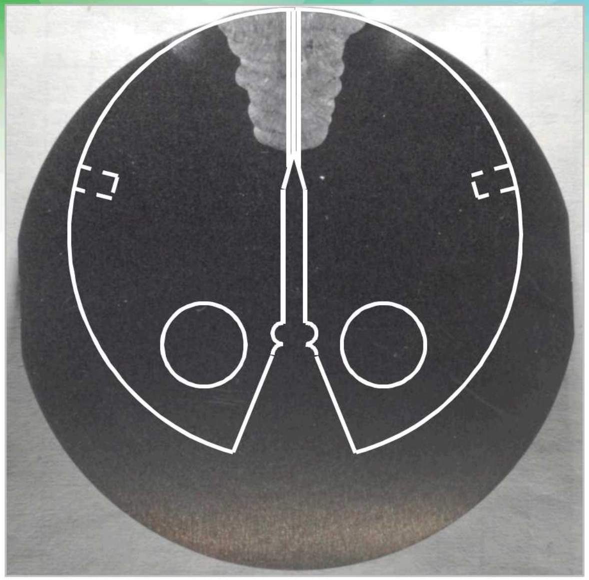
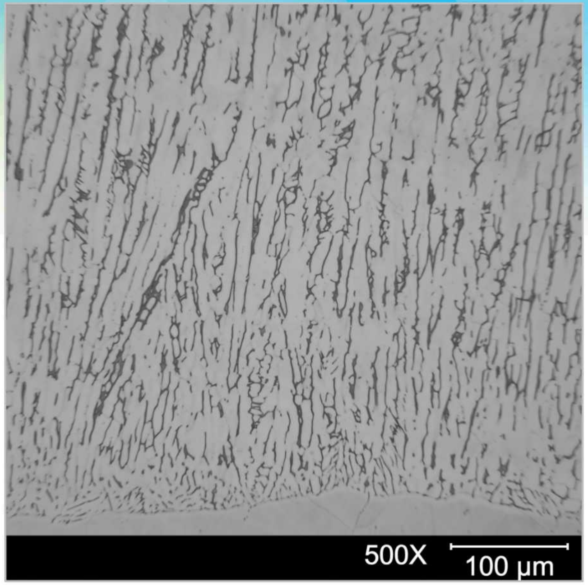
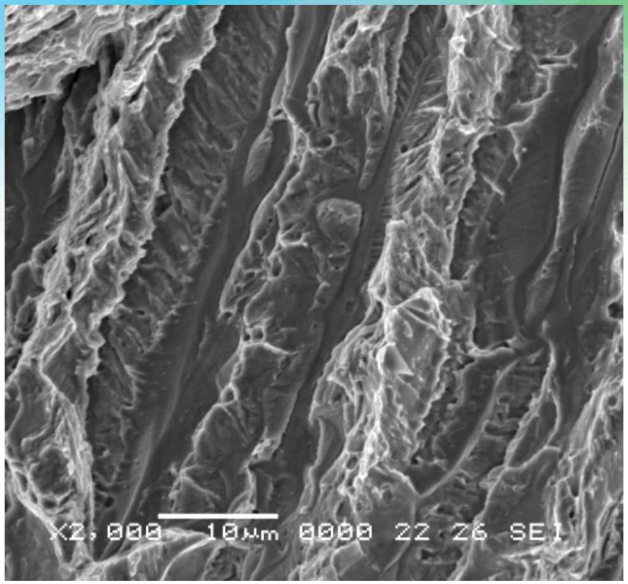
SAND2018-10200PE



Effects of Gaseous Hydrogen on Austenitic Stainless Steel Welds

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Derived from SAND2018-8850 PE

