SAND2022-7657C

Influence of High Pressure Hydrogen Gas and Pre-Charged Hydrogen on Fatigue Crack Initiation and Fatigue Life of 255 Super Duplex Stainless Steel

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ASME Pressure Vessels and Piping Conference 2022

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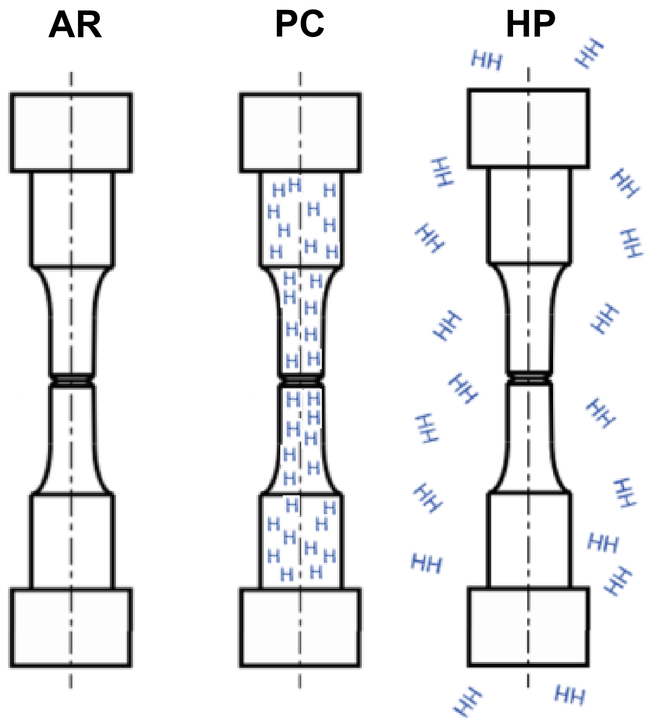
High-strength duplex stainless steel could be an alternative to lower strength austenitic stainless steels for components in hydrogen gas storage systems

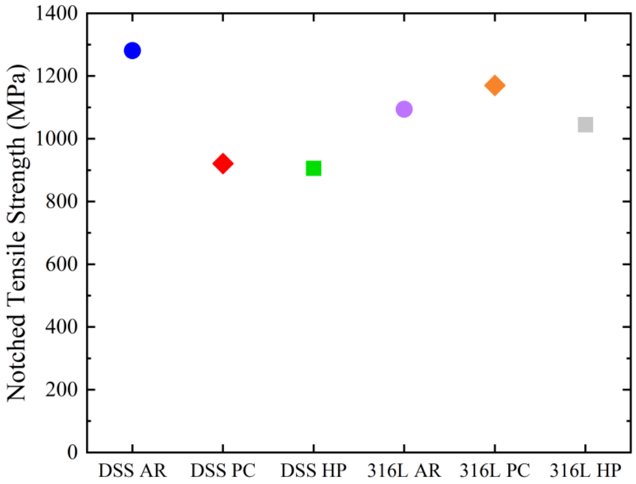
- Need to understand fatigue performance of austenite-ferrite duplex stainless steel in hydrogen environments
  - Compare results to strain-hardened 316L austenitic stainless
- Circumferentially-notched tensile (CNT) specimens (K_t=3.9) are fatigue tested in three different conditions
  - AR – as-received, in air
  - PC – pre-charged, 97 wt. ppm H
  - HP – high pressure, in 103 MPa H_2 gas
- Room temperature, constant load amplitude, R=0.1, f=1 Hz
- Direct current potential difference (DCPD) method to identify crack initiation
- One interrupted test for AR and PC conditions of electropolished specimens followed by EBSD to look at microstructural sites for crack initiation and growth

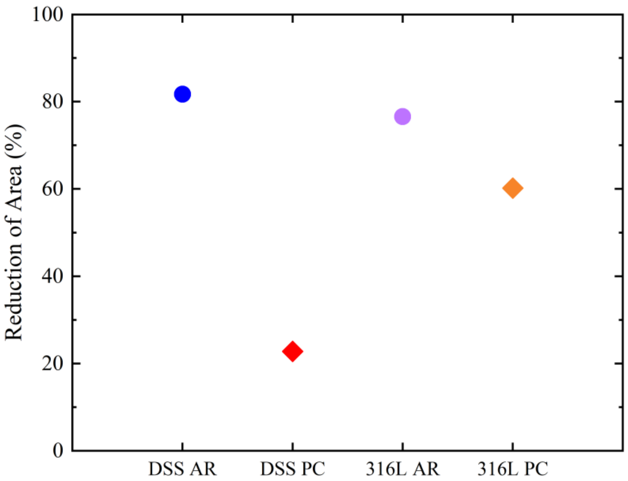
wt %	Cr	Ni	C	Mn	Si	Mo	N	Si	Fe
255 DSS Bar	25.9	6.21	0.018	0.87	0.38	3.28	0.224	0.38	Bal.
316L Bar	17.54	12.04	0.020	1.15	0.51	2.05	0.04	0.51	Bal.



