

EPRI-NRC Cooperative Research Project: PWSCC Crack Initiation Characterization of Alloys 600/182 and Alloys 690/52/152 - *Status Update*

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Outline

- Objectives
- Approach
- Material Selection
- Test Systems
- Program Status
- Results
- Path Forward

Objectives

- Obtain primary water stress corrosion cracking (PWSCC) initiation data for Alloy 182 to support the xLPR Code development project
 - Validate xLPR model fitting parameters to temperature, stress, and yield strength
 - Explore possible dependence on dissolved hydrogen
 - Understand uncertainties and accuracy of PWSCC initiation models

- Obtain PWSCC initiation data for Alloy 690/52/152 to develop inspection requirements for components made from these alloys
 - Support reviews of potential submittals requesting credit for the use of more resistant materials

Approach

- The NRC and EPRI have entered into a memorandum of understanding (MOU) to conduct cooperative research on PWSCC initiation testing at PNNL, with a total estimated project duration of about five years.
- Perform initiation testing on multiple heats/welds:
 - Alloy 182, to investigate the effects of stress, temperature, cold work, and possibly other factors for use in xLPR and to use as a benchmark for an Alloy 52/152 factor of improvement (FOI)
 - Alloy 600, to serve as a benchmark for an Alloy 690 FOI and a benchmark for Alloy 182 results
 - Alloy 690/52/152, to obtain FOIs

Material Selection

Overview

- Four heats / welds of each Alloy 182, 600, 690, and 52/152 were selected
- SCC CGR data were obtained for many of the materials in their as-produced condition
- PNNL has added 7.5% and 15% cold work (CW) through forging to the materials for relevance to service components (i.e., surface layer conditions) and to serve as a test accelerant
 - SCC crack growth rate (CGR) testing has revealed a strong effect of cold work on Alloy 600 CGRs
 - Strong increase in CGR is consistent with strong reduction in SCC initiation time for CW Alloy 600
 - Alloy 182 might exhibit the same correlation.
- Yield strength, hardness, and other characterizations are being performed on the cold forged materials

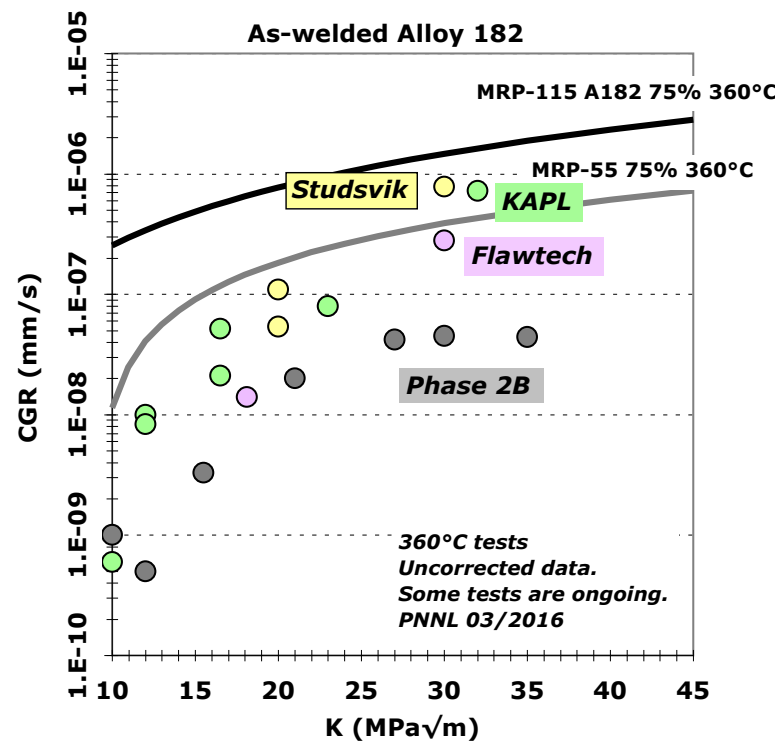
Materials, YS and HV for 15% CF Condition

