Update on SCC CGR tests on Alloys 690/52/152 at ANL – June 2011

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Presentation Topics

- Experimental approach
- SCC of 52M/182 WOL
- SCC of Alloy 152 Weld
- SCC of Alloy 690 HAZ

Experimental Approach - Transitioning to SCC

- ANL approach very similar to the widely-used method (increasing R and decreasing frequency) but with a few differences:

  - Precracking is always conducted in the environment[1]
  - Use of slow/fast sawtooth with increasing rise times
    - Loading takes into account possible ΔK and ΔK_{th} effects[2]
  - Monitor specimen response
    - Calculate cyclic CGRs based on rise time[3]
    - Monitor cyclic rates for environmental enhancement [4]
  - Attempt to transition only from those conditions that show environmental enhancement

[1] Provides (essential) baseline cyclic data

[2] $\Delta K/\Delta K_{th}$ effects have been observed/formulated for Alloy 690

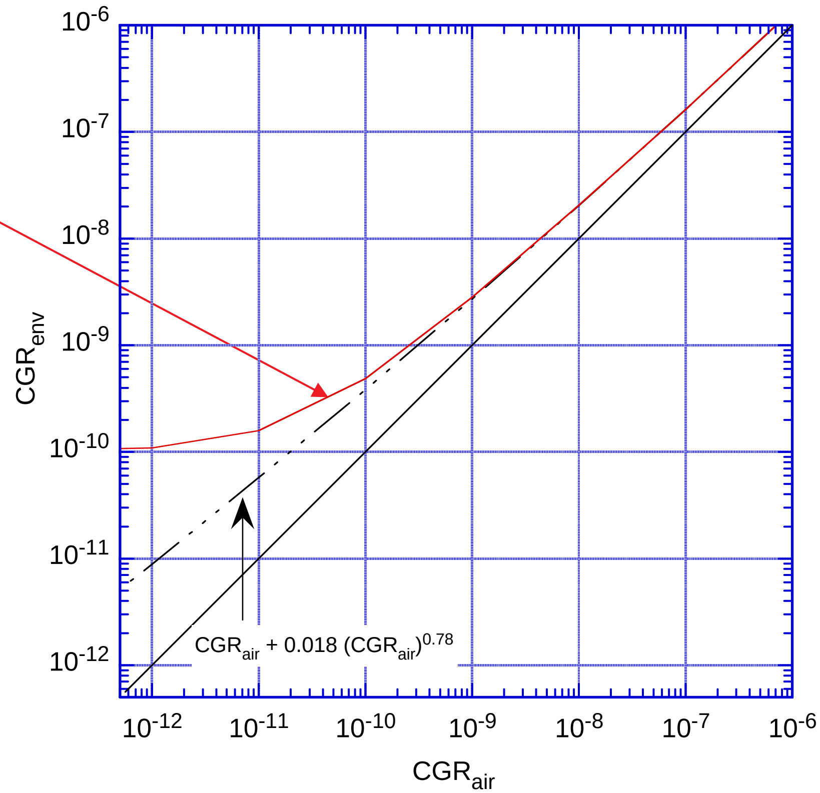
[3] Well-characterized cyclic CGR also enables the calculation of the SCC component for periods with hold times or constant load with periodic unloading

[4] Accomplished by plotting the measured in the environment vs. the rates that would be expected in air under the same loading conditions

*The Analysis of Cyclic CGR Data**

- Superposition model (Kassner & Shack)

$$\dot{a}_{env} = \dot{a}_{air} + \dot{a}_{CF} + \dot{a}_{SCC}$$

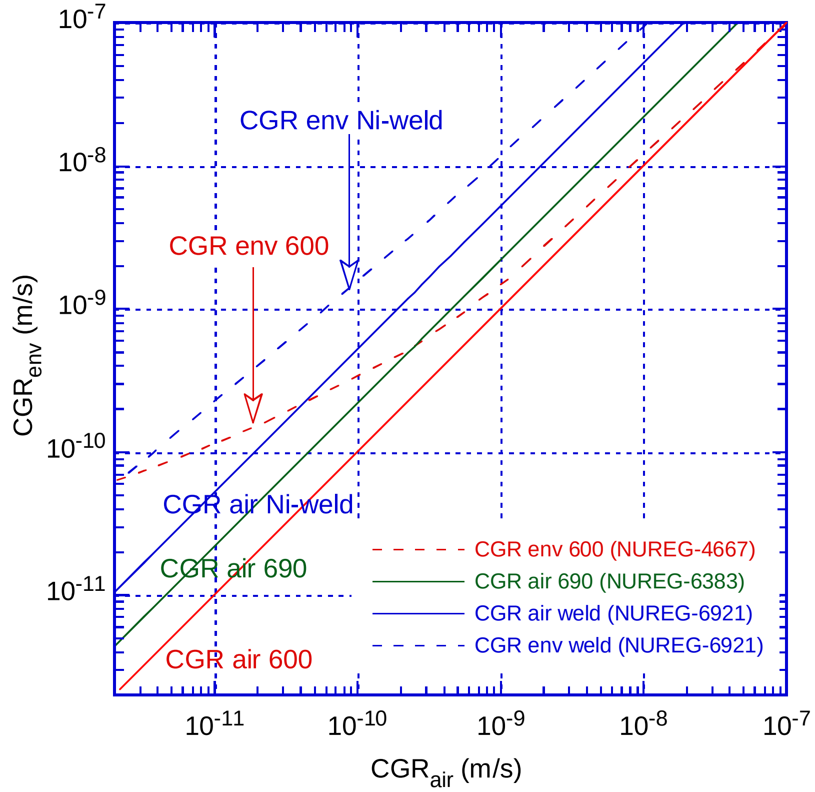


- *For Ni-welds:

$$\dot{a}_{air} + \dot{a}_{CF} = \dot{a}_{air} + 0.018 \cdot (\dot{a}_{air})^{0.78}$$

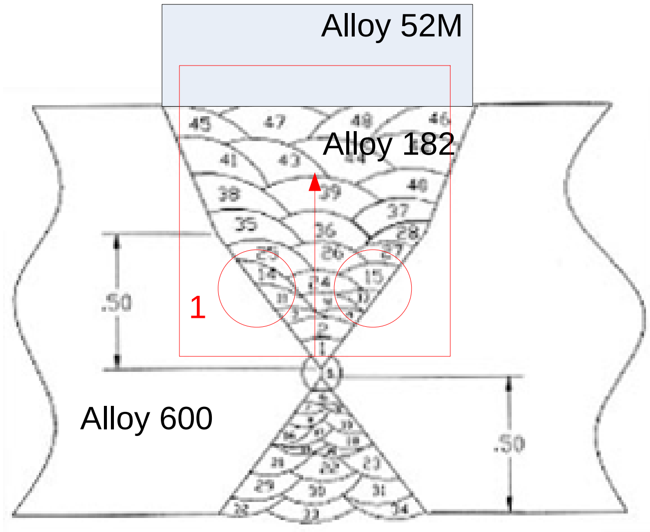
$$\dot{a}_{SCC} = \alpha \exp\left[-\frac{Q}{R}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right] K^{\beta}$$

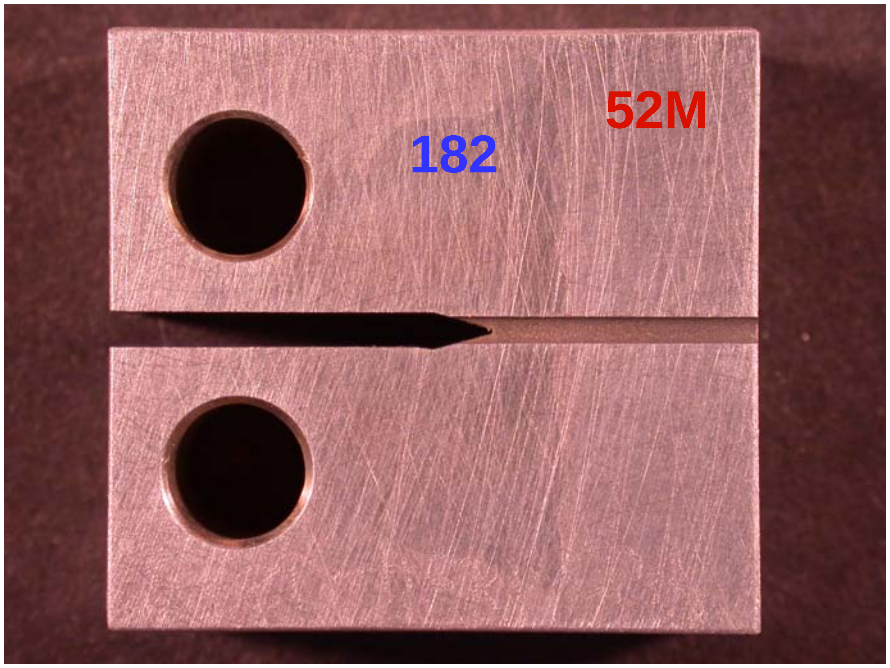
Expected behavior of cyclic rates: Alloys 600, 690, Ni-Alloy Weld



- Correlations established at ANL for a variety of alloys
- Fatigue behavior is highly reproducible

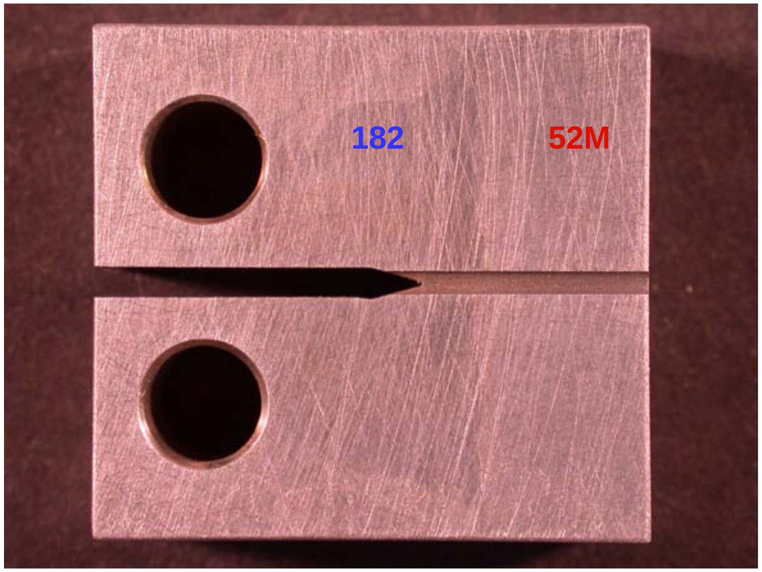
Alloy 52M/182 Weld Overlay

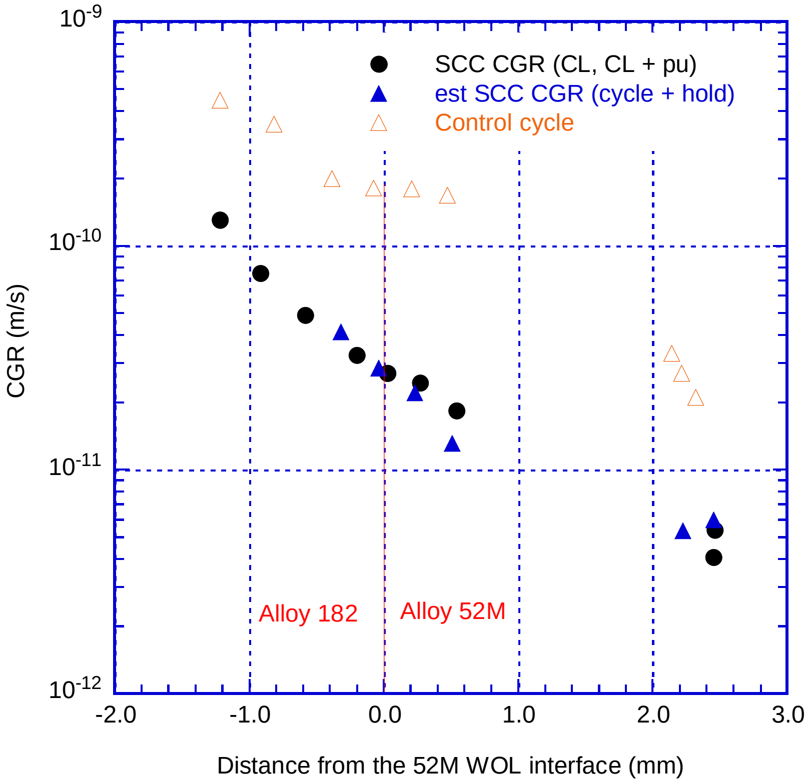




- Alloy 182 weld tested previously (without the WOL)
- Alloy 52M (Special Metals, Heat NX75W1TK) welded at ANL Central Shops using parameters used by industry
- CGR test objective: attempt to transition an SCC crack from Alloy 182 into 52M

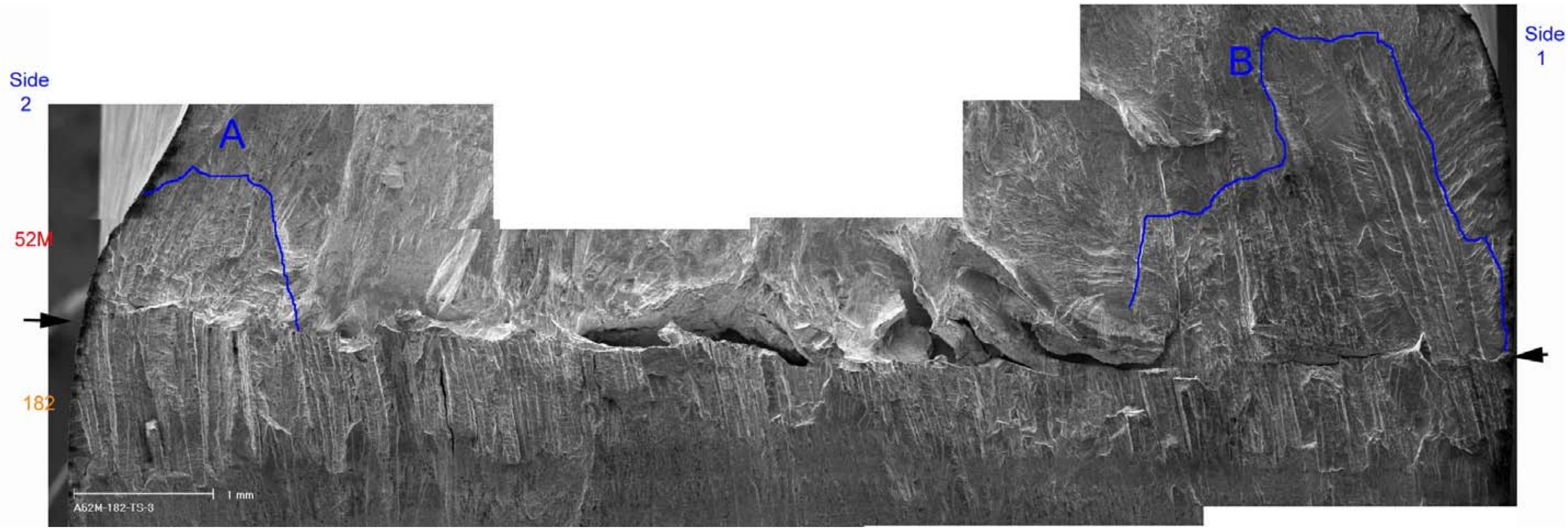
Alloy 52M/182 Weld Overlay – Summary of SCC CGR data vs. distance to the interface





