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Evaluating the resistance of austenitic stainless steel welds to hydrogen embrittlement

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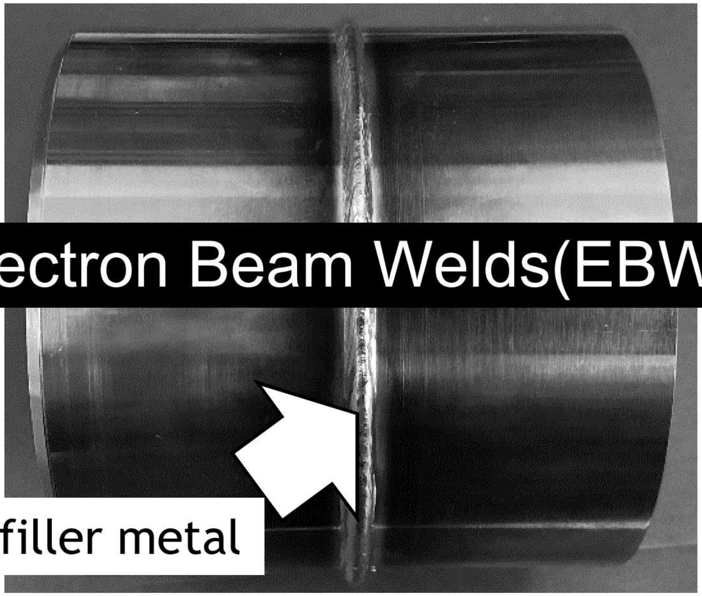
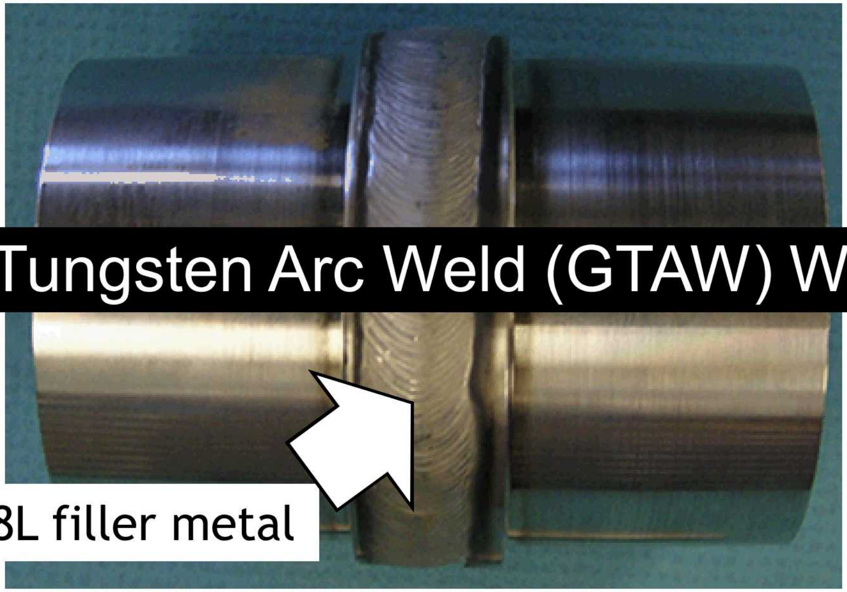
Two different welds were fabricated and tested