High pressure hydrogen and pre-charged hydrogen decreased notch tensile strength of 255 DSS by a similar amount

Hydrogen decreased reduction of area and notched tensile strength of 255 DSS more than for 316L



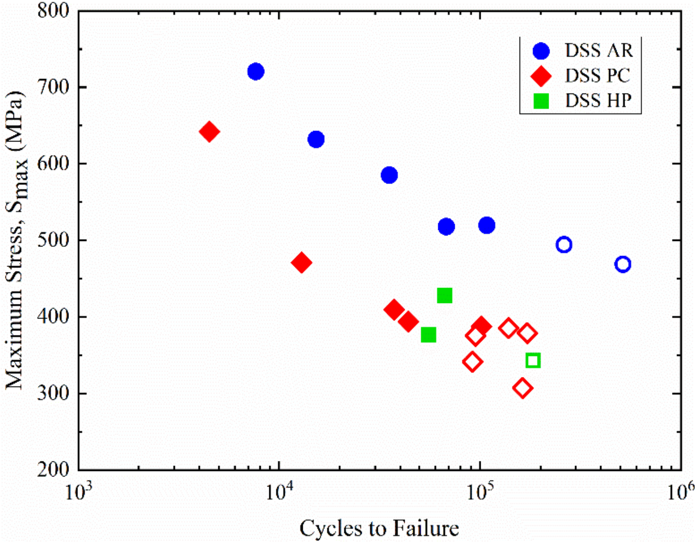


	RNTS PC	RNTS HP	RRA PC
255 DSS	0.72	0.71	0.28
316L	1.07	0.96	0.79

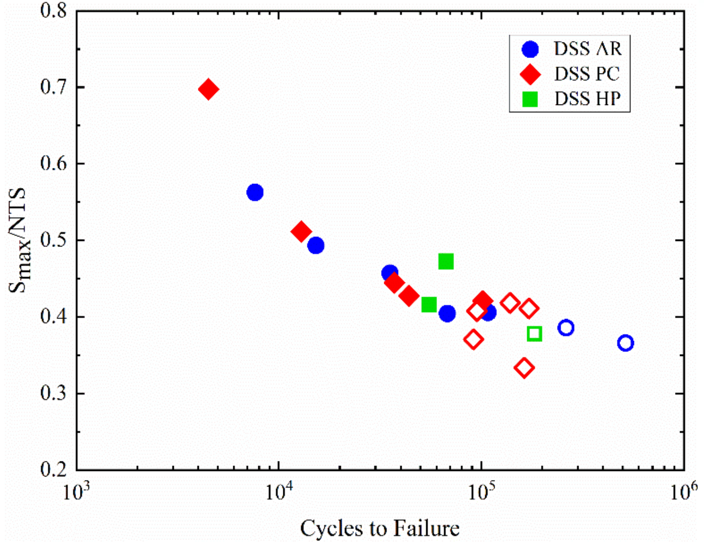
255 DSS has higher yield strength and ultimate tensile strength than strain-hardened 316L

	YS (MPa)	UTS (MPa)
255 DSS AR	708	852
316L AR	573	731

External hydrogen (HP) and internal hydrogen (PC) decreased fatigue life of 255 DSS by a similar amount



