GREAT DESIGNS IN STEEL

EFFECT OF LME CRACKING ON MECHANICAL PROPERTIES OF GEN3 STEEL SPOT WELDS

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Dr. Zhenke Teng and Dr. Ying Lu, *General Motors Global ME Body Welding*

Presentation outline

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- Introduction
- Approaches
  - Spot welding of GEN3 AHSS
  - Mapping cracks
  - Modeling cracks
- Results on weld strengths
- Summary and conclusions

Back in 2022…

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GREAT DESIGNS IN STEEL
TWENTY YEARS

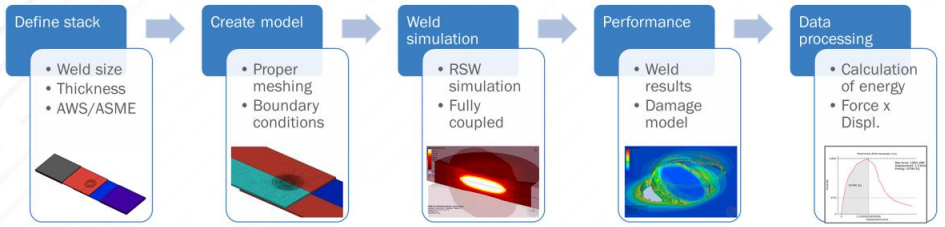
INTEGRATED PROCESS & PERFORMANCE MODELS FOR RSW OF 1ST & 3RD GEN STEELS

Fernando Okigami, and Wei Zhang, *The Ohio State University*
Hassan Ghassemi-Armaki, *General Motors R&D*
Zhenke Teng, *General Motors Global Manufacturing Engineering*

Integrated process-performance models

PROCESS & PERFORMANCE MODEL

20 YEARS GDIS



Process model:
- Coupled electro-thermo-mechanical finite element simulation
- Advanced contact formulation that detects fusion bonding and changes contact to glue

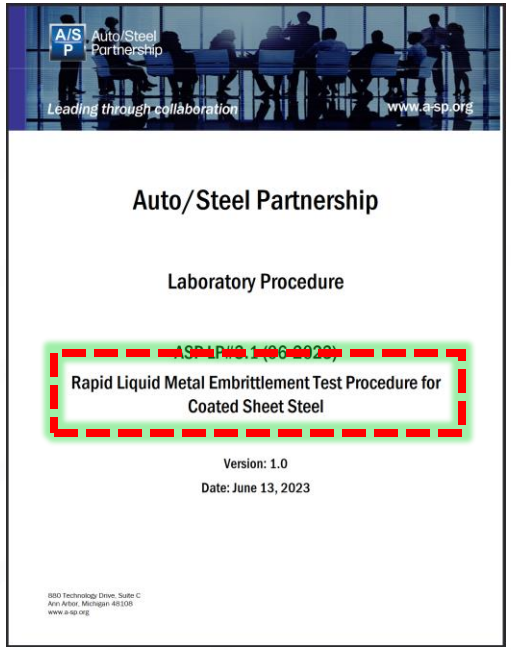
Performance model: mechanical simulation with failure

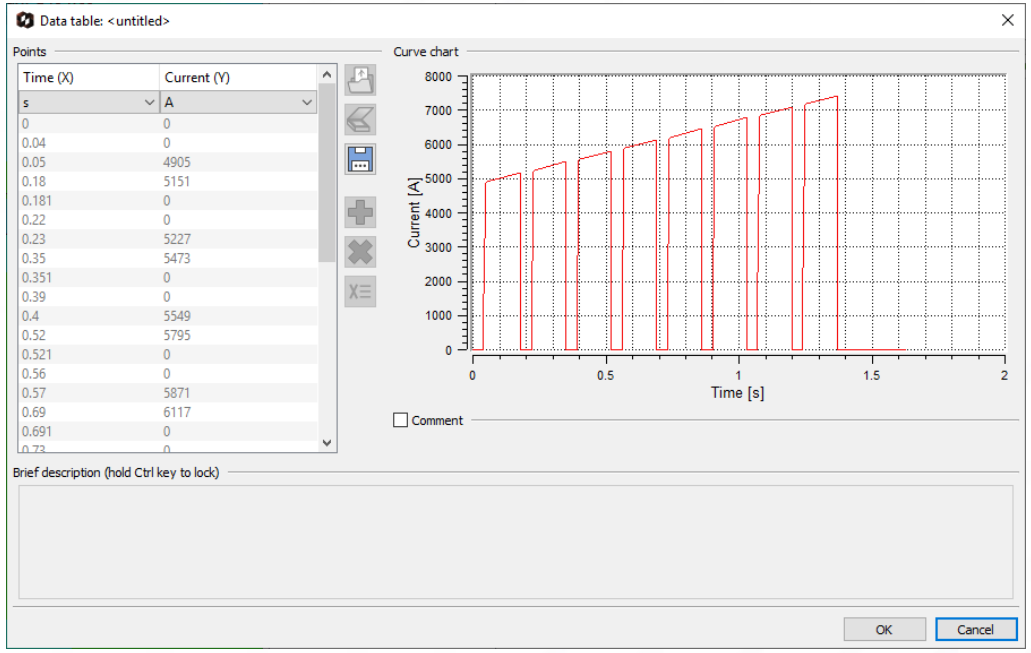
Same mesh and **glued connection** to facilitate automated integration of process and performance models

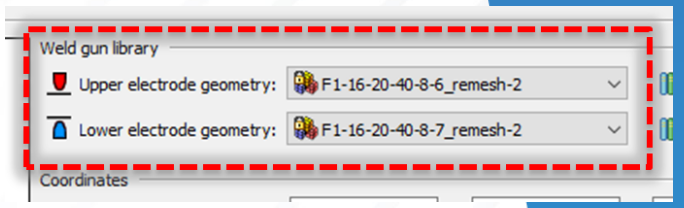
Predicting important aspects like:
- Temperature field
- 3D sample shape
- Indentation
- Notch shape
- Nugget size
- Microstructure
- Residual stress
- Plastic strain

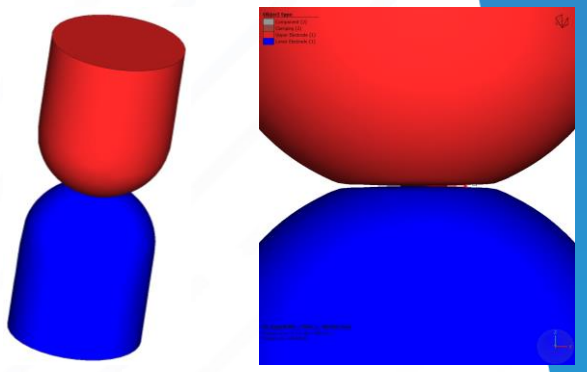
4

Experimentally generating LME cracks

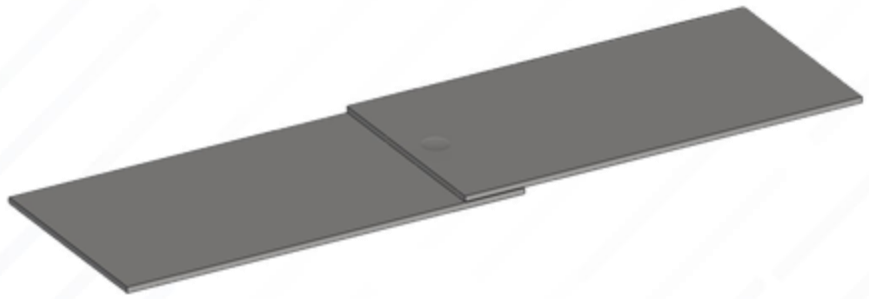




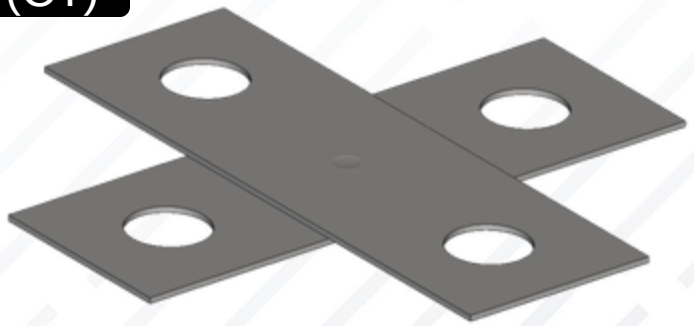




Lap Shear (LS)

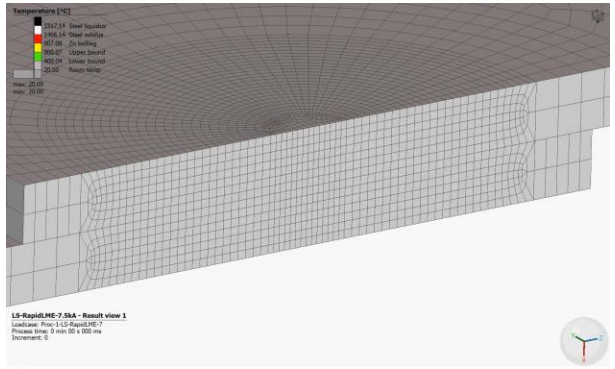


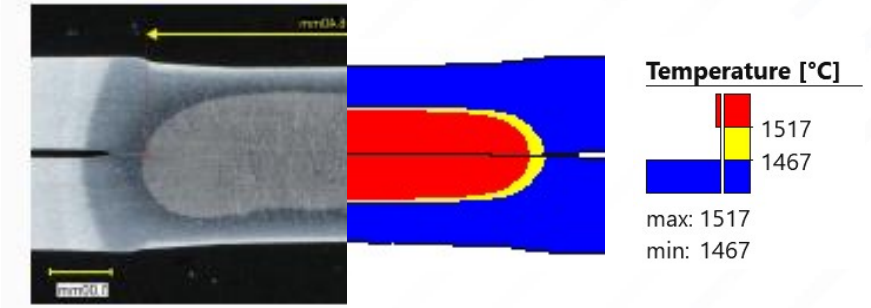
Cross Tension (CT)



