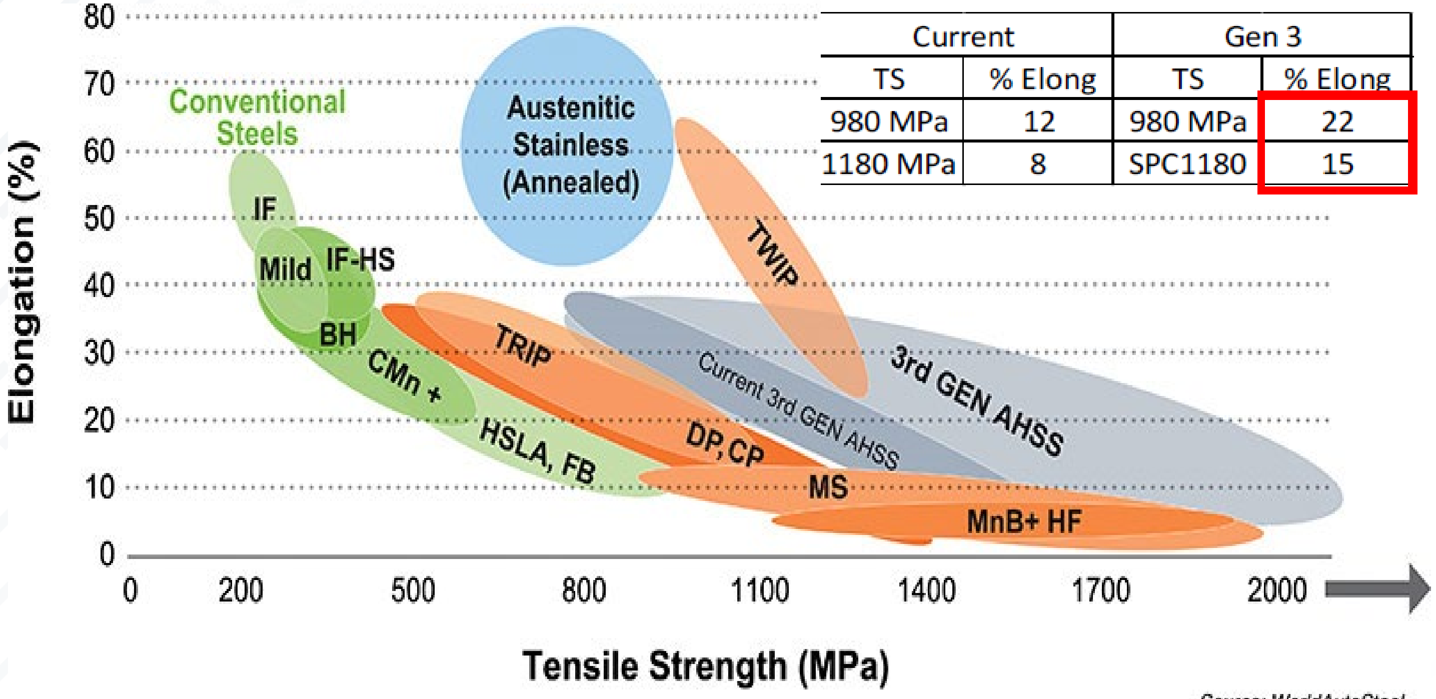
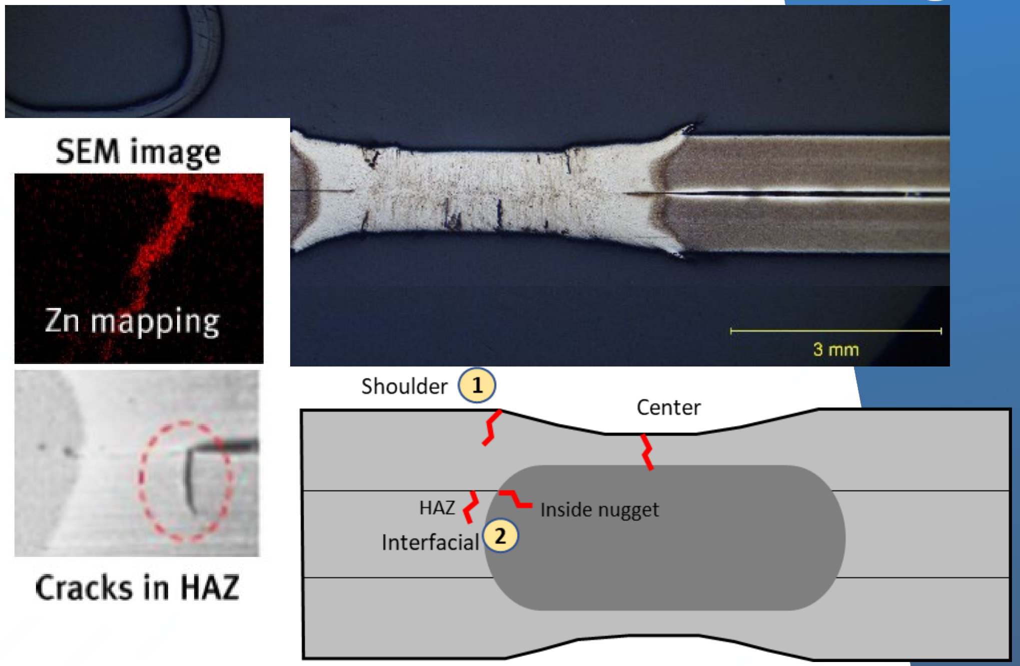
BACKGROUND



Current		Gen 3	
TS	% Elong	TS	% Elong
980 MPa	12	980 MPa	22
1180 MPa	8	SPC1180	15

Source: WorldAutoSteel



- Implementation of 3rd Gen AHSS supports automotive light-weighting initiatives while reducing costs compared to hot stamped materials
- Welding of 3rd Gen AHSS is challenged by the prevalence of LME cracking
- Establishment of welding conditions with acceptable quality is an industry-wide issue

THE BIG PICTURE

GOAL: To establish a method for evaluating the suitability of 3rd Gen AHSS for automotive manufacturing.