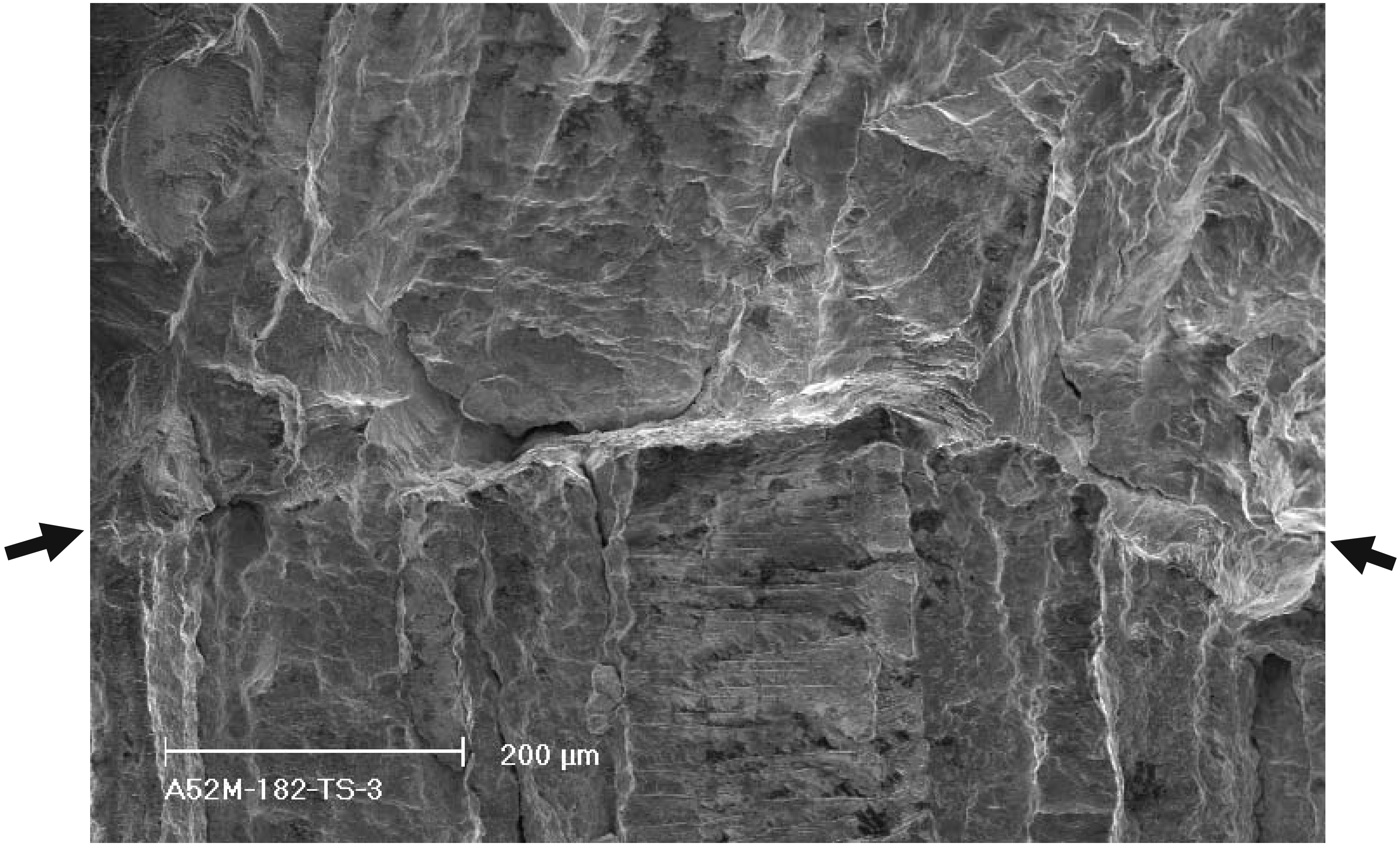
- SCC CGRs decrease as the crack approaches the interface, continues to decrease past the interface
- Control cyclic rates mirror the SCC behavior

Alloy 52M/182 WOL – Fracture Surface 1



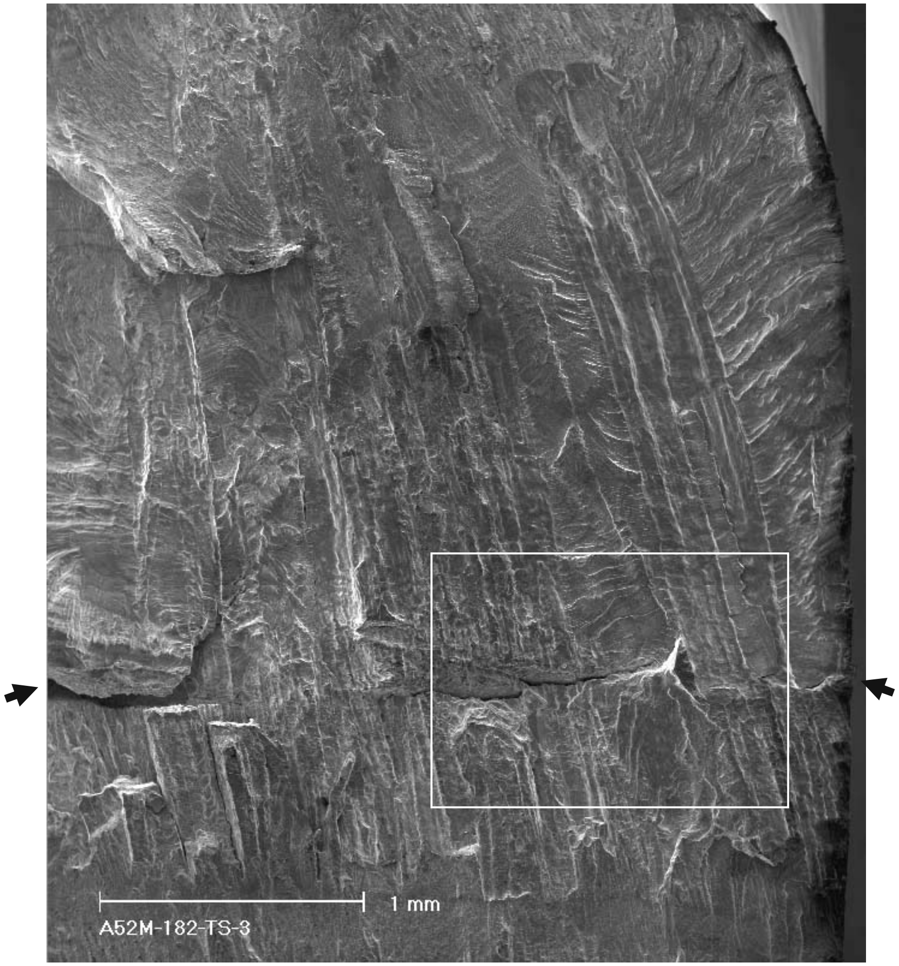
- Partial (40%) growth into Alloy 52M
- Areas A + B: average growth 0.35 mm, average CGR ≈ 3 × 10^{-11} m/s (consistent with DC potential)
- Area B: max growth 2.5 mm, max CGR ≈ 2 × 10^{-10} m/s

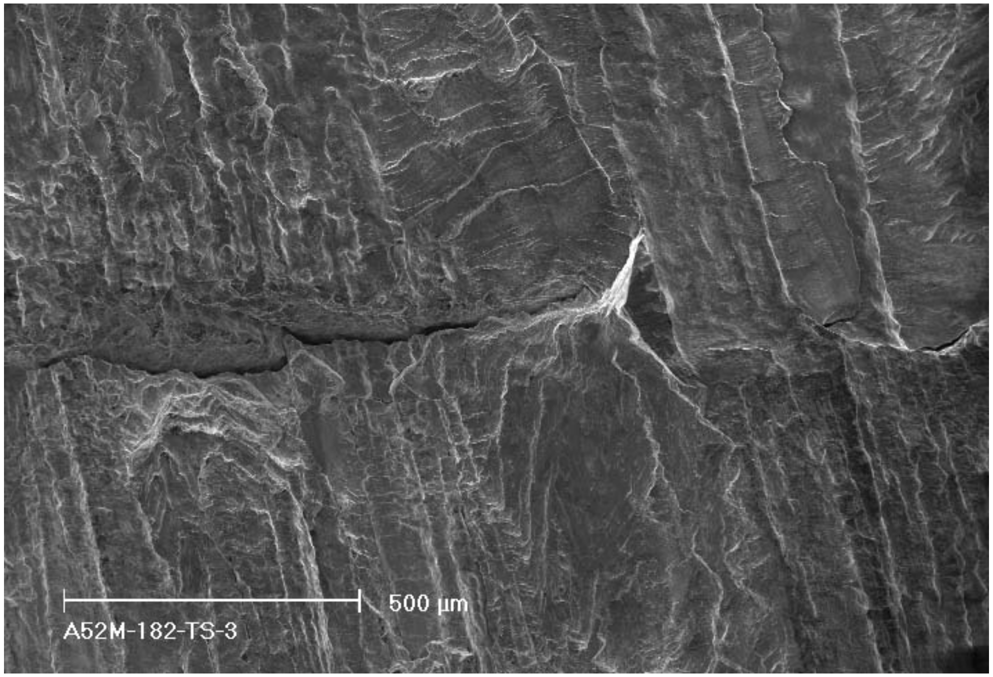
Alloy 52M/182 WOL – Crack Transition from Alloy 182 to Alloy 52M (region A)



- No change in fracture mode at the interface

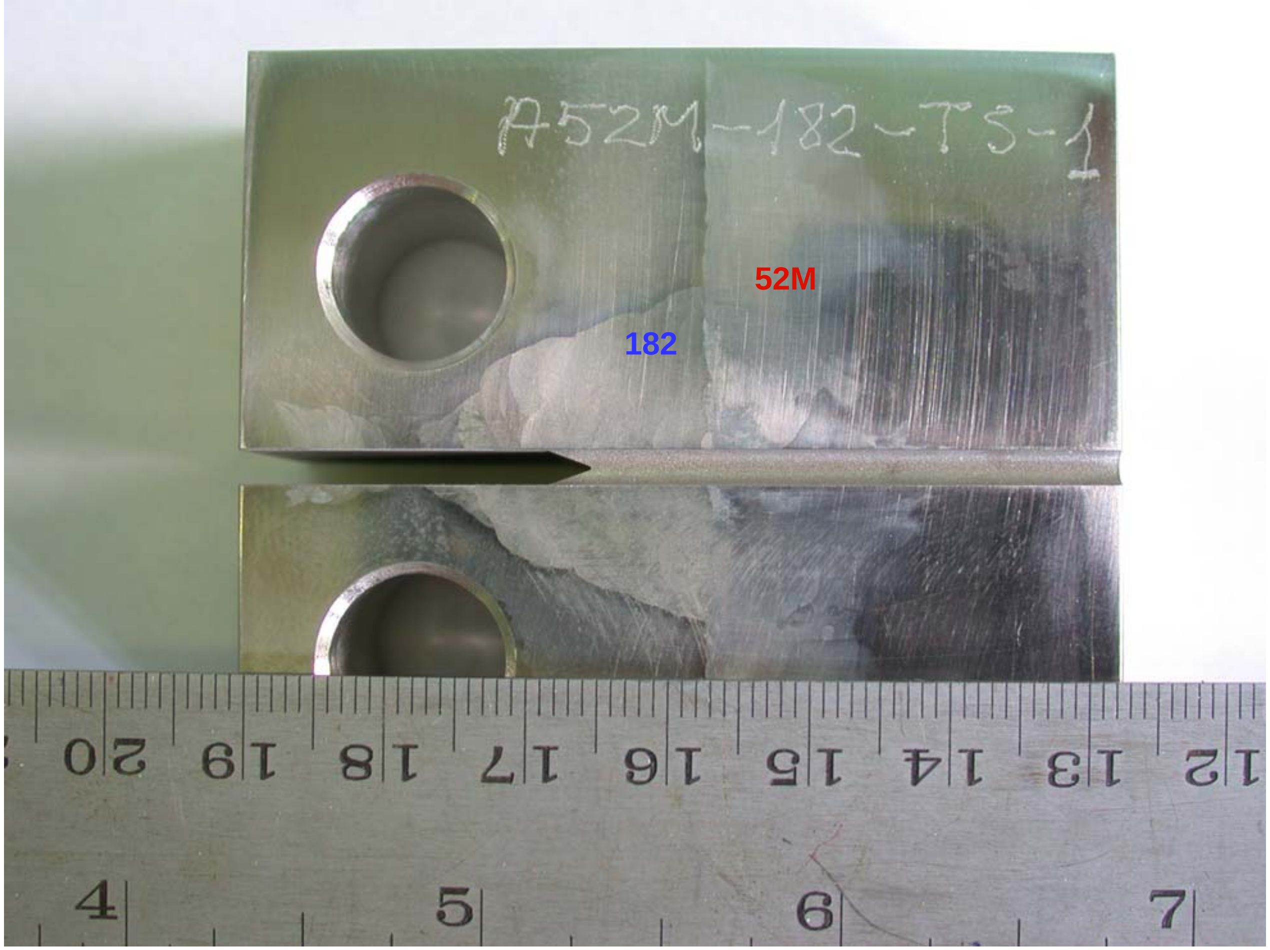
Alloy 52M/182 WOL – Crack Transition from Alloy 182 to Alloy 52M (region B)