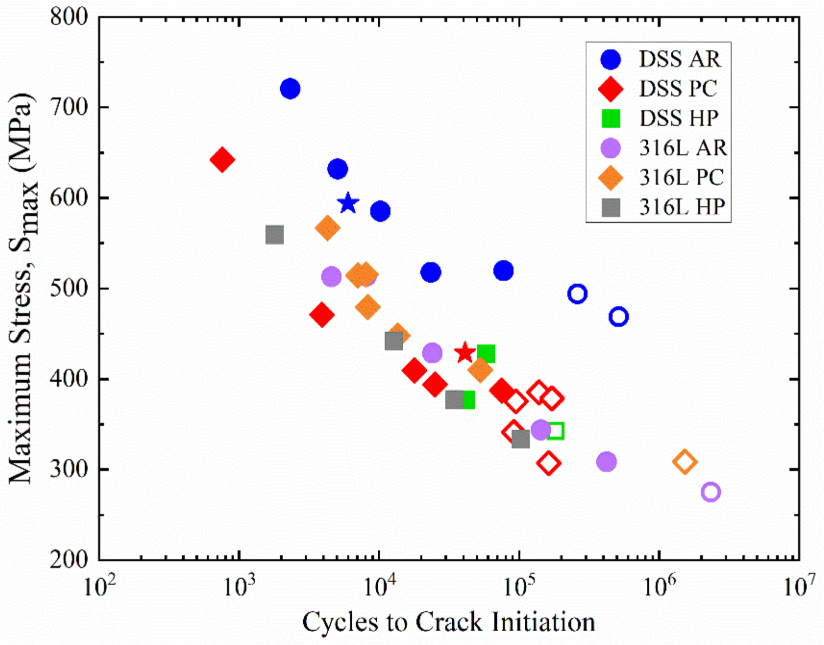
Empty symbols are tests that didn't reach failure



Normalization of applied stress by notched tensile stress (NTS) resulted in convergence of S-N curves

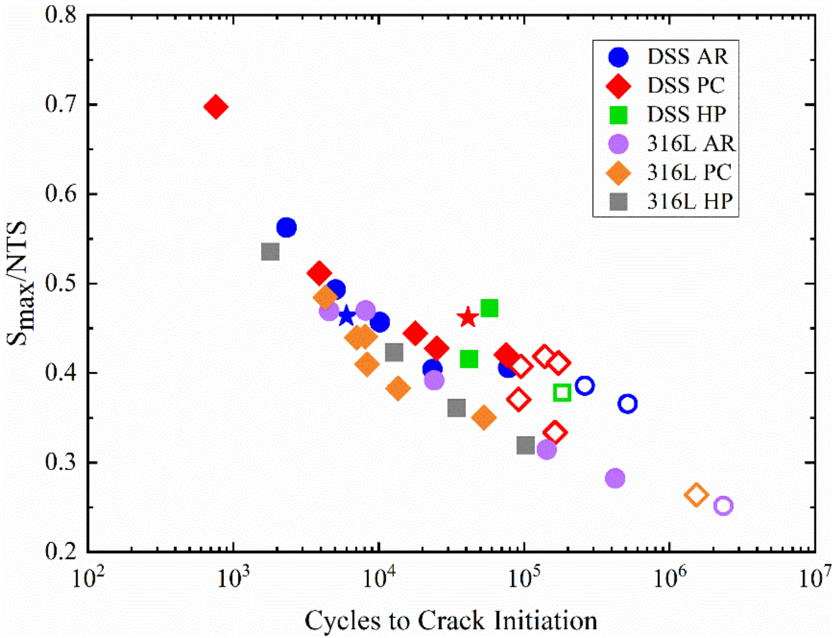
255 DSS and 316L have similar cycles to crack initiation in high pressure hydrogen and with pre-charged hydrogen

- Greater cycles to crack initiation for 255 DSS than for 316L in AR condition
  - Likely due to higher strength of 255 DSS
- Smaller decrease in cycles to crack initiation with hydrogen for 316L than for 255 DSS
- 255 DSS and 316L show similar fatigue life and crack initiation in hydrogen environments because the greater effect of hydrogen on 255 DSS is balanced by the greater strength level
- Cycles to failure and cycles to crack initiation show the same trends for both alloys



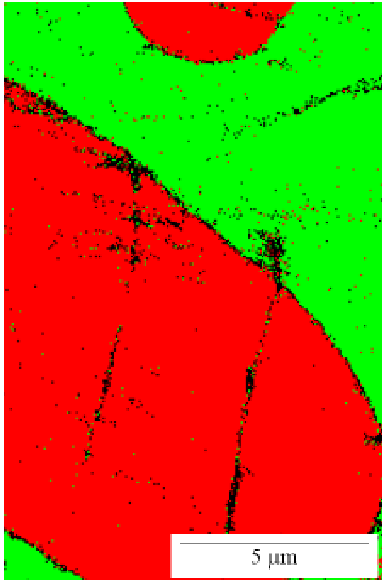
Normalization by the NTS collapsed the 255 DSS S-N_i curves into a single band and the 316L S-N_i curves into a separate band