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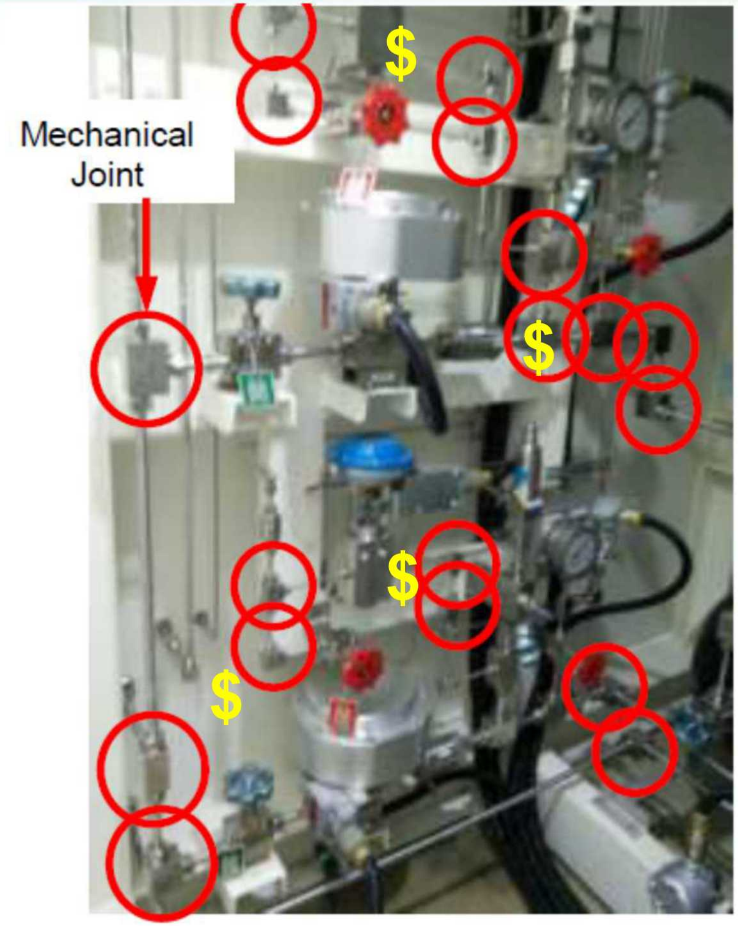
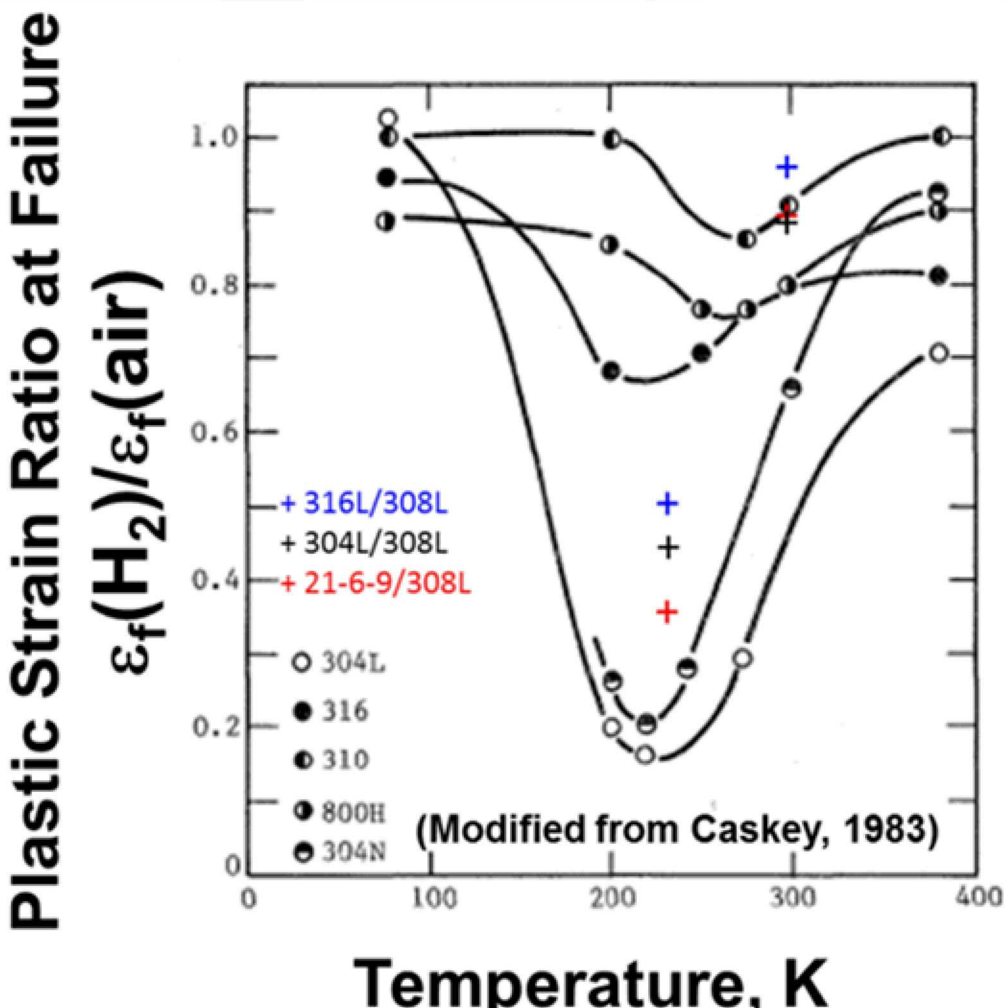
Welded joints are safely used in many hydrogen pressure systems