APPROACH: Toyota North America has partnered with industry research organizations to evaluate methods for the qualifying 3rd Gen AHSS for production

OUTCOME: Materials can be ranked against each other, and welding practices can be established that minimize cracking risk

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OVERVIEW

1. Select a Case Study
2. Compare material from multiple suppliers
3. Define baseline welding practices
4. Evaluate cracking risk in extreme conditions
5. Evaluate mechanical performance

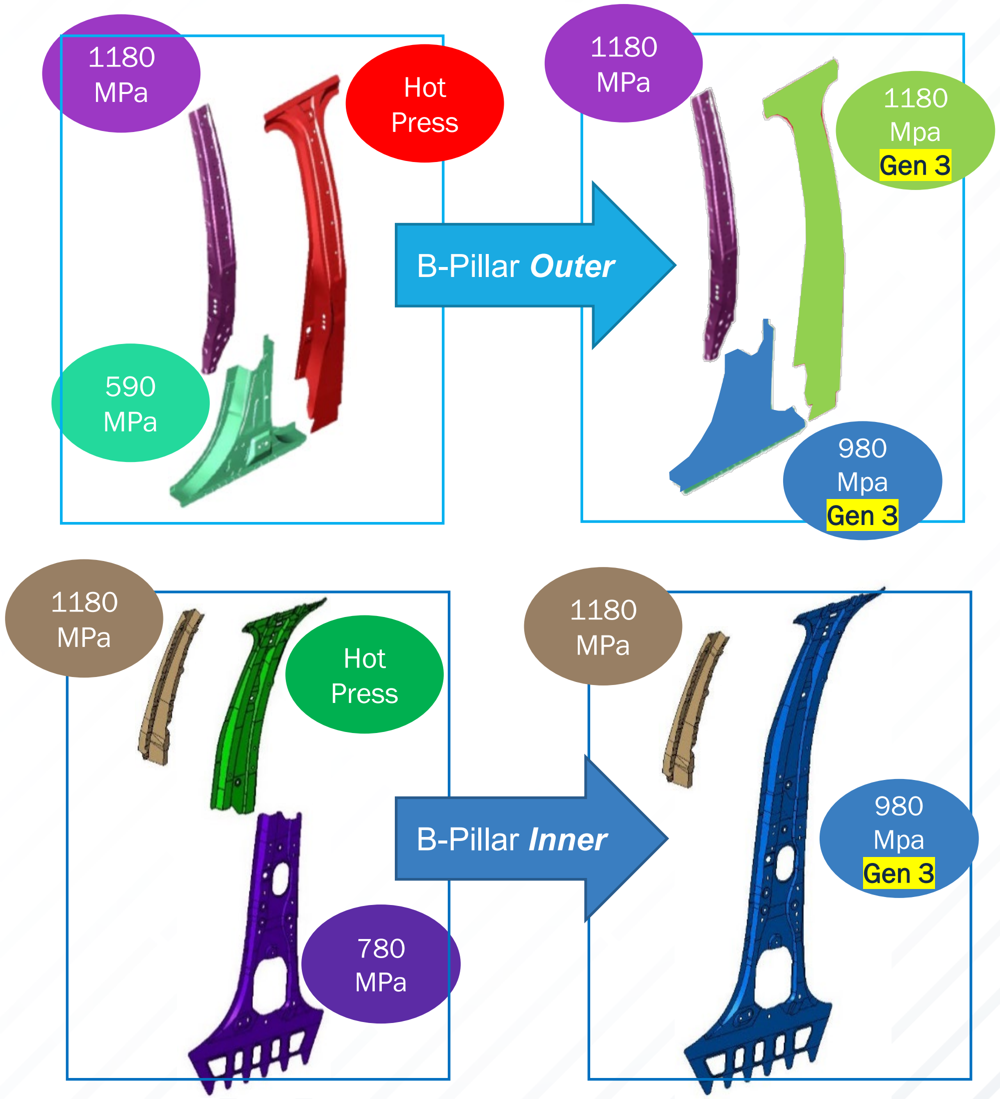
CASE STUDY

Method

- Select existing vehicle structure with hot stamped material
  - Structure must provide a range of welding configurations and use of 3rd Gen material must reduce weight and cost
- Redesign structure to **optimize use of 3rd Gen AHSS**

Selection

- B-Pillar assembly from current model vehicle selected for study
- Two pillar inner component changed to 3rd Gen AHSS
- Outer pillar structure **simplified from three to two panels** using 3rd Gen AHSS
- 29 weld configuration generated ranging from two to four sheets of material per stack-up and materials in the bare and galvannealed surface conditions
- **Weight reduction of over 500 grams and tens of cents of cost savings**



