GREAT DESIGNS IN STEEL

TWENTY YEARS

EVALUATION OF LME CRACKING SEVERITY IN HOMOGENEOUS & HETEROGENEOUS JOINTS OF 3RD GEN AHSS

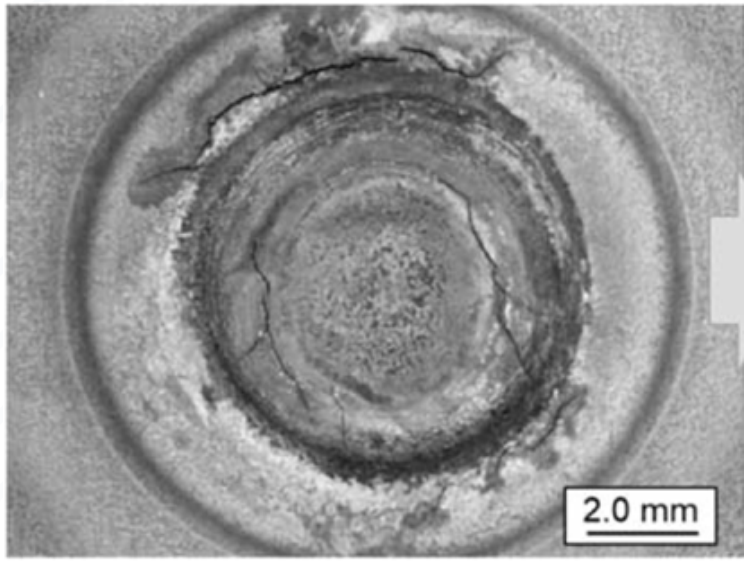
Kevin Teng[1], Warren Peterson[2], Hassan Ghassemi-Armaki[1]

1. General Motors Company
2. United Technical Solutions

On Behalf of Auto/Steel Partnership

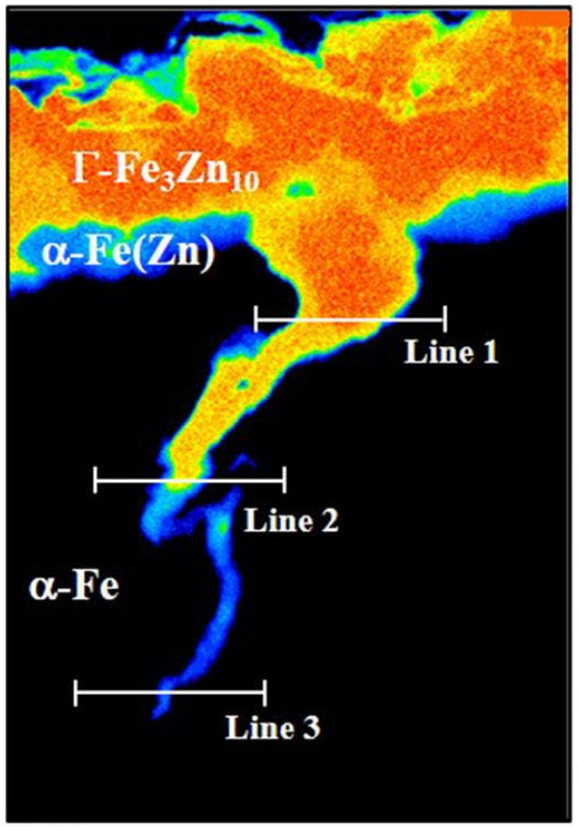
LIQUID METAL EMBRITTLEMENT (LME)

LME Cracks



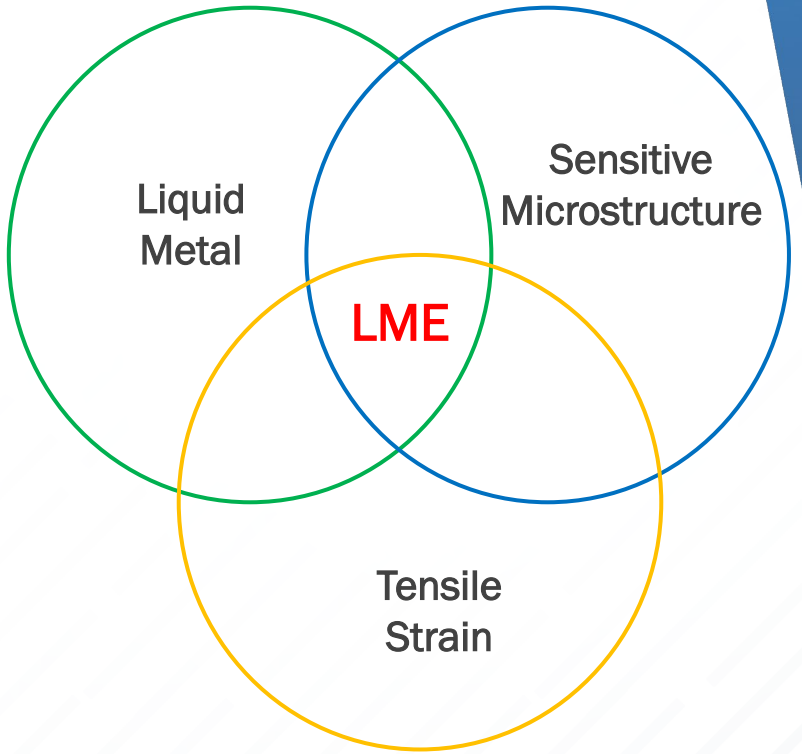
WorldAutoSteel, 2020

Deep zinc penetration into grain boundaries



Kang, Cho, Lee, DeCooman 2016

3 specific enablers



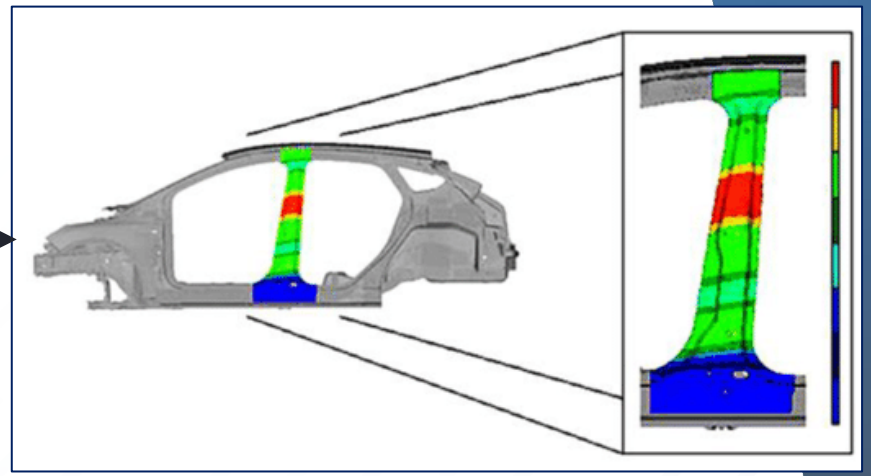
PROJECT GOALS

Develop a test procedure(s) to evaluate LME

- Susceptibility of materials: “Rapid LME Test”
- Cracking severity in production stack-ups
- Acceptance Criteria

Phase	Approach	Stack-Up	Time
1	Gleeble Test	2T Homogeneous	2018-2019
2	Rapid LME Test	2T Homogeneous	2019-2020
3	Weld Lobe LME Test	2T & 3T Heterogeneous	2020-2021
4	LME Acceptance Criteria	TBD	2021-2022