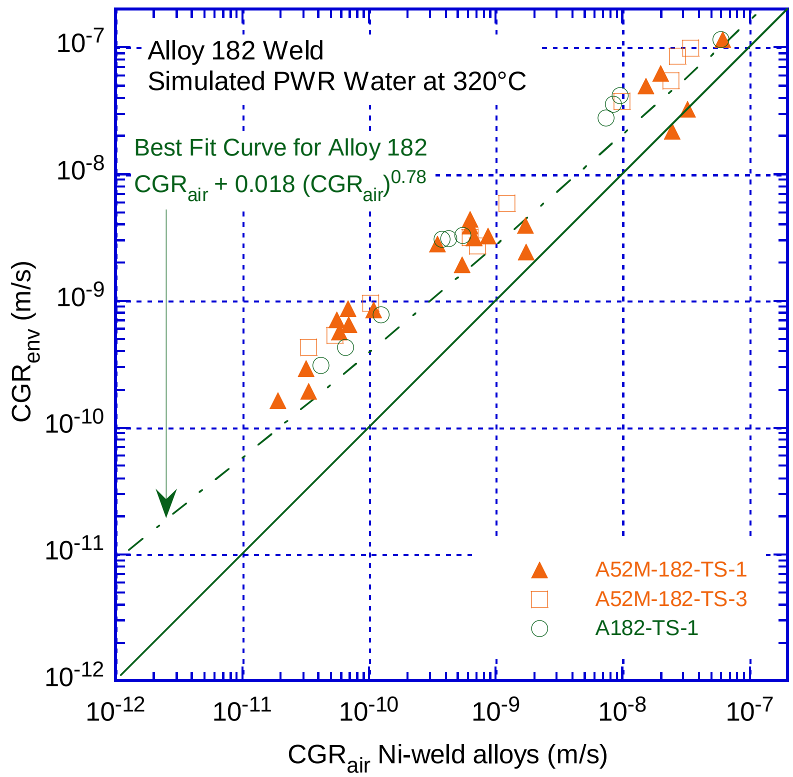
- No change in fracture mode at the interface

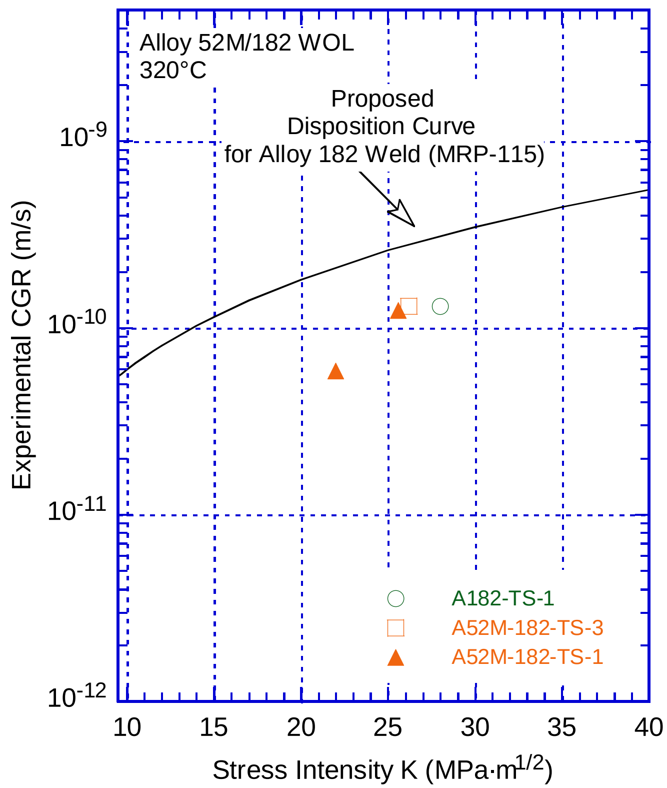
Alloy 52M/182 Weld Overlay – test in progress (A52M-182-TS-1)



- Objective: confirm behavior observed in the previous test
- 1T CT specimen in similar (TS) orientation, initial notch 8.2 mm from the interface

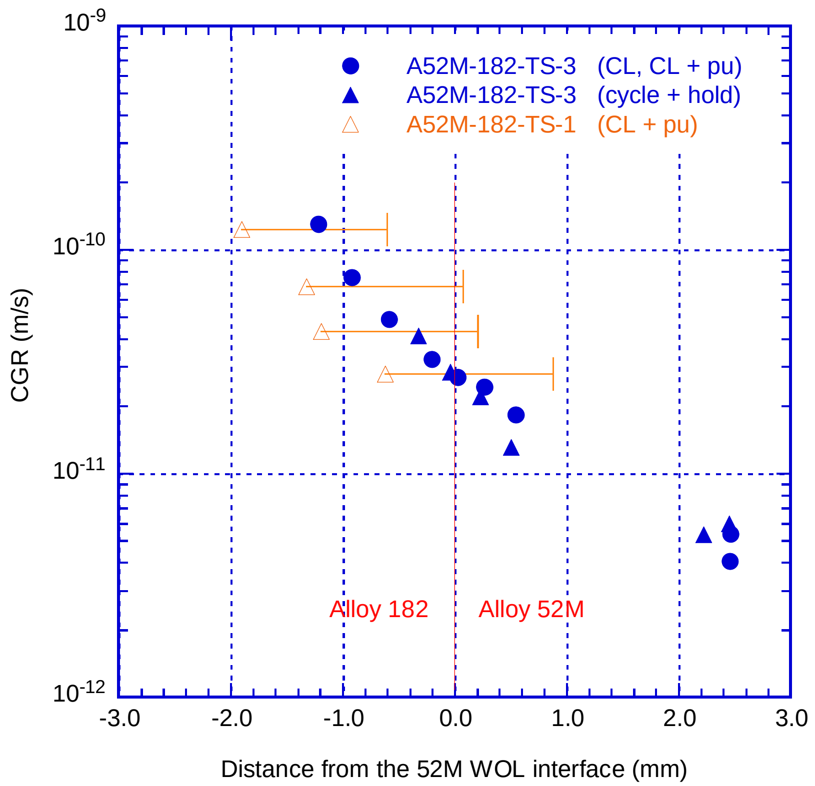
Alloy 52M/182 Weld Overlay – test in progress (A52M-182-TS-1)





- Cyclic rates similar to those obtained previously on the same weld (without the Alloy 52M WOL)
- SCC CGR similar approx. 2 mm from the interface

Alloy 52M/182 Weld Overlay – test in progress (A52M-182-TS-1)

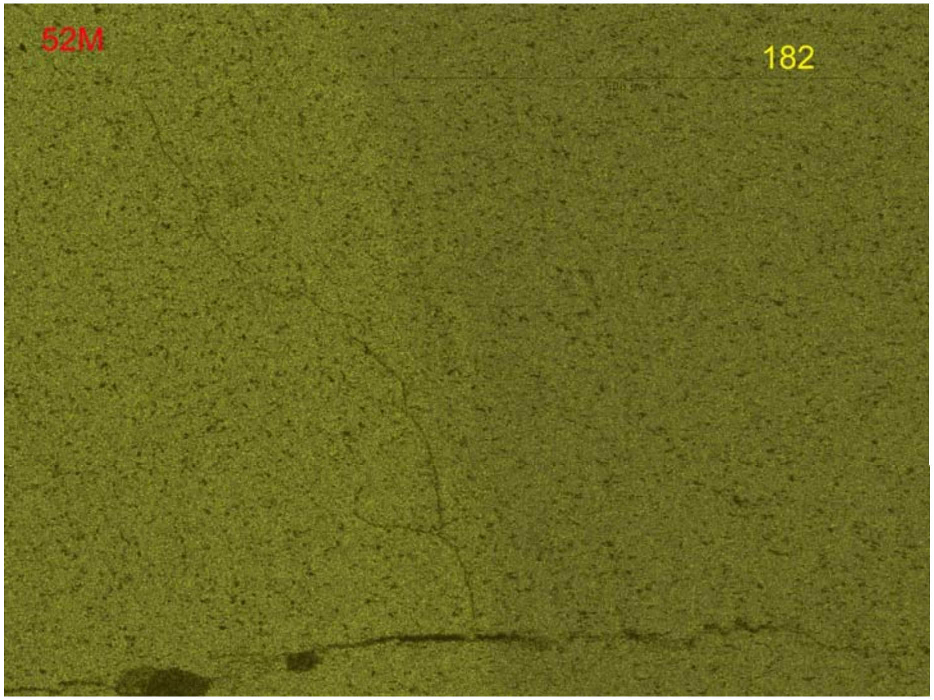


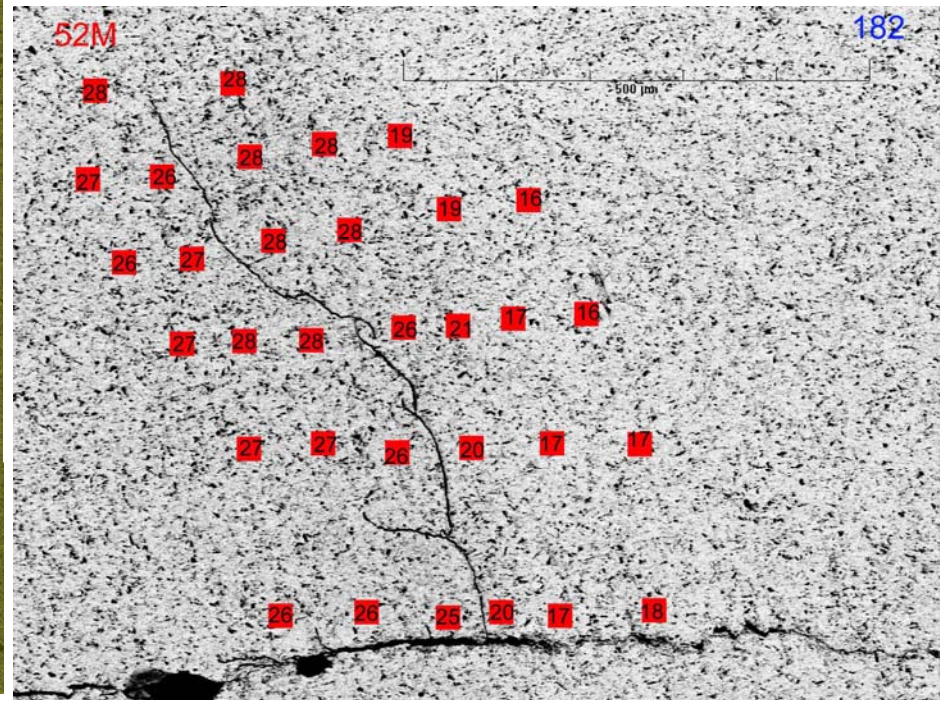
- SCC CGRs decrease as the crack approaches the interface
- Error bars: 20% uncertainty in DC potential measurements

Alloy 52M/182 Weld Overlay – key findings and future tests

- First test (A52M-182-TS-3): Interaction with the interface a concern

← Crack propagation





- Substantial growth (0.7 mm) in Alloy 52M in a direction parallel to the interface
- Crack appearance (branching) suggests an IG fracture mode