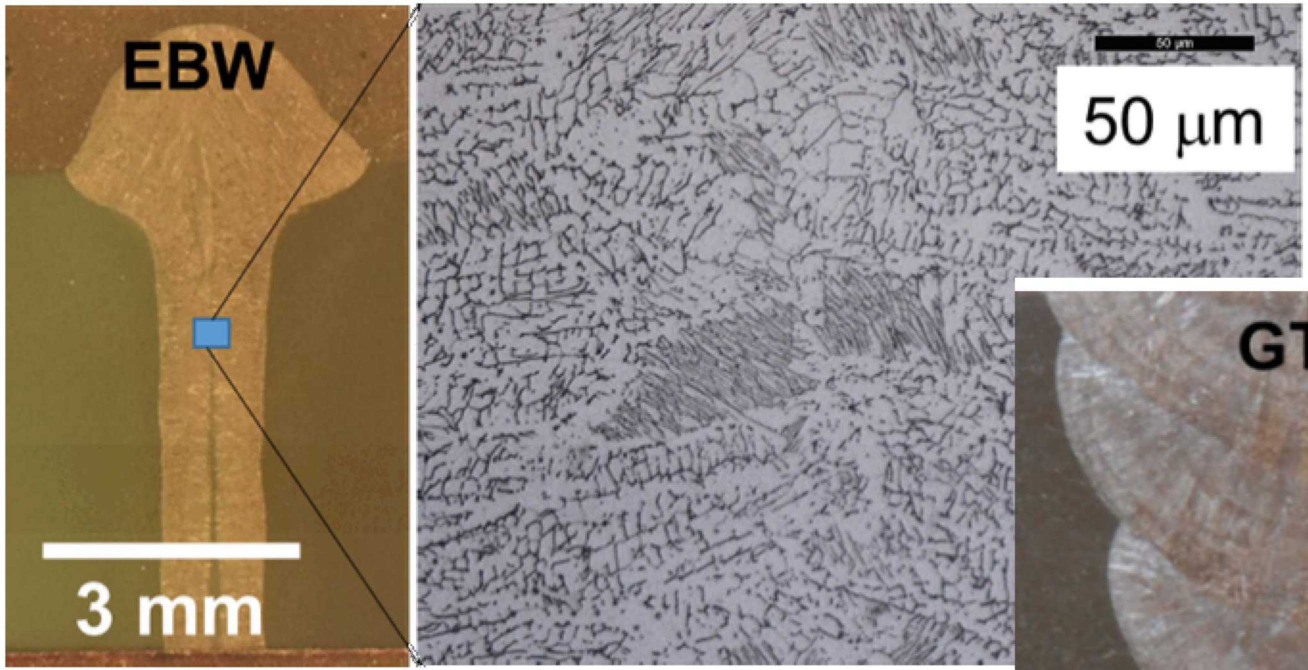


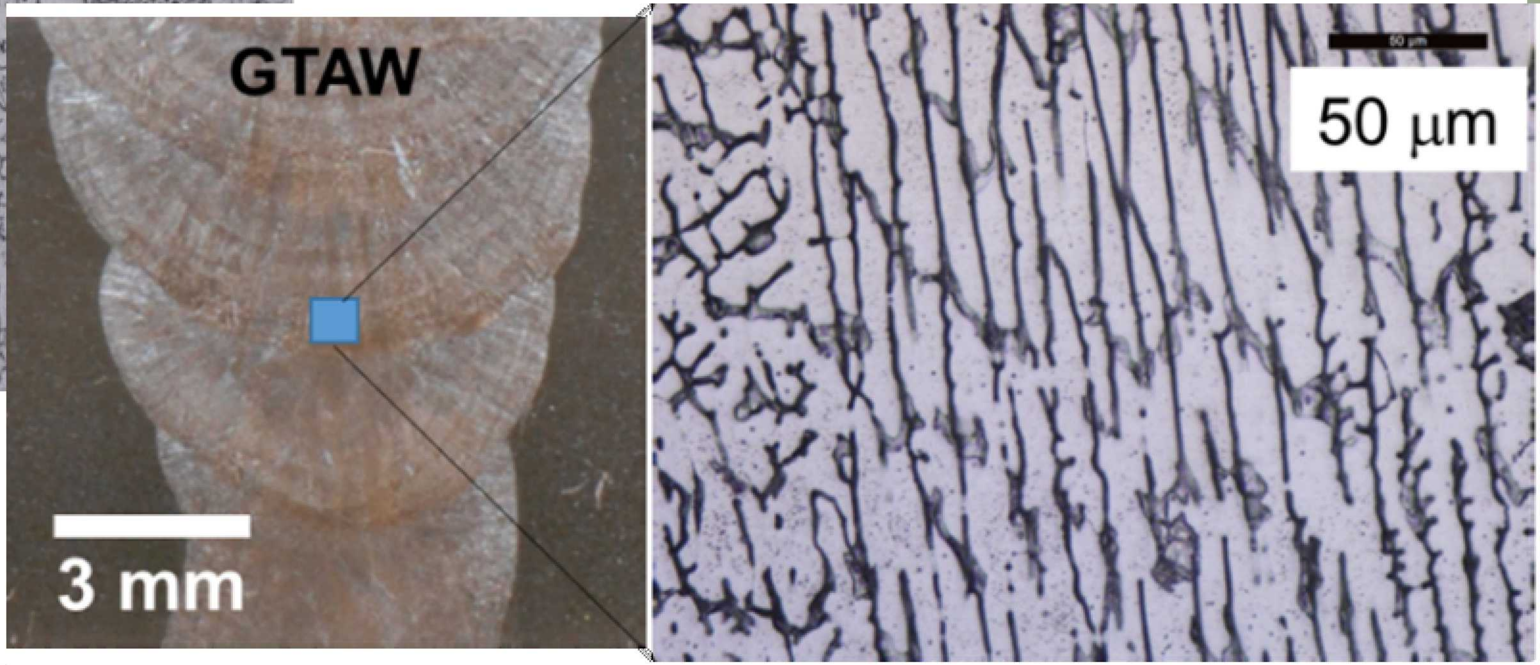
Weld rings with circumferential weld



Parameters	EBW	GTAW
Voltage	140 kV	9.4
Current	41 mA	205
Travel speed	76.2 cm/min	6.3
Notes:	• 24 s (1 s upslope, 1 s downslope) • Sharp focus +20 mA (sharp focus at 850 mA)	• Ar shield gas flow rate 0.85 Nm^3/h • Filler wire feed rate = 74 cm/min

E-beam weld microstructure is much finer than GTA weld





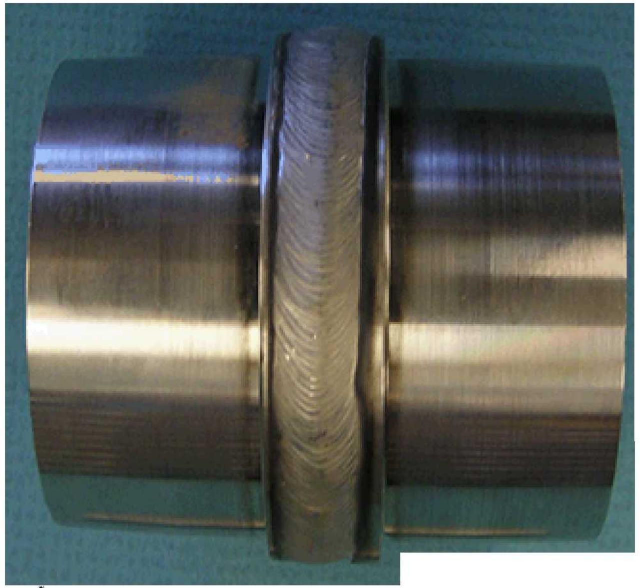
<u>Different phases</u>

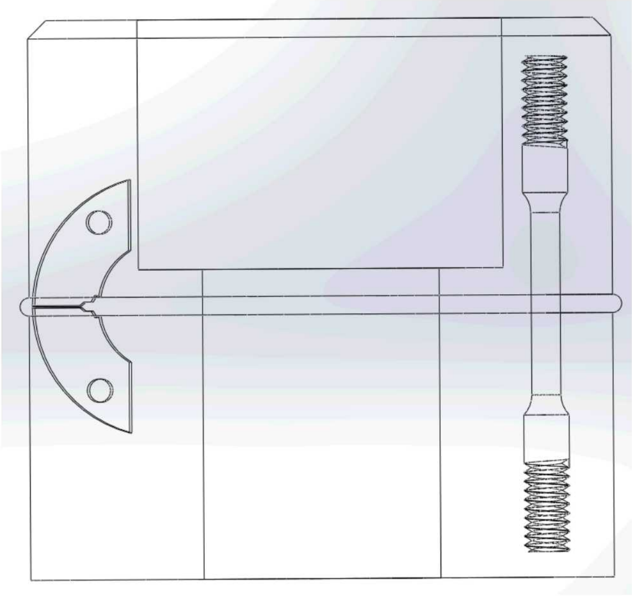
δ-ferrite (dark)

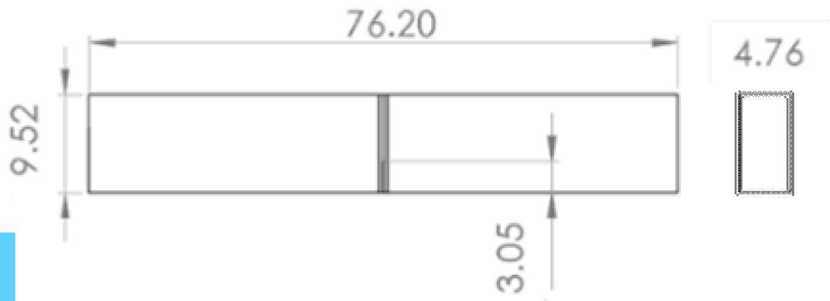
γ-austenite (white)

Material	Fe	Cr	Ni	Mn	Si	C	N	P	S	Yield Strength (MPa)
304L	Bal.	19.38	10.44	1.72	0.57	0.027	0.02	0.021	0.002	423
308L Filler	Bal.	20.5	10.3	1.56	0.50	0.028	0.055	0.006	0.012	N/A