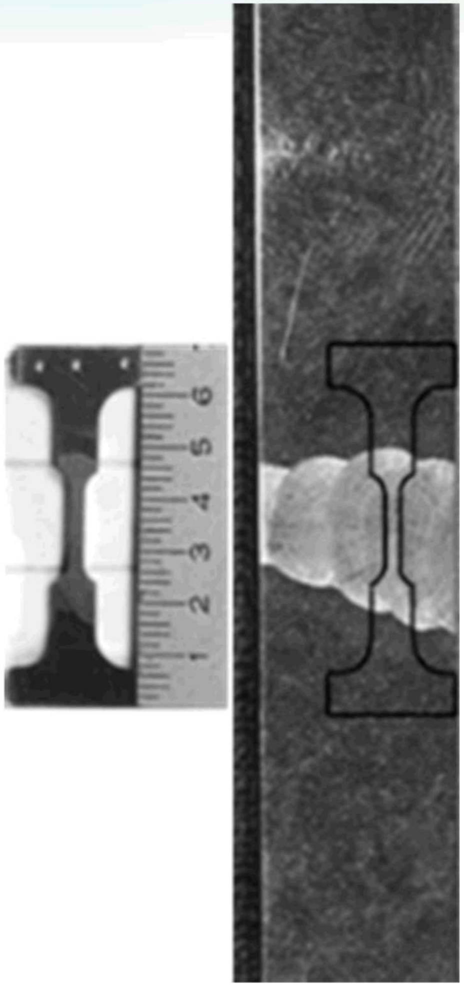
- Benefits of using welding over mechanical joints:
  - Lower cost
  - Reduce possibility of leaks
    - Improves safety
    - Reduces product loss
  - Less maintenance
    - Requires constant upkeep (re-tightening)
- Welded joints are used in hydrogen infrastructure



Fukumoto, ASME PVP2017-65155

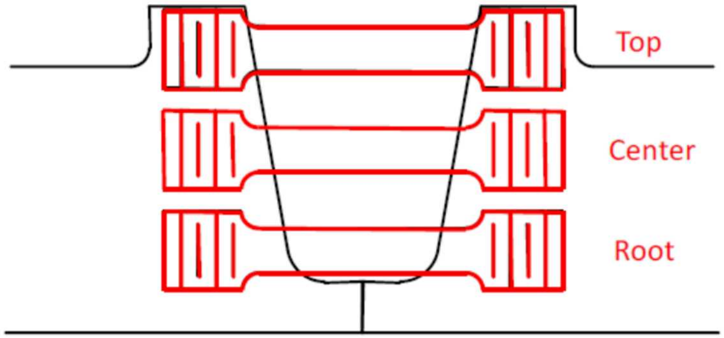
Ductility of GTA weld metal with internal H shows similar trends as base metal