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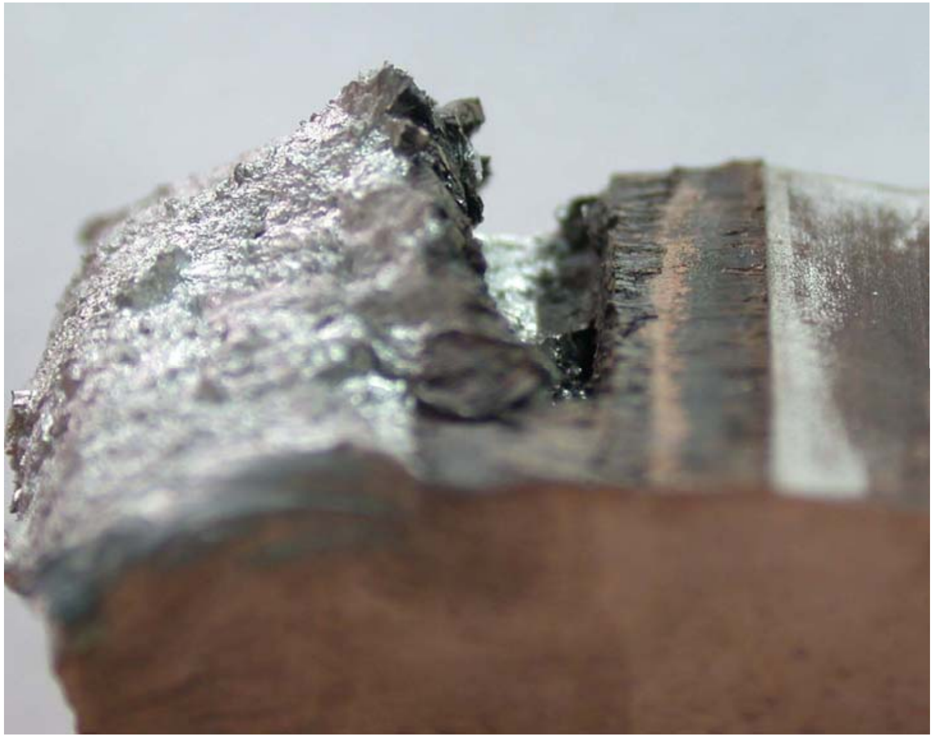
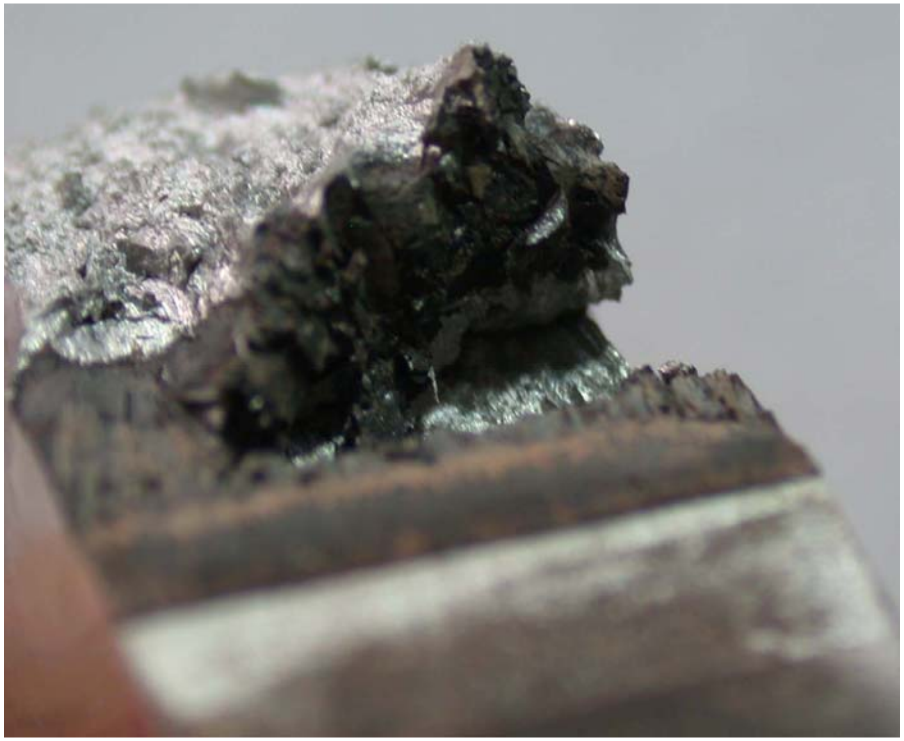
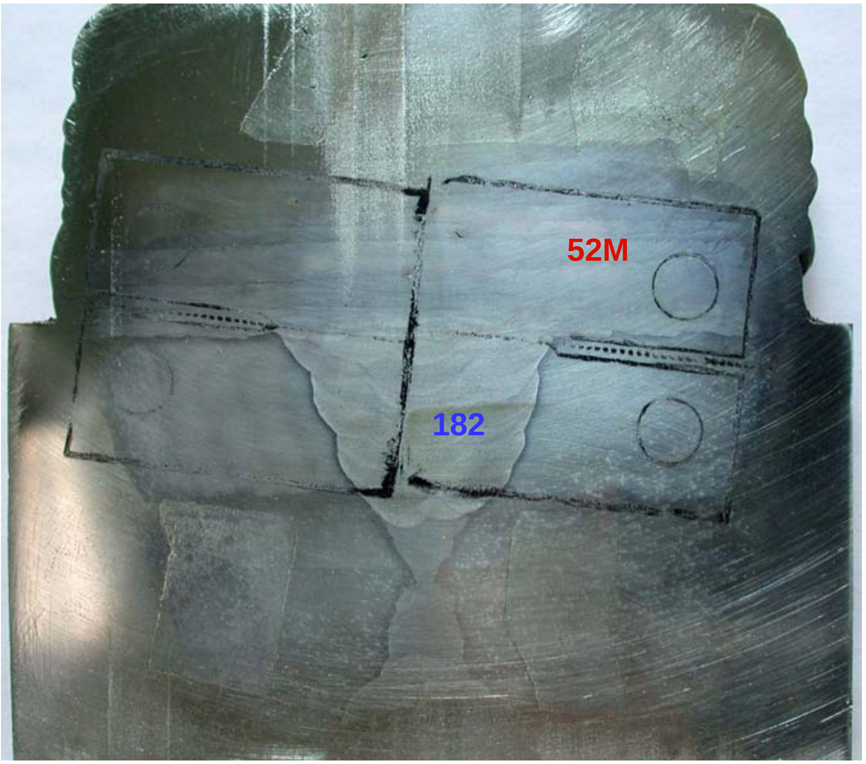
Alloy 52M/182 WOL – fractured specimen A52M-182-TS-3

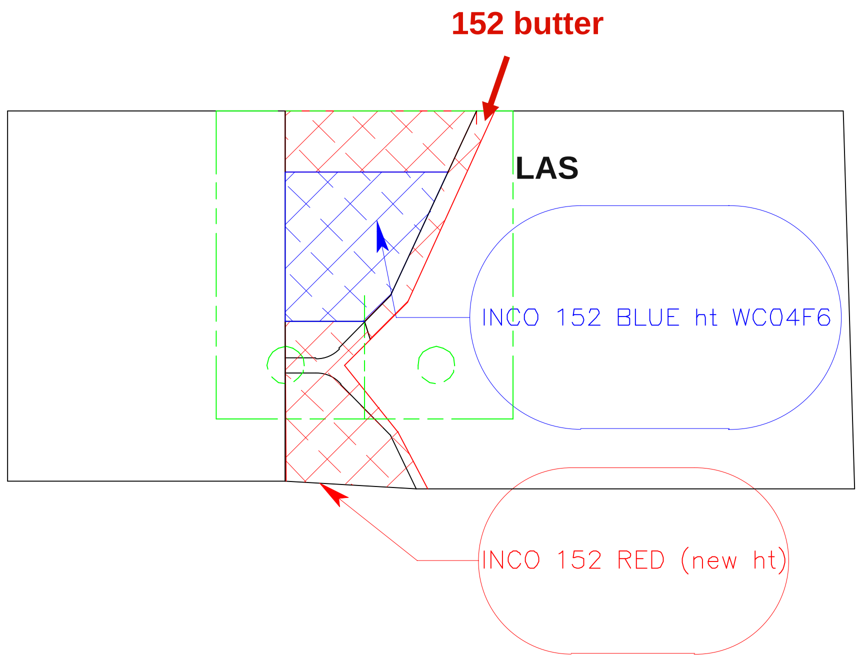




- Growth along the interface appears more severe than initially thought (based on the cross section): 2.2 mm (3000h), CGR $\approx 2 \times 10^{-10}$ m/s

Alloy 52M/182 Weld Overlay – dilution specimens





- CT specimens aligned along the 52M/182 and 152/LAS

Alloy 52M/182 WOL - Summary

- Tests were initiated in Alloy 182, and both cyclic and SCC known conditions were reproduced

- The 52M/182 interface seems to affect crack propagation in Alloy 182 ahead of the interface:

  - both SCC CGRs and environmental enhancement of cyclic rates decreased

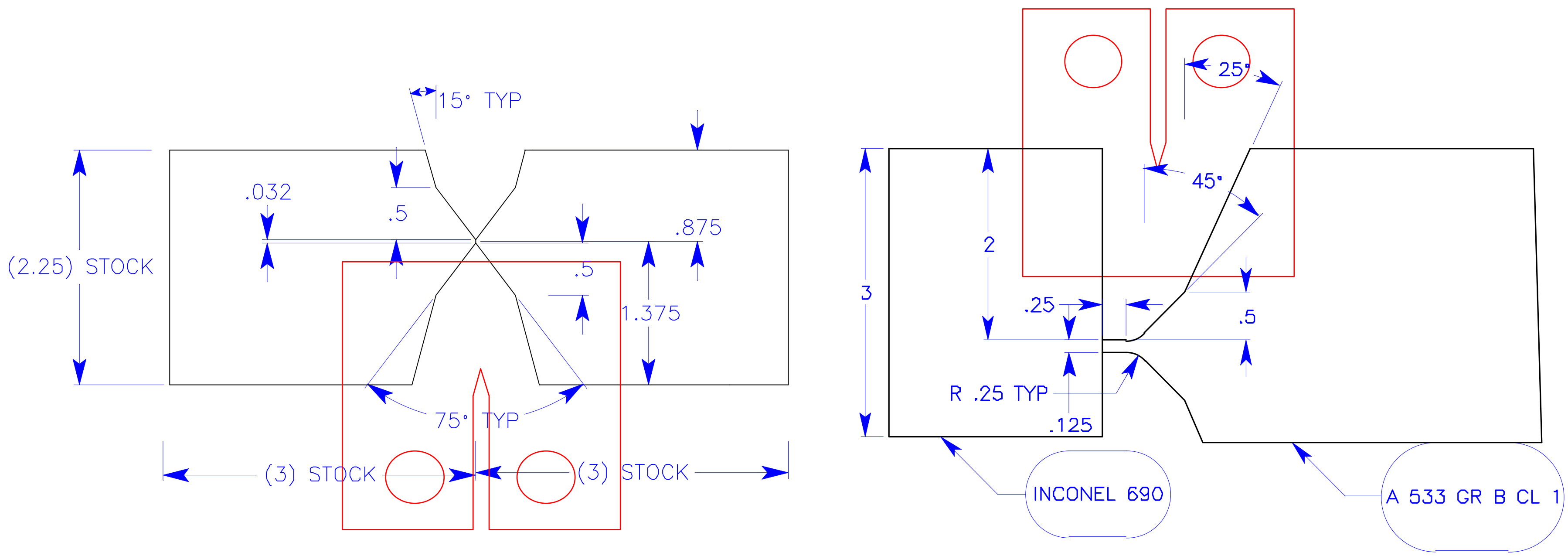
First completed test (emerging issues):

- Alloy 52M is susceptible to IG SCC, CGRs ≈ 10^{-11} m/s

  (consistent with Alloy 152 in IG fracture mode)

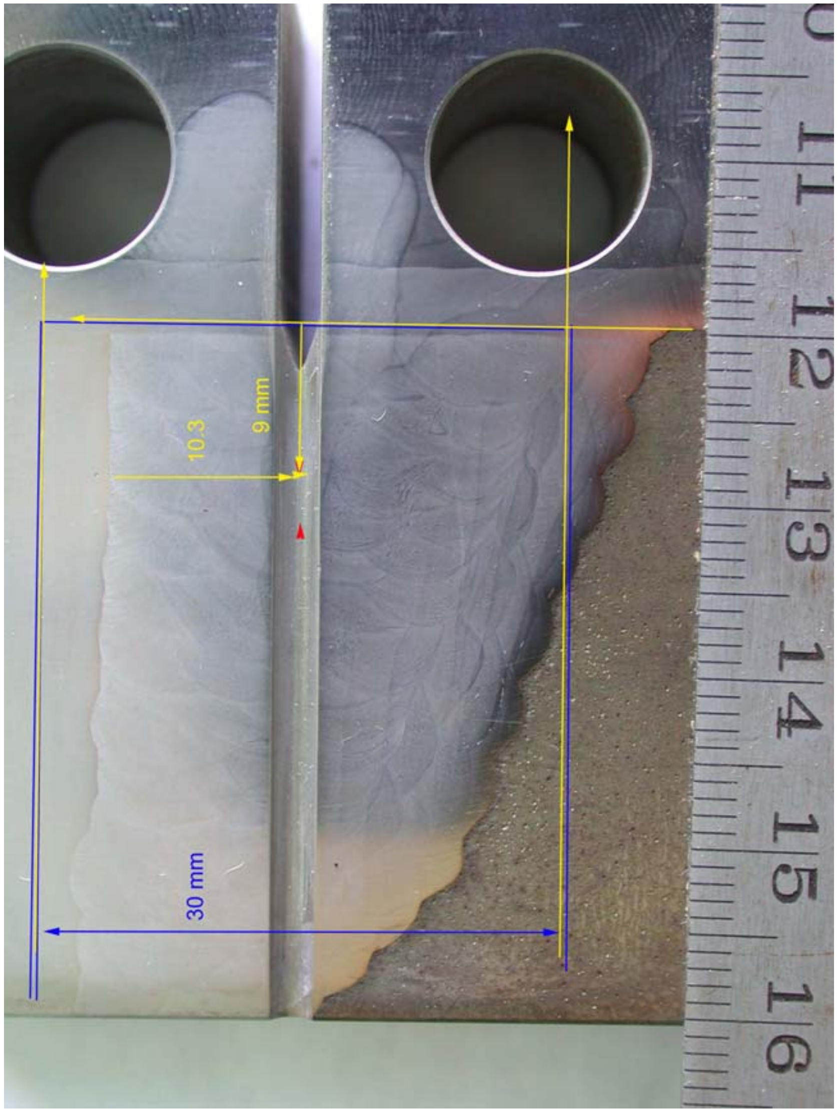
- Alloy 52M seems highly susceptible to cracking along the interface (SCC CGRs ≈ 10^{-10} m/s) – the effect of dilution will be addressed in future ANL tests

Alloy 152 Welds

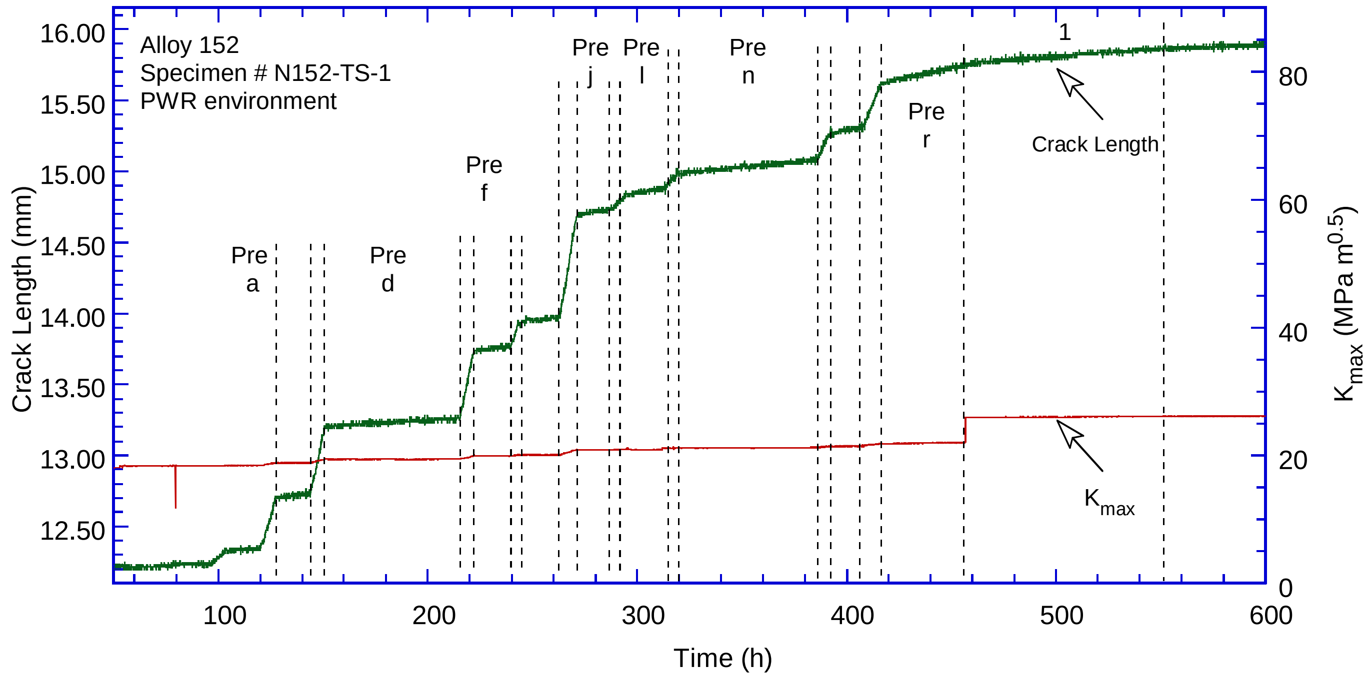


- New weld: same Alloy 152 heat WCO4F6 (152, 1/8) as the previous weld
- Welding procedure was qualified to ASME IX
- 1-T CT specimens cut in similar fashion, TS orientation
- Similar CGR testing conditions (320°C, 23 cc/kg H)