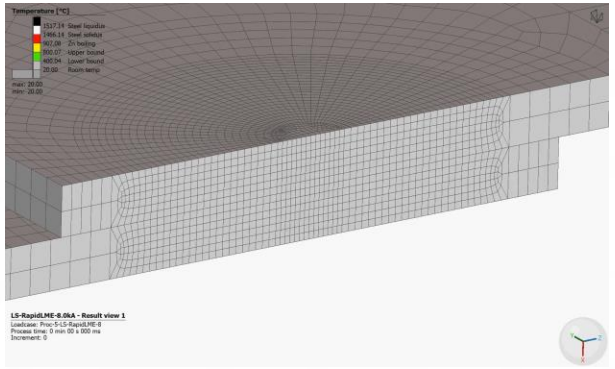
Spot welding simulation

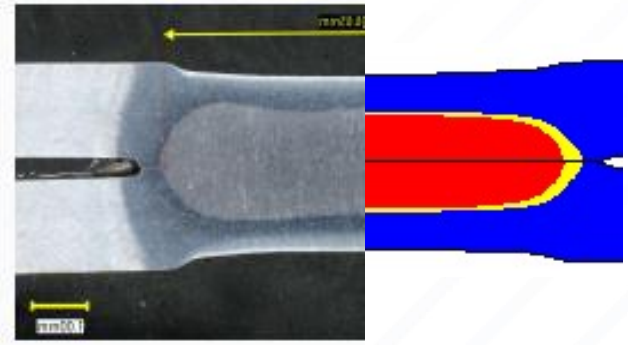
7.5kA



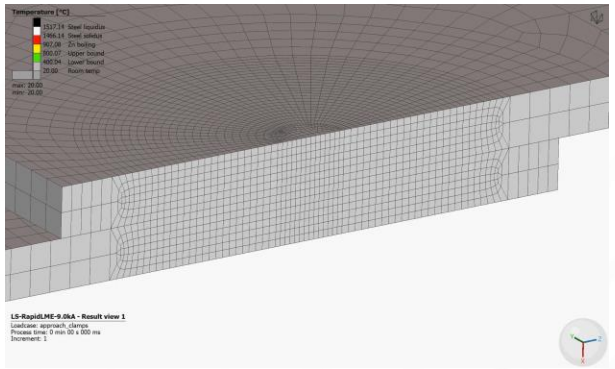


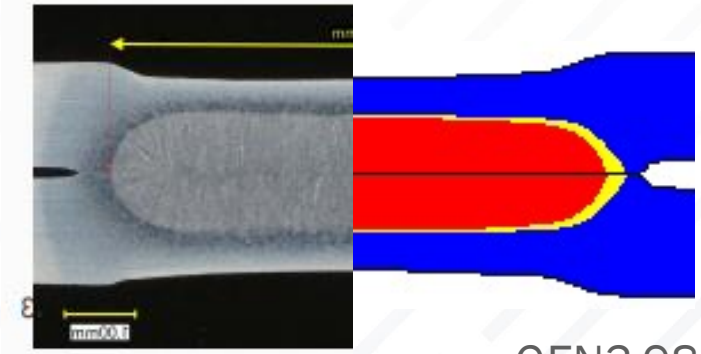
8.0kA





9.0kA





GEN3 980 without coating

Experimentally identifying LME cracks

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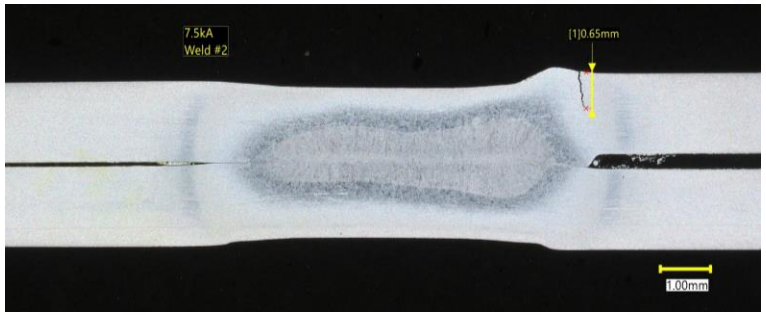
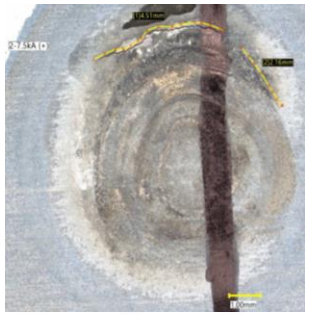
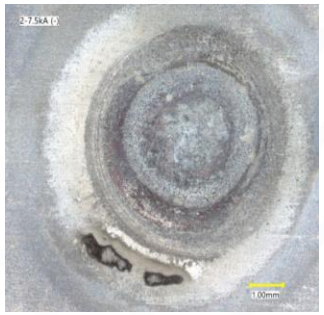
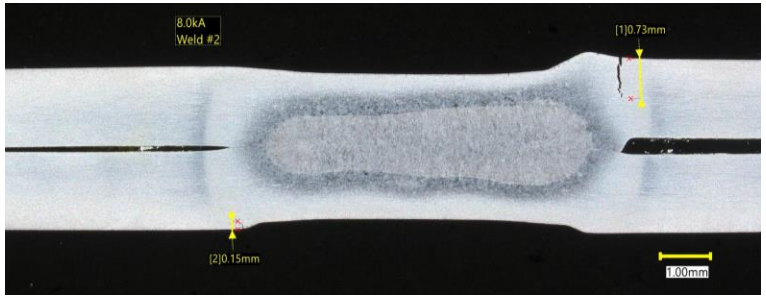
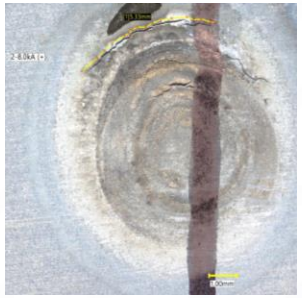
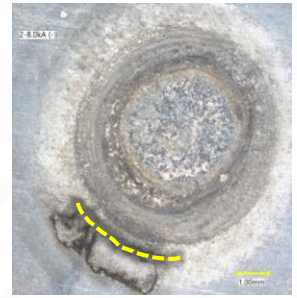
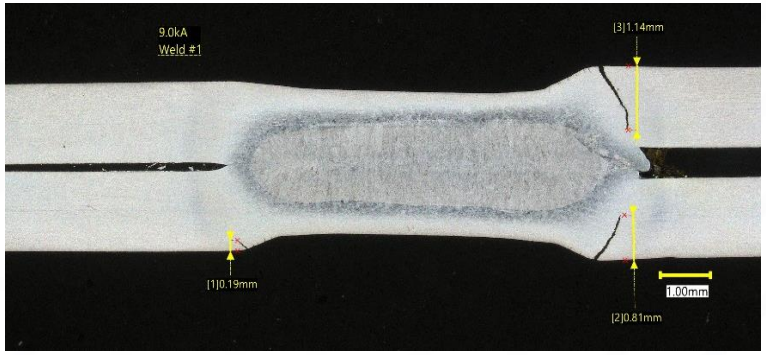
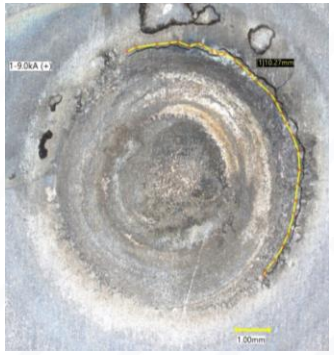
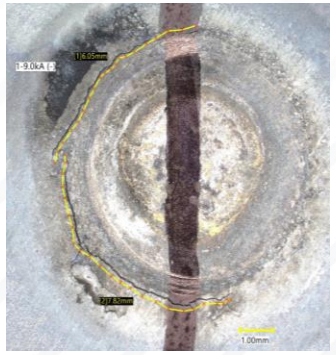
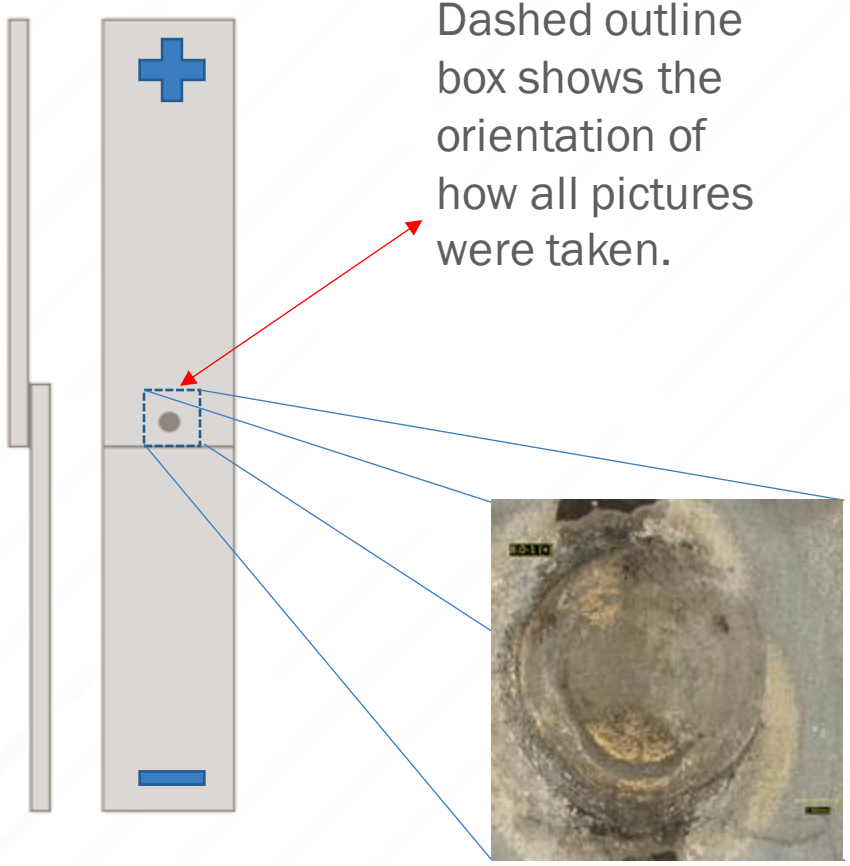
		Top sheet	Bottom sheet
7.5kA			
8.0kA			
9.0kA			

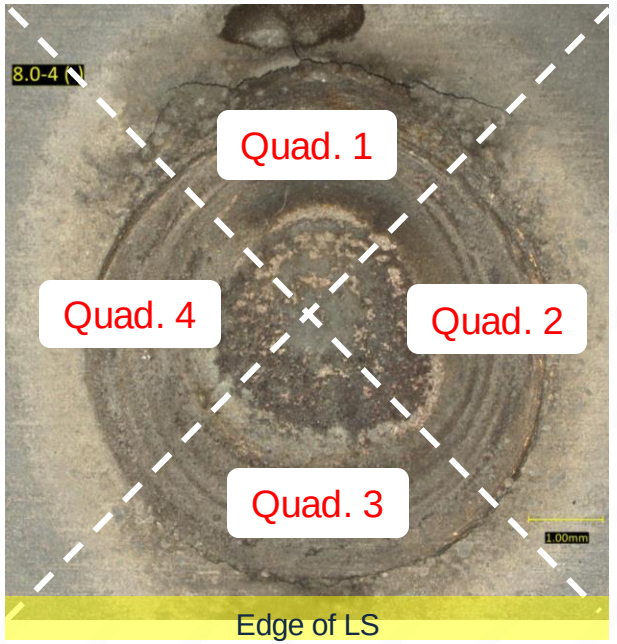
What are typical crack depths and lengths?