- Fatigue life and NTS may both be dictated by the evolution of the stress state at the notch and the effect of hydrogen on the deformation processes, which may be similar in tension and fatigue
- Collapse of 255 DSS and 316L S-N_i curves into separate bands may be due to significant microstructural differences

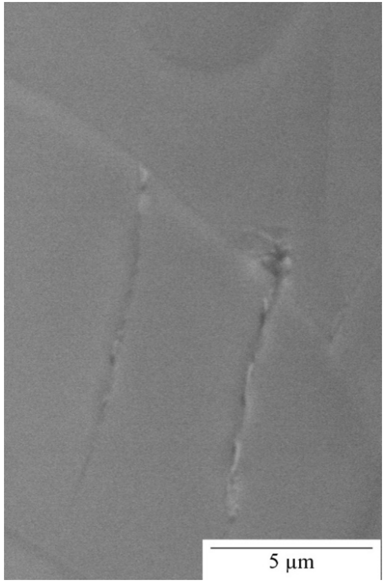


EBSD of cracks in notches: Smallest cracks in 255 DSS were observed in austenite in AR condition

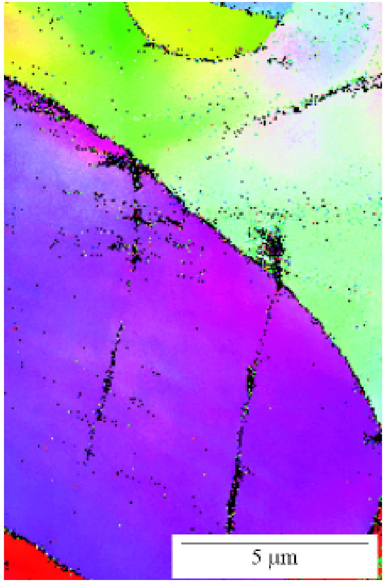
- EBSD scans performed in notch of electropolished specimens interrupted shortly after crack initiation
- Smallest cracks intersected γ/α phase boundary and propagated through austenite island
- No cracks smaller than 40 µm were observed in PC condition

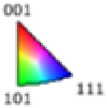


γ (austenite) – red
α (ferrite) - green



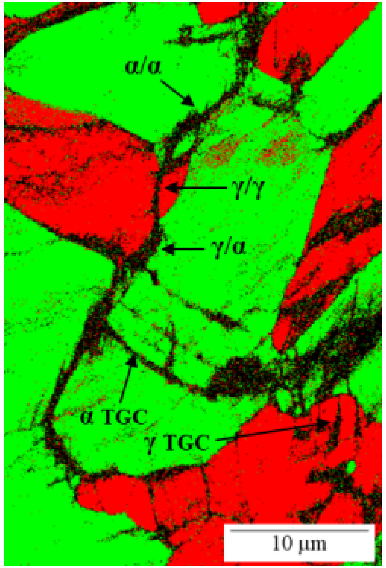
SEM image 255 DSS AR





In AR condition cracks propagated along γ/α phase boundaries, α/α grain boundaries, γ/γ grain boundaries, and transgranular through γ and α

- Transgranular cracks propagating parallel to slip traces were observed in both the austenite and ferrite
- Cracks observed to intersect triple points



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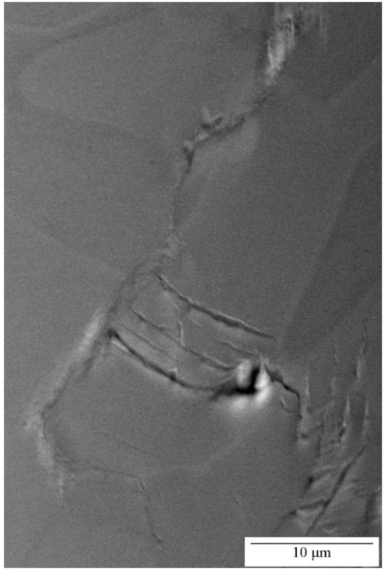
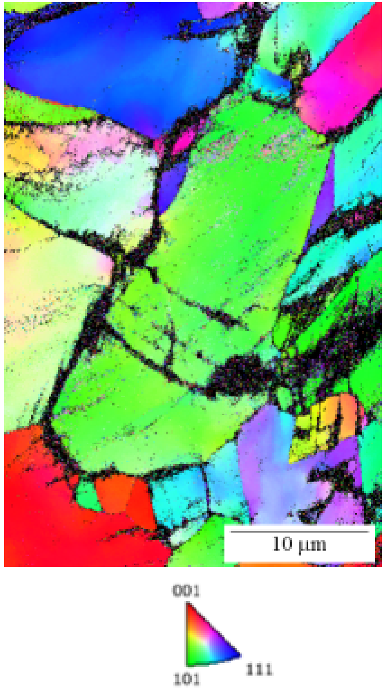
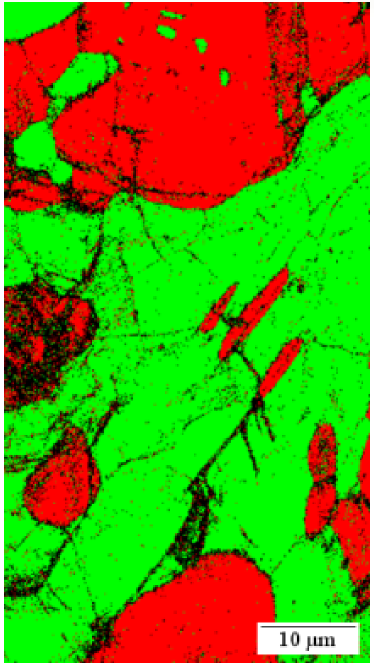