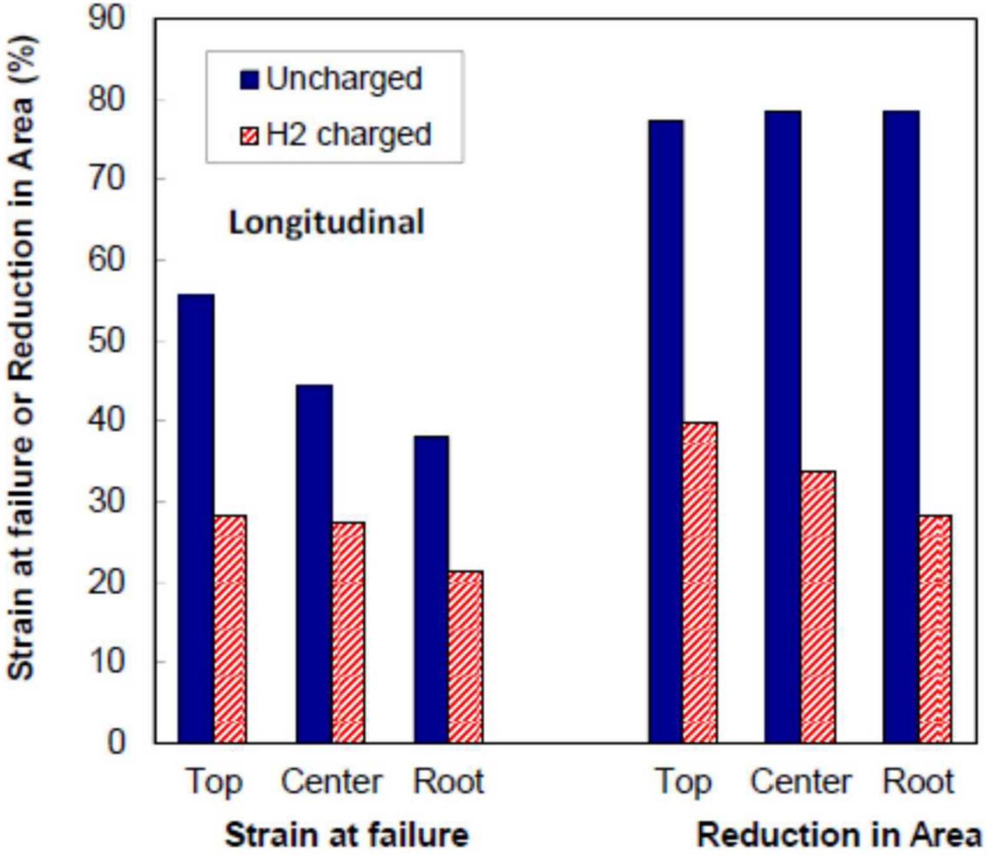




Ronevich, ASME PVP2017-65603

Tensile ductility of 304L/308L GTA welds show degradation but acceptable properties





Welds are characterized by gradients
- **Composition**
- **Ferrite**
- **Strength**
- **Ductility**

GTA = gas tungsten arc (also referred to as TIG)

Balch, ASME PVP2015-45591

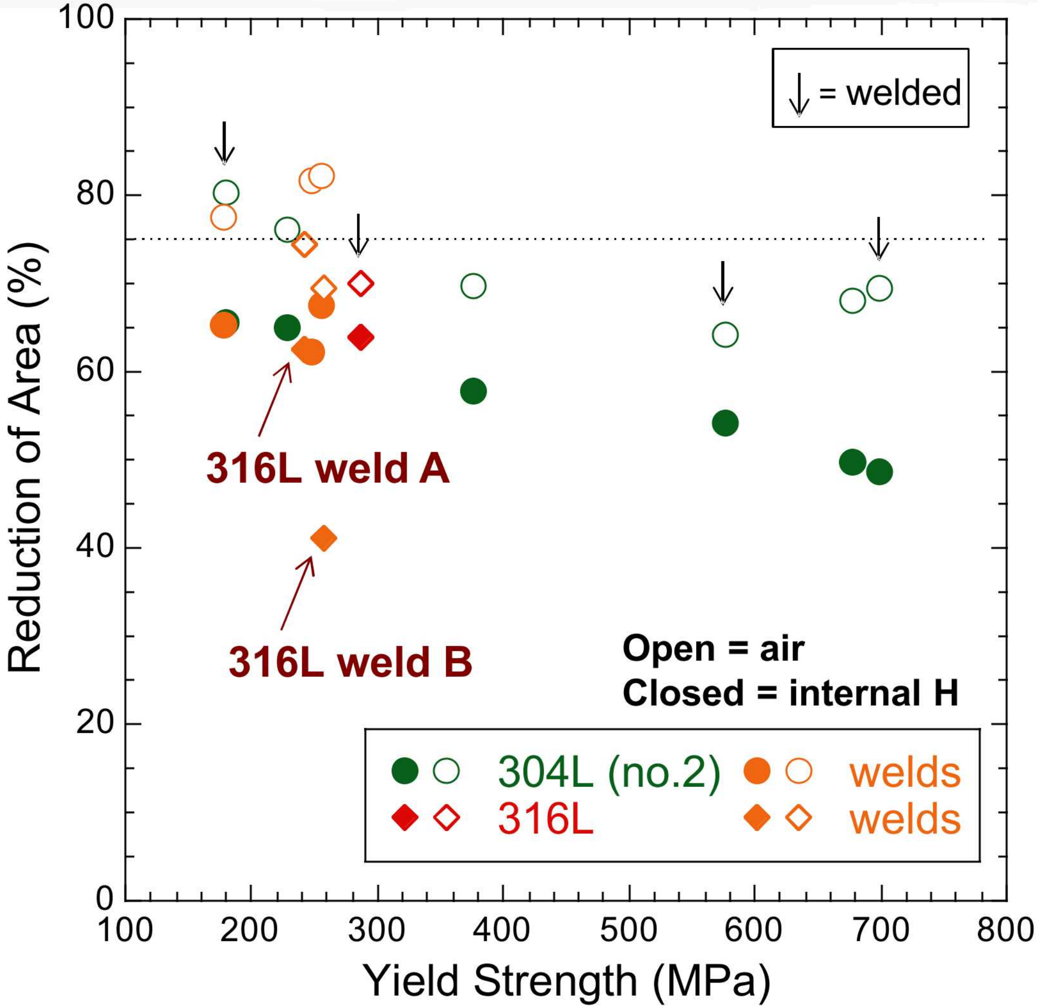
A variety of weld processes showed only small loss in RA when tested in hydrogen