Experimentally determining spatial distribution of LME cracks

Lap Shear Weld Sample



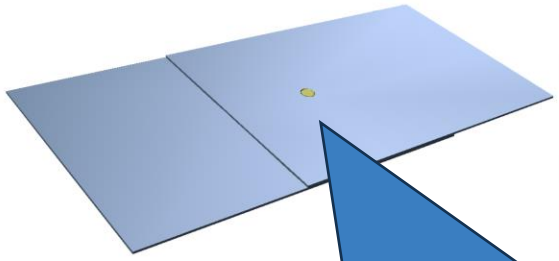
Dashed outline box shows the orientation of how all pictures were taken.



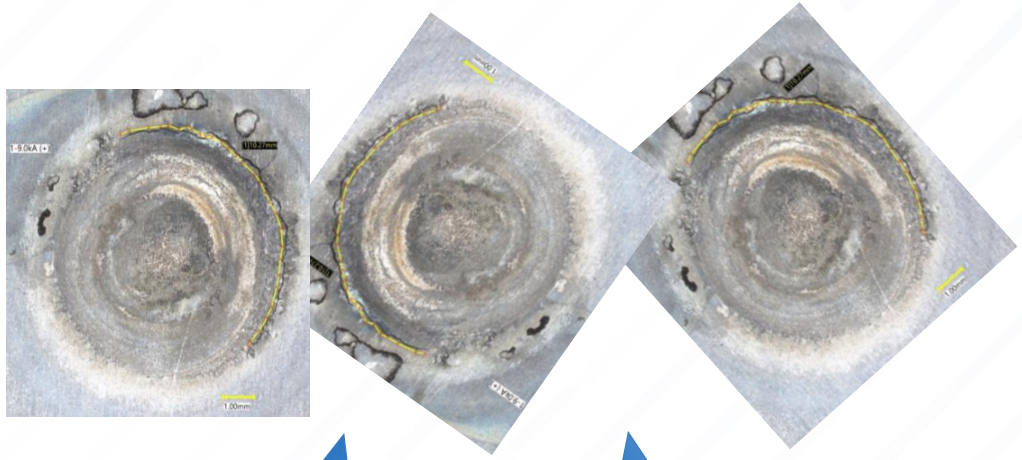
	Number of Crack Occurrences on Positive Side	Number of Crack Occurrences on Negative Side
Quad. 1	5	6
Quad. 2	1	2
Quad. 3	6	4
Quad. 4	0	0
Toatl number of Cracks from 5 welds	12	12

What locations are more prone to cracking in a lap-shear configuration?

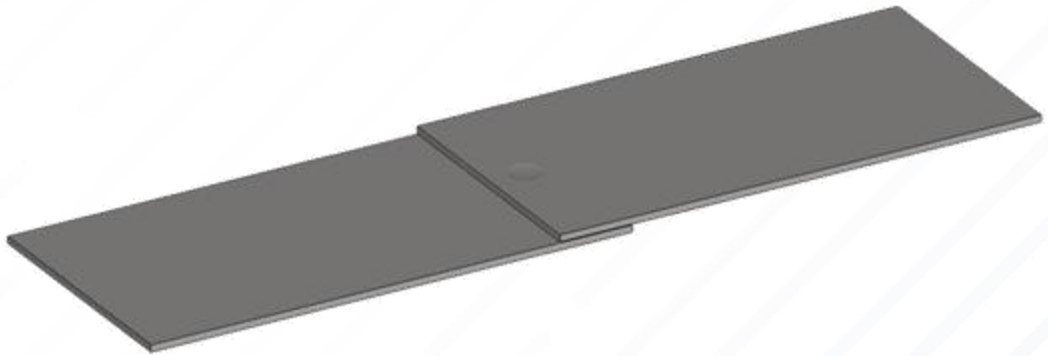
Mapping cracks in the model

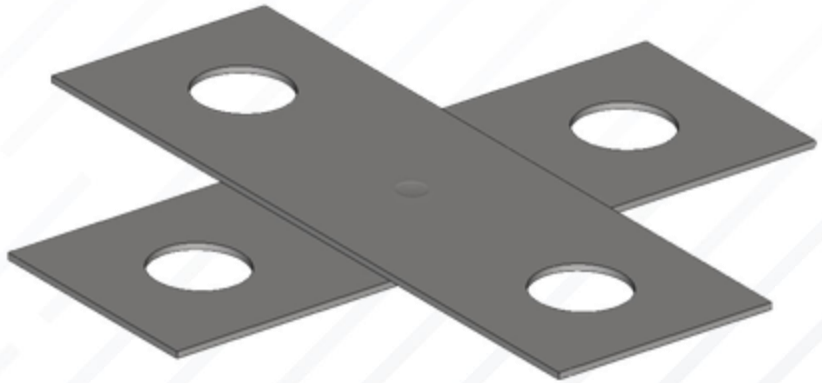


Stack-up for LME crack measurement
(not the same as LS and CT)



?

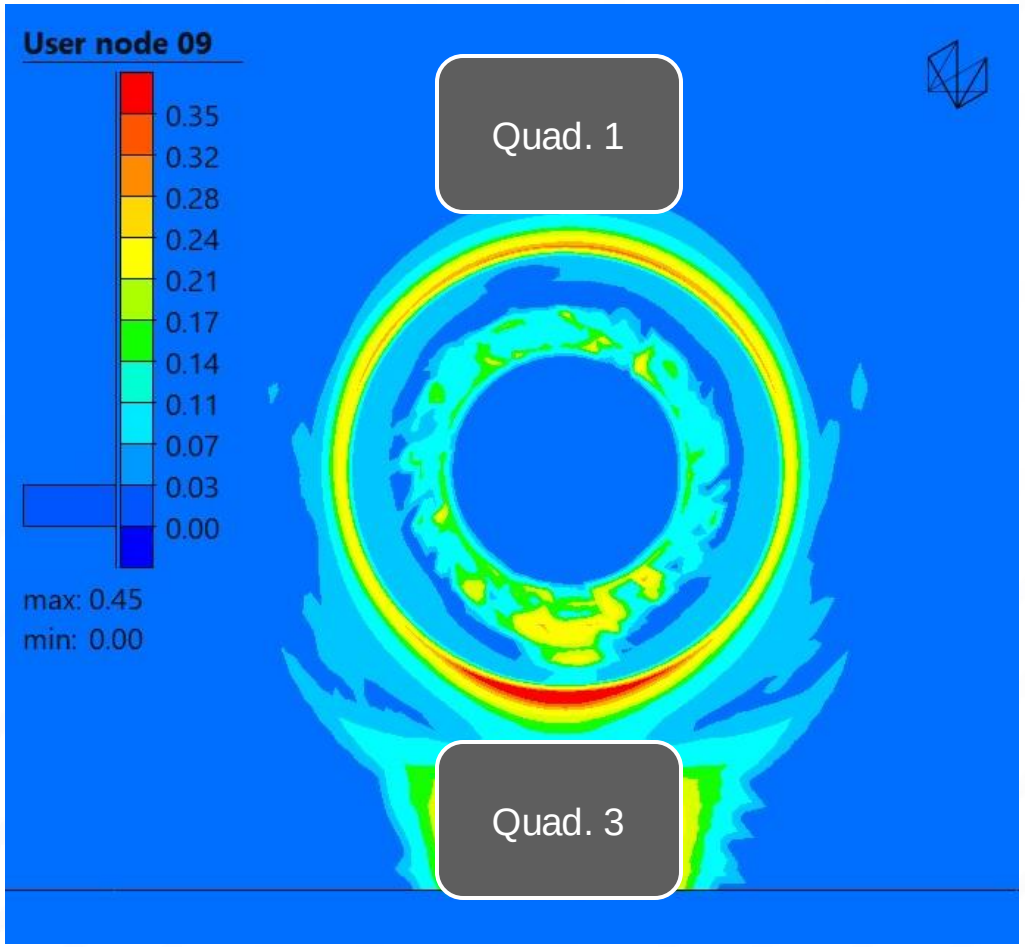


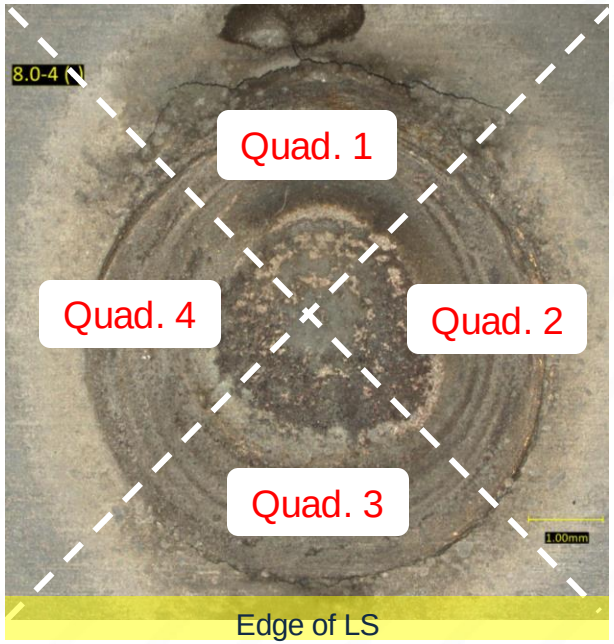


How should cracks be oriented when mapping them onto the model?