Alloy 152 Weld specimen N152-TS-1



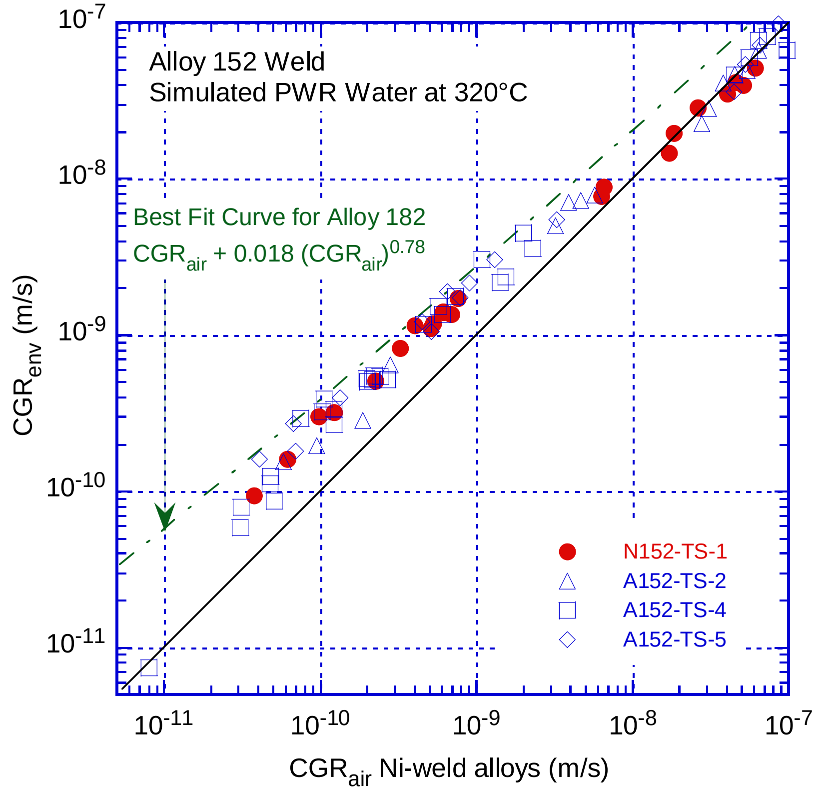
Alloy 152 specimen N152-TS-1 – in-situ precracking

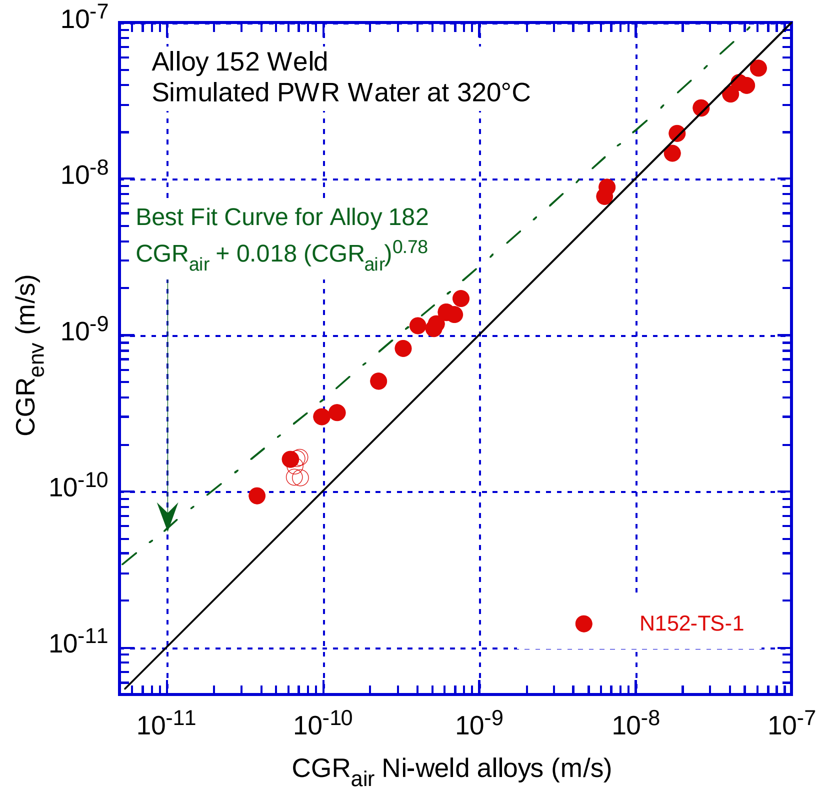


Objectives:

- Create a sharp crack tip
- Confirm the expected fatigue behavior for the specimen
  - high frequency (>0.5 Hz) establishes the baseline “air” curve
  - consistent fatigue data ensures the straightness of the crack front

Alloy 152 specimen N152-TS-1

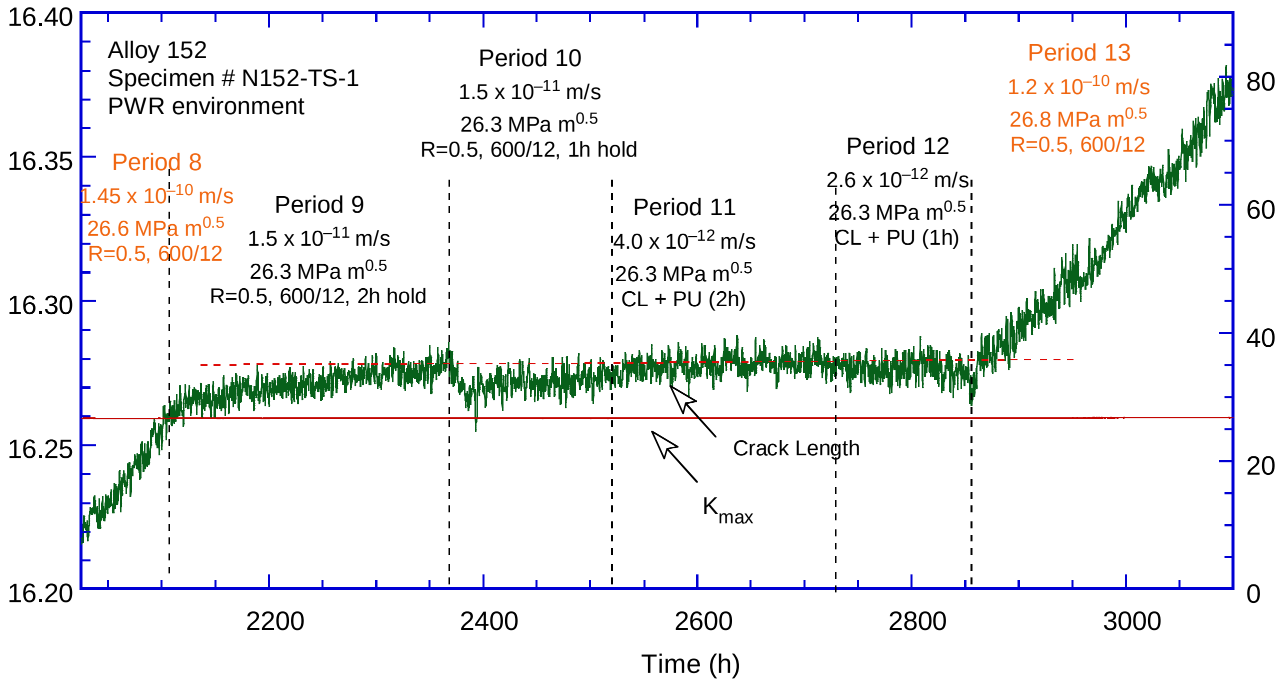




- Known fatigue and corrosion fatigue behavior (analysis based on 129 tests in air and water, NUREG-6921) reproduced, 3x environmental enhancement
- R=0.5, 600/12 was chosen as transitioning condition, $CGR_{air} \approx 6 \times 10^{-11}$ m/s*, close to expected SCC CGR, hence, will preserve IG SCC behavior

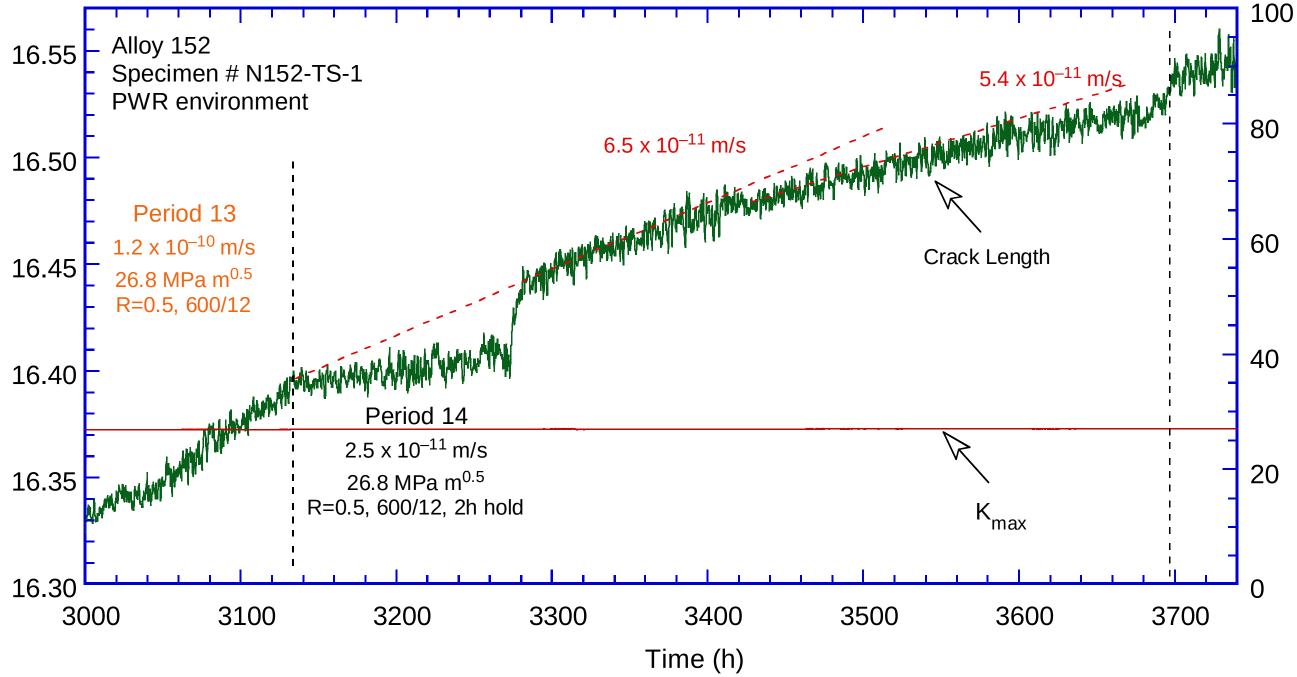
*at K=30 MPa $m^{1/2}$, 350°C, $CGR_{air} \approx 1.5 \times 10^{-10}$ m/s

Alloy 152 specimen N152-TS-1



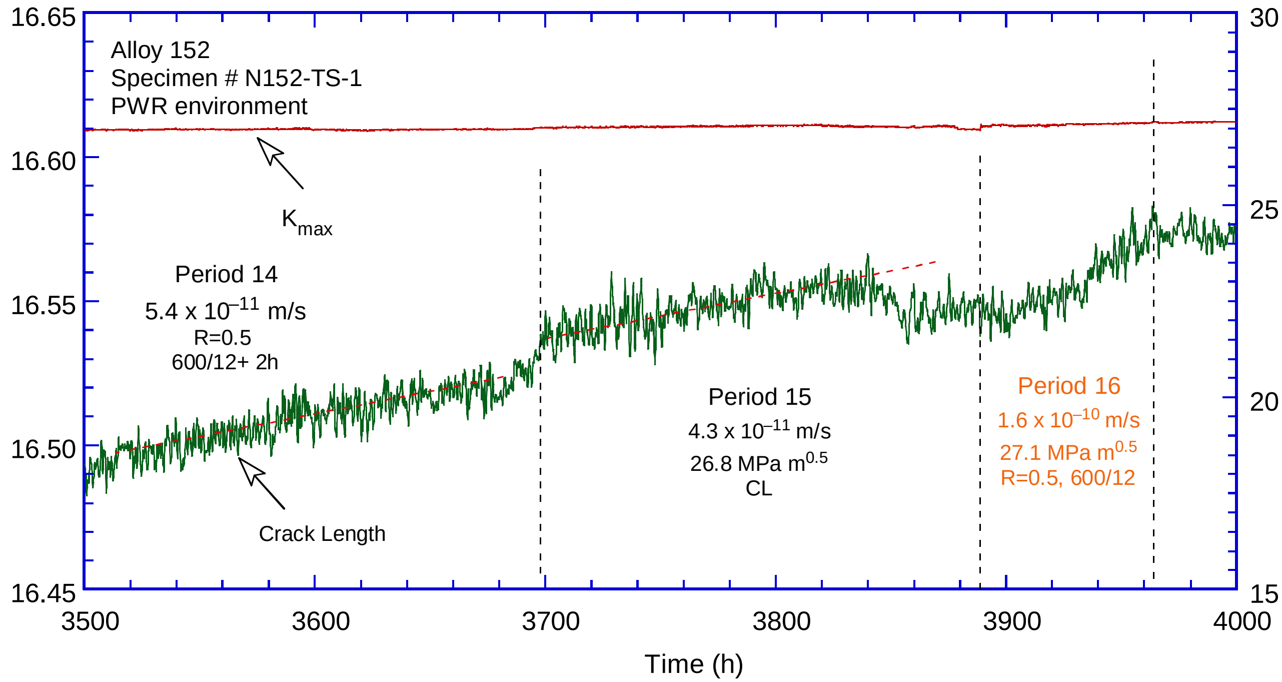
- Ligaments pose a problem early on (good news)
- CL + PU (either 2h or 1h) too gentle
- Start and end by reproducing known conditions
- IG SCC fracture mode is suspected – must be preserved (use R=0.5, 600/12)