Extracted specimens for tensile testing & fracture testing from welds

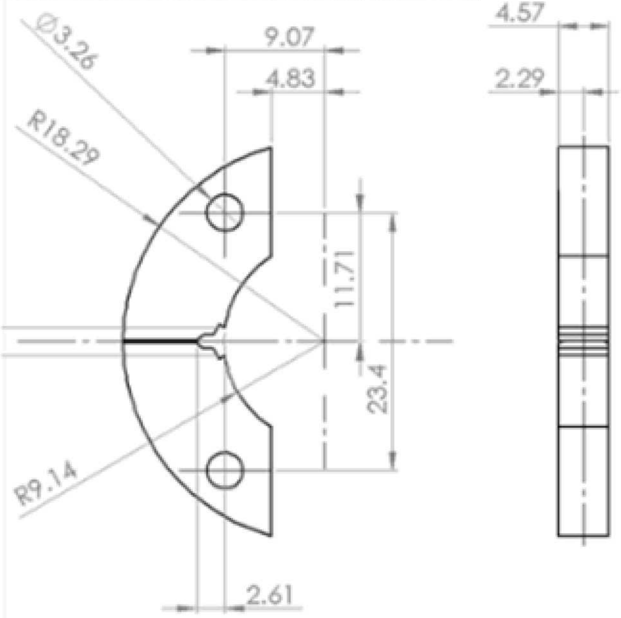






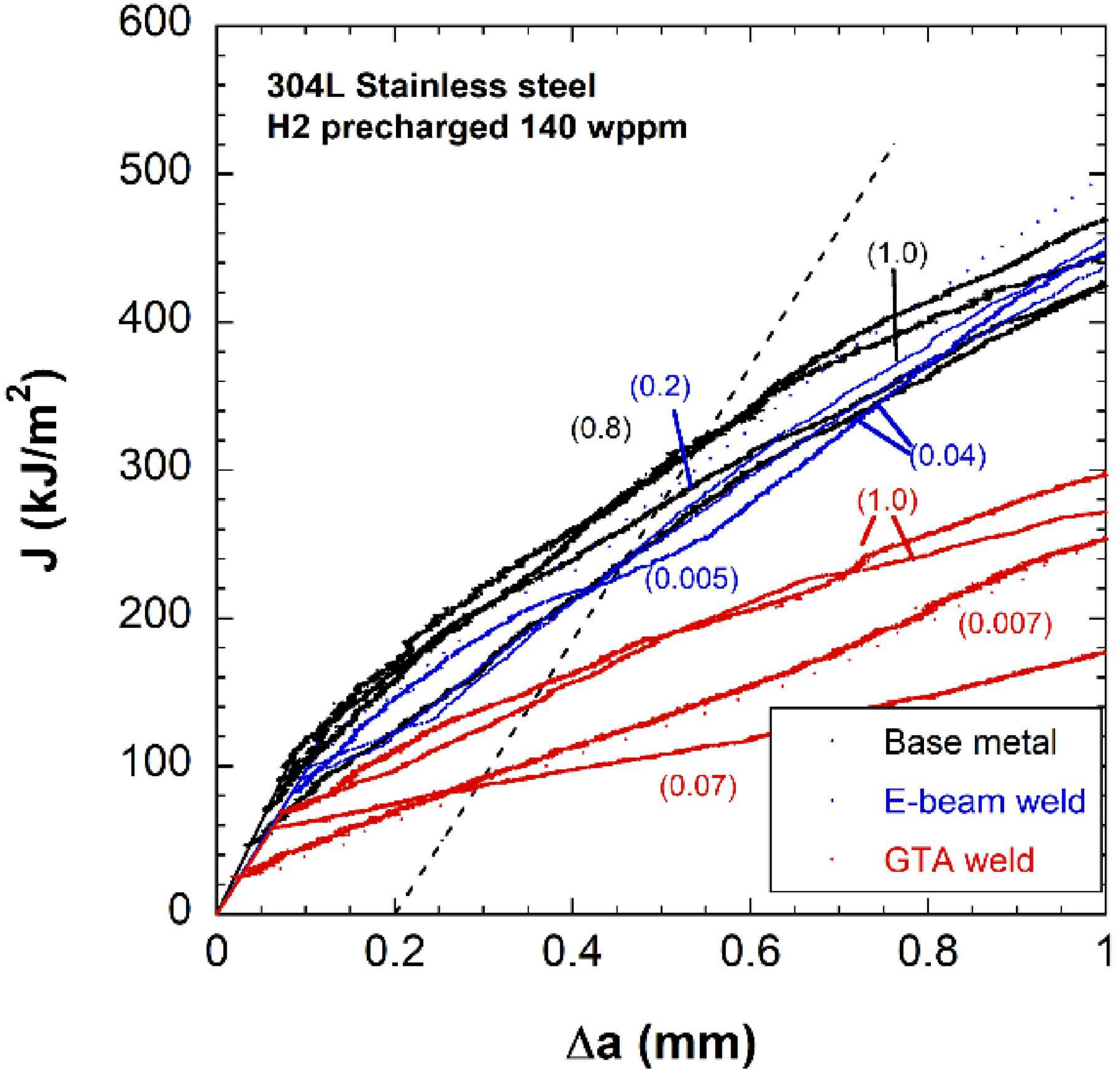
GTAW
3-point bend

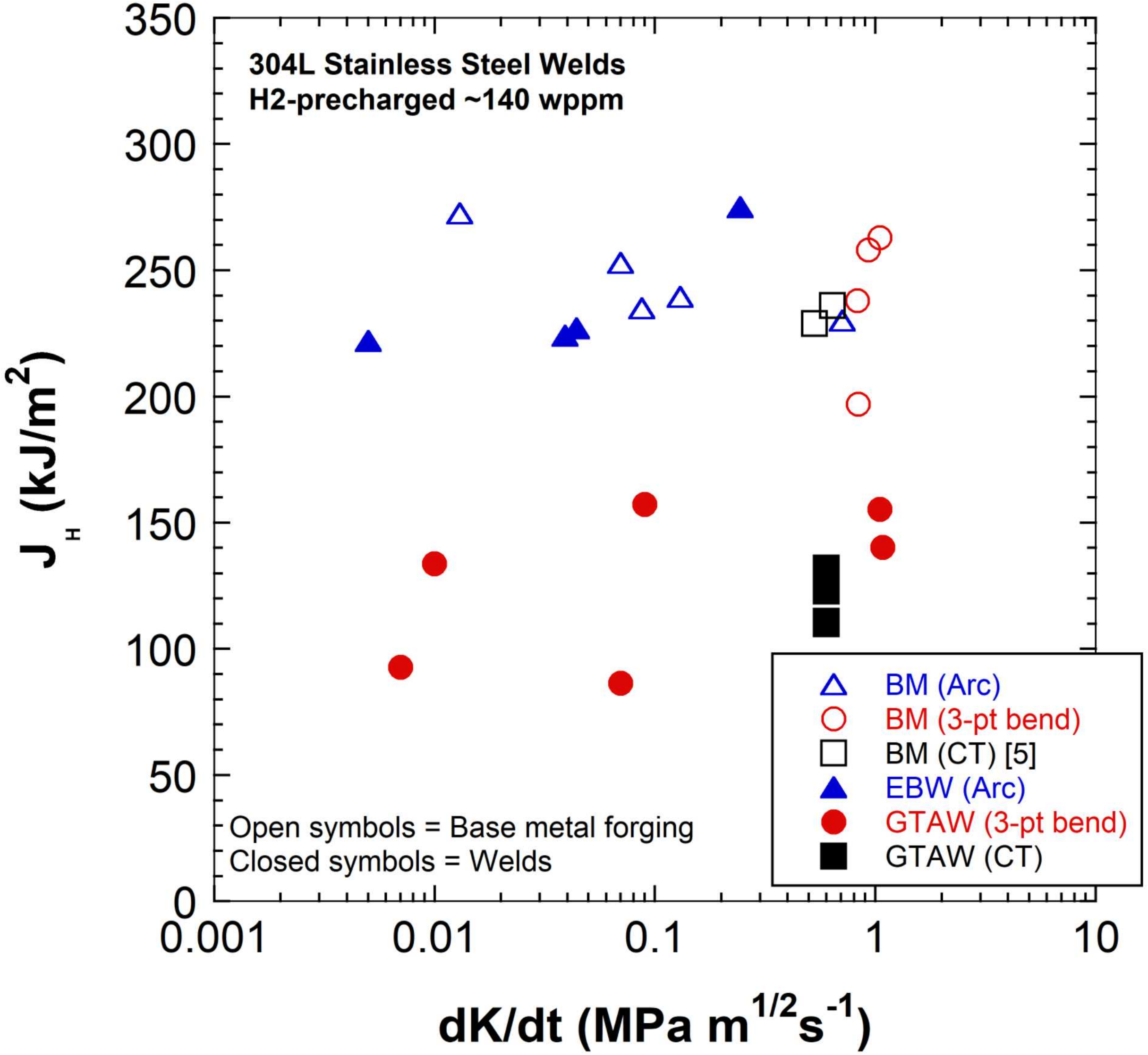
Units in mm



EBW
Arc specimen

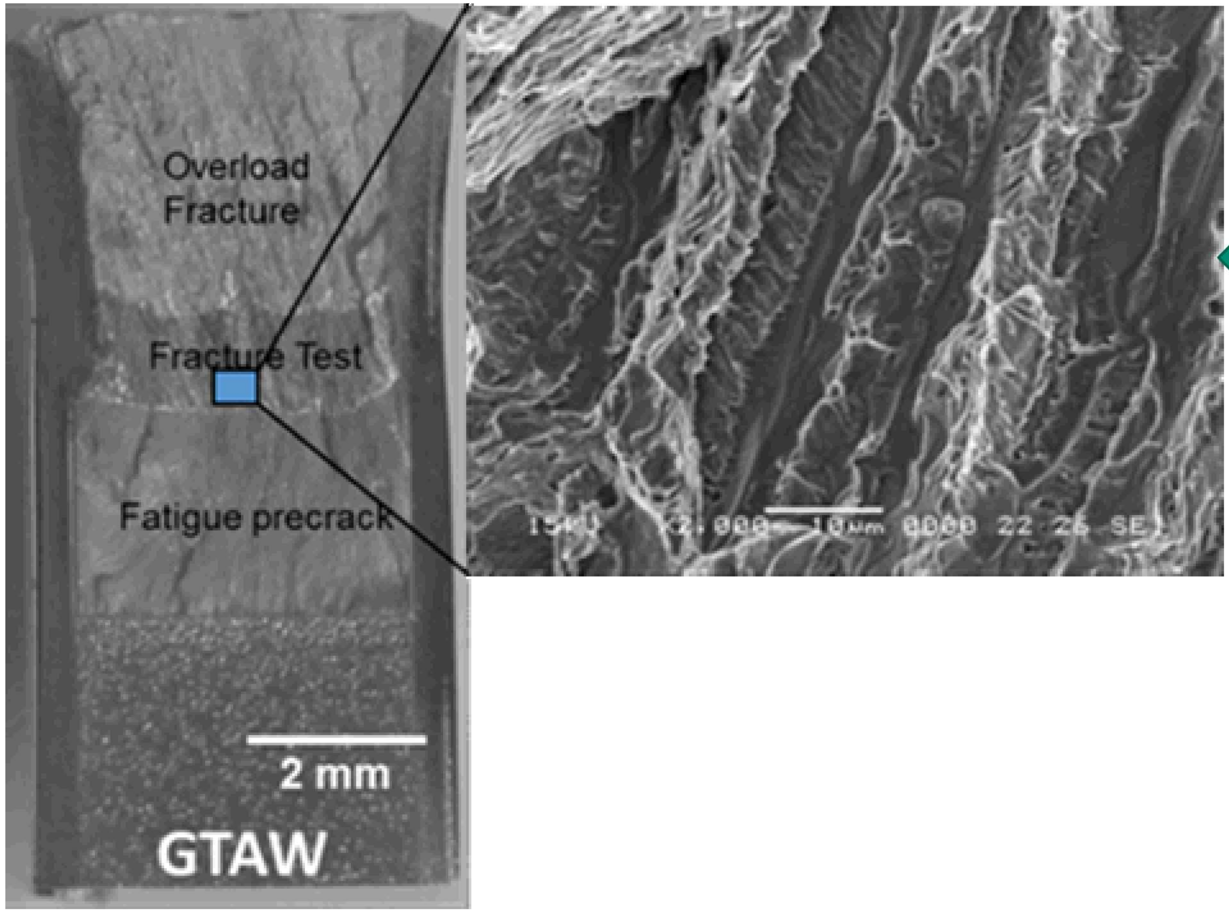