LME ratio vs experimental data

LME ratio introduced in the A/SP J7.1 project





	Number of Crack Occurrences on Positive Side	Number of Crack Occurrences on Negative Side
Quad. 1	5	6
Quad. 2	1	2
Quad. 3	6	4
Quad. 4	0	0
Toatl number of Cracks from 5 welds	12	12

Good correlation for Type A/B cracks supports the model's ability to accurately predict Type C cracks

But Type C is not visible…

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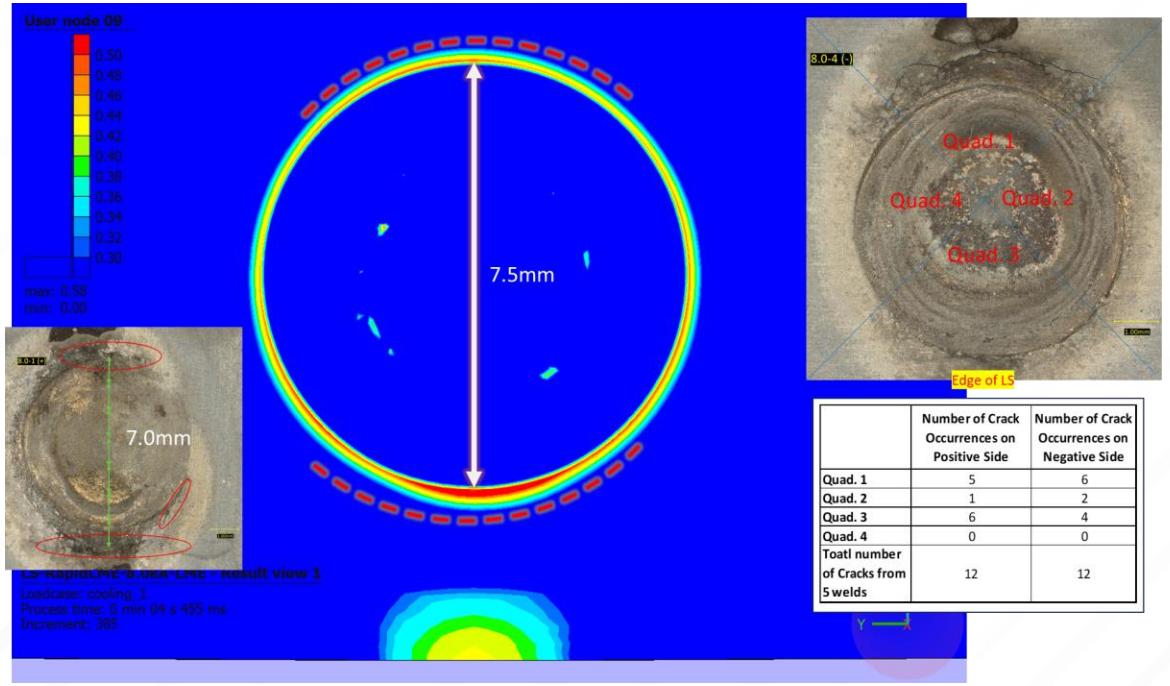
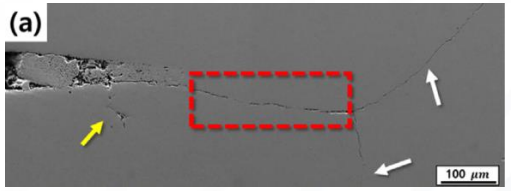
Type A and B according to the experiment



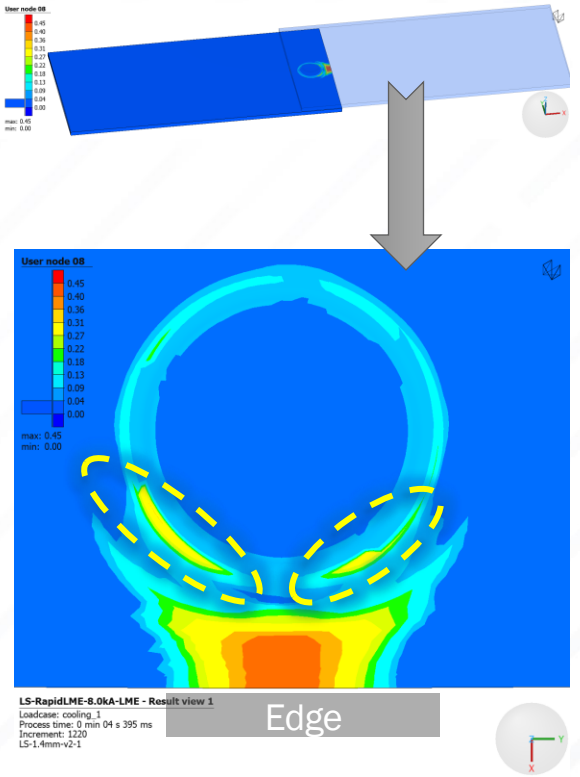
	Number of Crack Occurrences on Positive Side	Number of Crack Occurrences on Negative Side
Quad. 1	5	6
Quad. 2	1	2
Quad. 3	6	4
Quad. 4	0	0
Toatl number of Cracks from 5 welds	12	12

Through-thickness Type C cracks don't seem to go as deep as Type A or Type B. This is also captured by the LME ratio calculation since ratios for Type C are lower than A and B.

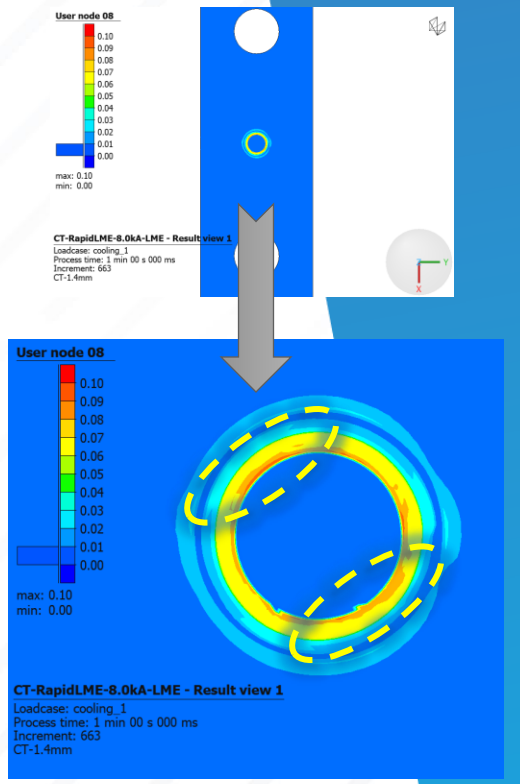


Type C as identified in the model (LME ratio)

Lap-shear



Cross-tension



Large difference between LS and CT

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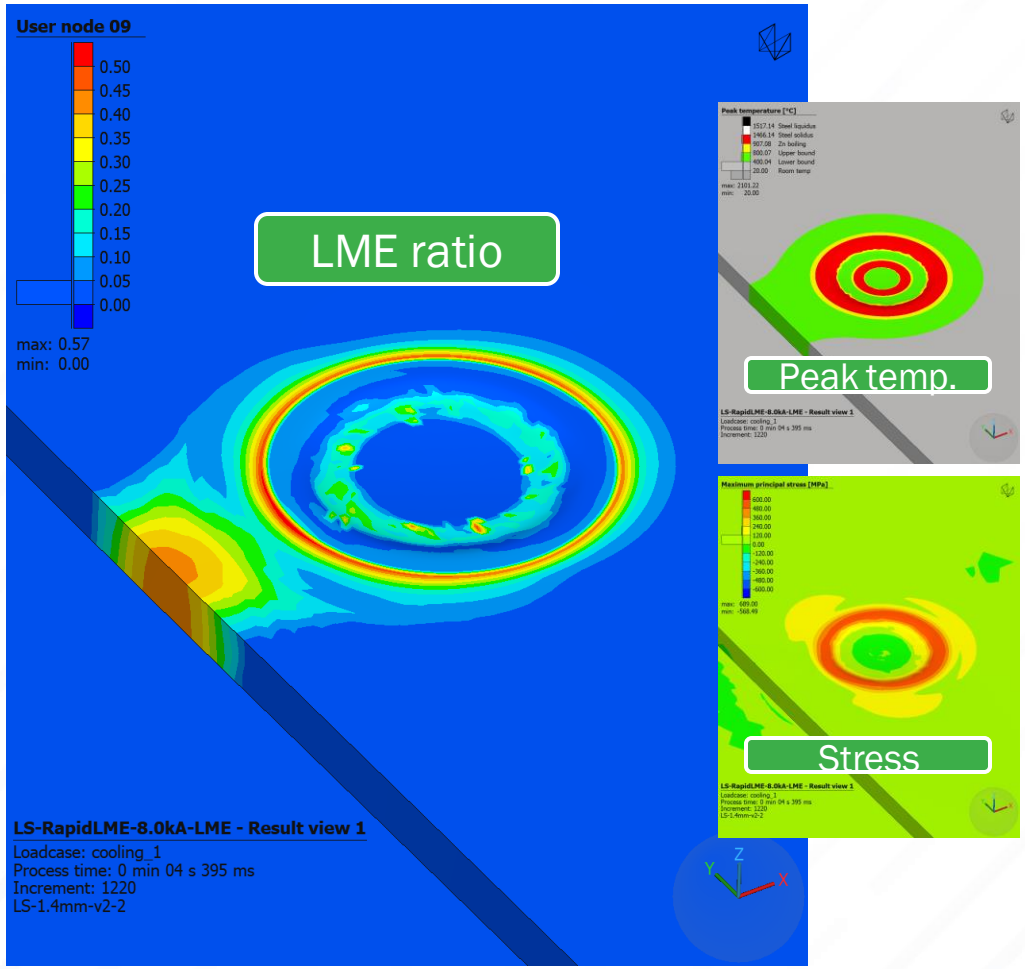
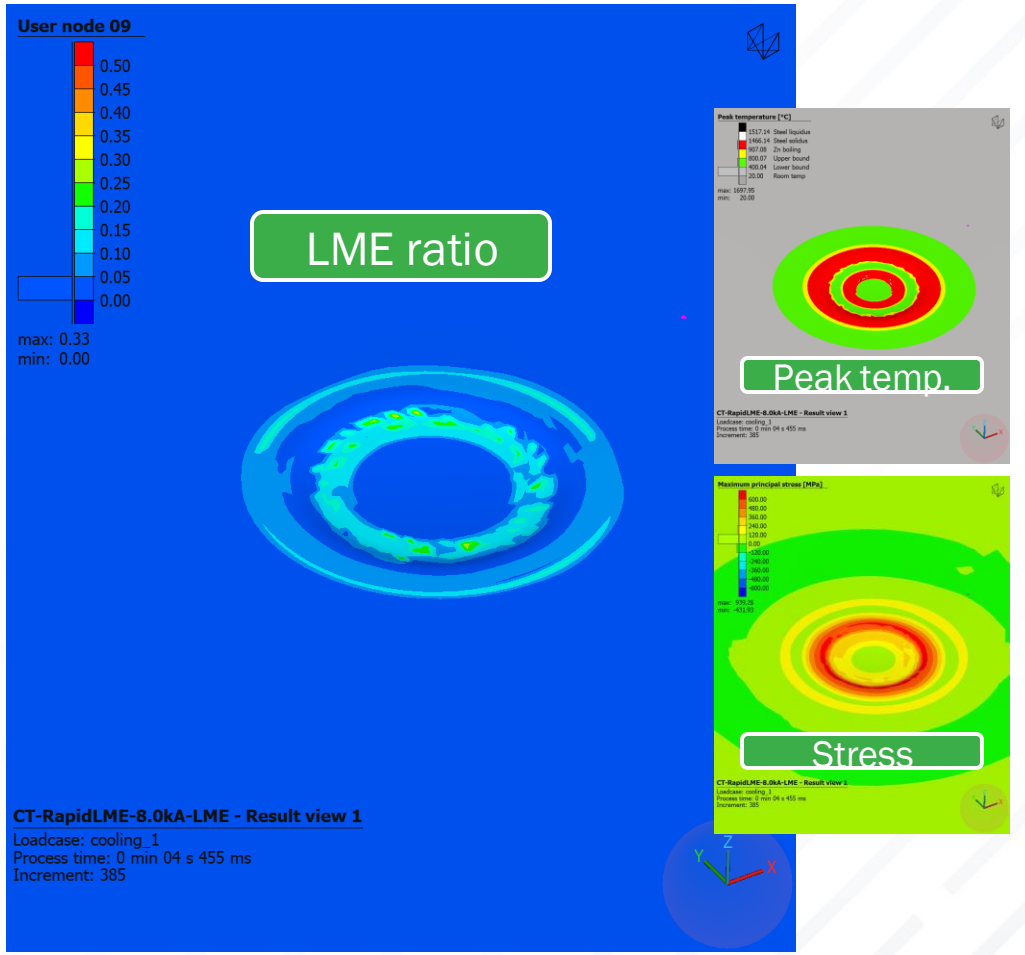
Lap-shear