MATERIAL COMPARISON – H-COUPON TEST

LME requires three specific conditions

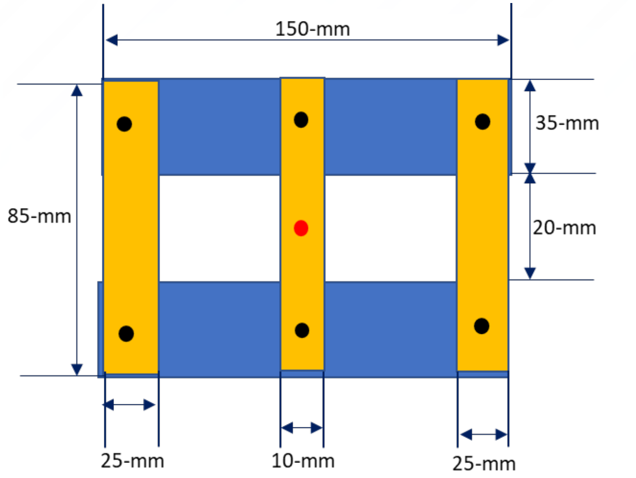
1. The presence of a liquid metal (zinc)
2. Surface strain
3. Susceptible microstructure: large grain, austenitic

H-coupon developed on test crack sensitivity over a range of induced strain

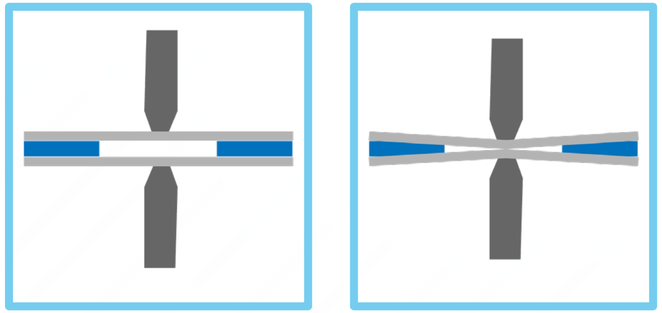
- Configuration creates a bending beam problem
- By changing the gap between welded sheets, the value of strain at the edge of the weld can be adjusted

H-Coupon test creates cracking in two locations

- Primary crack location at the weld interface where induced strain is highest from coupon design
- Secondary cracks form on the top surface of the weld where significant electrode indentation occurs



Citation: Gould, J. E. and Amanuel, L. 2021. Influence of gap on the susceptibility of interfacial failure for spot welds on advanced high-strength steels. EWI Light Paper Series, EWI, Columbus, OH.

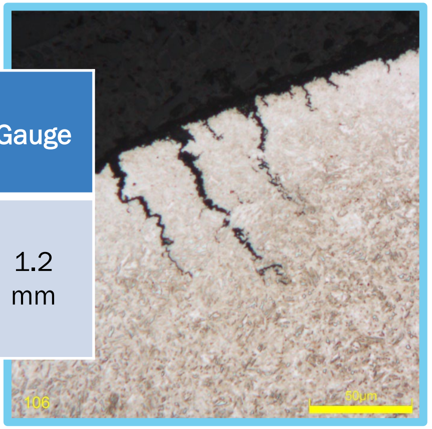


Material/Gap		ε_{max} (%)	Force (kgf)	Current On-time (ms)	Elect. Dia (mm)
Supplier X/Y		-	-	-	-
	0t	0.00%	420	267	6
	1t	0.54%	500	267	6
	2t	1.08%	590	267	6
	3t	1.62%	680	267	6

MATERIAL COMPARISON RESULTS

- Known to be variation in weldability of 3rd Gen AHSS
  - Prevalence of LME cracking
- Material provided by two top suppliers for weld evaluation
- Material performance characterized by plotting retained button area versus the maximum applied strain

Supplier	Material	Coating Condition	Gauge
X, Y	980 MPa 3rd Gen AHSS	Galvannealed	1.2 mm

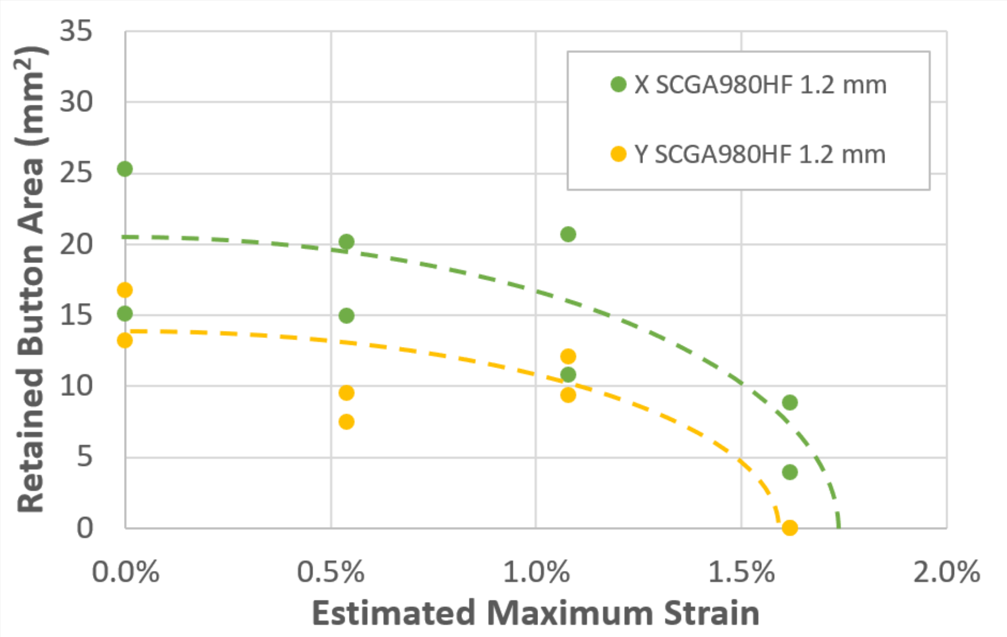


Exterior Liquation Cracking on Supplier Y weld made with a 1-t Gap

Re-filled Liquation Cracks Supplier Y Weld made with a 2-t Gap

Key Takeaways

- Materials were ranked against each other
- Galvannealed material found to be significantly less sensitive to LME cracking that galvanized
  - Alloying of the coating leaves less free zinc on the surface
- It is critical that chemistry of material supplied to manufacturing be tightly controlled to ensure quality



DEFINE NOMINAL WELD CONDITIONS

Objective: Use standard weld practice to determine baseline weldability for selected materials.