Alloy 152 specimen N152-TS-1



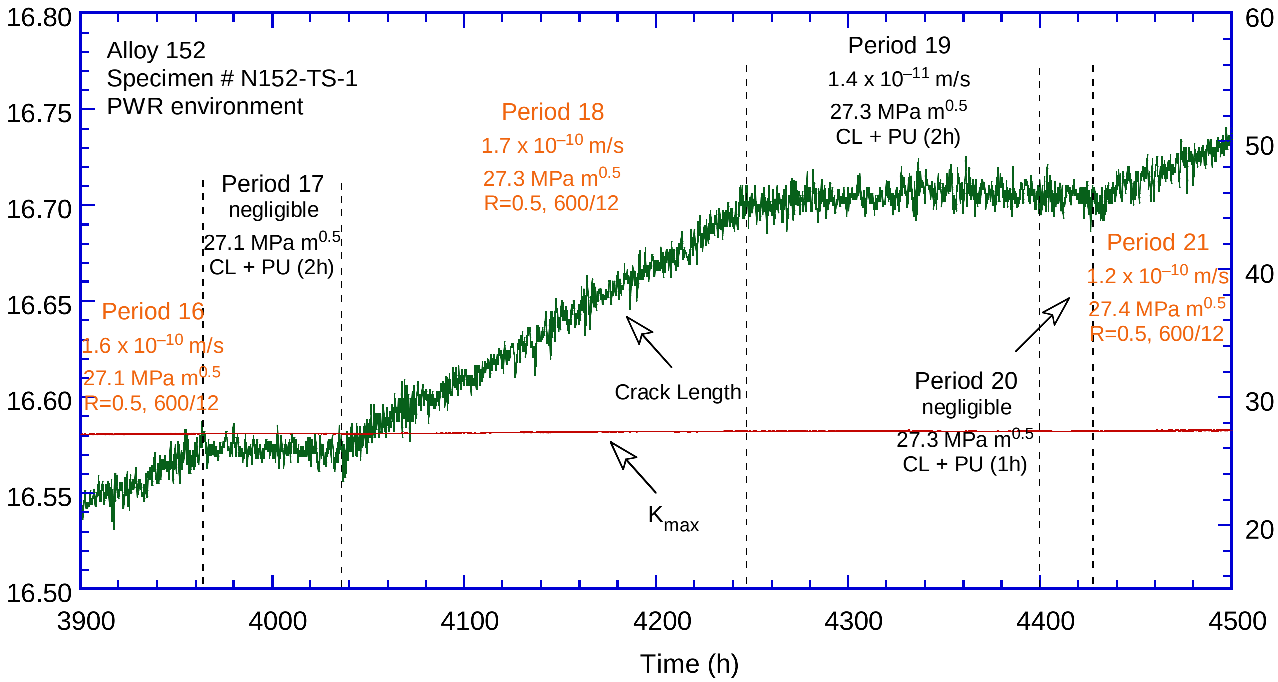
- Period 14: average SCC CGR component 4.6×10^{-11} m/s (cycle + hold is actually gentler than CL + PU)

Alloy 152 specimen N152-TS-1



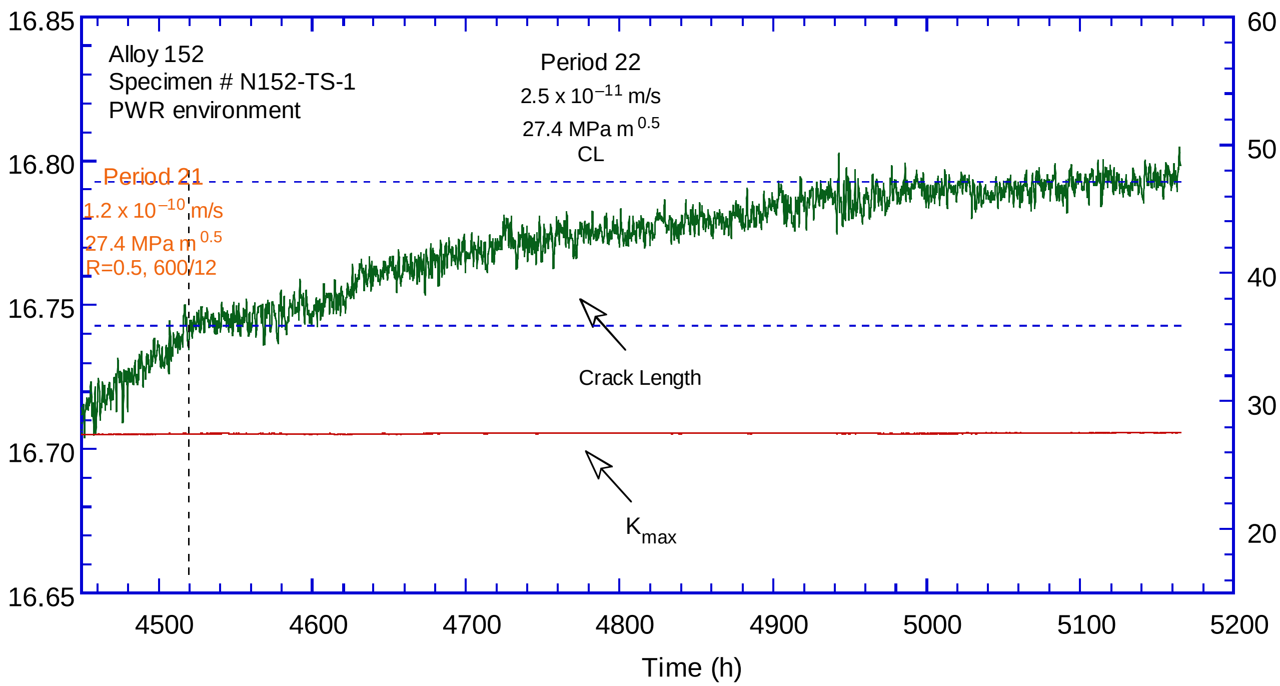
- Previous rate confirmed at CL in test period 15
- Ligaments begin to affect the crack length readings
- Reintroduced cycle – note the lag

Alloy 152 specimen N152-TS-1



- Attempt CL + PU (either 2h or 1h) - too gentle
- Start and end by reproducing known conditions (and preserve the fracture mode)

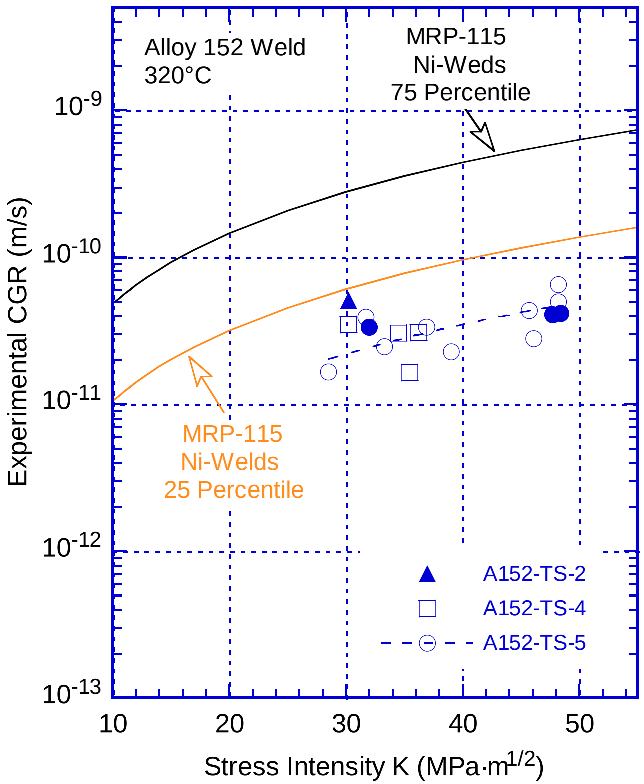
Alloy 152 specimen N152-TS-1



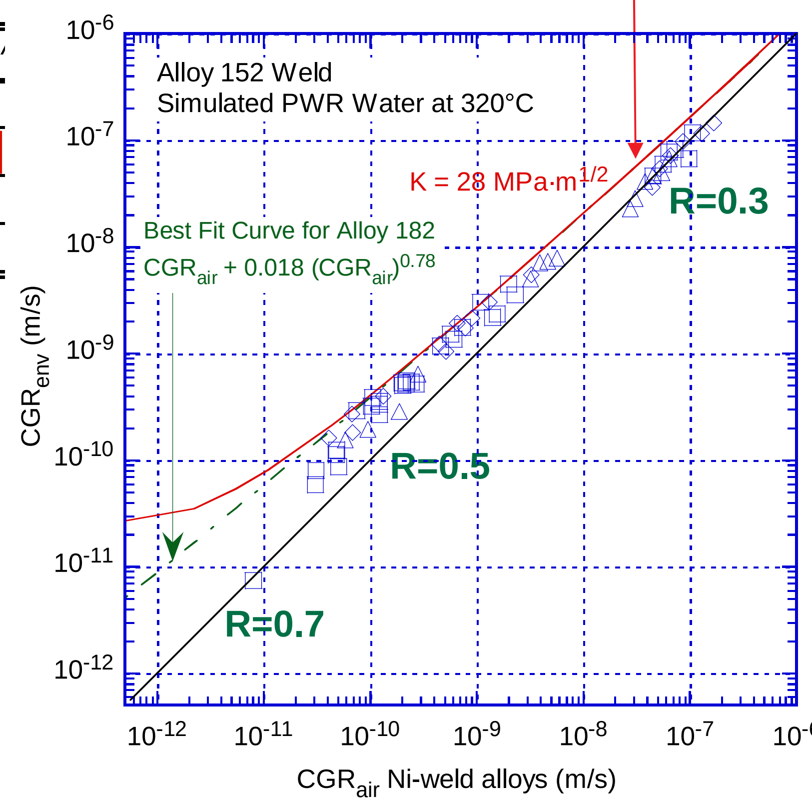
- SCC CGR consistent with those measured previously

The Analysis of Cyclic CGR Data for Alloy 152 – Implications for the SCC test management

$$\dot{a}_{env} = \dot{a}_{air} + \dot{a}_{CF} + \dot{a}_{SCC}$$



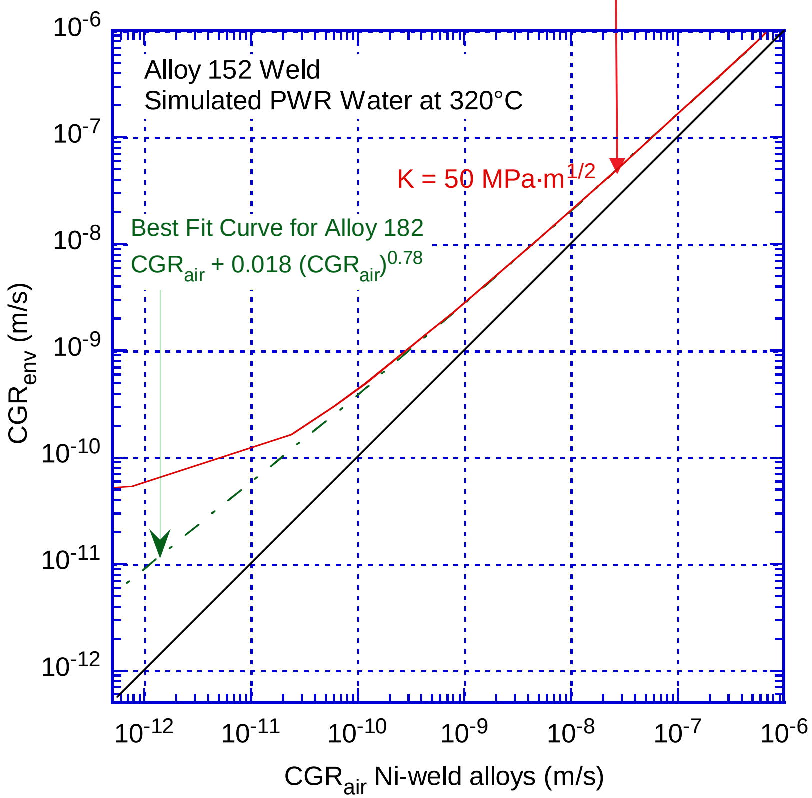
y = m1 * (M0)^	
	Value
m1	8.7892e-14
Chisq	5.835e-22
R	0.37161



- Need to balance the need for environmental enhancement with the optimal test condition (to measure SCC), keeping in mind the effects of R and rise time
- Expected curve for the total CGR in the environment very close to the CF curve – quality mechanical and CF data for the alloy at hand becomes critical