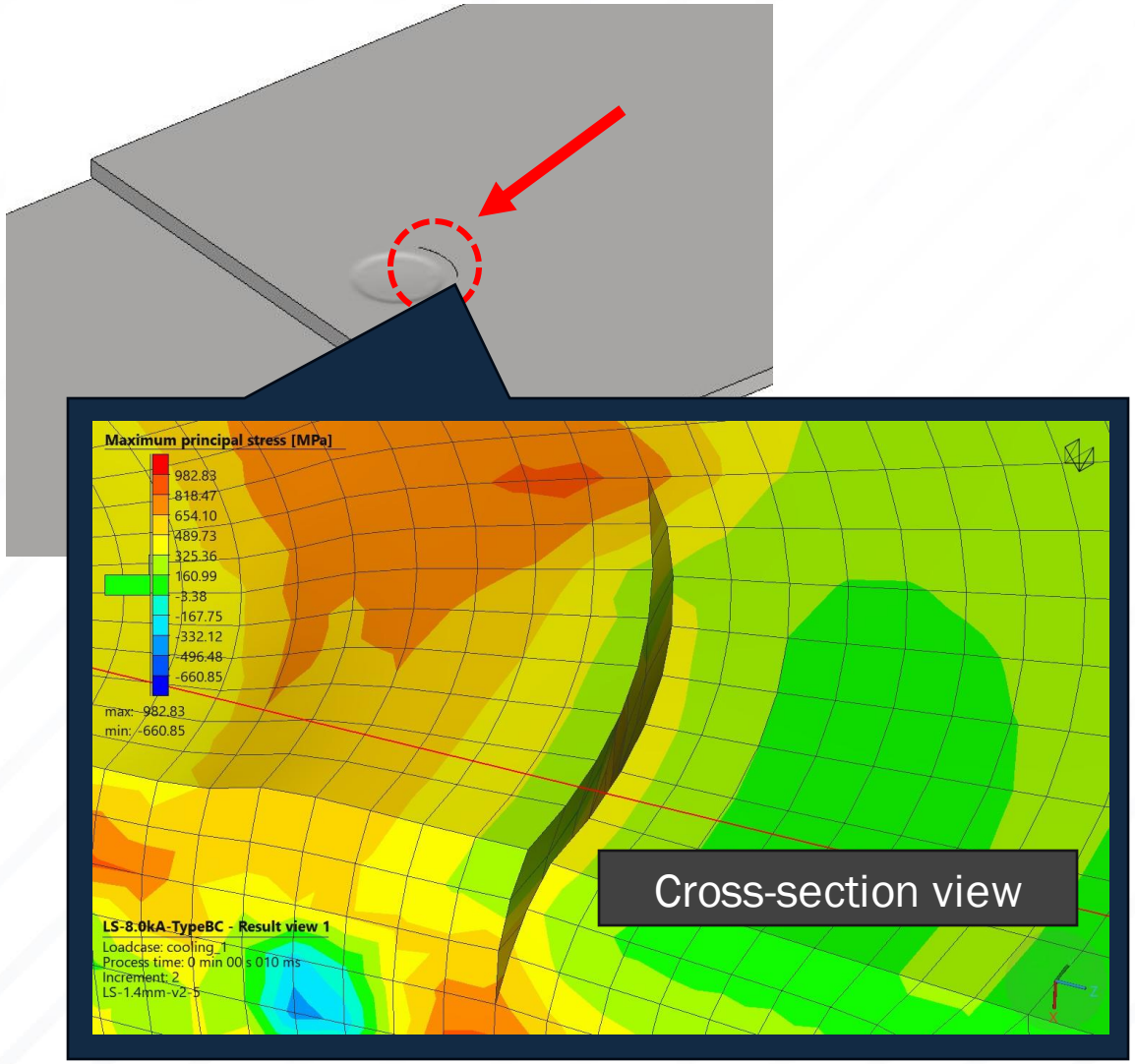


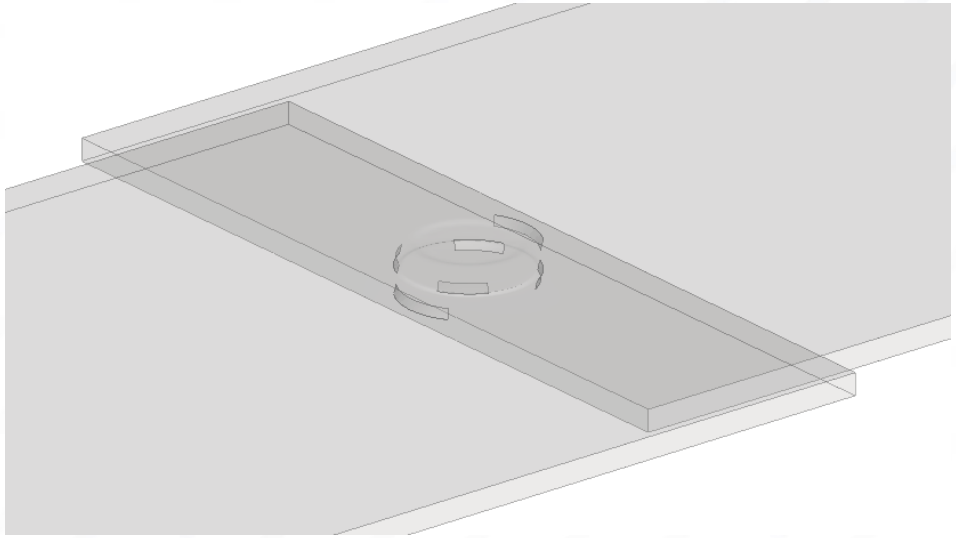
Cross-tension



Cross-tension seems to be less prone to LME cracks given its lower LME ratio

Introducing LME cracks in the model

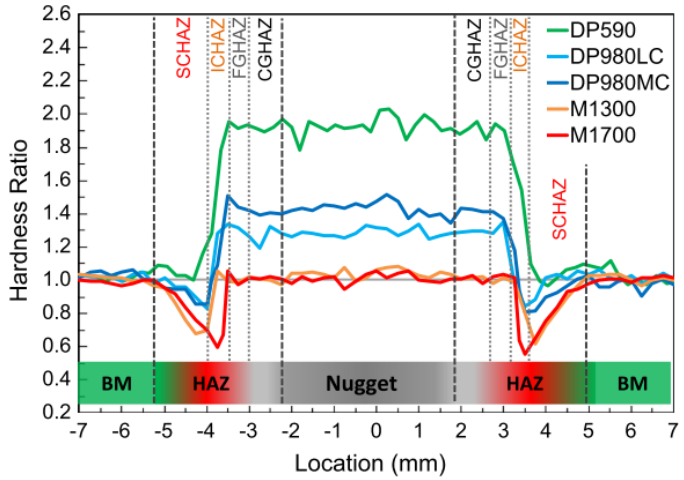


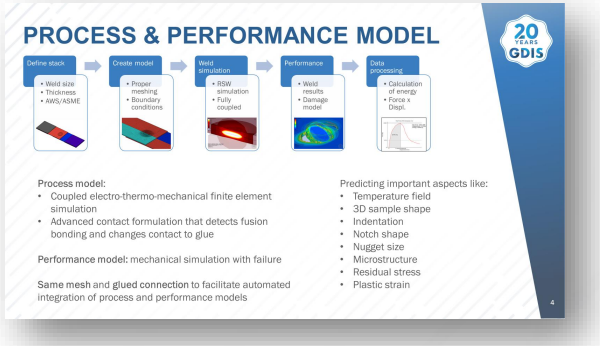


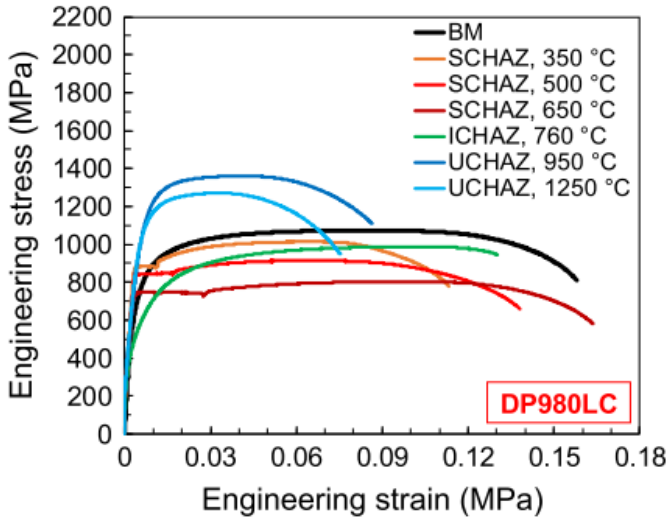
Sharpness of LME cracks maintained

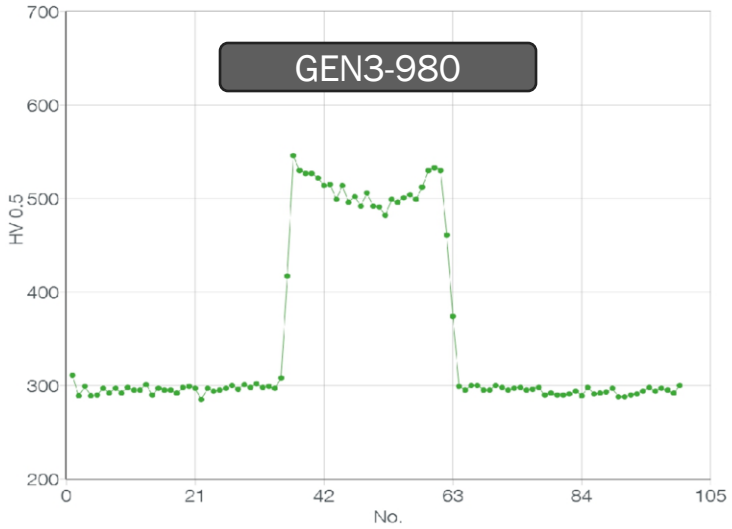
Instead of deleting elements from the mesh, we used a new technique that duplicates nodes