Example Target Application



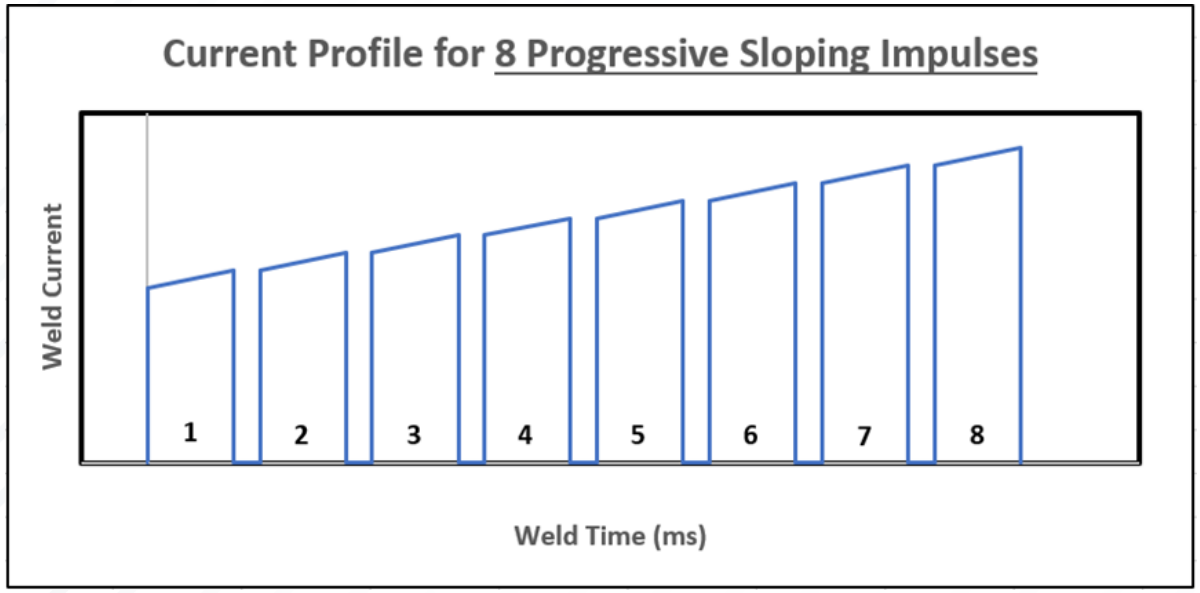
Typical B Pillar Stack-up
Body side outer (0.7 mm mild steel) +
B Pillar Outer (1.6 mm 3rd Gen 980) +
B Pillar Inner (1.6 mm 3rd Gen 980/DP)

PROJECT APPROACH

- Develop a method(s) to evaluate cracking severity of 2T and 3T heterogeneous stack-ups

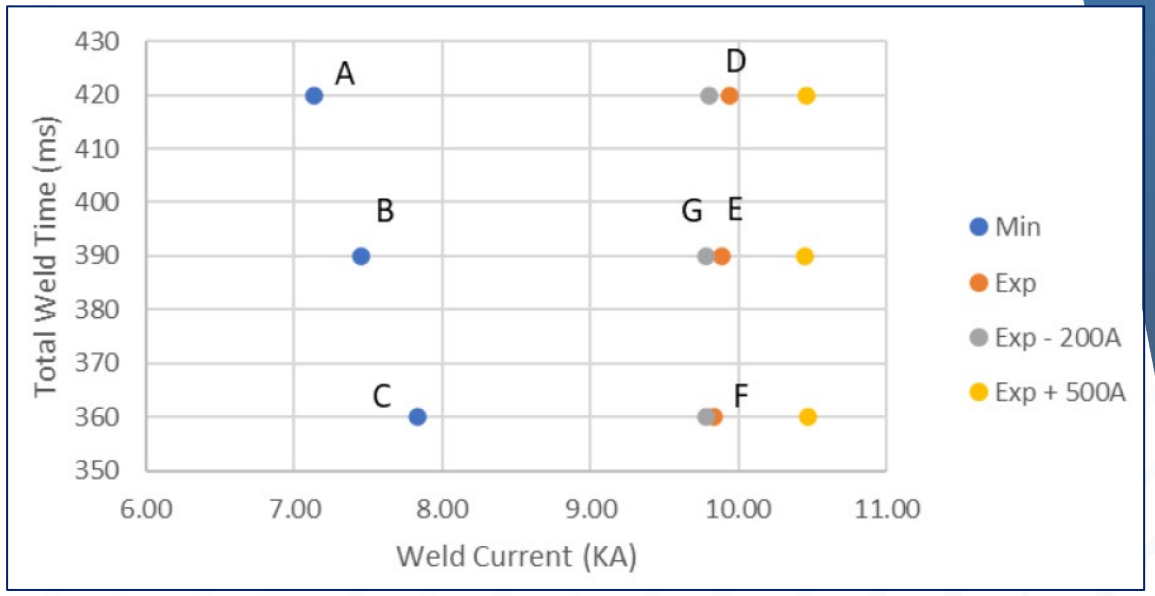
Rapid LME

- Upslope pulsation to increase heat input gradually
- High-heat welding condition



Weld Lobe LME

- Traditional weld schedules
- Production welding conditions



https://www.steel.org/wp-content/uploads/2020/09/20200312-General-Motors-Rapid-LME-Testing-Procedure-for-Automotive-Sheet-Steels-v20.pdf

PROJECT APPROACH: STACK-UPS

Materials

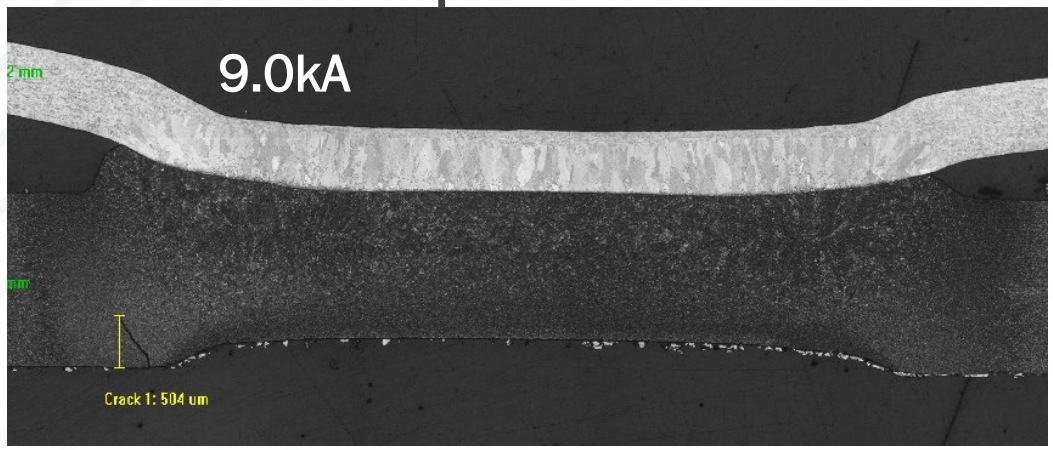
Material #	Material Description	Steel Sample Bank Designation	Thickness	Rapid LME Rating
1	3rd Gen 980 - GI	Lot#168: 1.60 mm CR600Y980T-RA-SE-GI	1.6 mm	-1.0B
2	3rd Gen 980 – GI	Lot#203: 1.00 mm CR600Y980T-RA-xx-GI	1.0 mm	3.0D
3	3rd Gen 980 - GI	Lot#134: 1.6 mm CR600Y980T-RA-GI	1.6 mm	1.5D
4	3rd Gen 1180 - GI	Lot#166: 1.00 mm CR1000Y1180T-RA-SE-GI	1.0 mm	-4.0D
5	CR4 - GI	Lot#221: 0.70 mm CR4 GI 60G60G	0.7 mm	