Table 1. Tensile test data of the materials investigated

	UTS (MPa)	0.2YS (MPa)	El_t (%)	RA (%)	
Base metal	577	292	59.0	—	
SMAW weld	550	340	27.6	64.4	
	540	291	31.4	64.5	98 MPa H2
SAW weld	591	304	34.5	71.2	
	567	378	23.0	67.9	98 MPa H2
TIG weld	574	386	32.4	79.8	
	652	411	23.7	71.9	98 MPa H2

He, ASME PVP2018-84453

Orbital tube welds exhibited similar RA compared to tube base metal

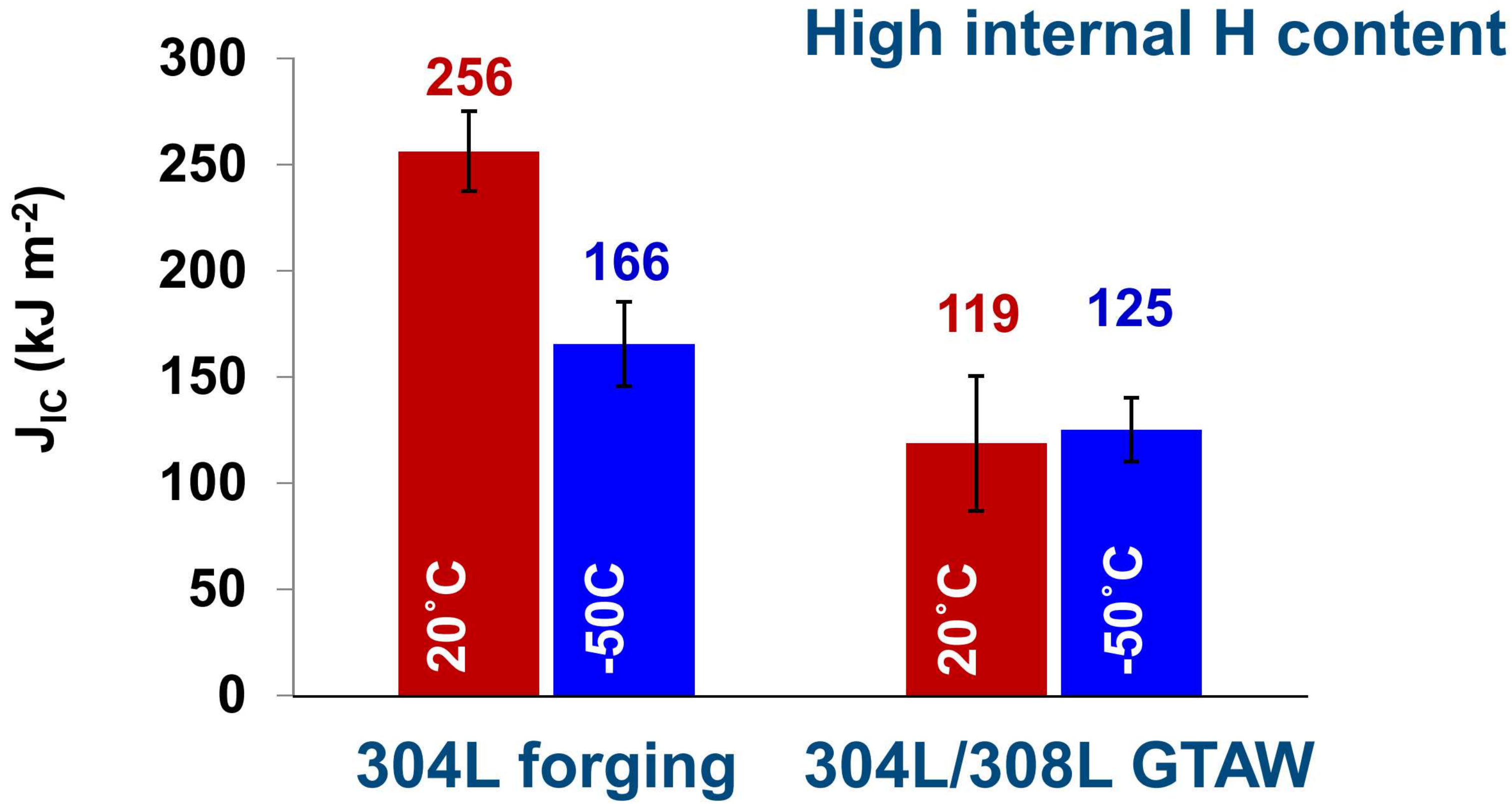


- The yield strength of the welded specimens are similar to annealed tubing
- Tensile ductility of welded specimens with internal H can be similar to tubing