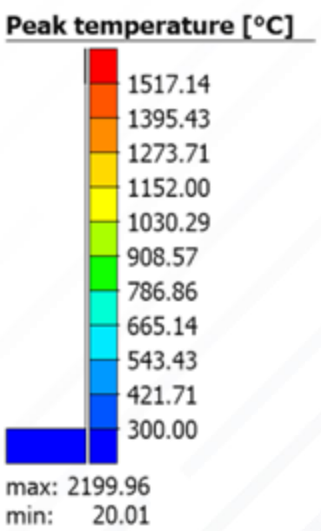
Including HAZ properties

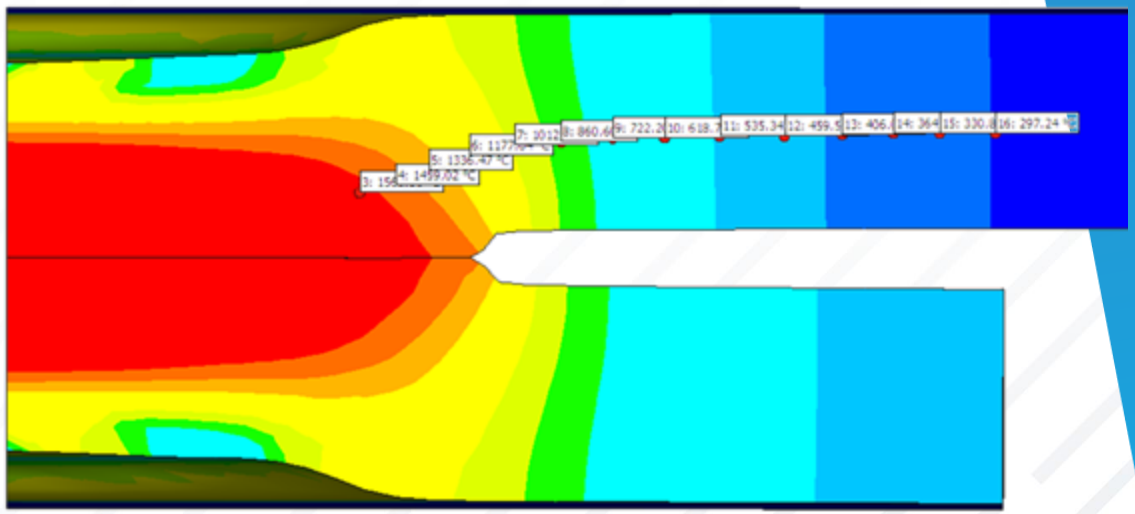












Numerical prediction of performance

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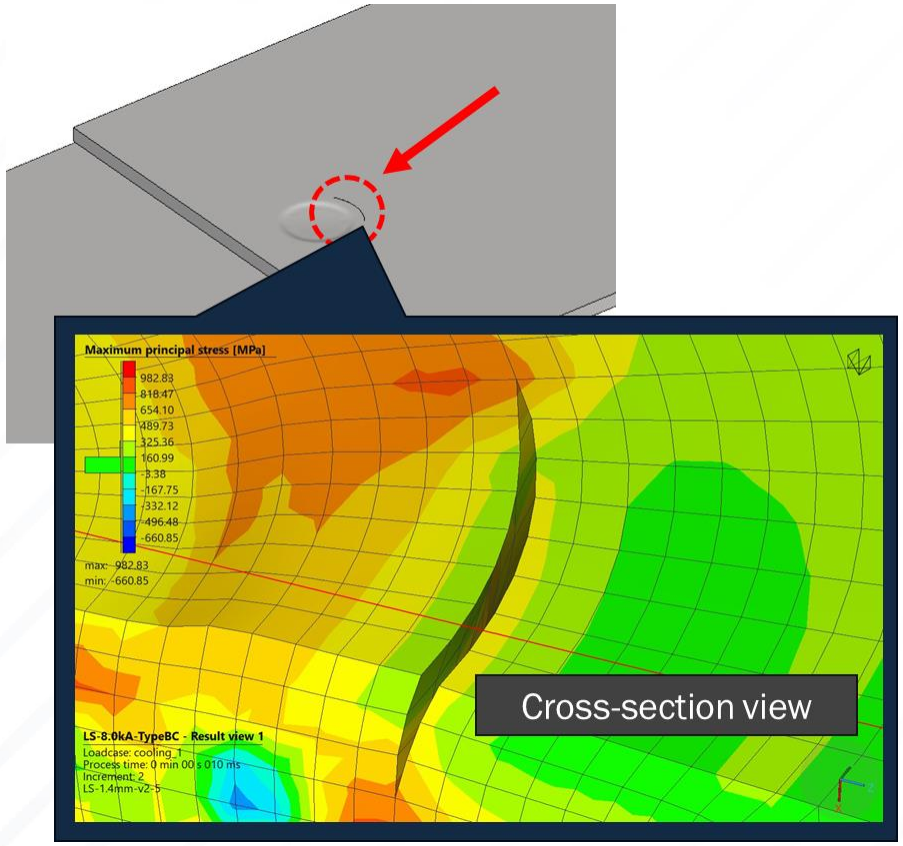
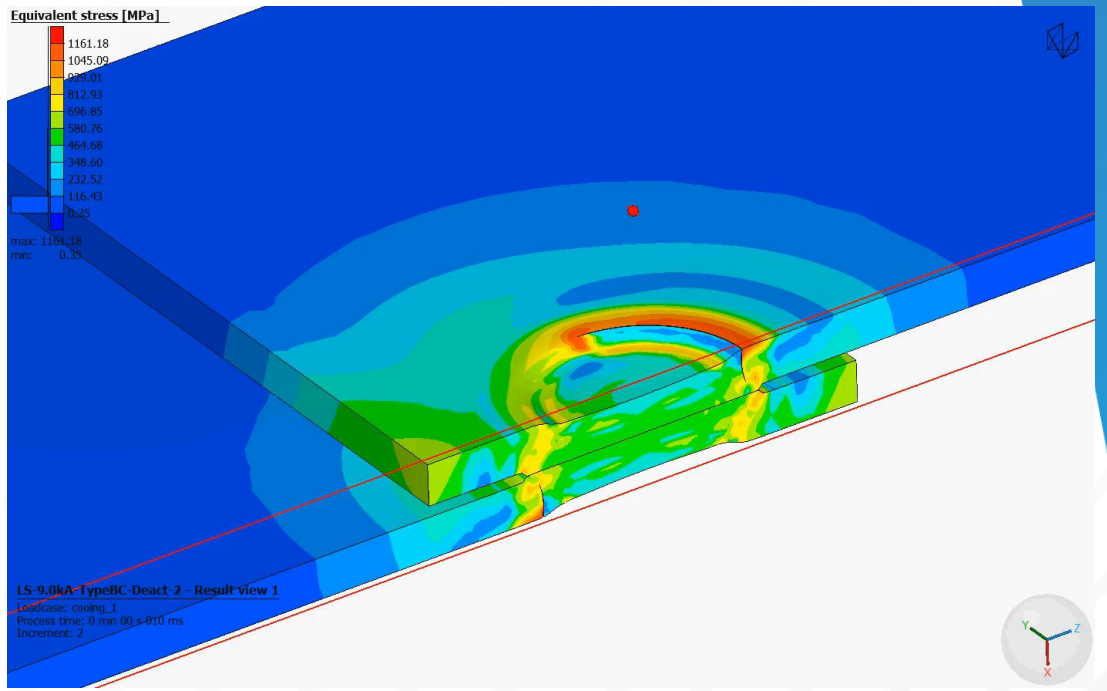
Crack nucleation (LME)

This happens during welding, in a brittle manner

Crack growth (Johnson-Cook (JC) damage)

This happens while pulling the samples





There is a complex interplay between LME cracks and strain-based material failure during loading