Rising-displacement fracture tests showed decrease of fracture resistance (J_H) of GTA weld compared to base metal



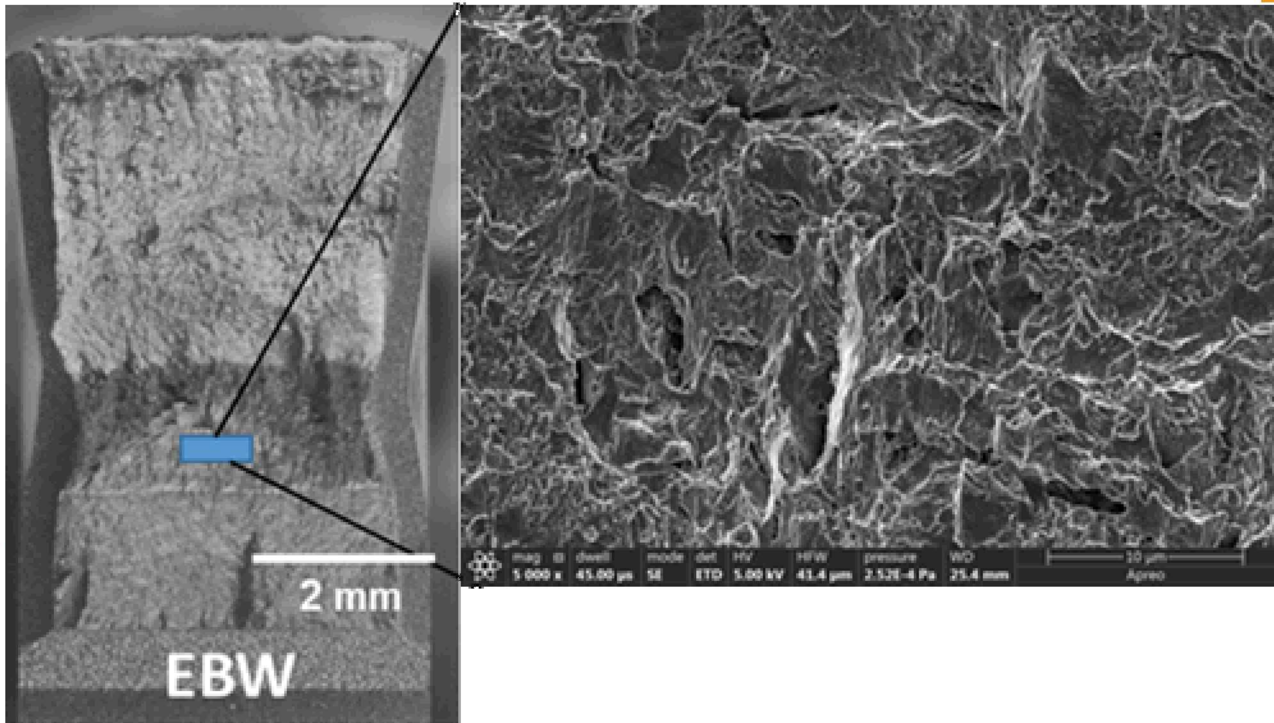


E-beam weld (EBW) exhibited similar fracture threshold to base metal over range of testing rates