Stack-Ups

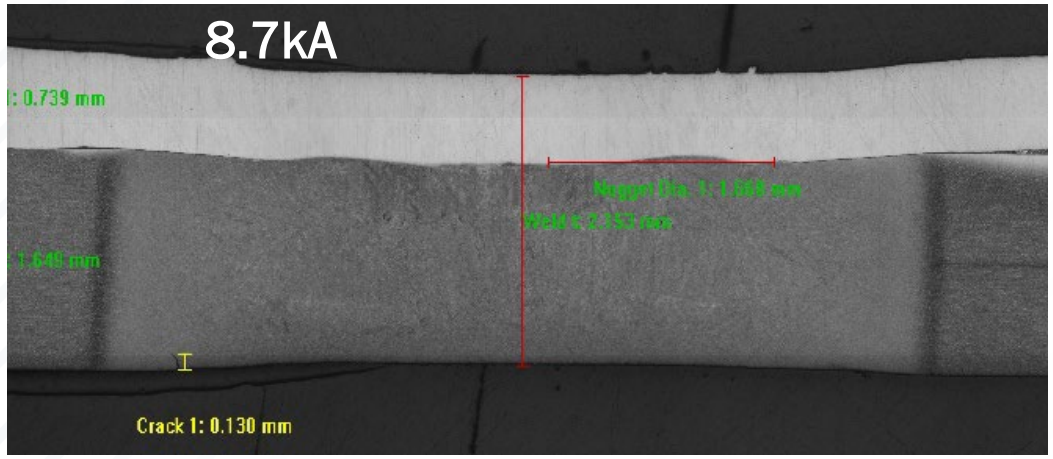
Stack-Up #	Sheet 1	Sheet 2	Sheet 3	
1	Lot#168: 1.6 mm 3rd Gen 980 - GI	Lot#168: 1.6 mm 3rd Gen 980 - GI		2T Homogeneous Lab Capability Repeatability
2	Lot#203: 1.0 mm 3rd Gen 980 - GI	Lot#203: 1.0 mm 3rd Gen 980 - GI		
3	Lot#134: 1.6 mm 3rd Gen 980 - GI	Lot#134: 1.6 mm 3rd Gen 980 - GI		
4	Lot#166: 1.0 mm 3rd Gen 1180 – GI	Lot#166: 1.0 mm 3rd Gen 1180 – GI		
5	Lot#168: 1.6 mm 3rd Gen 980 – GI	Lot#221: 0.70 mm CR4 GI		2T Heterogeneous
6	Lot#203: 1.0 mm 3rd Gen 980 – GI	Lot#221: 0.70 mm CR4 GI		
~~7~~	~~Lot#134: 1.6 mm 3rd Gen 980 – GI~~	~~Lot#221: 0.70 mm CR4 GI~~		
8	Lot#166: 1.0 mm 3rd Gen 1180 – GI	Lot#221: 0.70 mm CR4 GI		
~~9~~	~~Lot#168: 1.6 mm 3rd Gen 980 – GI~~	~~Lot#168: 1.6 mm 3rd Gen 980 - GI~~	~~Lot#221: 0.70 mm CR4 GI~~	3T Heterogeneous
10	Lot#203: 1.0 mm 3rd Gen 980 – GI	Lot#203: 1.0 mm 3rd Gen 980 - GI	Lot#221: 0.70 mm CR4 GI	
~~11~~	~~Lot#134: 1.6 mm 3rd Gen 980 - GI~~	~~Lot#134: 1.6 mm 3rd Gen 980 - GI~~	~~Lot#221: 0.70 mm CR4 GI~~	
12	Lot#166: 1.0 mm 3rd Gen 1180 – GI	Lot#166: 1.0 mm 3rd Gen 1180 – GI	Lot#221: 0.70 mm CR4 GI	

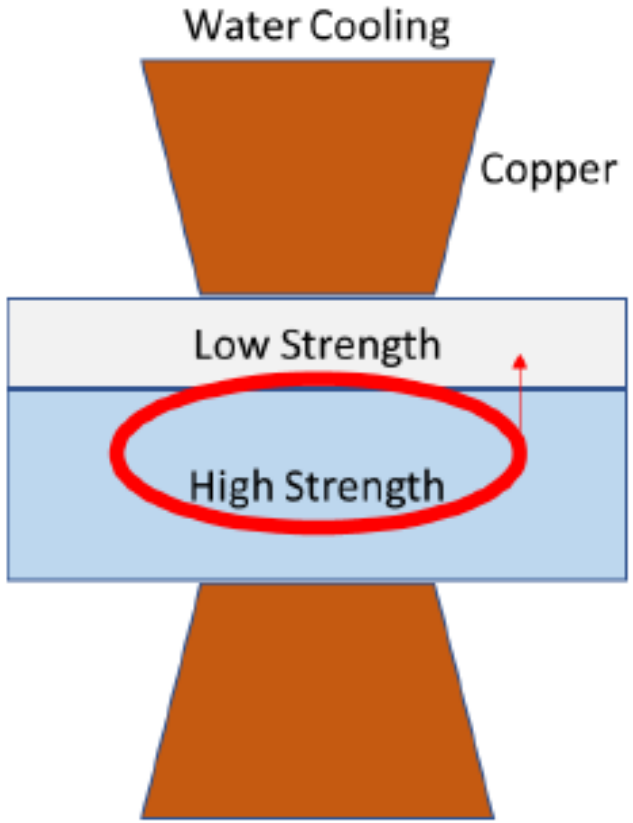
CHALLENGE: LOW WELD PENETRATION

Rapid LME



Weld Lobe





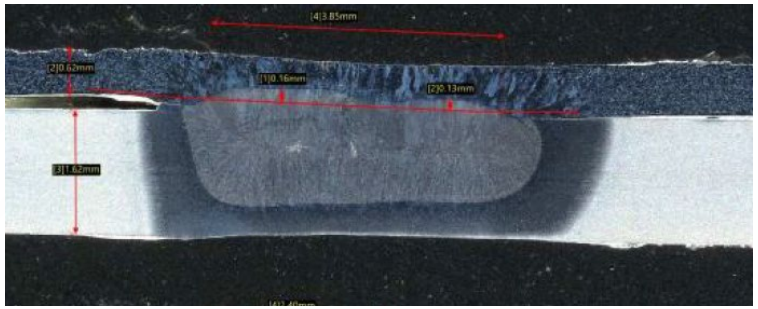
Heat Balance:

- Electrode Face
- Electrode Chemistry
- Polarity
- Weld Time
- Weld Force

Insufficient weld penetration into the thin mild steel material (discrepant weld)