Experimental mechanical testing results

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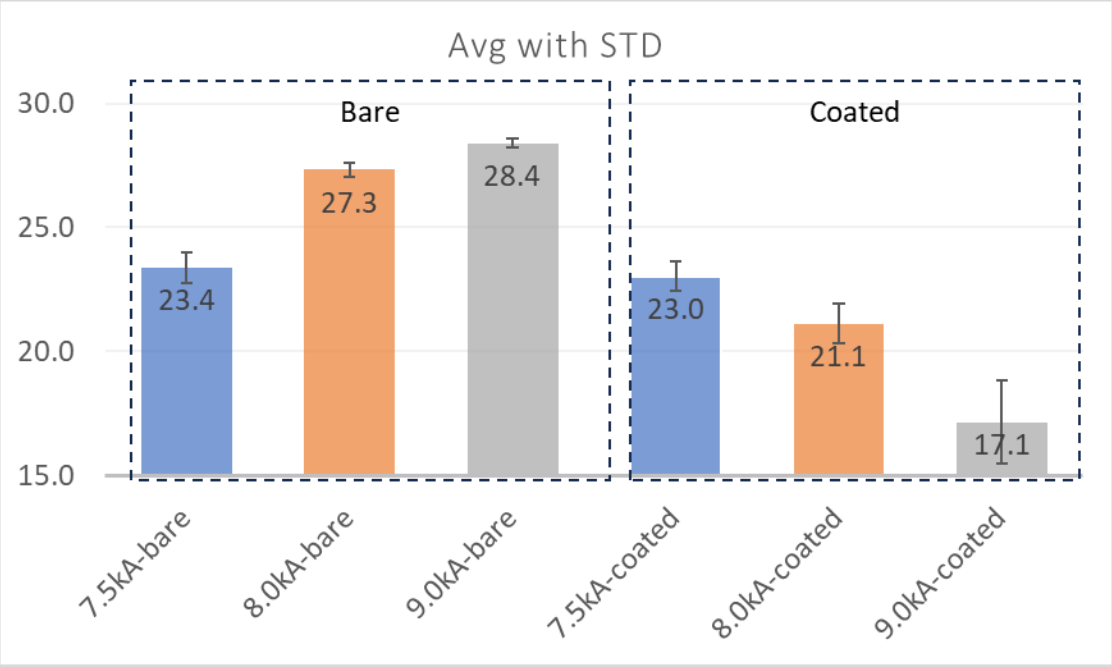
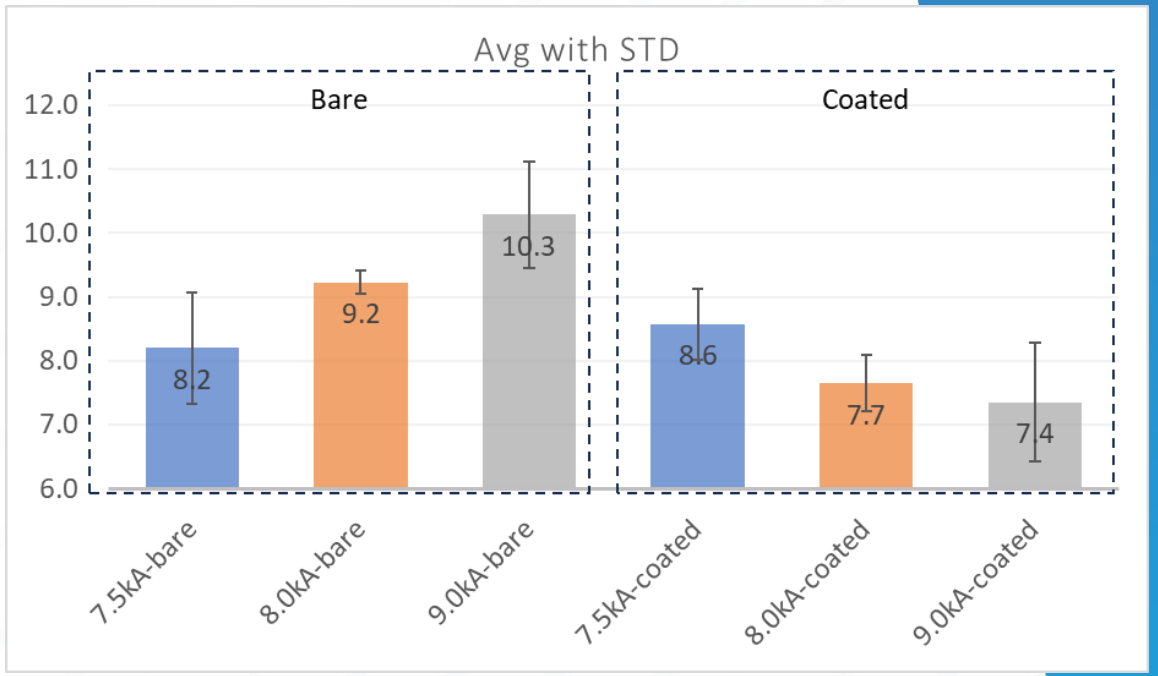
Lap-shear



Cross-tension

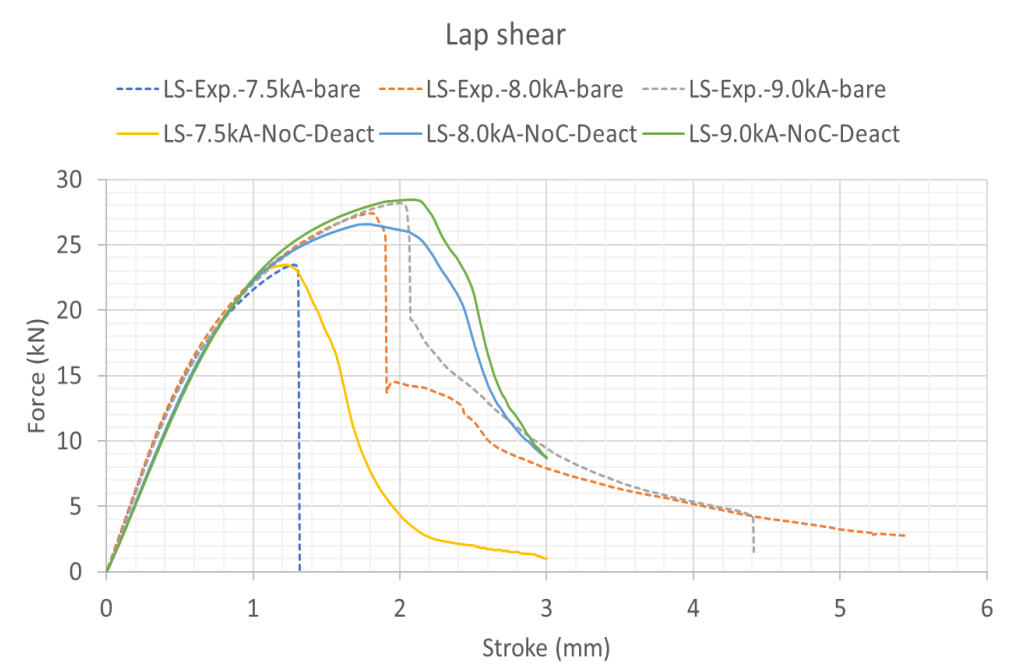


Increasing current in coated samples leads to worse performance as compared to bare samples. Spread in joint peak force for coated samples is considerably high (i.e., large scatter).

Model calibration for uncoated

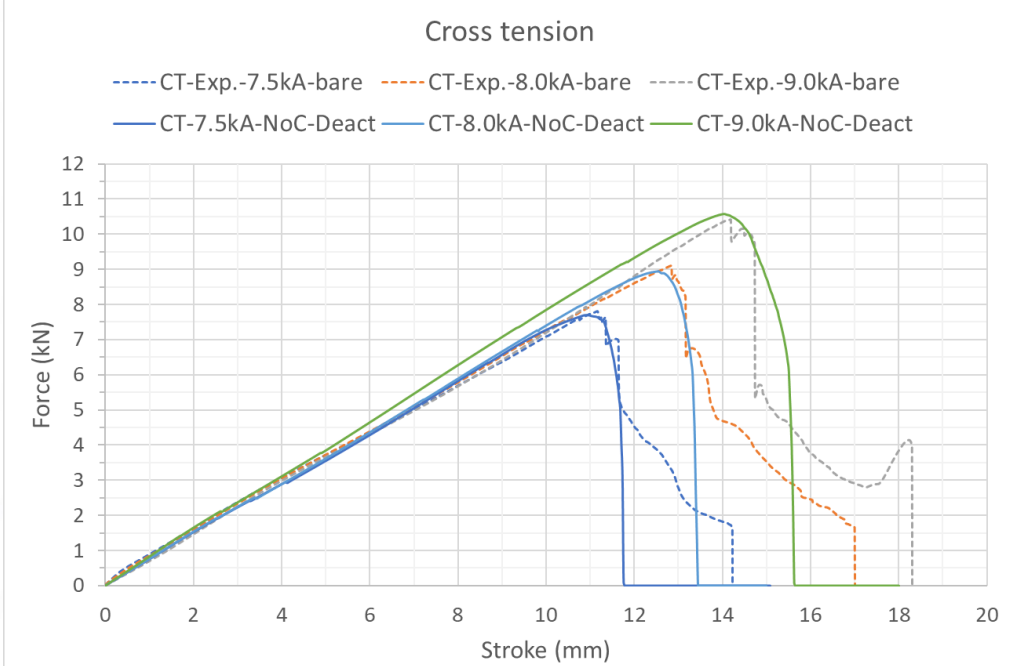
This sets the baseline for comparison

Lap-shear



	Experiment (kN)	Model (kN)	Acc.
7.5kA	23.5	23.6	100.4%
8.0kA	27.5	26.5	96.3%
9.0kA	28.5	28.7	100.7%