Fracture surfaces reveal different preferred crack paths of two welds



GTAW appears to extend predominantly along elongated dendritic ferrite



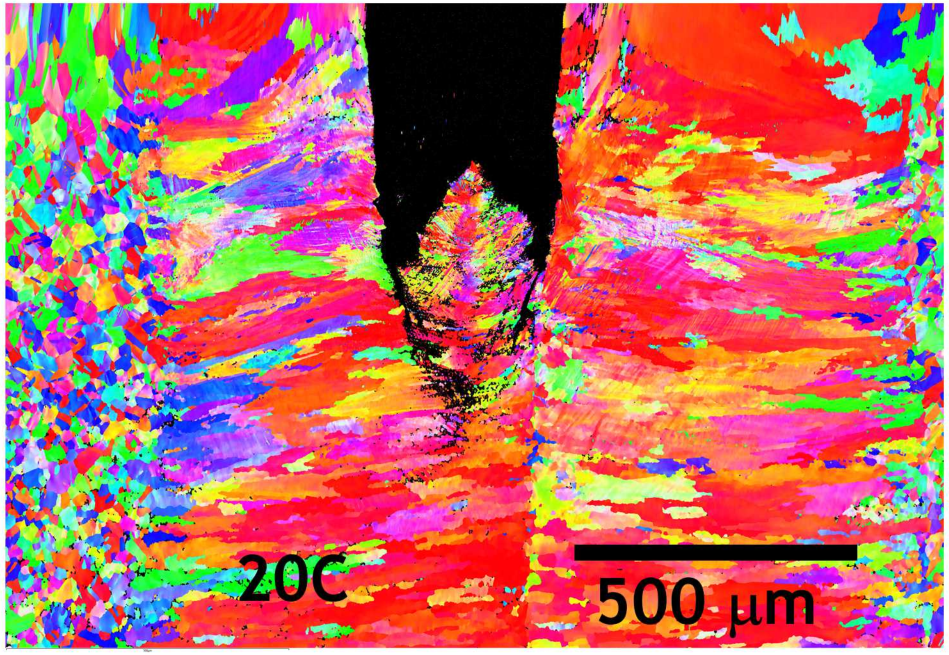
EBW show no elongated features, similar to base metal

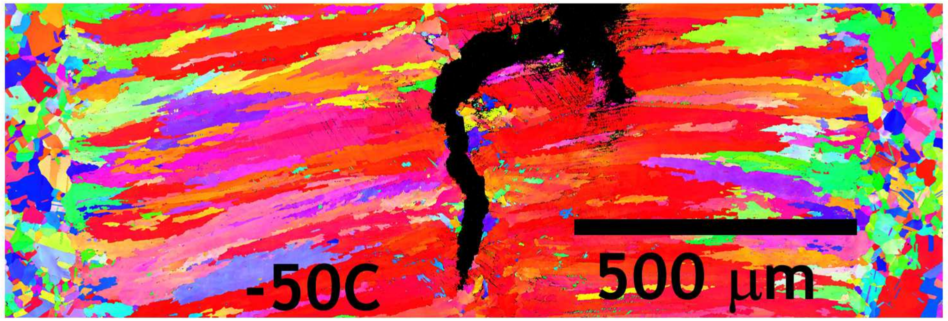
Grain orientation influences crack path in different welds