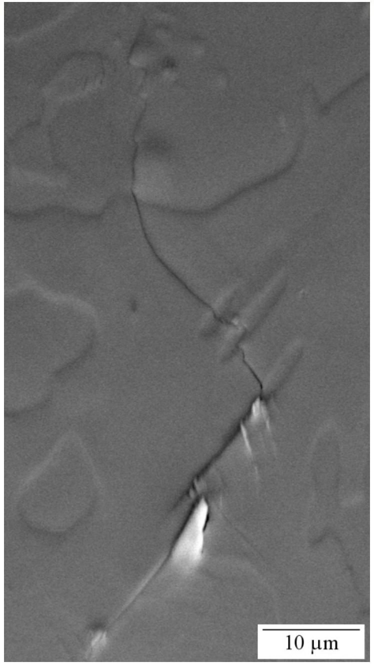
SEM image 255 DSS AR



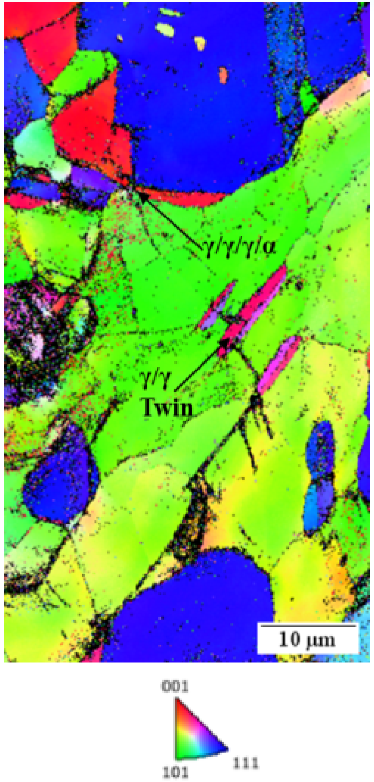
Cracks in 255 DSS PC condition propagated along twin boundaries in γ, in addition to along phase boundaries and transgranular through γ and α



γ (austenite) – red
α (ferrite) - green



SEM image 255 DSS PC



- Cracks in PC condition also intersected triple points and quadruple points
- Triple points, austenite islands, and phase and grain boundaries likely act as microstructural stress concentrators at which crack initiation occurs and through which cracks preferentiall propagate for both AR and PC conditions
- Fatigue crack propagation sites are different for 255 DSS than previously observed for strain-hardened 316L (entirely transgranular and not parallel to slip traces)

Summary

- High pressure hydrogen gas (HP) and pre-charged hydrogen (PC) similarly decreased the fatigue life and cycles to crack initiation of 255 duplex stainless steel.
- Normalization of the applied stress by the notched tensile stress caused the S-N curves of 255 DSS for HP and PC environments to collapse into a narrow band with the as-received (AR) condition.
- 255 DSS exhibited similar fatigue life to strain-hardened 316L with external (HP) and internal (PC) hydrogen.
- Cycles to crack initiation determined with DCPD exhibited the same trends as cycles to failure for 255 DSS.
- For both with and without internal hydrogen, small cracks in 255 DSS appeared to preferentially intersect microstructural stress concentrators, including phase boundaries, grain boundaries, austenite islands, and triple points.

Questions?

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