Cross-tension

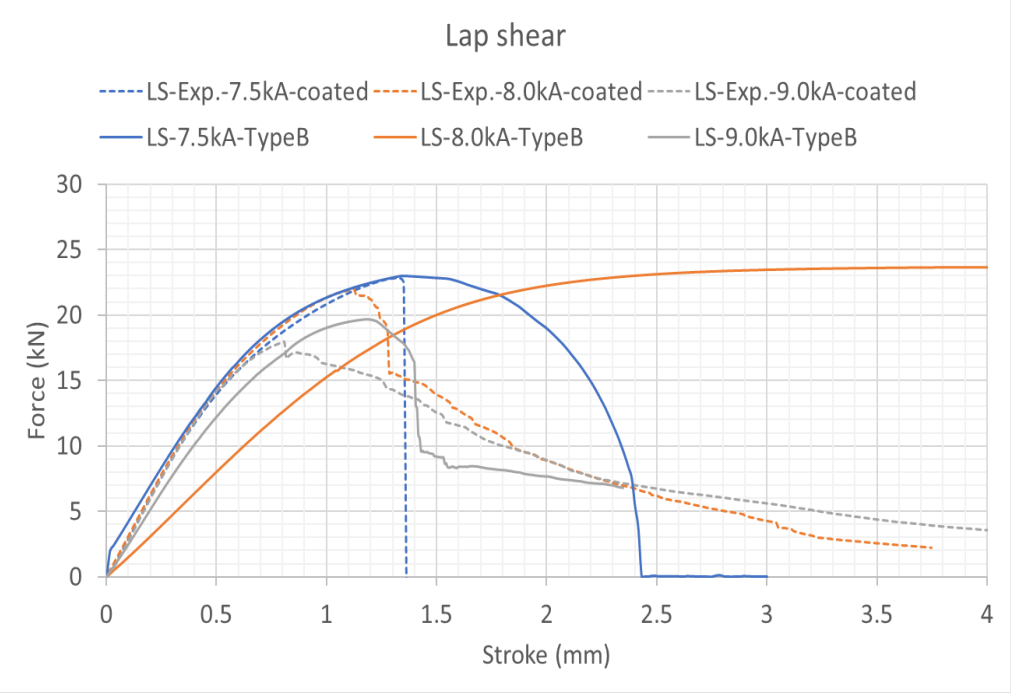


	Experiment (kN)	Model (kN)	Acc.
7.5kA	7.9	7.8	98.7%
8.0kA	9.1	9.0	98.9%
9.0kA	10.5	10.6	100.9%

Predicted weld performance for Zn-coated

If only Type B is present

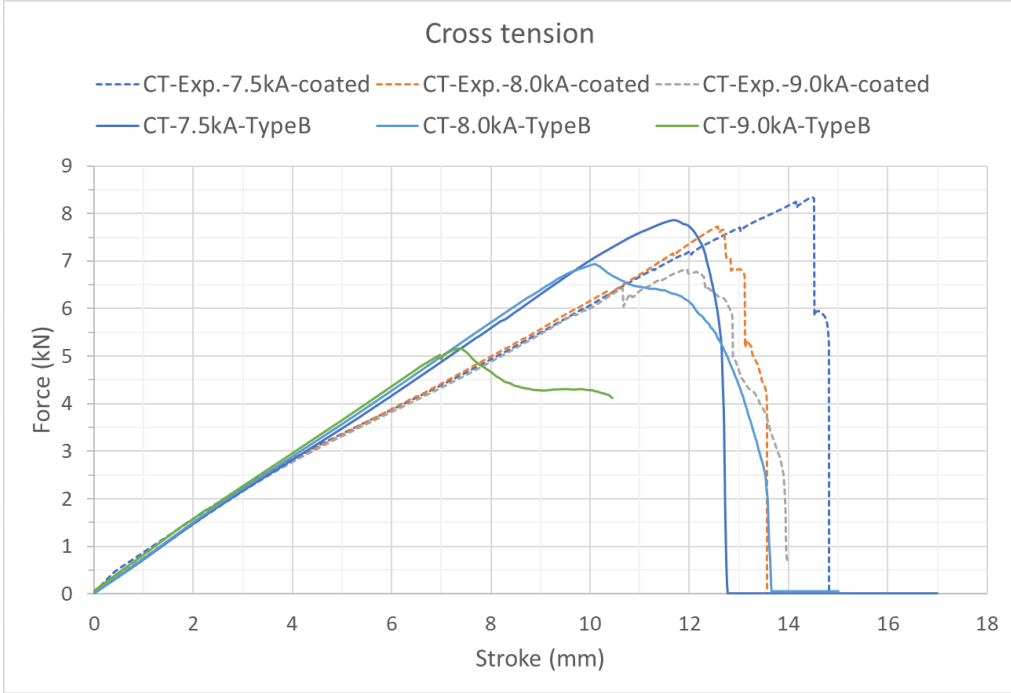
Lap-shear



	Experiment* (kN)	Model (kN)	Acc.
7.5kA	22.8	22.9	100.4%
8.0kA	21.9	23.6	107.7%
9.0kA	17.9	19.6	109.4%

*Experiment may contain the three types of cracks

Cross-tension

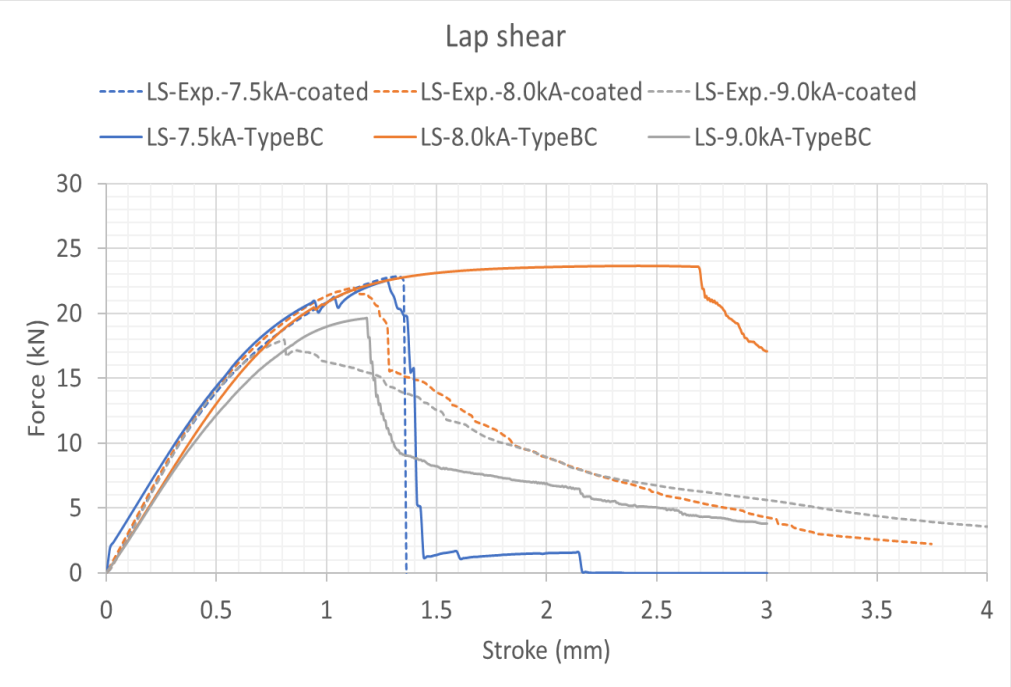


	Experiment* (kN)	Model (kN)	Acc.
7.5kA	8.3	7.8	93.9%
8.0kA	7.7	6.9	89.6%
9.0kA	6.8	5.3	78.0%

Predicted weld performance for Zn-coated

If Type B + Type C is present

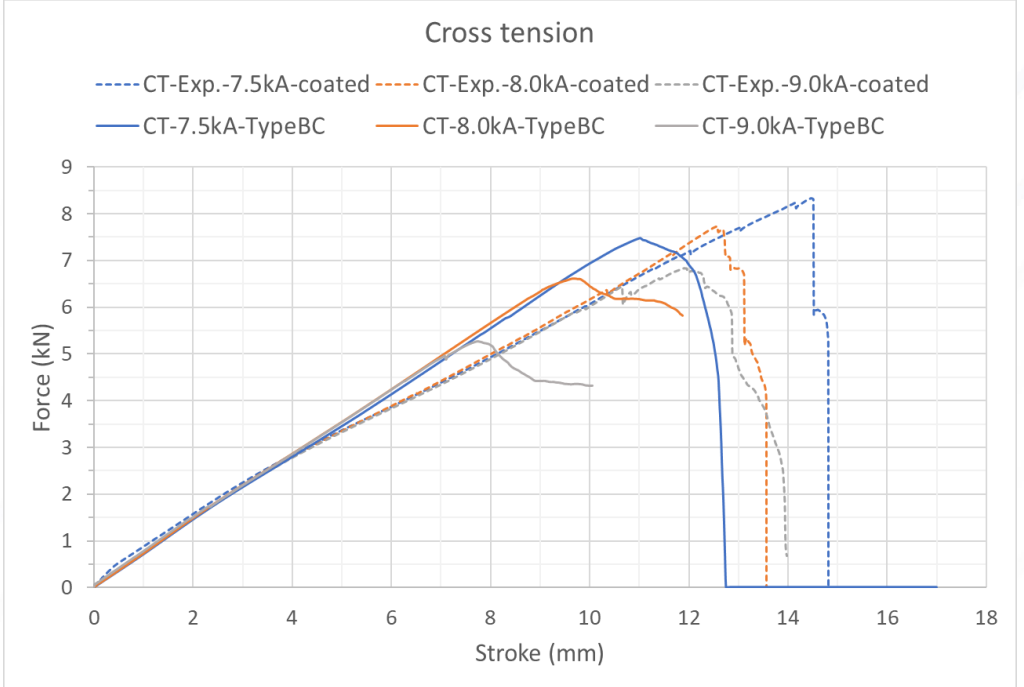
Lap-shear



	Experiment* (kN)	Model (kN)	Acc.
7.5kA	22.8	22.5	98.7%
8.0kA	21.9	23.6	107.5%
9.0kA	17.9	19.5	108.7%

*Experiment may contain the three types of cracks

Cross-tension



	Experiment* (kN)	Model (kN)	Acc.
7.5kA	8.3	7.5	90.3%
8.0kA	7.7	6.6	85.7%
9.0kA	6.8	5.3	78.0%

Summary and conclusions

GDIS

Regarding the modeling approach:

- It is necessary to **simulate the resistance spot welding process** so that the correct local HAZ properties are accounted for
- LME cracks can be modeled in finite element simulations via **direct node duplication** in the mesh
- A suitable **damage model** should be selected to calculate crack growth
- Element removal threshold in the damage model plays a major role on peak force

Regarding LME effects:

- Type B cracks seem to be **very detrimental** to the weld peak force
- **Through-thickness Type C** cracks do not seem to affect results considerably
- Type B combined with through-thickness Type C cracks do not cause much further losses in peak force
- The effects of interfacial type C is ongoing
- The effects observed above were identifies in both **lap-shear and cross-tension** configurations

To increase model accuracy:

- Characterize the specific GEN3 using Gleeble/hardness (scaled available data from previous work)
- CT data to validate how crack depth varies along its length (assumed constant depth in this work)

Next steps:

- Investigate the effects of hybrid cracks (type A + B + C) on the weld mechanical property degradation
- Define acceptance criteria for individual crack types as well as their combinations

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