DOE: WELD PENETRATION

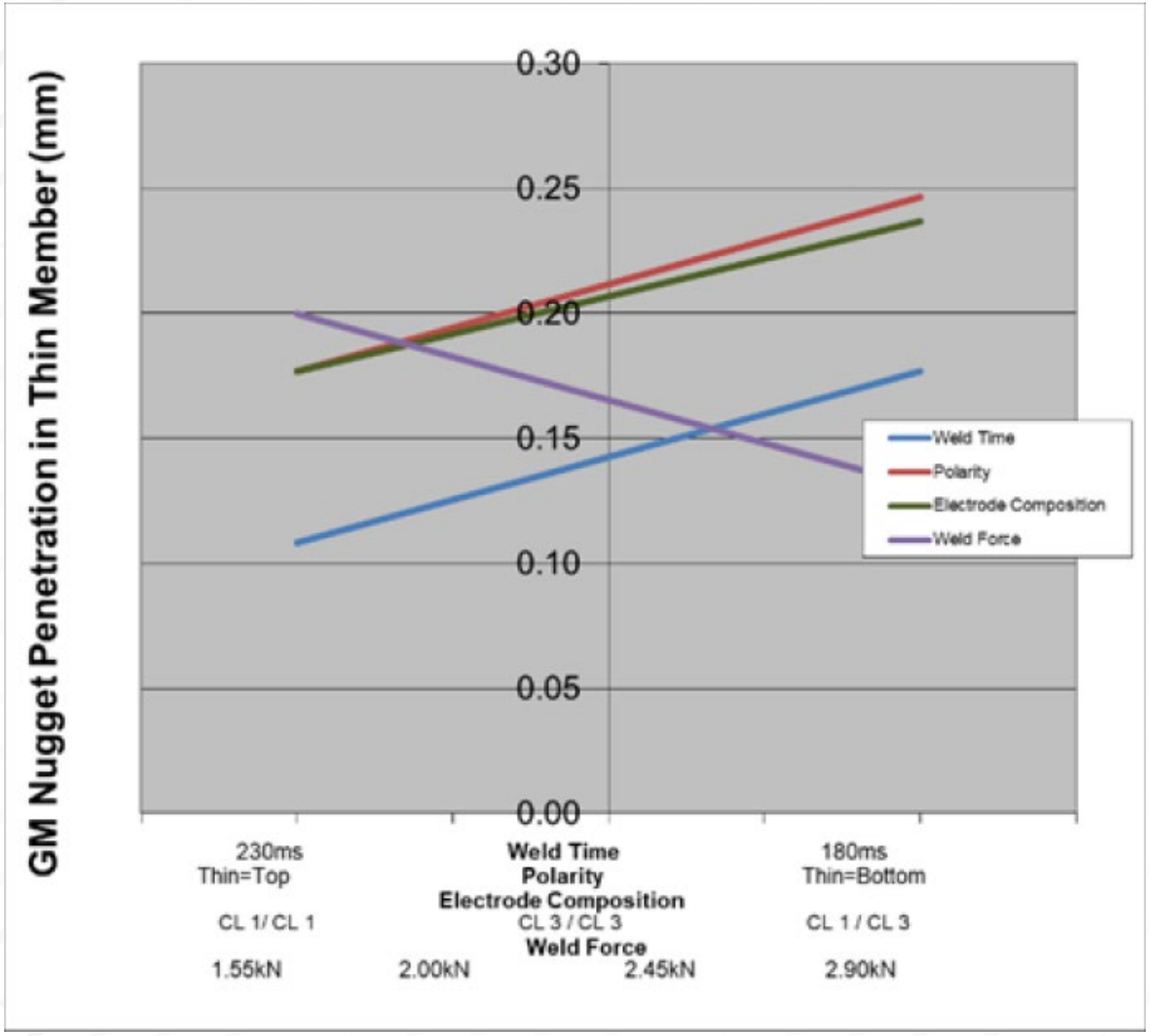
Factor	Levels
Weld Time	2
Polarity	2
Electrode Composition	4
Weld Force	4



Run	Weld Time (ms)	Polarity (+:thin on top)	Electrode Composition (Top/Bottom)	Weld Force (kN)	Nugget Pentration (mm)
1	230	Positive	Class 1/Class 1	1.55	0.05
2	230	Positive	Class 3/Class 3	1.55	0.413
3	230	Positive	Class 3/Class 3	2.45	0.296
4	230	Negative	Class 1/Class 1	2.00	0.212
5	230	Negative	Class 1/Class 1	2.90	0.254
6	230	Negative	Class 3/Class 3	2.90	0.039
7	180	Positive	Class 3/Class 3	1.55	0.154
8	180	Positive	Class 3/Class 3	2.45	0.346
9	180	Positive	Class 1/Class 3	2.45	0.329
10	180	Negative	Class 3/Class 3	2.00	0.501
11	180	Negative	Class 1/Class 3	2.00	0.358
12	180	Negative	Class 1/Class 3	2.90	0.358
13	180	Positive	Class 1/Class 3	1.55	0.212

Identify optimal weld conditions to improve weld penetration

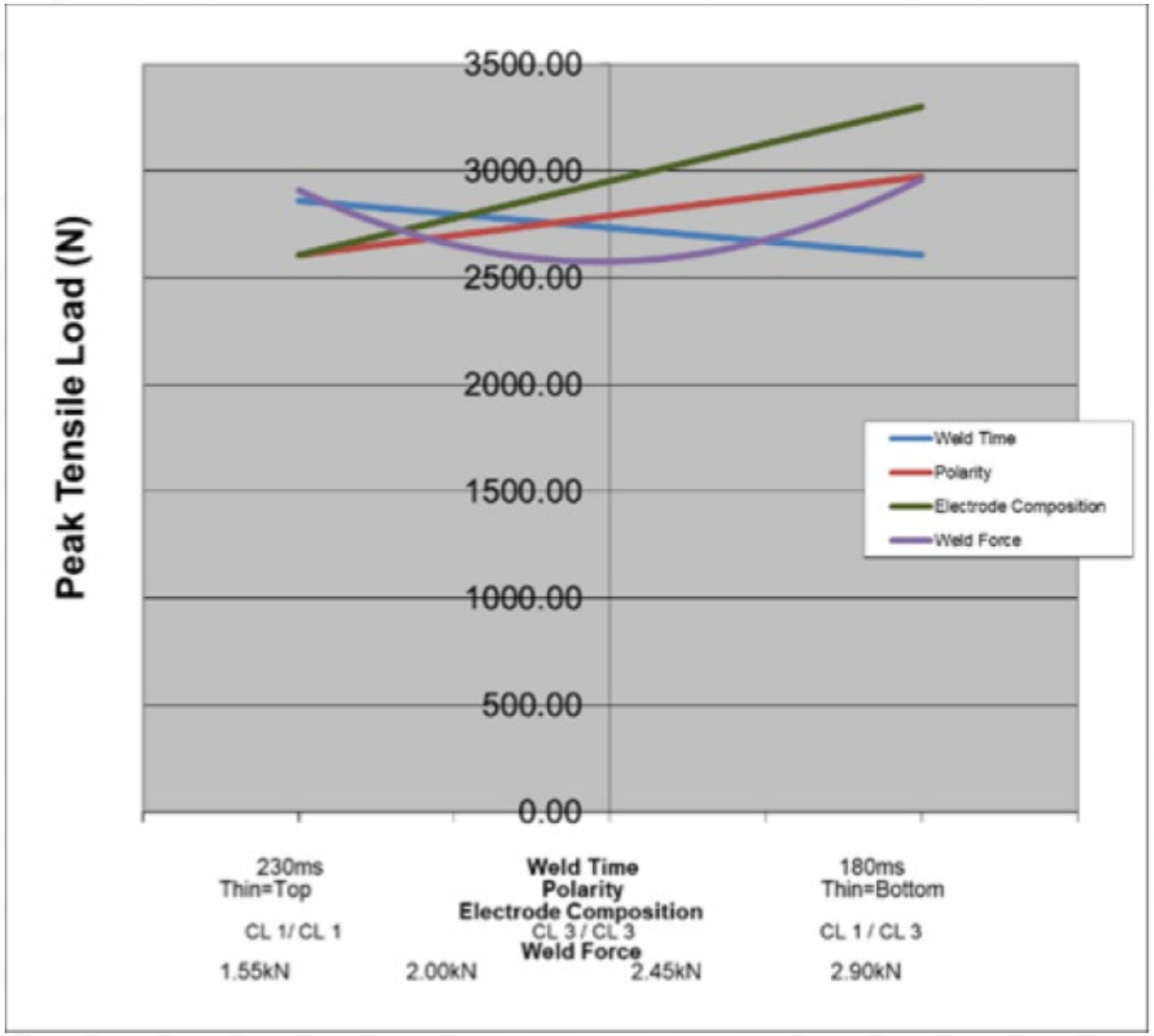
ROBUSTNESS PLOT: WELD PENETRATION



Increase Penetration:

- Weld Time: Low
- Weld Force: High
- Polarity: Thin on Positive
- Electrode: C1/C3 Combo

ROBUSTNESS PLOT: SHEAR TENSION PEAK LOAD



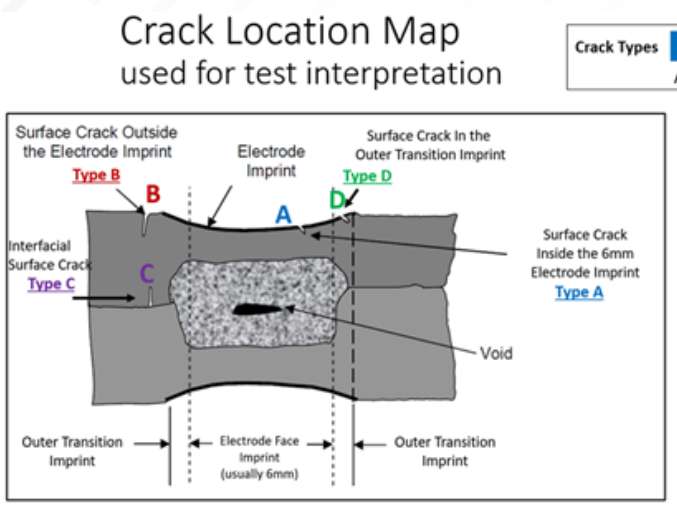
Increase Peak Load:

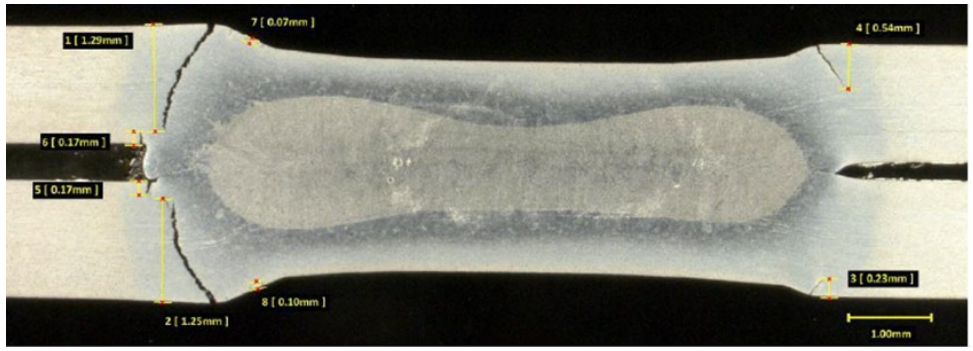
- Weld Time: No effect
- Weld Force: High
- Polarity: No effect
- Electrode: C1/C3 Combo

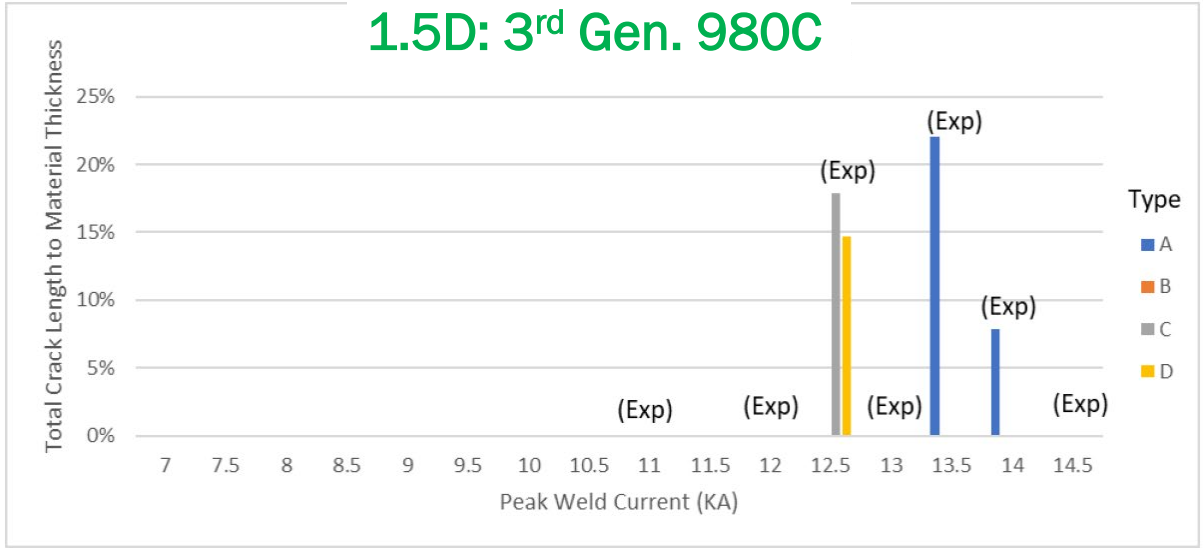
- Successfully identified weld conditions to improve weld penetration

- But not able to be confidently applied to all potential stack-ups

HOW TO INTERPRET DATA?







RAPID LME: CRACK INDEX

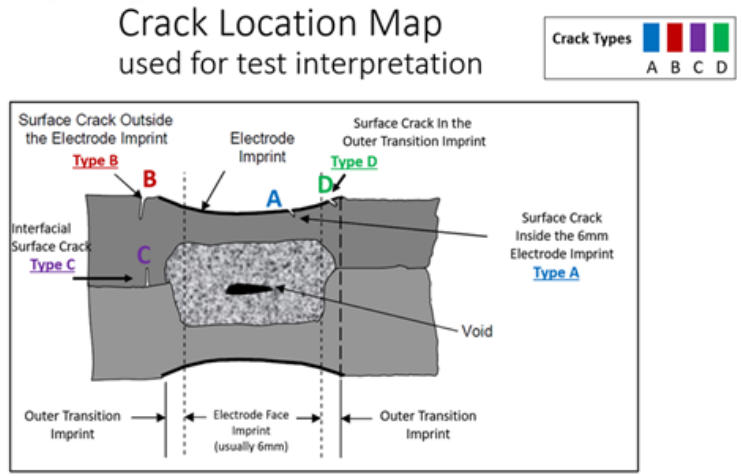
Stack-Up	Maximum Crack (Total, mm)	Maximum Crack (Excluding Type A, mm)	Crack Index (Total)	Crack Index (Excluding Type A)
1.0mm 3rd Gen 980 + 1.0mm 3rd Gen980	0.59	0.20	0.093	0.013
1.0mm 3rd Gen 980 + 0.7mm CR4	0.77	0.77	0.119	0.064
1.0mm 3rd Gen 980 + 1.0mm 3rd Gen980 + 0.7mm CR4	0.53	0.53	0.253	0.123
1.0mm 3rd Gen 1180 + 1.0mm 3rd Gen 1180	0.96	0.94	1.858	1.655
1.0mm 3rd Gen 1180 + 0.7mm CR4	0.65	0.65	0.480	0.266
1.0mm 3rd Gen1180 + 1.0mm 3rd Gen 1180 + 0.7mm CR4	1.60	1.60	0.857	0.669