The Analysis of Cyclic CGR Data – Alloy 152

$$\dot{a}_{env} = \dot{a}_{air} + \dot{a}_{CF} + \dot{a}_{SCC}$$



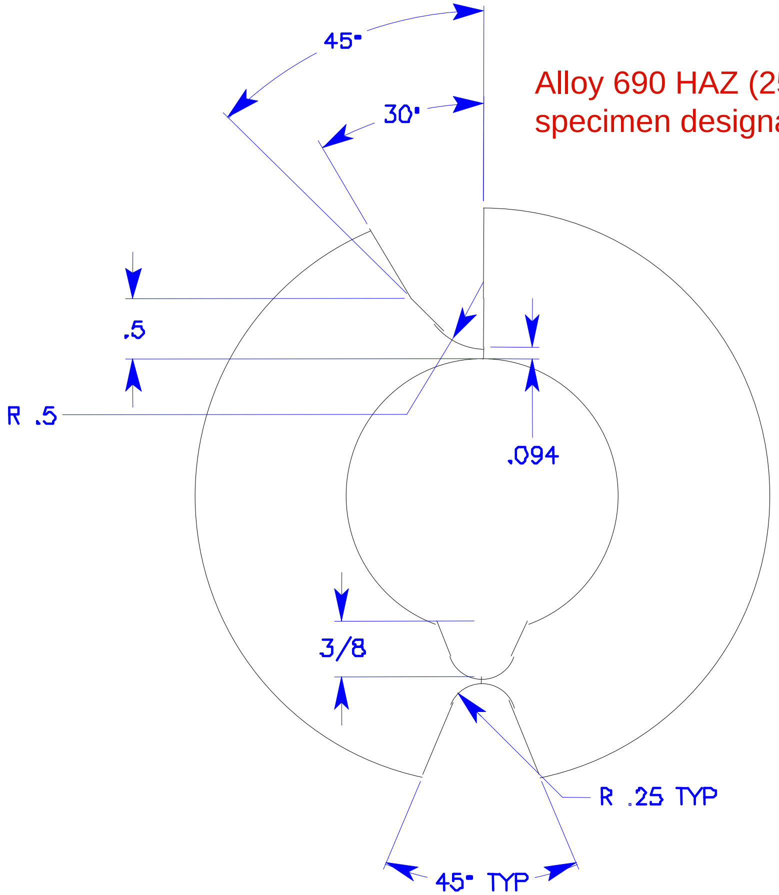
- Larger K (50 MPa $m^{1/2}$) would certainly help, however,
- The need for quality mechanical and CF data for the alloy at hand remains important

Alloy 152 - Summary

Test in progress on the new weld:

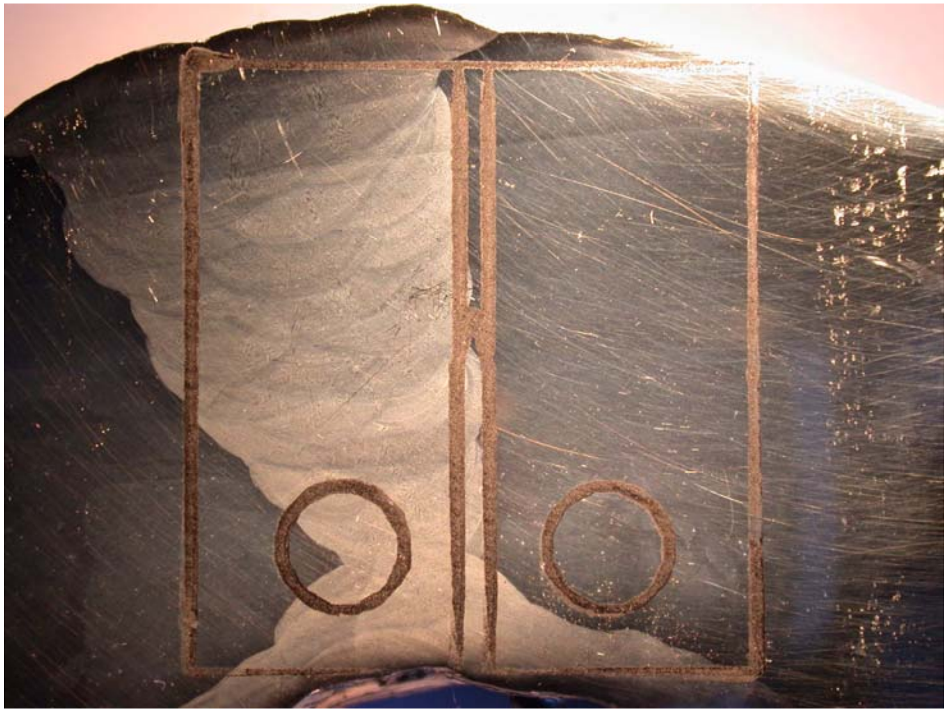
- Known fatigue and corrosion fatigue behavior were reproduced
- Select loading conditions show environmental enhancement of cyclic CGRs
- The SCC CGRs in simulated PWR water at 320°C appear to be in the 10^{-11} m/s, consistent with previous results

CRDM Alloy 690 HAZ



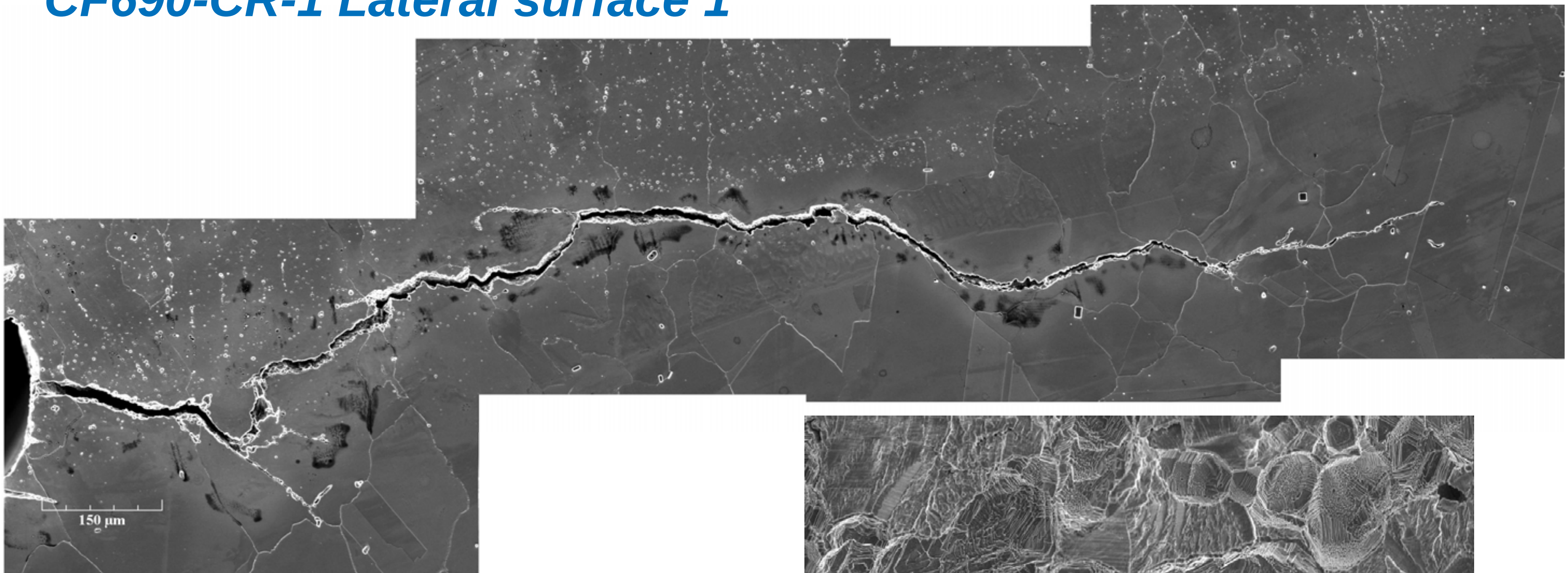
Alloy 152 Weld (B-P7)
specimen designation C152

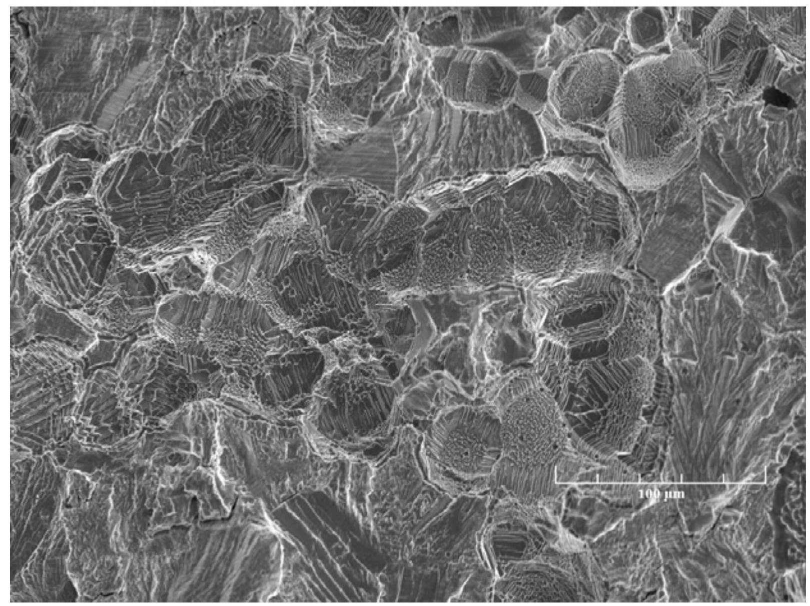
Alloy 690 HAZ (2541-Heat WP142, Valinox)
specimen designation CF690-CR-XX