- Baseline criteria for weldability set as current range – 2-kA demonstrates robustness for manufacturing
- AWS D8.9 selected as standard for welding and testing practices

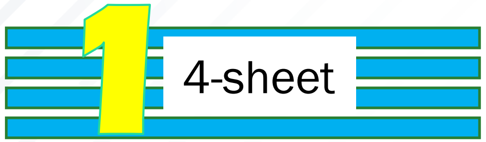
Classification of Steels for Resistance Spot Welding and Testing Purposes (AWS D8.9)		
Group	Min Tensile Strength	Typical Products (YS/TS)
1	≤ 350 MPa	Mild 140YS/270TS, BH 180YS/TS BH 210YS/320TS, BH 240YS/340TS
2	350 - 500 MPa	BH 260YS/370TS, HSLA 280YS/350TS HSLA 350YS/450TS, DP 300YS/500TS
3	> 500 - 800 MPa	DP 350YS/600TS, TRIP 350YS/600TS DP500YS/800TS, TRIP 500YS/800TS CP 700YS/800TS
4	> 800 MPa	DP 700YS/1000TS, Mart 950YS/1200TS Mart 1150YS/1400TS, Mart 1250YS/1520TS

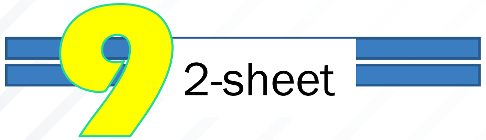
Case study: B-Pillar study generated 29 stack-ups for weld evaluation.

- 3rd Gen AHSS from supplier X provided in 980 and 1180MPa
- Changes to AWS D8.9 made in order to align with production procedures
  - Electrode tips were aligned, but not dressed or broken in
  - Only one weld was made per peel testing coupon
- Weld parameters selected based on governing material: thinnest outside sheet
  - Adjustments made as need to achieve desirable current range
- Weld size at all interfaces considered to develop current range
  - $4\sqrt{t}$ to expulsion

Material ID	Tensile Strength (MPa)	Steel Type	Coating Condition	Gauge (mm)
980 Gen III GA	980	Gen III AHSS	Galvannealed	1.20
1180 Gen III B	1180	Gen III AHSS	Bare	1.40
HP	--	Hot pressed	Aluminized	1.60
1180 DP B	1180	Dual phase	Bare	2.00
1180 DP GA	1180	Dual phase	Galvannealed	1.60
1180 DP B	1180	Dual phase	Bare	1.60
1180 DP B	1180	Dual phase	Bare	1.40
1180 DP GA	1180	Dual phase	Galvannealed	1.20
1180 DP GA	1180	Dual phase	Galvannealed	1.00
1180 DP B	1180	Dual phase	Bare	1.00
780 DP B	780	Dual phase	Bare	1.60
590 DP GA	590	Dual phase	Galvannealed	1.60
590 DP GA	590	Dual phase	Galvannealed	1.40
440 CR	440	Cold rolled	Bare	1.60
270 CR GA	270	Cold rolled	Galvannealed	0.65

WELD STACK-UPS FROM CASE STUDY





Stack No.	Materials	Stack No.	Materials	Stack No.	Materials
1	0.65-mm 270 CR GA 1.4-mm 1180 DP B 1.4-mm 1180 Gen III B	11	1.4-mm 1180 Gen III B 1.4-mm 1180 Gen III B 1.2-mm 980 Gen III GA	21	1.2-mm 980 Gen III GA 1.2-mm 1180 DP GA 1.2-mm 1180 DP GA
2	0.65-mm 270 CR GA 1.4-mm 1180 Gen III B	12	1.2-mm 980 Gen III GA 1.2-mm 980 Gen III GA	22	1.4-mm 1180 Gen III B 1.2-mm 980 Gen III GA
3	0.65-mm 270 CR GA 1.4-mm 1180 Gen III B 1.2-mm 980 Gen III GA	13	1.2-mm 980 Gen III GA 1.2-mm 1180 DP GA 1.2-mm 980 Gen III GA	23	1.4-mm 1180 Gen III B 1.2-mm 980 Gen III GA 2.0-mm 1180 DP B
4	0.65-mm 270 CR GA 1.4-mm 1180 Gen III B 1.4-mm 1180 Gen III B	14	1.2-mm 980 Gen III GA 1.6-mm 440 CR 1.2-mm 1180 DP GA	24	1.6-mm 590 DP GA 1.2-mm 980 Gen III GA
5	0.65-mm 270 CR GA 1.4-mm 1180 Gen III B 2.0-mm 1180 DP B	15	1.4-mm 1180 Gen III B 1.4-mm 1180 DP B	25	1.0-mm 1180 DP B 1.4-mm 1180 Gen III B 1.6-mm 1180 DP B
6	0.65-mm 270 CR GA 1.2-mm 980 Gen III GA 1.2-mm 980 Gen III GA	16	1.4-mm 1180 Gen III B 1.4-mm 1180 DP B 1.6-mm HP	26	1.6-mm SPC780DU 1.0-mm SPC 1180DUB 1.4-mm 1180 Gen III B
7	1.4-mm 1180 Gen III B 1.4-mm 1180 DP B 1.0-mm 1180 DP B	17	1.2-mm 980 Gen III GA 1.2-mm 1180 DP GA	27	1.2-mm 980 Gen III GA 1.4-mm 1180 Gen III B
8	1.4-mm 1180 Gen III B 1.2-mm 980 Gen III GA 1.4-mm 1180 Gen III B 1.2-mm 980 Gen III GA	18	1.2-mm 980 Gen III GA 1.2-mm 1180 DP GA 1.6-mm 1180 DP GA	28	1.2-mm 980 Gen III GA 1.6-mm 440 CR
9	1.4-mm 1180 Gen III B 1.2-mm 980 Gen III GA 1.2-mm 980 Gen III GA	19	1.2-mm 980 Gen III GA 1.2-mm 1180 DP GA 1.4-mm 590 DP GA	29	1.6-mm 1180 DP B 1.4-mm 1180 Gen III B
10	1.4-mm 1180 Gen III B 1.4-mm 1180 Gen III B 1.0-mm 1180 DP B	20	1.2-mm 980 Gen III GA 1.2-mm 1180 DP GA 1.0-mm 1180 DP GA		