$$Crack\ Index = \frac{nL}{Nt}$$

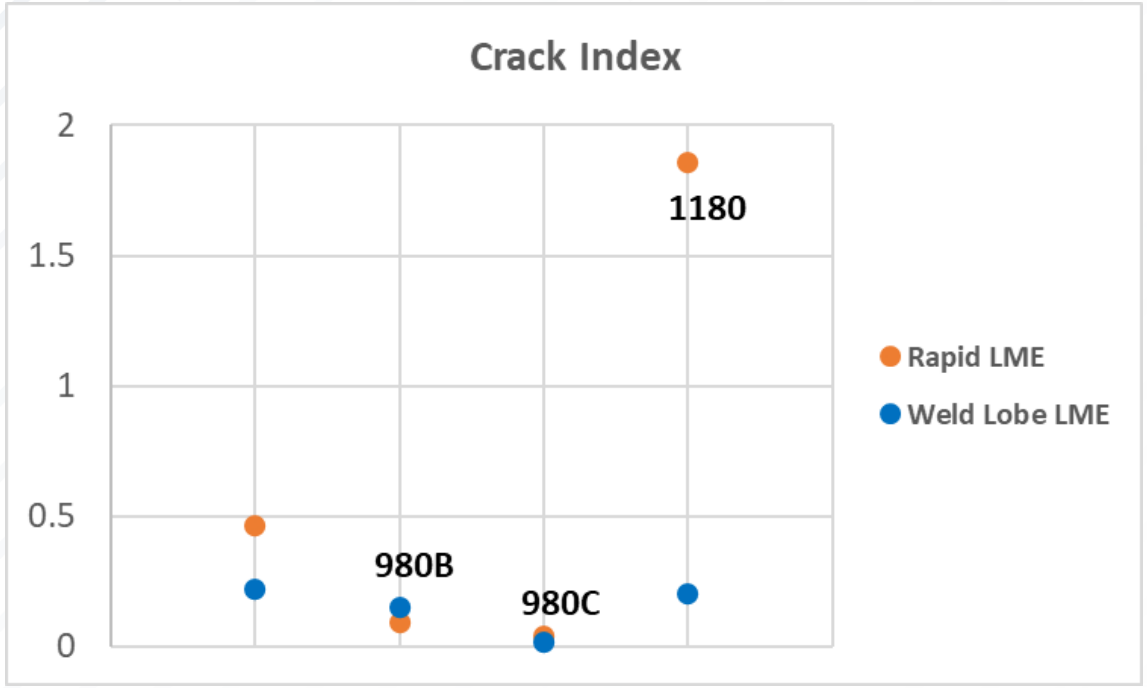
n: number of cracks,
L: average crack length
N: number of examined cross-sections
t: material thickness

E. Winjtes et al. Welding in the World, 2019

Crack Location Map
used for test interpretation

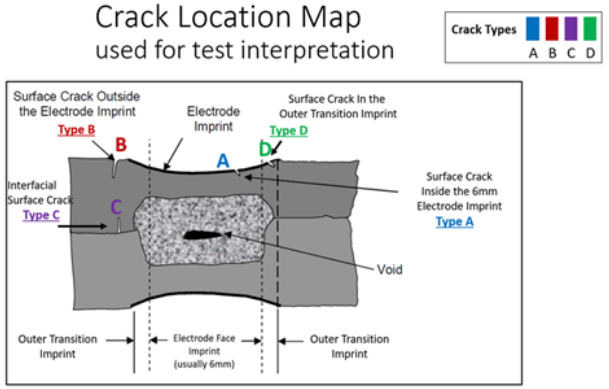


LME SUSCEPTIBILITY RATING

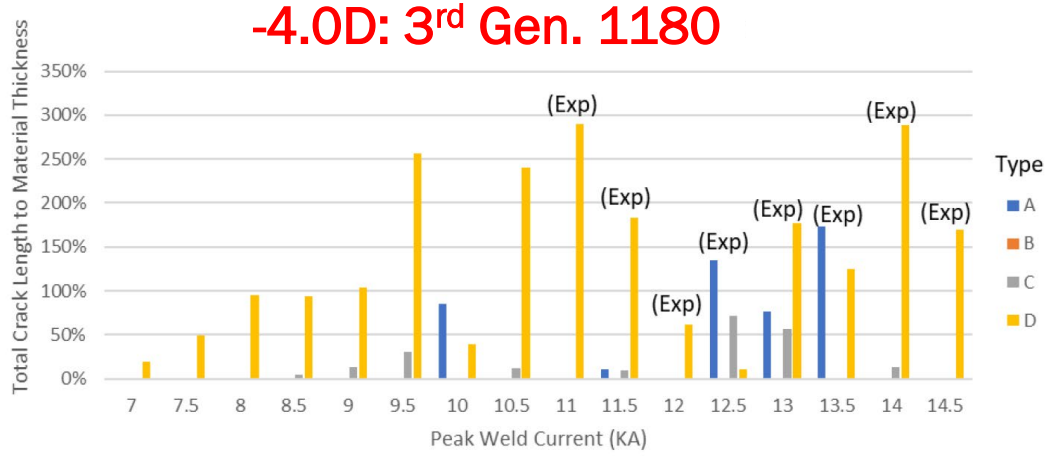


Rapid LME is very effective in rating LME susceptibility

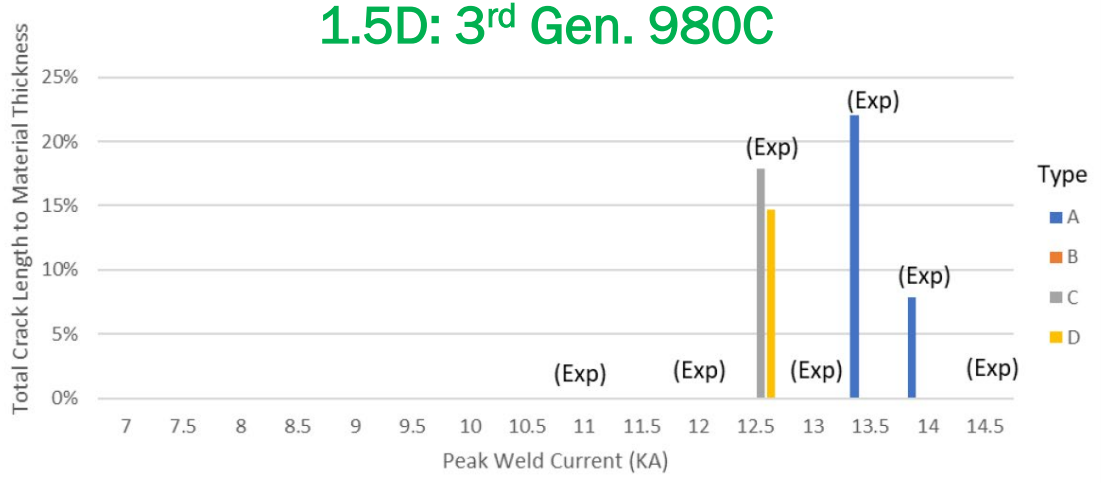
Crack Location Map
used for test interpretation