- 316L welds (A and B) resulted in different effects of H
  - Weld B is still very ductile

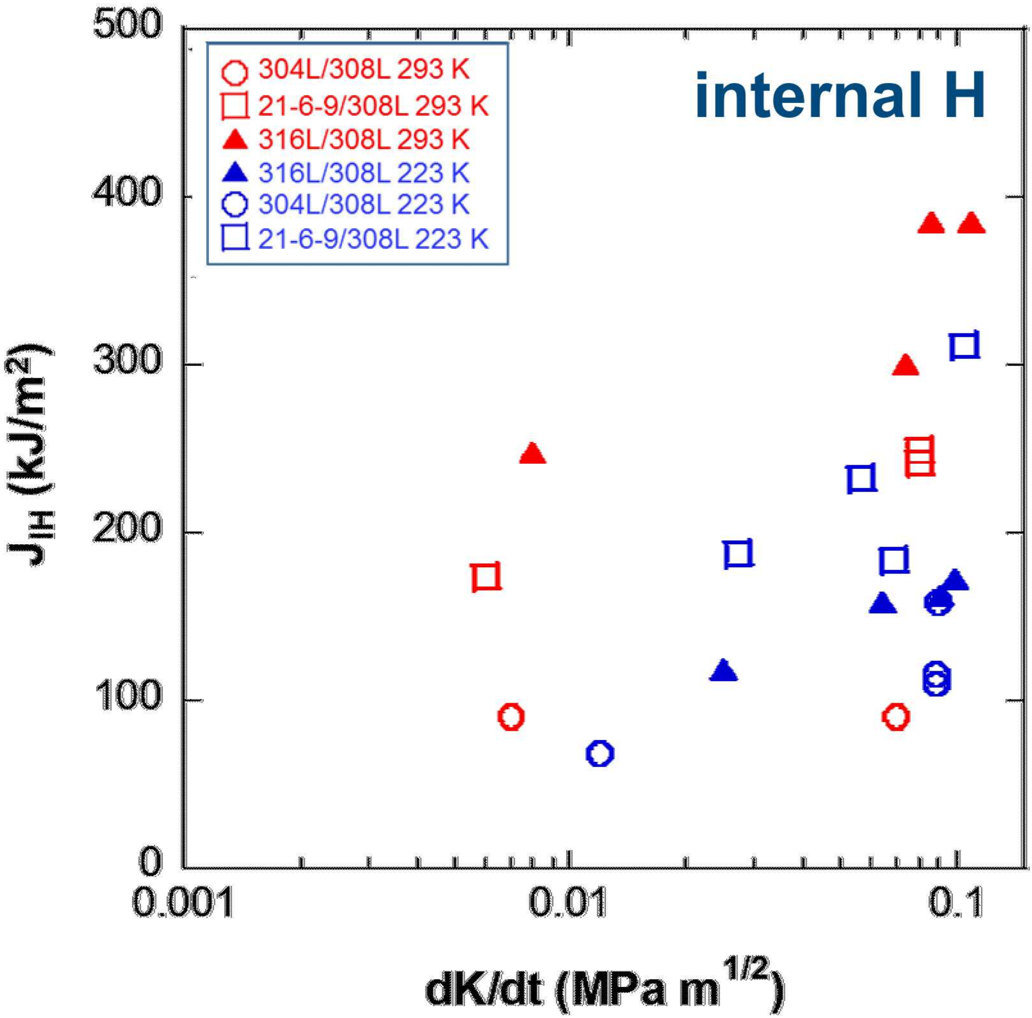
Hughes, IJHE 2014

Toughness of GTA welds is less than base metals, but remains very high – even at low temperature



Jackson, Corr Science 77 (2013)

Test rate effects can be apparent in fracture testing of GTA welds of austenitic stainless