EBW

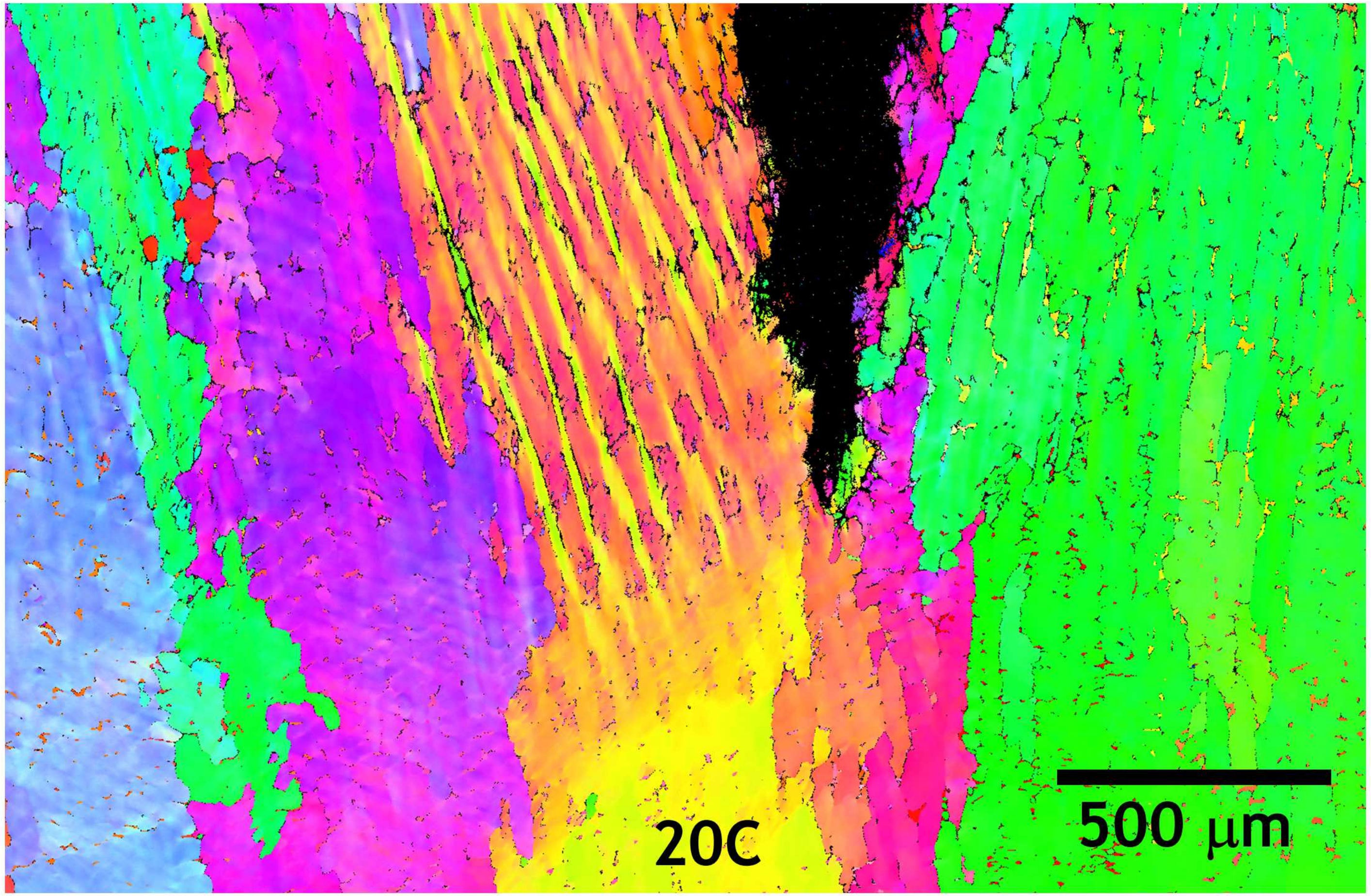
*Crack path is down in all images

GTAW





Crack branching is observed



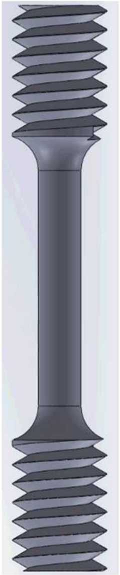
Cracks growth along elongated features

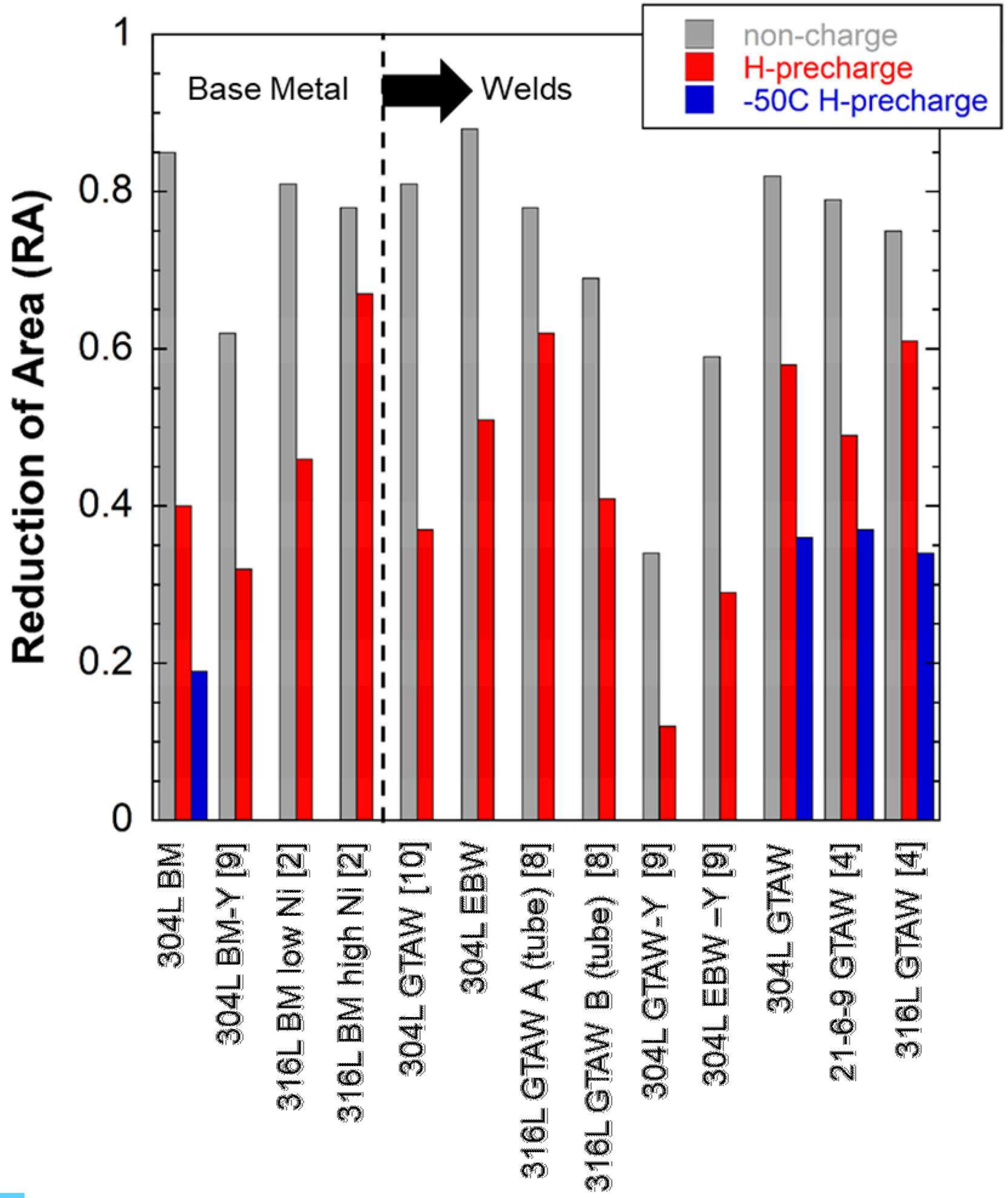
Crack deflection due to grain orientation in EBW improves fracture resistance

Tensile Test Results: Reduction of Area of welds and base metals were similar

304L from this study

	Reduction of Area (RA)	
Material	**non-charged**	**H-charged**
Base Metal	0.85	0.40
EBW	0.88 / 0.89	0.50 / 0.51
GTAW	0.82	0.58





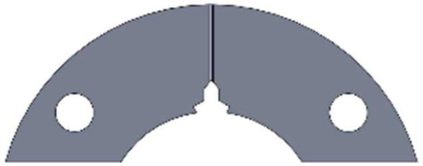
General trends:

- Not significant difference between welds and base metals
- Nickel content appears to improve RA (316L)
- Low Temp decreases RA
- Lowest RA was in 304L GTAW-Y [9] due to high ferrite content (base metal also had relatively low RA)

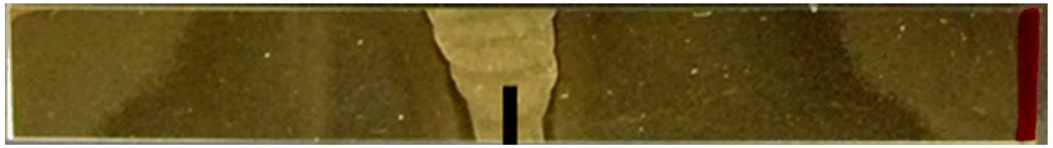
[2] San Marchi, 2008
[4] Ronevich, 2017
[8] Hughes, 2014
[9] Younes, 2013
[10] Balch, 2015

Subcritical cracking threshold: Variability in trends of welds and base metals

Arc

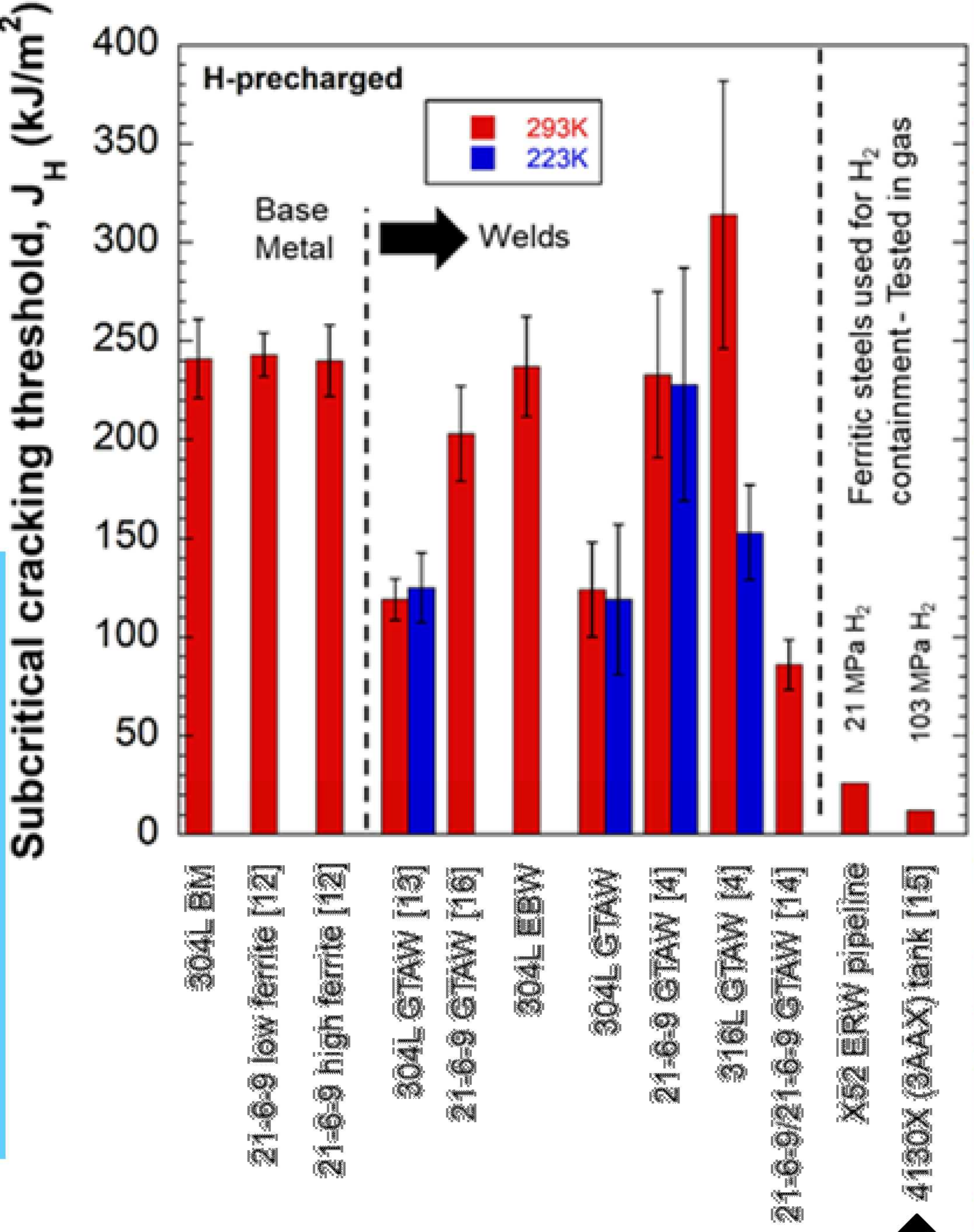


3-pt bend



General trends:

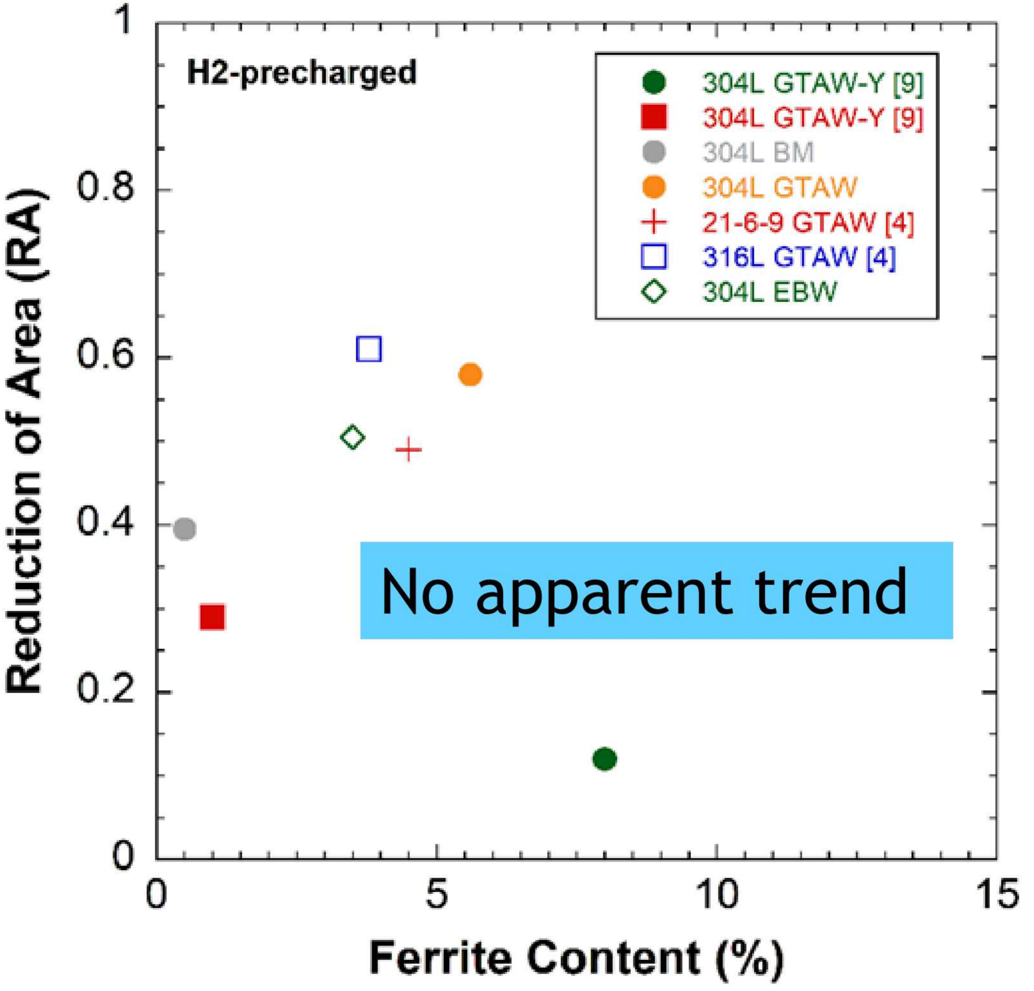
- Without H_2 → no detectable crack propagation
- Similar J_H values among base metals
- Welds exhibit reduction in J_H compared to base metals
  - Except 316L, 21-6-9 GTAWs and 304L EBW
- Low Temp has negligible effect on J_H for 304L and 21-6-9 welds but reduces 316L GTAW
- Comparison to ferritic steels (pressure vessel, pipeline) fracture resistance (J_H) is much greater in austenitic stainless steel welds



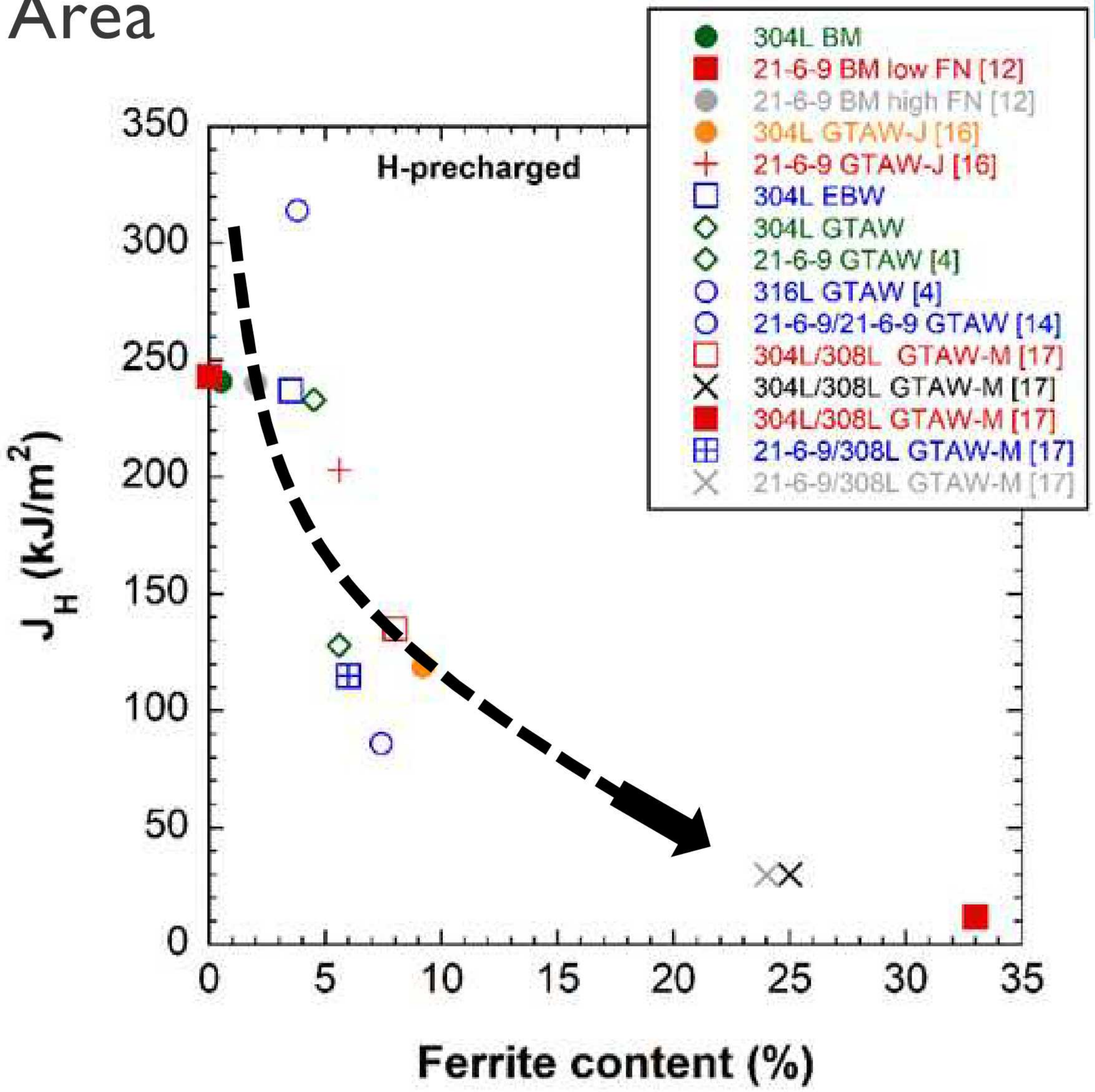
Laboratory gas cylinders

[4] Ronevich, 2017
[12] Nibur, 2009
[13] Jackson, 2013
[14] Somerday, 2009
[15] Nibur, 2012
[16] Jackson, 2012