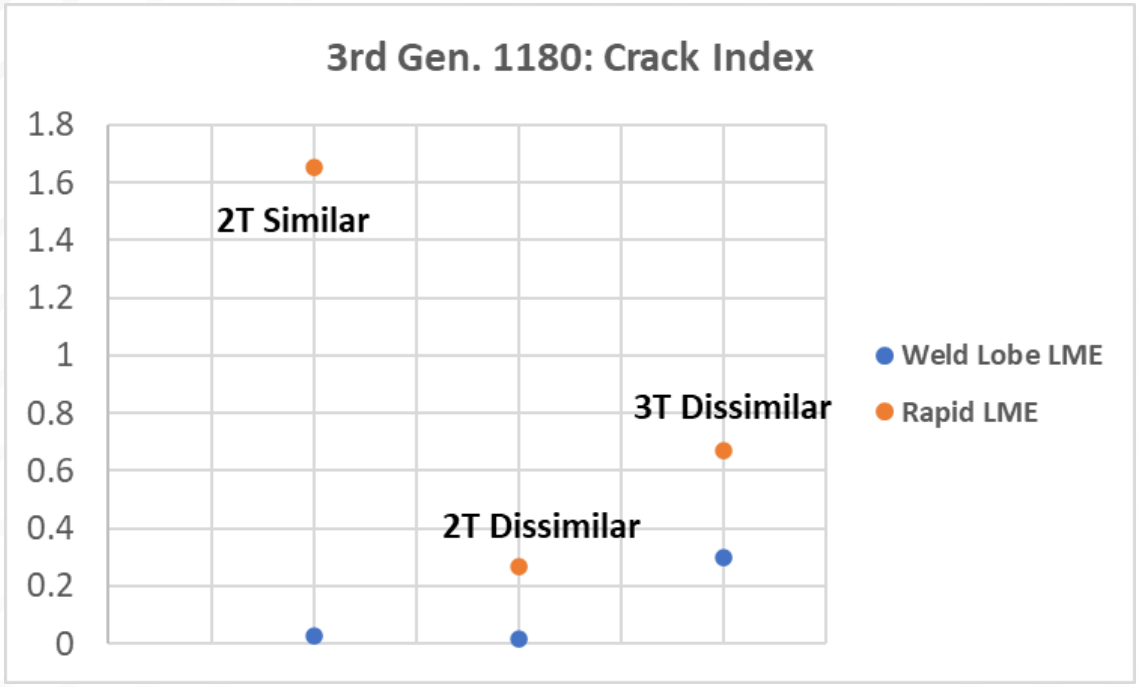
-4.0D: 3rd Gen. 1180

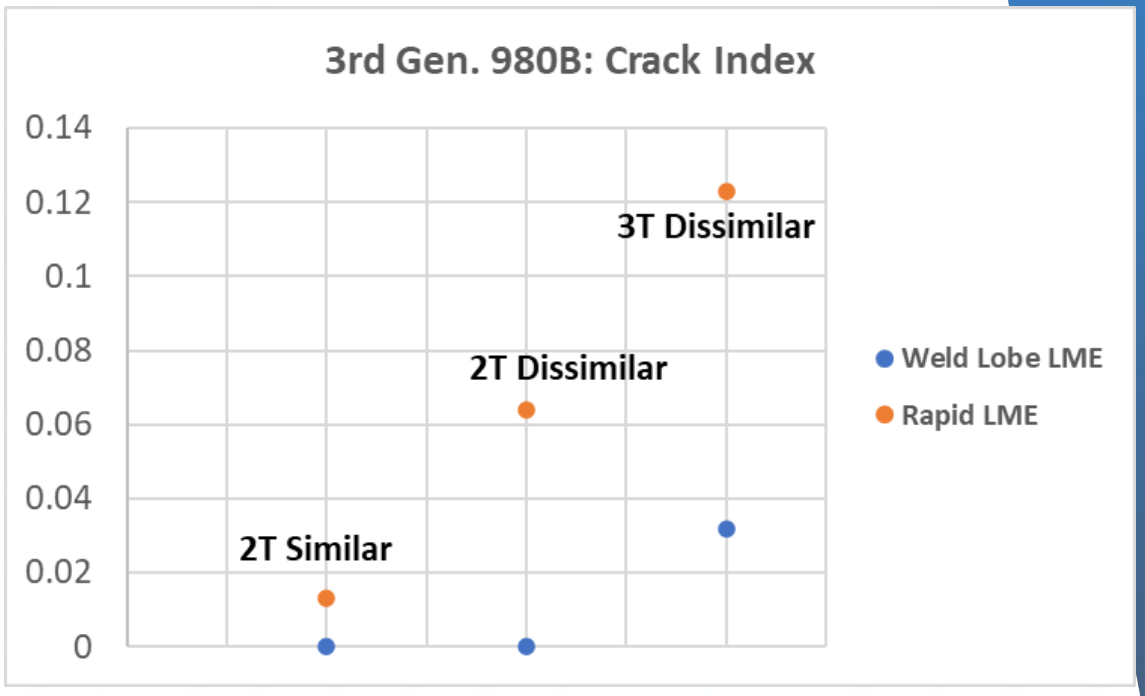


1.5D: 3rd Gen. 980C



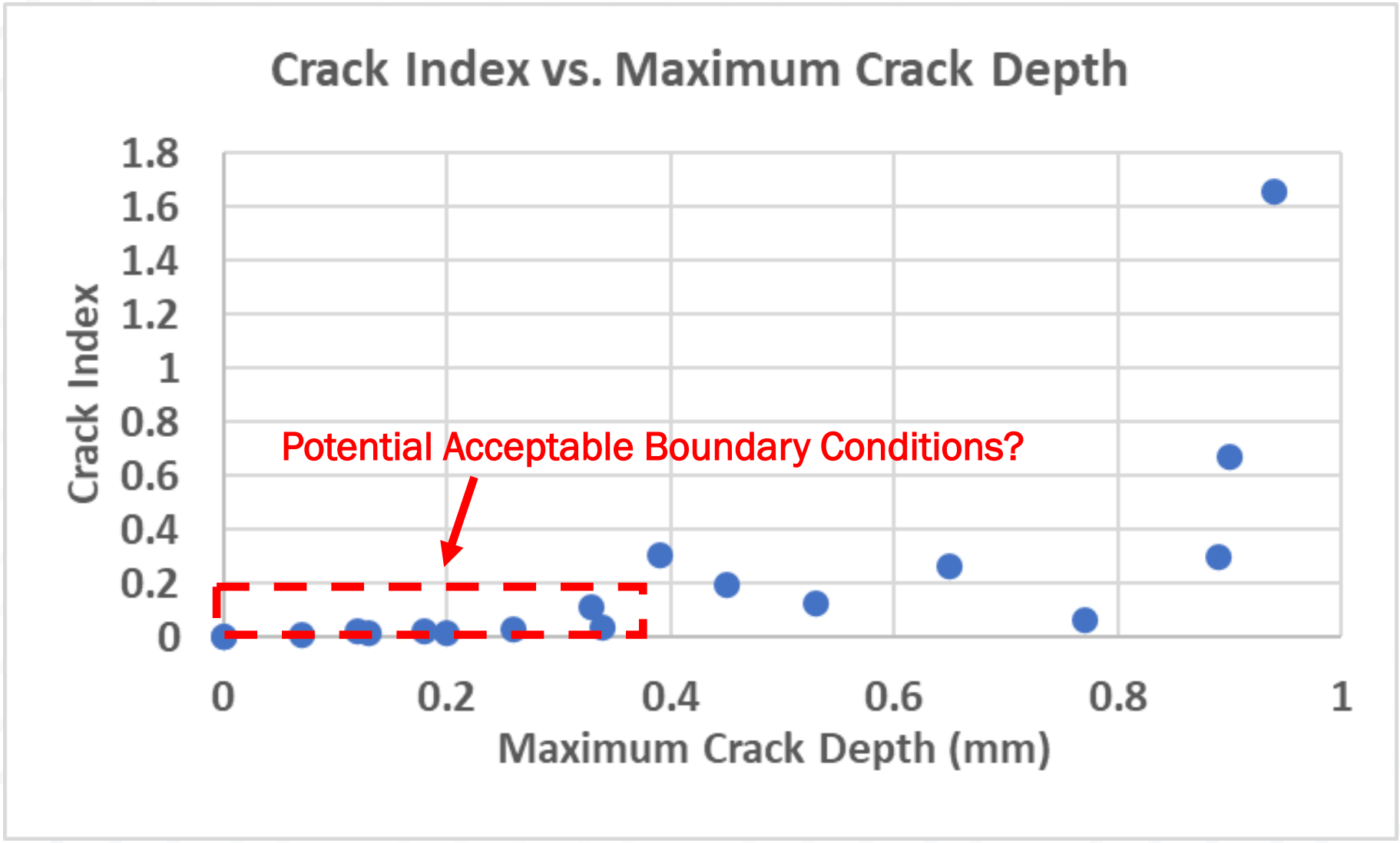
HETEROGENEOUS STACK-UPS





- Rapid LME also effectively differentiate the cracking severity in dissimilar stack-ups
- Limitation: schedule not designed for heterogeneous stack-ups; low weld penetration
- The Weld Lobe LME Test is better suited for assessing the potential for LME cracking in complex multi-thickness stack-ups

CRACK INDEX VS. MAXIMUM CRACK DEPTH



SUMMARY

- **The Rapid LME Test is best for assessing LME susceptibility of AHSS**
  - ❖ Quickest, most reliable, and least expensive means for LME susceptibility
  - ❖ Grades found susceptible also performed poorly in the Weld Lobe Test
  - ❖ Limitations: weld schedules are not designed for heterogeneous stack-ups, low weld penetration issue

- **The Weld Lobe LME Test is better suited for assessing the potential for LME cracking in complex multi-thickness automotive spot welded joints**