WELD PRACTICE RESULTS

Successful welding practices found for all 29 stack-ups

- Average current range of 2.5
  - All but four stack-ups exhibited current ranges in excess of 2 kA, smallest current range of 1.4 kA

Five stack-ups required weld practices deviating form AWS D8.9

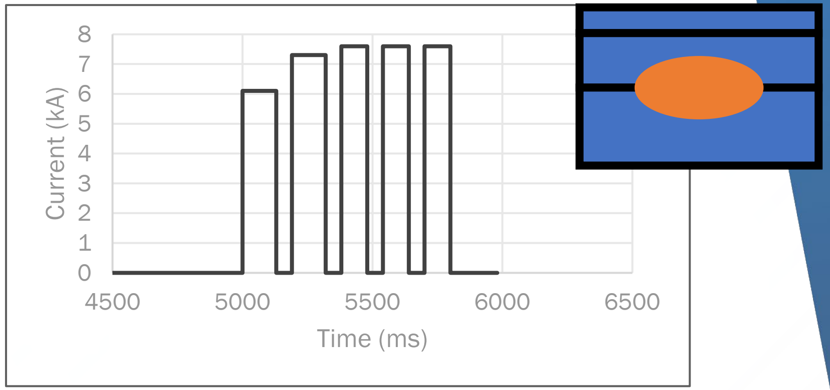
- Thin-thick-thick combinations presented most challenges
  - Nugget growth at geometric center of stack-up
  - Electrodes act as heat sink on thin sheet material
  - Challenges balancing nugget growth at thin interface and expulsion at thick interface

Two methods for thin-thick-thick welding with the same philosophy: Controlling current and force to create sufficient weld nugget at thin sheet interface without expulsion at thick sheet interface

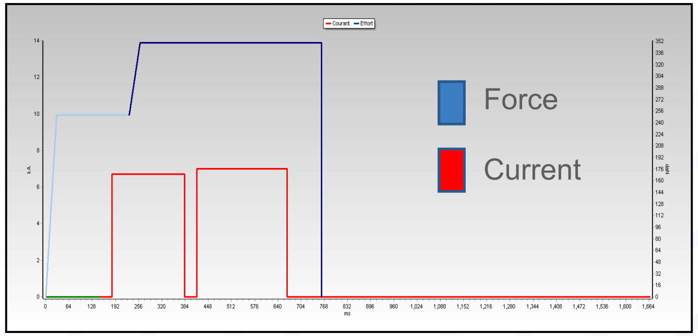
- Multi-pulse welding successful in most scenarios
- Two stage force required for extreme heat imbalance

Thin-thick-thick stack-ups represent a significant challenge for the automotive industry and are the subject of ongoing investigation with A/SP

Complex Multi-Pulse Weld Schedule



Two-Stage Force Weld Schedule



EVALUATE CRACKING RISK
– INTRODUCE PRODUCTION DISTURBANCES

Weld quality must be maintained in all production conditions

Five disturbances selected to represent extreme conditions

1. Off angle electrodes
2. Panel gap
3. Electrode offset
4. Weld on sheet edge
5. Worn electrodes

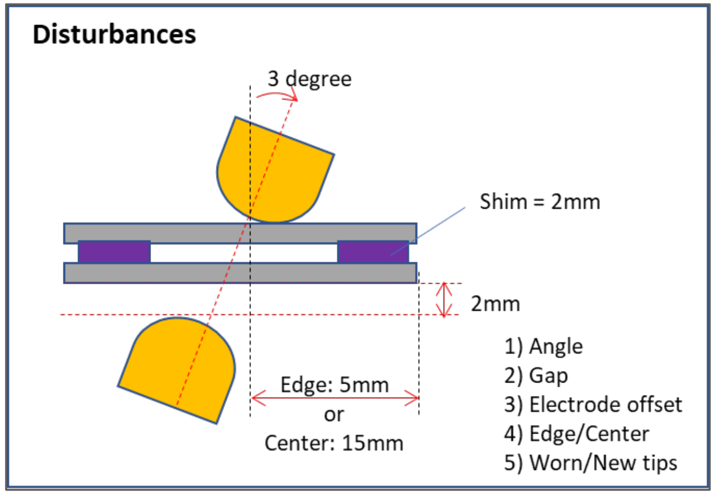
Two key areas of crack concern: shoulder and interface