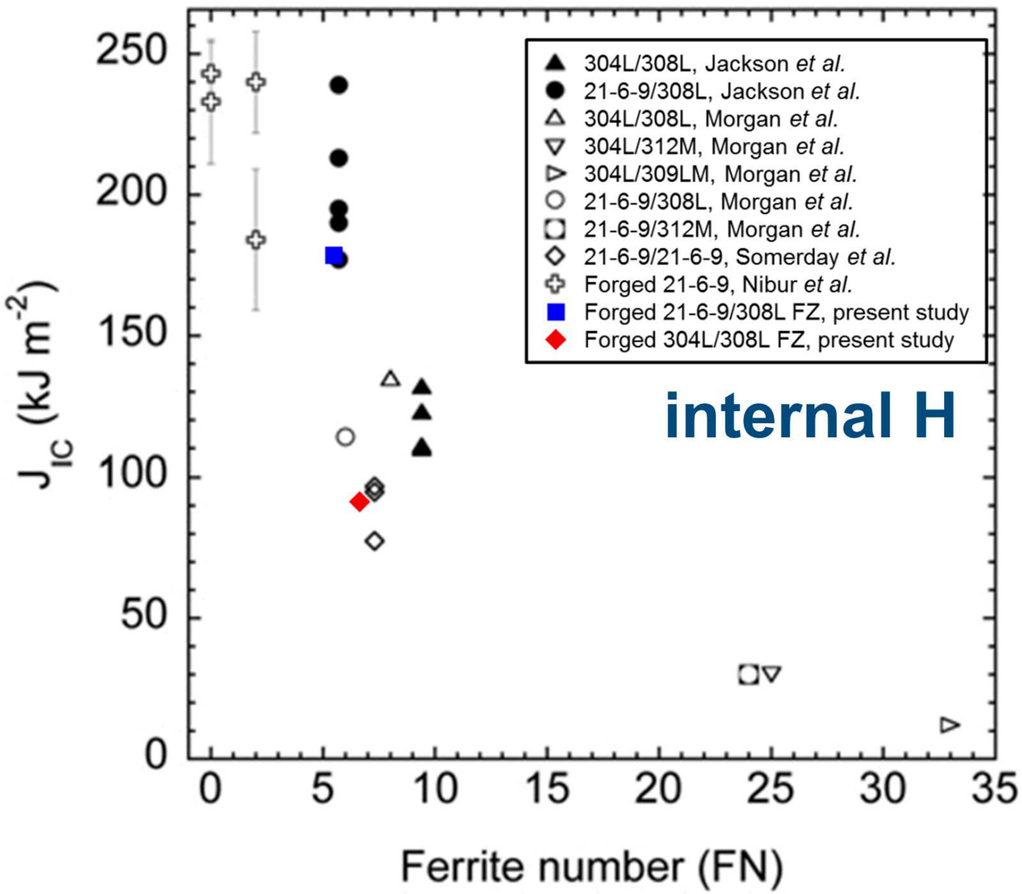


- Welds of diverse set of austenitic stainless steels show similar fracture trends
    - Especially at low temperature
- Fracture resistance remains relatively high, even for low temperature and low nickel content
- Same welds as for tensile testing

Ronevich, ASME PVP2017-65603

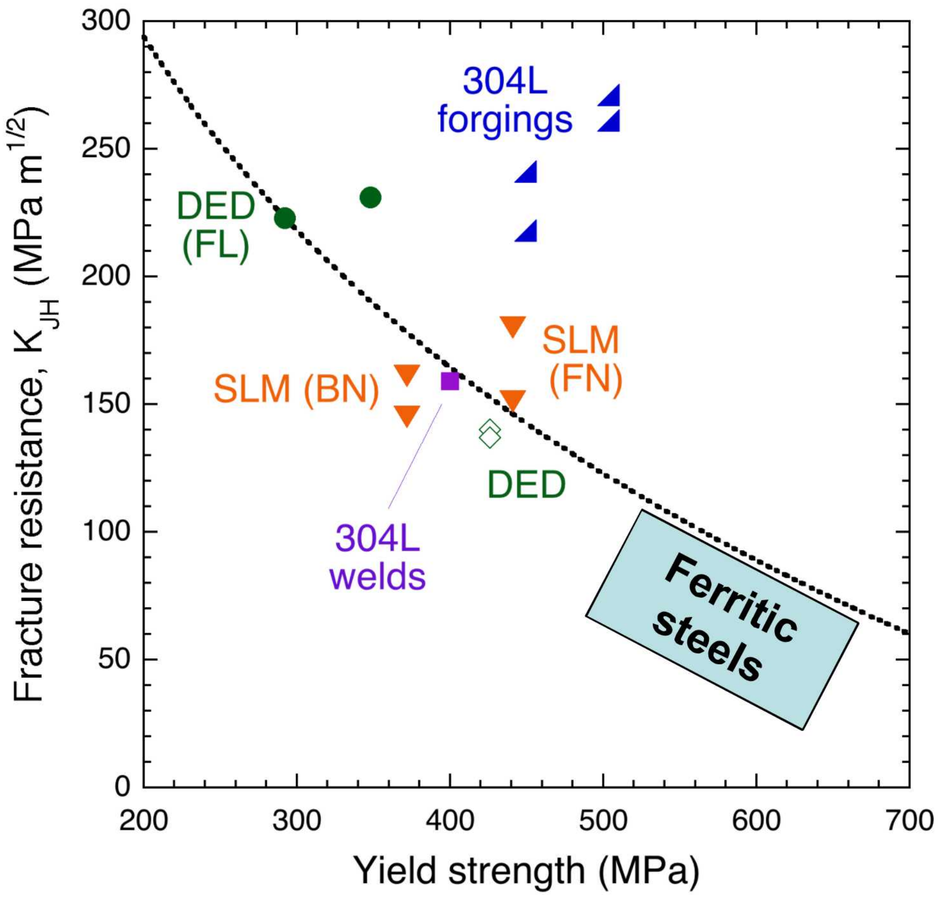
Fracture toughness of GTA welds decreases with increasing ferrite content