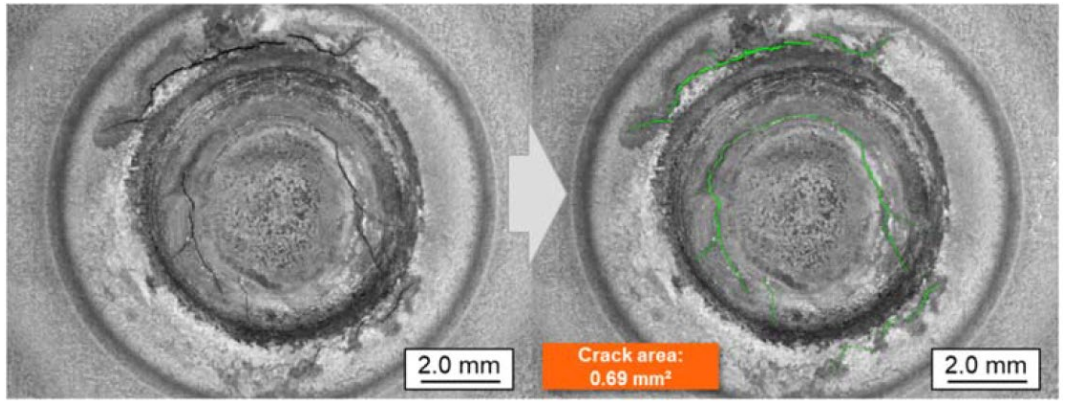
- **Crack index is effective to quantitatively characterize the cracking severity in both homogeneous and heterogenous stack-ups**

- **Future work will focus on methodology development for LME characterization to establish recommended acceptance criteria**

FUTURE WORK: CRACK ACCEPTANCE CRITERIA

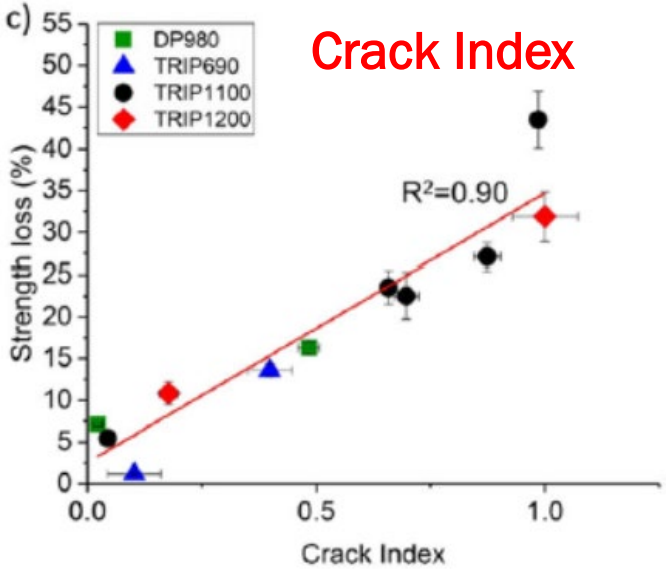
- Maximum crack depth?
- Percentage of materials thickness?
- Cracking area?
- Number of cracks?
- Crack index?
- Types of cracks?
- NDT?

Crack Area



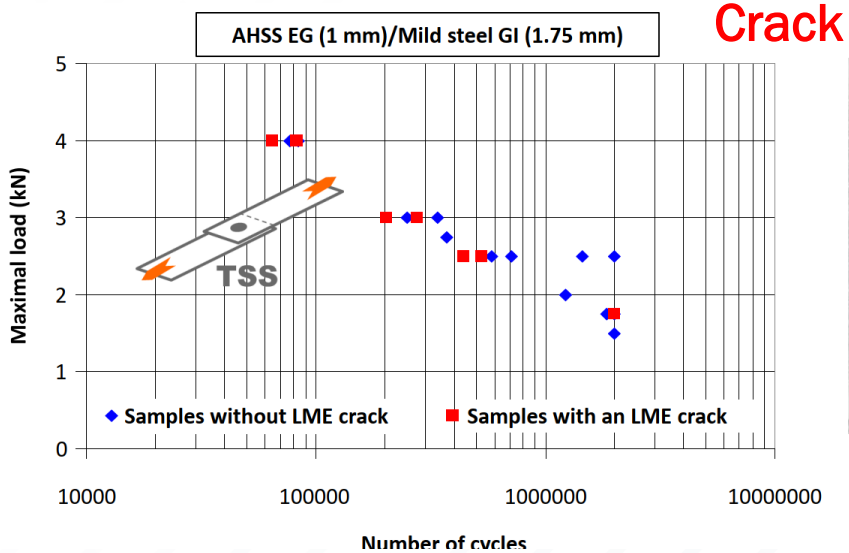
WorldAutoSteel, 2020

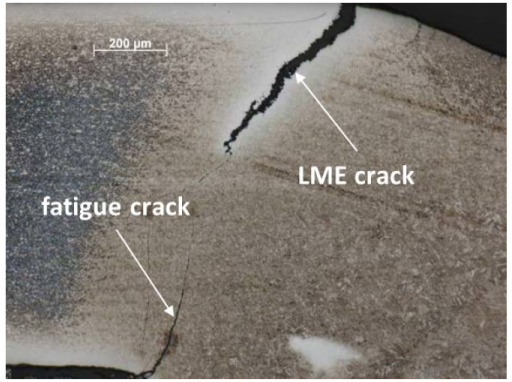
Crack Index



C. DiGiovanni, Welding in the World, 2020

Crack Depth





ArcelorMittal, IABC 2017

FOR MORE INFORMATION

Kevin Teng

Project Lead

General Motors Company

Zhenke.Teng@gm.com

Eric McCarty

Project Manager

Auto/Steel Partnership

emccarty@steel.org

More Questions? Meet Kevin at the Auto/Steel Partnership booth after this presentation.

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