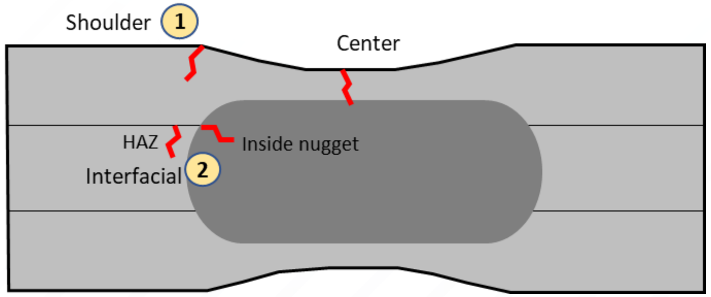
- Highest impact to weld quality

Significant time and resources required to test each disturbance individually for all 29-weld stack-ups in case study

Use of DOE allowed to test effect of all disturbance conditions on should cracking, interfacial cracking, and mechanical performance with minimum time and resources

- 90% reduction in required welds

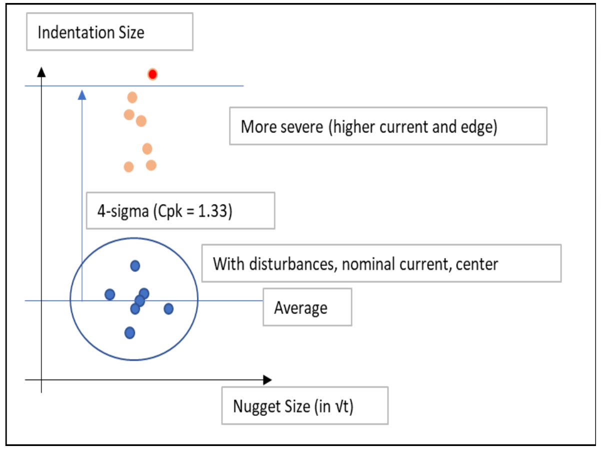


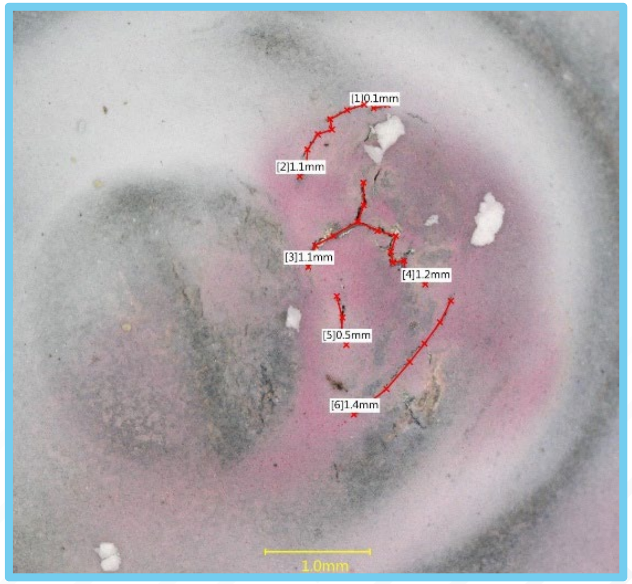


SHOULDER CRACKING

Goal: Create graphical representation of the potential for shoulder cracking in each stack-up

- 69-Trial DOE used to test the effect of five weld disturbances, weld size, and cooling water flow rate
- Die penetrate testing used to locate surface cracks
- Optical microscope used to quantify cracking
- Cracking only occurred in 16% of trails, limited to 10% of overall number of coupons made
    - In only 2 of 69 conditions did the majority of coupons in the trail exhibit cracking
    - Low level of cracking made data analysis and graphical representation difficult, but showed robustness of the welds





INTERFACIAL CRACKING PREDICTION

Interfacial cracking driven by hold times

Excessively short hold times

- Molten zinc on the free surfaces
- Rapid developing stress as electrodes release
- Liquation related cracking

Excessively long hold times

- High carbon contents of AHSS and Gen III steels
- Quenching of the weld nugget to martensite
- Susceptibility to brittle fracture
- Interfacial failure