- Two specimens CF690-CR-1 and CF690-CR-3: test plane parallel to the HAZ

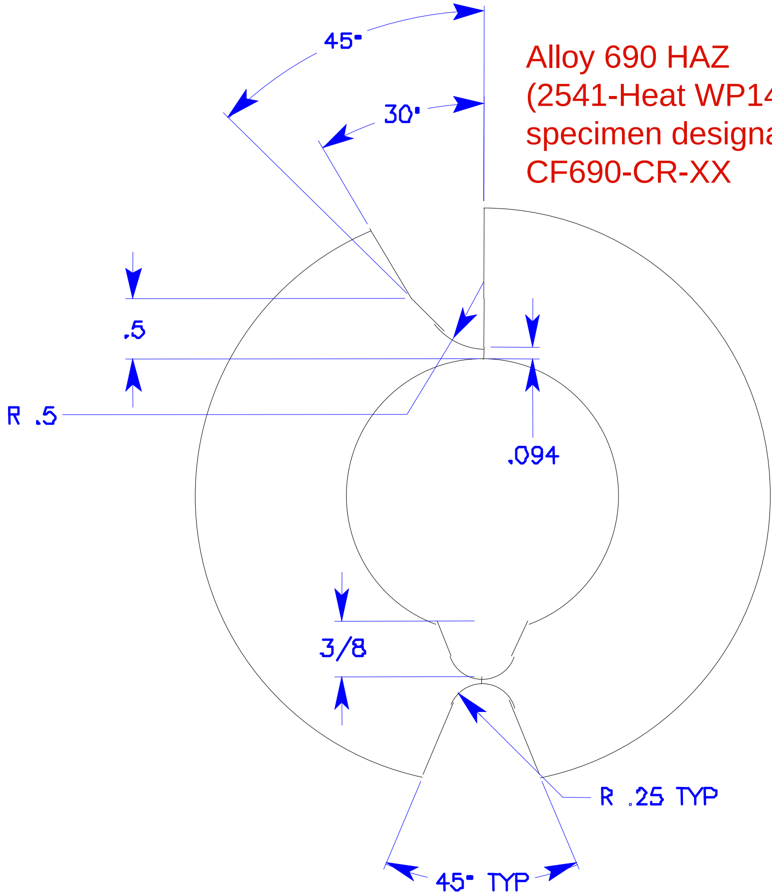
CF690-CR-1 Lateral surface 1





- Crack seems to follow the fusion line
- Granular fracture mode

CRDM Alloy 690 HAZ

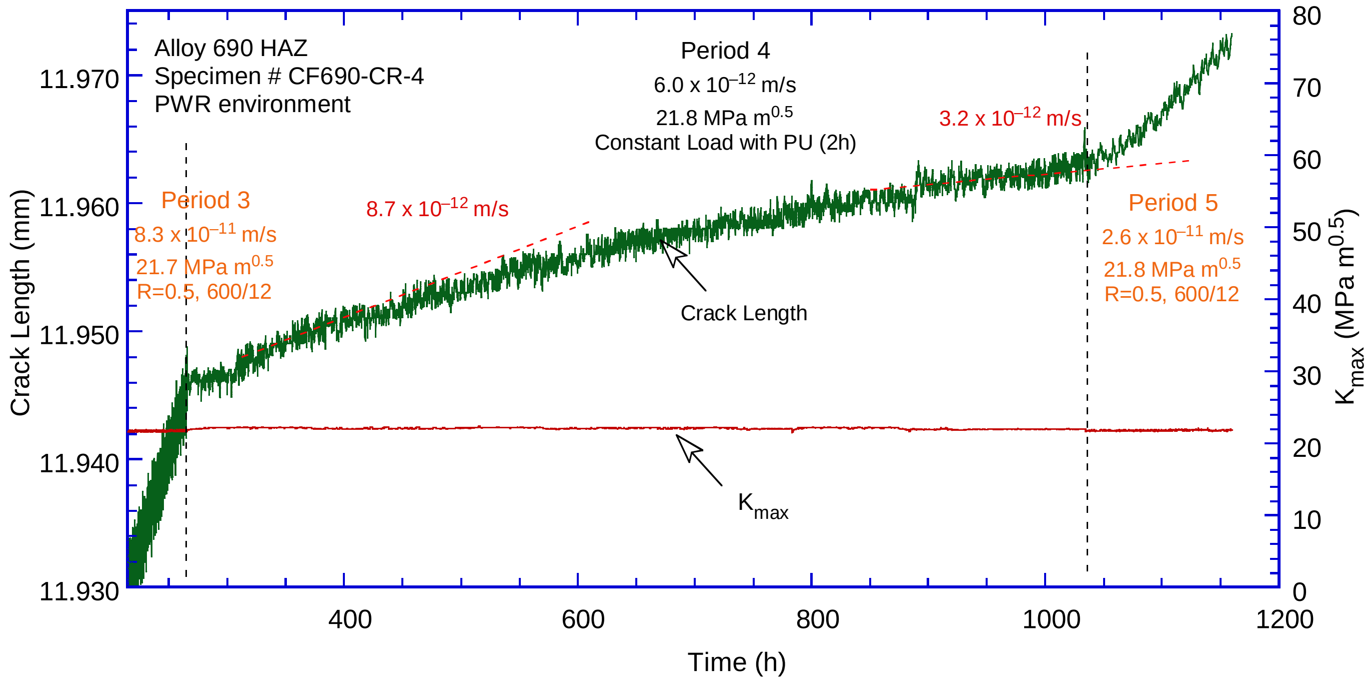


Alloy 690 HAZ
(2541-Heat WP142, Valinox)
specimen designation
CF690-CR-XX

Alloy 152 Weld (B-P7)
specimen designation C152

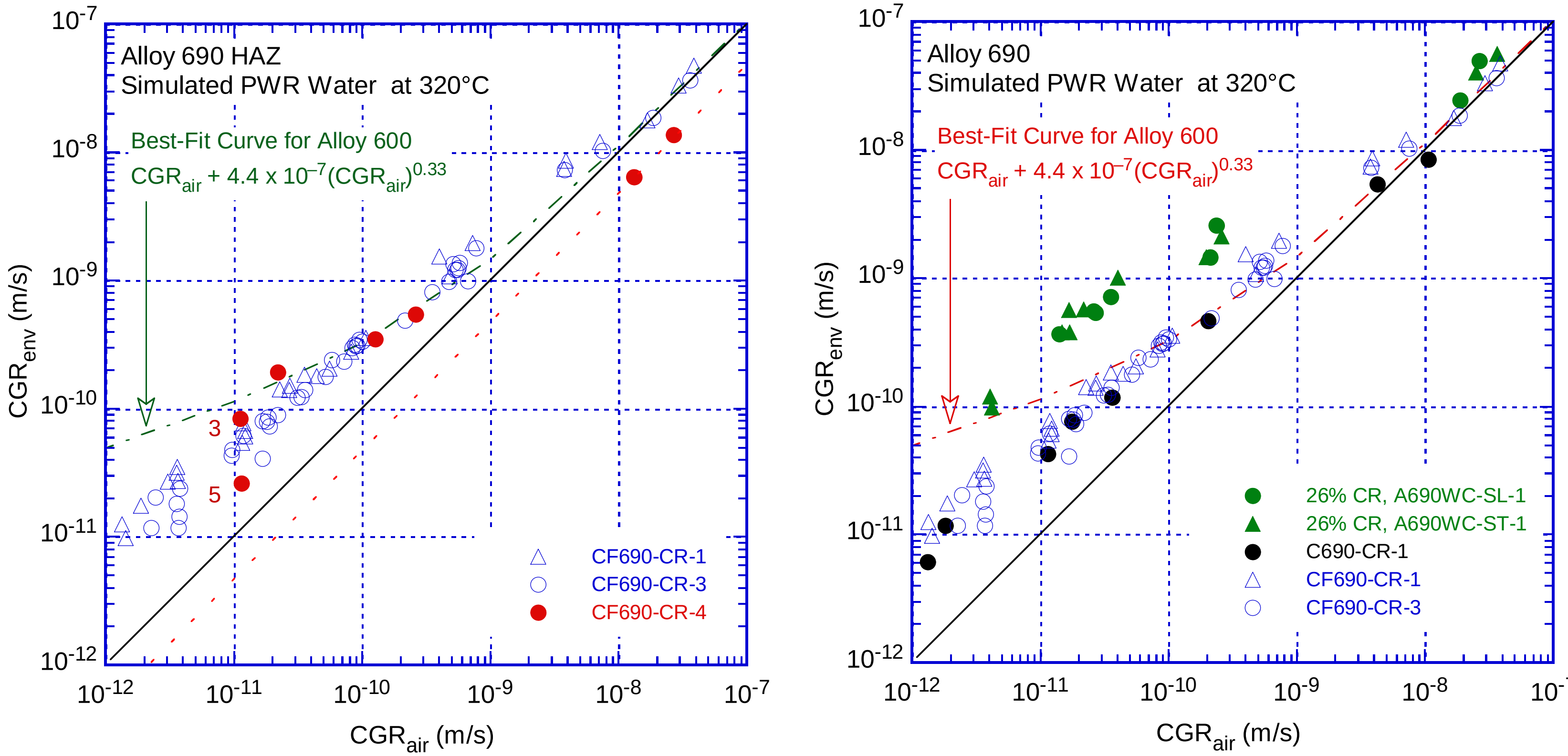
- Current approach: test plane at an angle to the HAZ

CRDM Alloy 690 HAZ Specimen CF690-CR-3



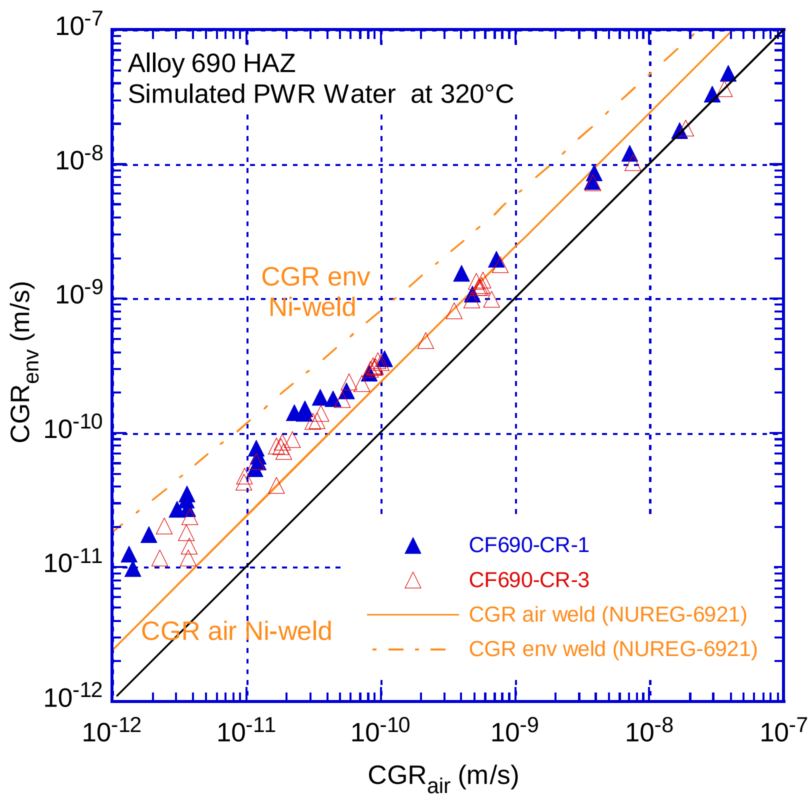
- Constant load with periodic unloading (2 h) CGR ≈ 9 ×10^{-12} m/s initially
- On average, CGR factor 2x higher than that for the alloy in the as-received condition

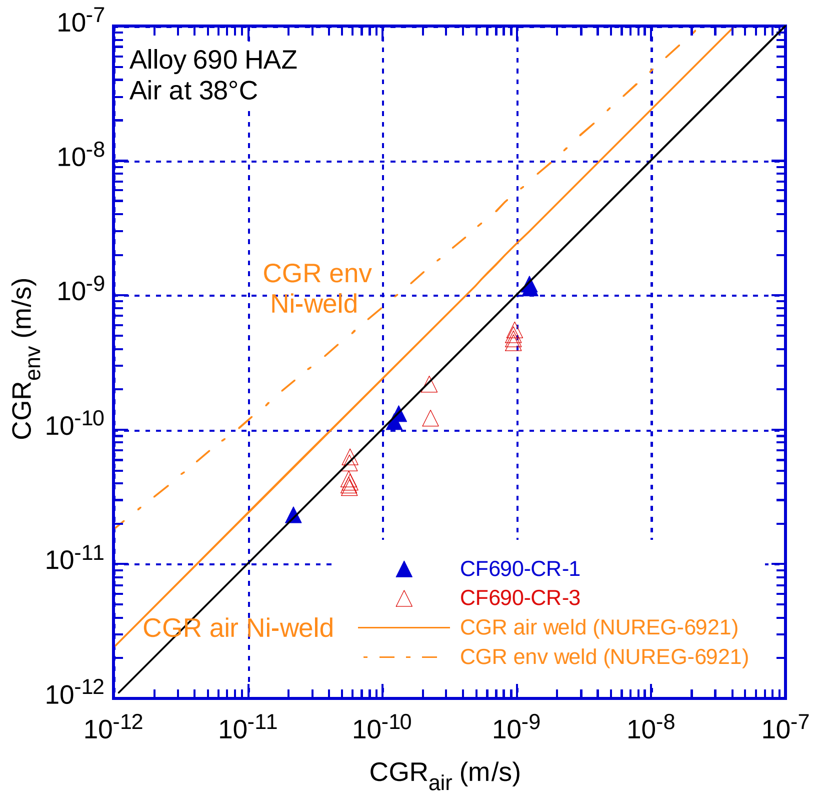
Cyclic CGRs for Alloy 690 HAZ vs. as-received and 26%-CR



- Cyclic rates for the third specimen consitent with those measured previously; the new approach shows some promise
- Environmental enhancement for Alloy 690 HAZ is similar to that for the as-received alloy
- Cyclic rates for Alloy 690 HAZ specimens are smaller than those for 26%-CR alloy

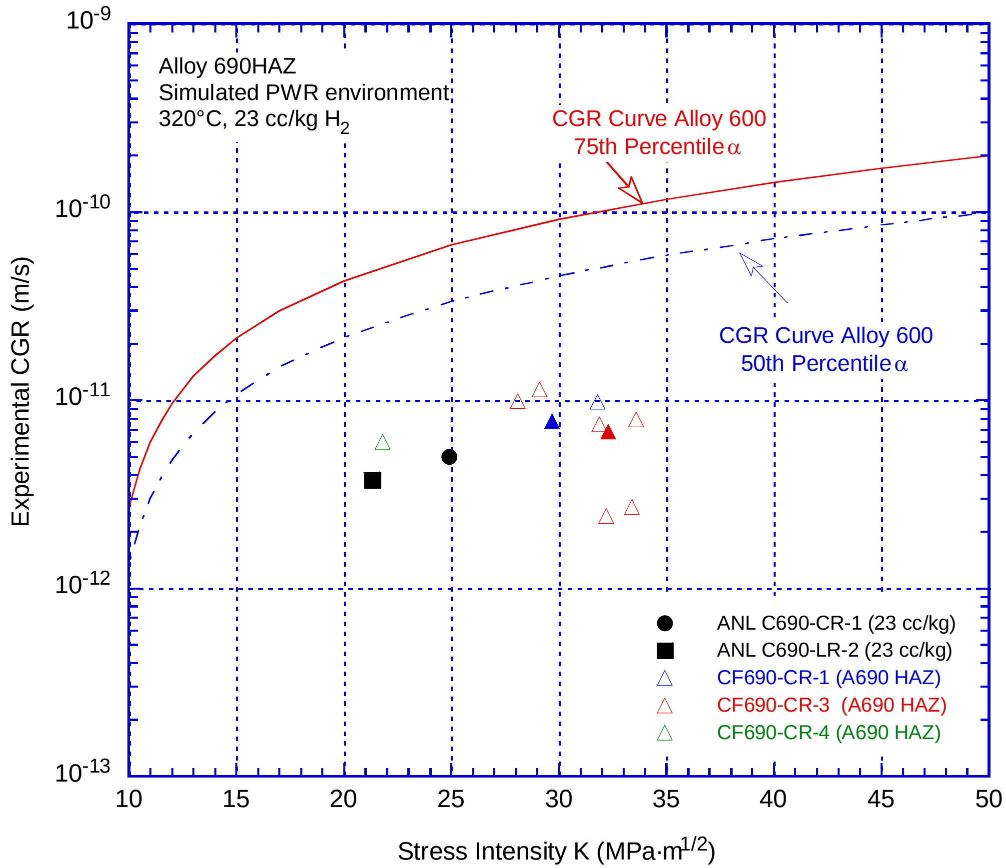
Cyclic CGR data for Alloy 690 HAZ vs. Ni-base Welds





- Cyclic CGRs are consistent with Alloy 690 (and not the weld)
- Fatigue and corrosion fatigue data for the alloys of interest (152/52/52M) and in the orientation of interest would be very useful

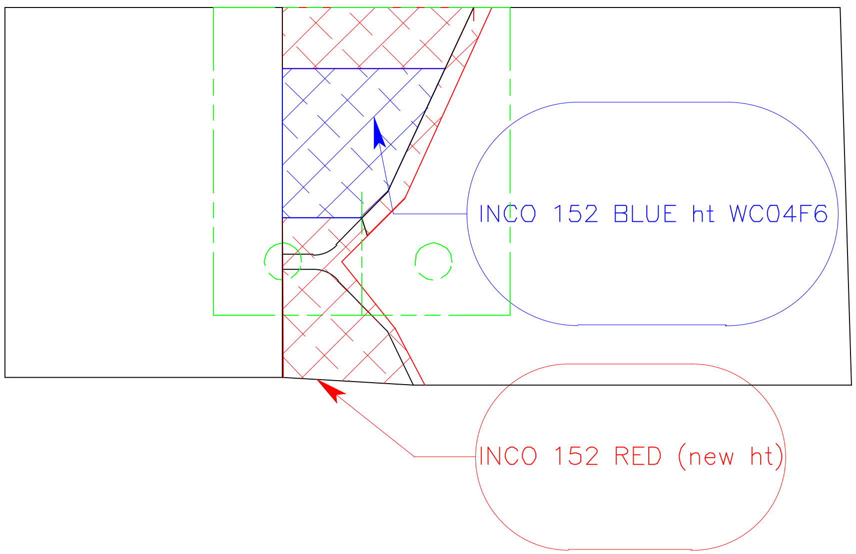
SCC CGRs vs. K for Alloy 690 HAZ



- Good agreement between CGRs at constant load (solid) and CGRs determined from cyclic loading
- Overall, HAZ CGRs are similar or only slightly higher than those for the as-received alloy
- Last test: CGR factor 2x higher than that for the alloy in the as-received condition

Alloy 690 HAZ future tests

- CRDM Alloy 690 HAZ testing will continue (attractive because cyclic and SCC data in the base alloys already exists)
- New Alloy 690 HAZ specimens from the new weld: combined effect of HAZ (+ banding)



Alloy 690 plate Heat NX3297HK12 (ATI Wah Chang)

Alloy 533-Gr B Heat A5401 (Midland reactor lower head)

Alloy 152 Heat WC0F6 (Special Metals)

Alloy 690 HAZ - Summary

- The cyclic CGRs of Alloy 690 HAZ appear to shows only slight difference vs. as-received Alloy 690

- The SCC CGRs for Alloy 690 HAZ appear to be only slightly higher that those for the as-received condition tested

- Fracture mode of Alloy 690 HAZ:
  - appears to depend on the proximity to the fusion line (1^{st} test)
  - predominantly TG, with granular appearance (dendritic features – 1^{st} test), TG facets, IG secondary cracks near the fusion line
  - new approach (fracture surface at an angle vs. fusion line) in progress

- Overall, both cyclic and SCC seem to be controlled by Alloy 690 in the as-received condition (TG)