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Hydrogen Accelerated Fatigue Crack Growth of Multiple X100 Pipeline Steel Welds

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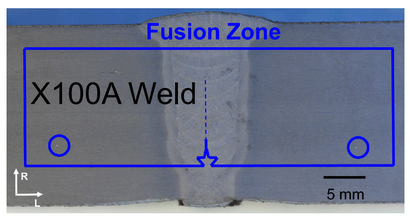
Purpose

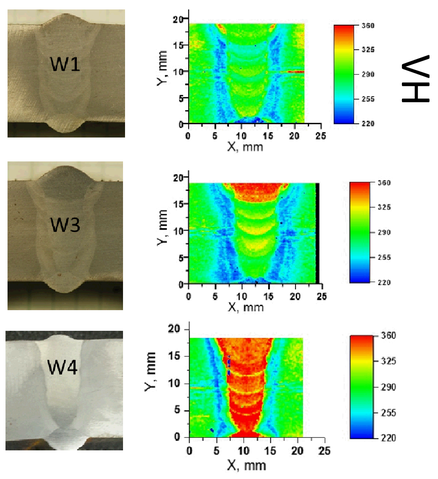
- Measure fatigue crack growth rates (FCGR) of 4 different consumable welds fabricated from same X100 base metal
  - De-couple residual stress effects from FCGR
- Compare performance to lower strength welds

X100 Consumable Welded Pipe

1) Original X100A Girth weld (anonymous vendor)
2) W1 – ER100S-G weld wire
3) W3 – ER120S-1 weld wire
4) W4 – Low Transformation Temp. Wire (LTTW)

*Fabricated from same X100 base metal

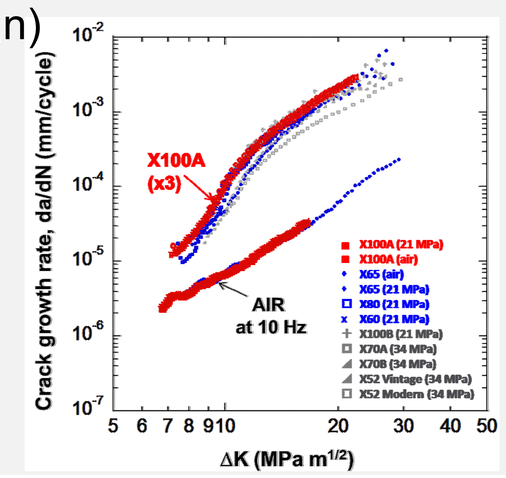




- ASTM E647 test coupons (ESET) were removed from weld
- Crack propagated radially from I.D. to O.D.

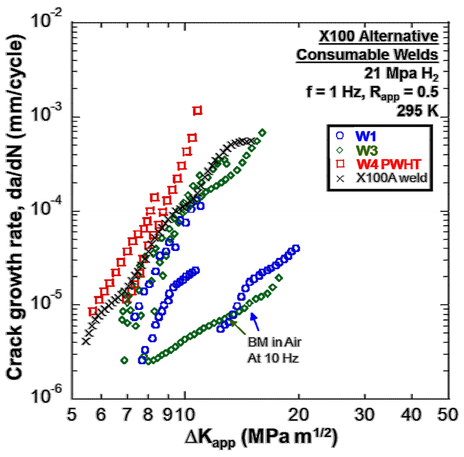
Code Limitations on Using Higher Strength Pipe

- Hydrogen Piping and Pipeline ASME B31.12 Code places limitations on specified min. yield strength of hydrogen pipe
  - For Prescriptive design, < 482 MPa (X70)
  - For Performance-based design, < 551 MPa (X80)
- Thickness premiums are required on strengths greater than 358 MPa (under Prescriptive design)
- Conservatism limits cost savings achievable by using higher strength, thinner walled pipes
- Recent testing has shown similar fatigue behavior in high strength (>690 MPa) compared to lower strength steels in H_2 gas

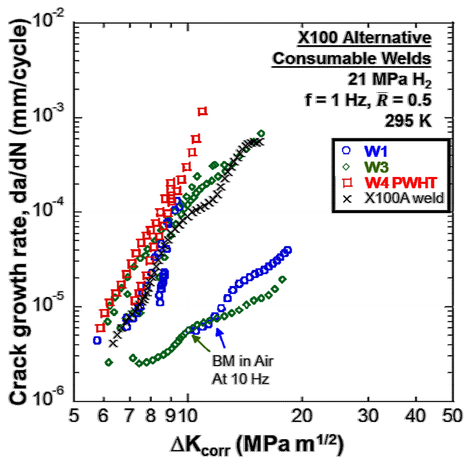


Fatigue Crack Growth Rate (FCGR)