- Generic trend of lower fracture toughness with greater ferrite content
- Some ferrite is necessary to prevent solidification cracking during welding
- Fracture toughness remains large with hydrogen



Ronevich, PVP2015-45432: adapted from Jackson, Corr Science 60 (2012)

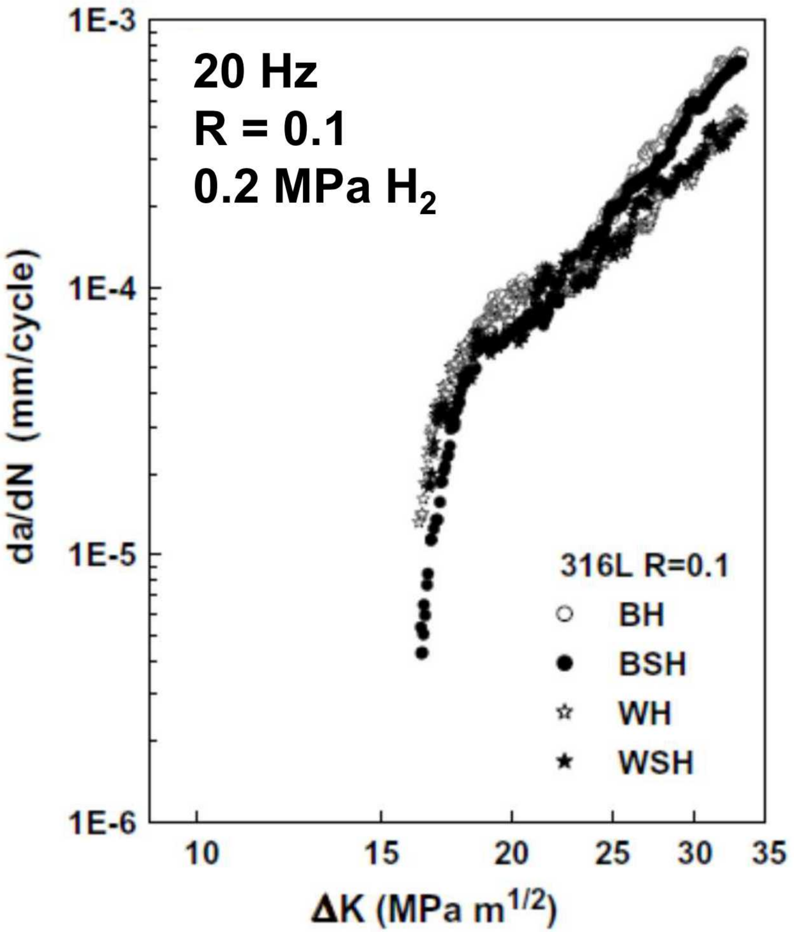
Fracture resistance of austenitic stainless steel welds is superior to pipeline steels



Ferritic steels

- **used for hydrogen pressure vessels and pipelines,**
- **display significantly lower fracture toughness than austenitic stainless steel welds**

Acceleration of fatigue crack growth of austenitic stainless steel welds in hydrogen is modest compared to low-alloy and carbon steels



- **Base metals and welds exhibit similar fatigue crack growth rates**

<u>316L base metal and autogenous weld</u>
B = base metal
BS = base metal sensitized (650C/100hr)
W = weld
WS = weld sensitized (650C/100hr)
H = indicates tested in H_2

Tsay, Corr Science (2008)

Summary of austenitic stainless steel welds tested with hydrogen

- Tensile ductility
  - Welds exhibit similar trends to base metals
  - temperature trends are similar
- Fracture toughness
  - Welds tend to exhibit greater reductions that base metal, but toughness remains high
  - Welds exhibit less temperature dependence
- Fatigue crack growth rate
  - Limited data on welds
  - Relatively similar behavior for base metals and welds
- Austenitic stainless steel welds retain their integrity in diverse hydrogen/stress environments much better than other welds which are commonly fielded (such as pipelines)