Ferrite content appears to have larger affect on fracture threshold (J_H) than on Reduction of Area



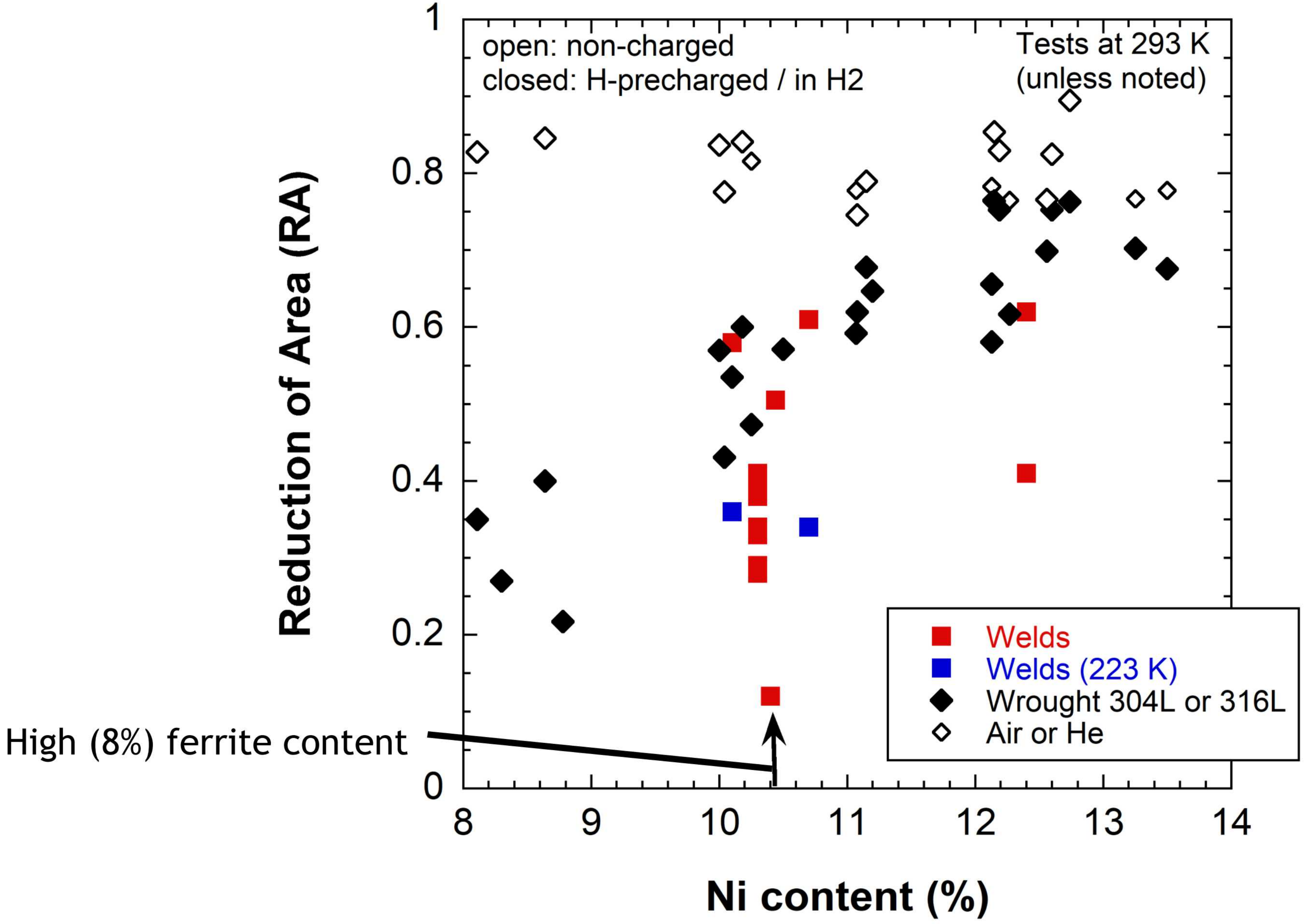
[4] Ronevich, 2017
[9] Younes, 2013



[4] Ronevich, 2017
[12] Nibur, 2009
[14] Somerday, 2009
[16] Jackson, 2012
[17] Morgan, 2005

Ferrite dendrites provide preferential path for cracks and results in reduced fracture resistance (J_H)

Increased nickel content appears to improve Reduction of Area in Welds similar to Base Metals



[4] Ronevich, 2017
[9] Younes, 2013
[10] Balch, 2015
[18] San Marchi, 2014
[19] Switzner, 2012

Summary

- Reduction of Area and fracture threshold were measured for two different 304L welds: Gas Tungsten Arc Weld (GTAW) and Electron Beam Weld (EBW)
- Finer microstructure and lack of aligned ferrite dendrites correlated with higher fracture resistance (J_H) in the E-beam weld
- Ferrite content appears to affect fracture resistance (J_H) in a detrimental manner more than it does Reduction of Area.
- Increasing nickel content appears to improve Reduction of Area in welds and base metals alike.
- Despite reduction of RA and J_H with hydrogen, austenitic stainless steel welds retain high ductility and toughness compared to other common materials of construction for high pressure hydrogen gas containment.

Questions

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[2] C. San Marchi, B. P. Somerday, X. Tang, and G. H. Schiroky, "Effects of alloy composition and strain hardening on tensile fracture of hydrogen-precharged type 316 stainless steels," *International Journal of Hydrogen Energy,* vol. 33, no. 2, pp. 889-904, 2008.

[4] J. Ronevich, C. San Marchi, and D. K. Balch, "Temperature effects on fracture thresholds of hydrogen precharged stainless steel welds PVP2017-65603," presented at the ASME 2017 Pressure Vessels & Piping Conference, Waikoloa, HI, 2017.

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[9] C. M. Younes, A. M. Steele, J. A. Nicholson, and C. J. Barnett, "Influence of hydrogen content on the tensile properties and fracture of austenitic stainless steel welds," *International Journal of Hydrogen Energy,* vol. 38, no. 11, pp. 4864-4876, 2013/04/15/ 2013.

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[12] K. A. Nibur, B. P. Somerday, D. K. Balch, and C. San Marchi, "The role of localized deformation in hydrogen-assisted crack propagation in 21Cr–6Ni–9Mn stainless steel," *Acta Materialia,* vol. 57, no. 13, pp. 3795-3809, 2009.

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[14] B. P. Somerday, M. Dadfarnia, D. K. Balch, K. A. Nibur, C. H. Cadden, and P. Sofronis, "Hydrogen-Assisted Crack Propagation in Austenitic Stainless Steel Fusion Welds," *Metallurgical and Materials Transactions A,* vol. 40, no. 10, pp. 2350-2362, 2009.

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