Different allowable hold times based on cooling profile

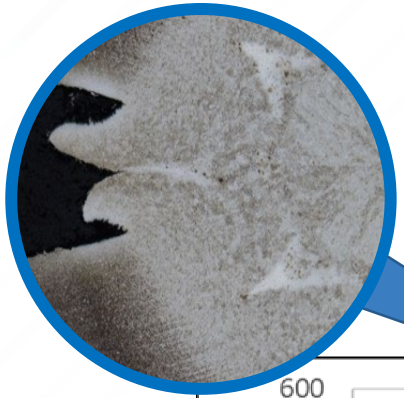
- Current
- Weld time
- Stack-up

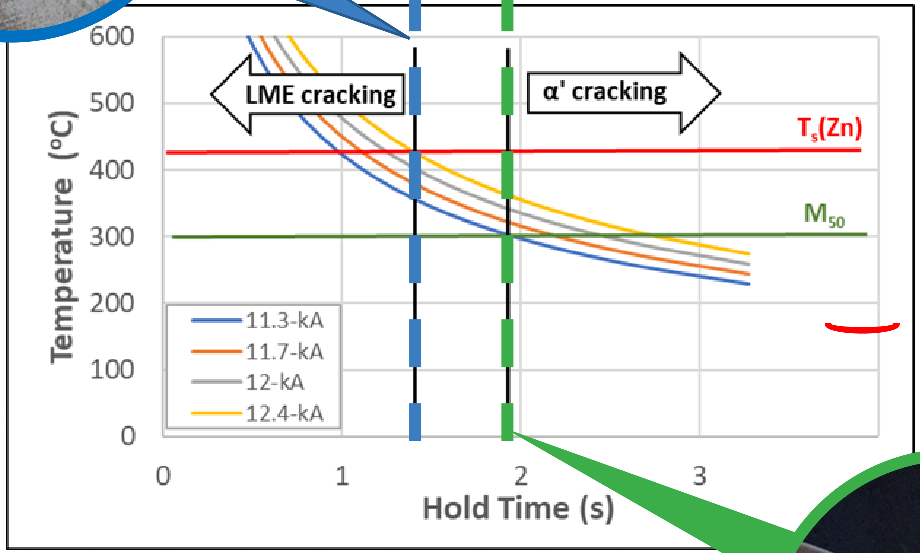
Allowable hold times defined as:

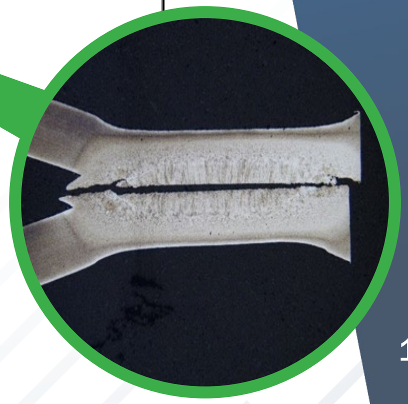
- > $t_{m(Zn)}$ for the maximum current used
- < t_{M50} for the minimum current used

Minimum acceptable range of hold times

81-trail DOE used to study disturbance condition, weld size, and hold times to acceptable hold time range for all 29 stack-ups



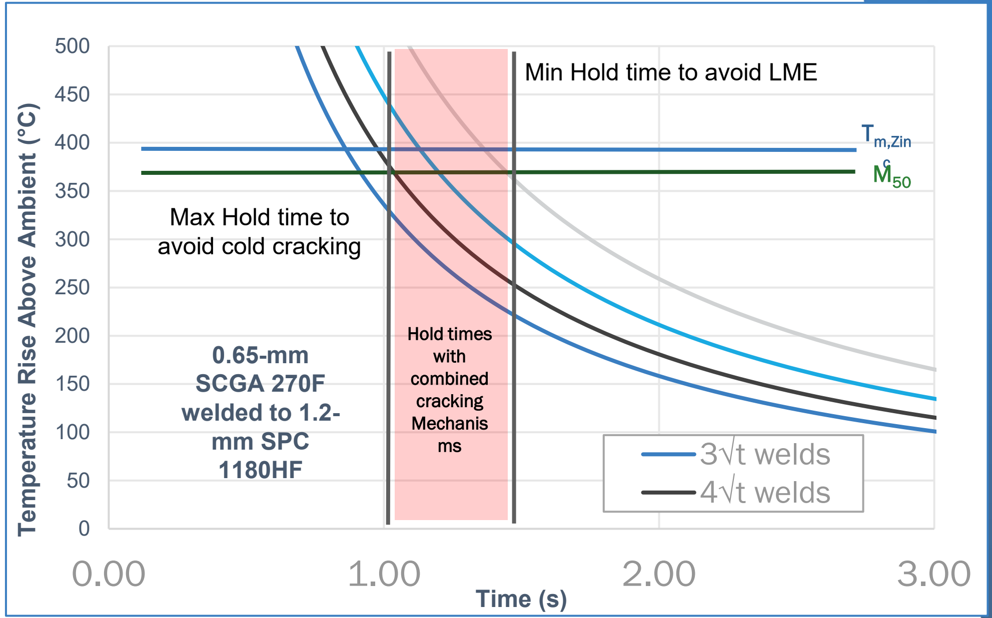




INTERFACIAL CRACKING RESULTS

Overlap of hold times for zinc solidus and M50 when considering all acceptable weld sizes

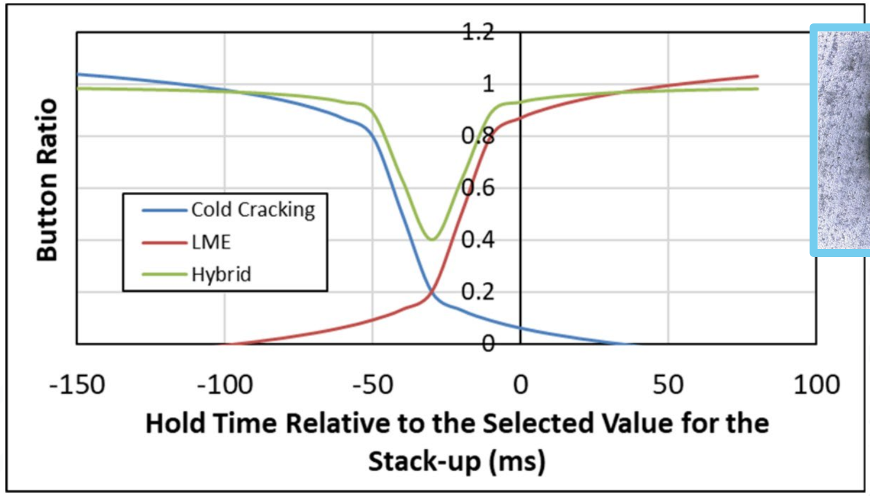
- Closeness of M50 temperature to zinc solidus (20-120C) caused overlap of necessary hold times for the two cracking mechanisms as weld size was varied from 3sqrt(t) to expulsion
- No hold time range could be established between the two conditions



A single critical hold time balancing LME and interfacial cracking selected for each stack-up, combining the effects of both in DOE analysis

Cracking in specimens was characterized by a combination of mechanisms

- LME cracks provide initiation sites, martensitic structure allows easy propagation



Long hold times favored to eliminate risk of both cracking mechanisms, but trough response also allows for the use of short hold times

MECHANICAL PERFORMANCE AND FINAL CRACKING ASSESSMENT

Final assessment of the weld stack-ups included and tensile shear, instrumented peel, die penetrant testing.