Raw $\Delta K_{applied}$ data → ΔK_{corr}: σ_{res} effects removed



** PWHT= post weld heat treated



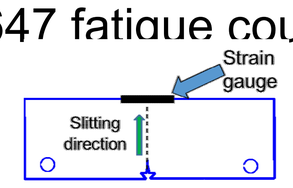
$$K_{norm} = (\Delta K)^{1-n} * \left(K_{max-app} + K_{res}\right)^{n}$$

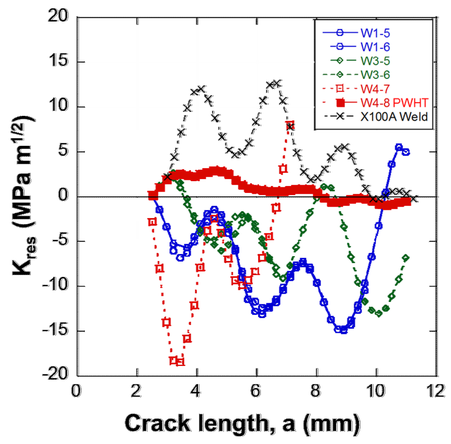
$$\Delta K_{corr} = K_{norm} * (1 - \bar{R})^{n} \text{ where n=0.25}$$
And $\bar{R}$ = 0.5

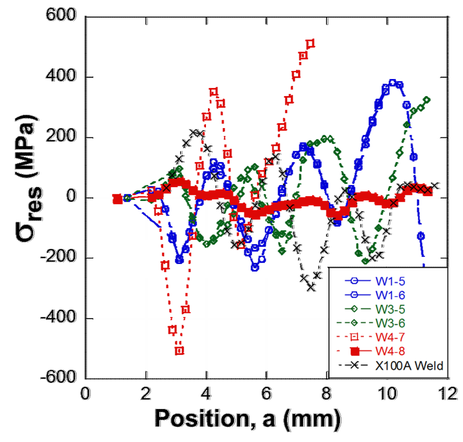
- All X100 weld data exhibit hydrogen accelerated FCGR
- Removal of σ_{res} shifted FCGR curves & reduced scatter

Residual Stress Measurements

- Slitting method on identical ASTM E647 fatigue coupon
  - Mount strain gauge on back face
  - Extend wire EDM and make incremental measurements of strain

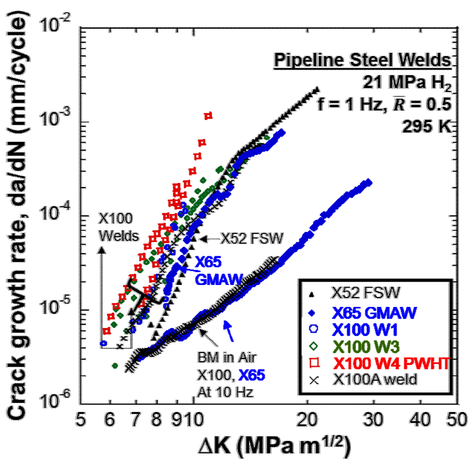






- Significant σ_{res} and K_{res} values were measured in welds which influence R-ratio $R_{tot} = \frac{K_{min} + K_{res}}{K_{max} + K_{res}}$
- Additional corrections to FCGR curves made to adjust ΔK to account for R_{tot} → da/dN vs ΔK_{corr}
- Post weld heat treatment (PWHT) performed on W4 to relieve large compressive σ_{res} to allow testing

Higher Strength vs Lower Strength Welds



- Higher strength welds appear to have higher FCGR at low ΔK (< 10 MPa $m^{1/2}$)
- Higher FCGR does not preclude use of high strength pipeline welds but needs to be accounted for in design

Conclusions

- Four different X100 welds exhibited similar hydrogen-assisted fatigue after K_{res} effects are removed.
- Higher strength welds appear to exhibit higher FCGR compared to lower strength welds.
- Measurements of FCGR on high strength steels welds inform potential acceptance of higher strength pipes into hydrogen infrastructure