- Optimum welding conditions selected based on all previous work
- Mechanical testing performed at each interface of weld stack-up
- 48-trail DOE used to impact of disturbance conditions and mechanical test configuration on weld performance

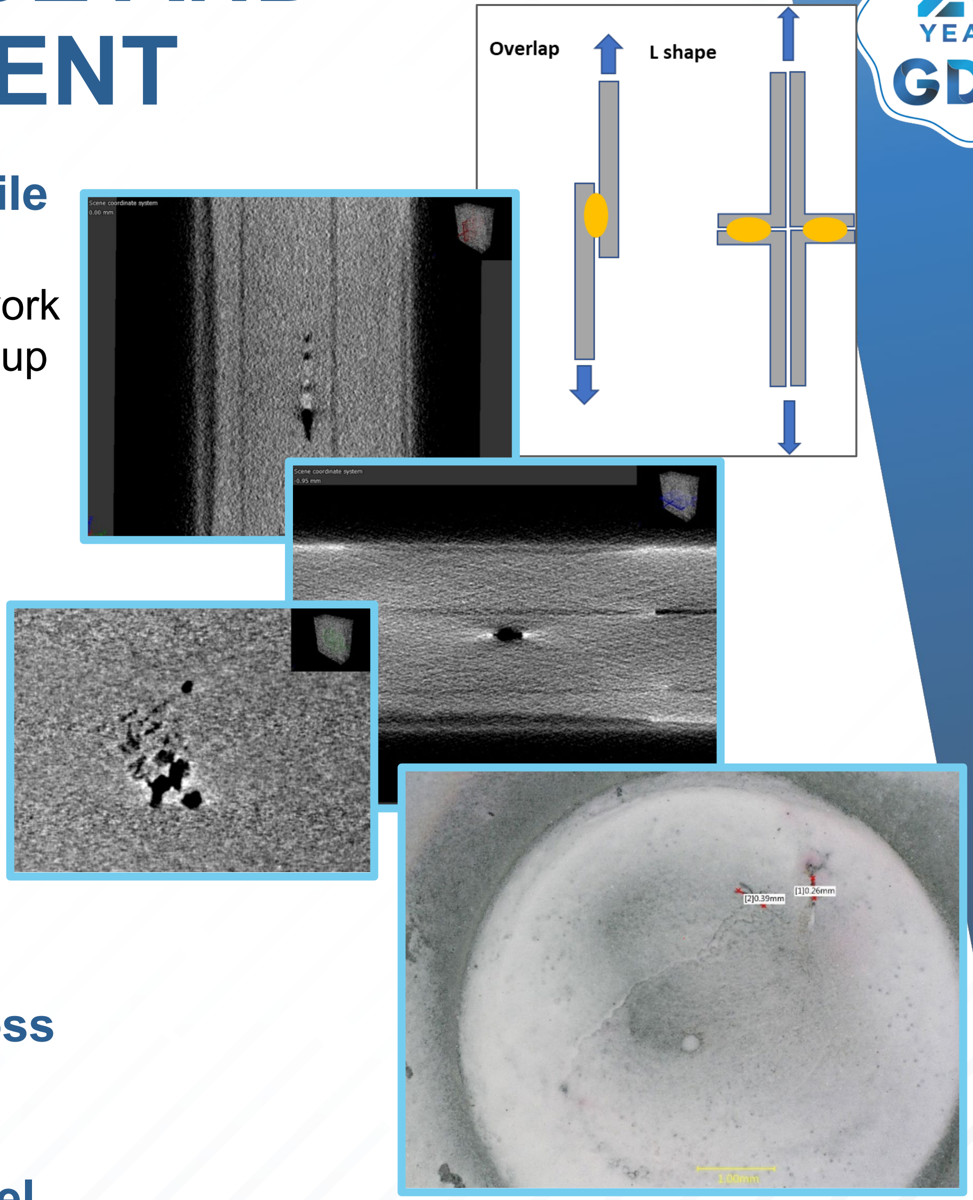
Computer tomography used on select samples to access weld porosity

- Low across all trials

Surface cracking occurred in 3 of 48 trials, and did not represent most welds made under a specific set of conditions

Welding under disturbed conditions only result in slight loss of joint strength

Shear strengths ranged from 4 to 20 times greater than peel strengths



CONCLUSIONS AND FUTURE WORK

- Material chemistry plays a critical role in weldability of 3rd Gen AHSS
- Galvannealed materials show a lower risk of LME cracking compared to galvanized
- AWS D8.9 can be used to generate reliable welding practices for most stack-ups including 3rd Gen AHSS
- Nugget penetration into thin outer sheets of material presents a significant challenge – resistivity of 3rd Gen AHSS makes this more difficult than in the past
  - Work to understand and mitigate this issue is being done through the Auto Steel Partnership
- There is no clearly defined acceptance criteria for 3rd Gen AHSS
  - Responsibility currently lies with each automotive manufacturer to define and acceptance level
  - Ongoing work across the industry to fully understand the impact of crack length and location on weld strength

FOR MORE INFORMATION

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