Material	ID	YS@360°C (MPa)	Hardness (kg/mm ²)
Alloy 182 Build-up	Studsvik 8001231	550	240-345
Alloy 182 DMW	Flawtech 844305	515, 525	225-345
Alloy 182 DMW	Phase 2B	460, 500	225-330
Alloy 182 U-Groove	KAPL 823030	580, 590	250-350
Alloy 600 Plate	NX6106XK-11	575	270
Alloy 600 Plate	522068	450	240
Alloy 600 Plate	33375-2B	540	265
Alloy 600 CRDM	WNP5	520	240
Alloy 152 U-groove	MHI 307380	500	225-345
Alloy 52 U-groove	MHI NX2686JK	470	225-315
Alloy 52M Butter	ENSA DPM Butter	430	240-300
Alloy 152M U-groove	IHI 444537/WC83F8	550, 560	255-345
Alloy 690 CRDM	RE243	415, 420	240
Alloy 690 CRDM	WP142	445, 455	247
Alloy 690 Plate	114092	460	260
Alloy 690 Plate	B25K-2	515	270

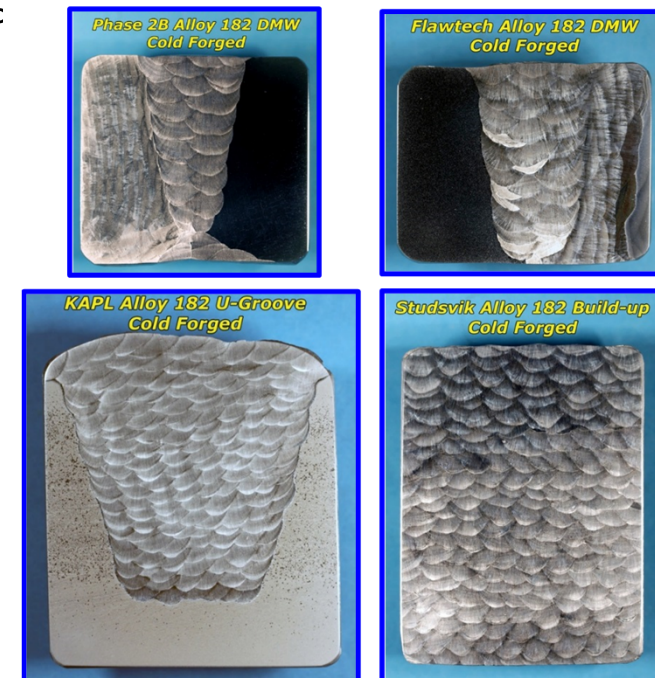
Material Selection

Alloy 182 CGR Characterization

- Crack growth rate characterization of all four Alloy 182 weldments has been completed for as-welded material
- Response measured to stress intensity of as low as $10 \text{ MPa}\sqrt{\text{m}}$
- Identify relative susceptibilities and possibly a correlation between CGR and initiation times.
- High SCC CGRs in Studsvik and KAPL suggest possibility of low SCC initiation times
 - CGR is lower than the A182 disposition curve, but higher than the A600 curve.



Alloy 182 Welds



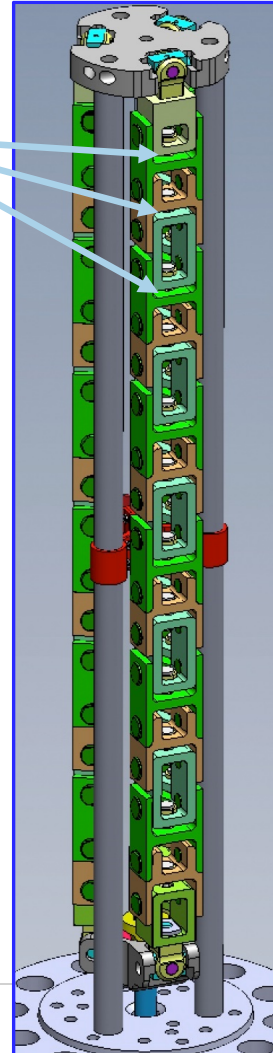
Test Systems

- PNNL Systems
 - Multiple 36-specimen, 6-specimen and 3-specimen testing systems available
 - Developed under the NRC-EPRI cooperative research program, NRC peening program, borrowed from the DOE LWRS program, owned by PNNL.
- Direct current potential drop (DCPD) is used to detect crack initiation in-situ; DCPD voltage across specimen increases strongly at the point of initiation due to crack extension
- All specimens within a single system are at the same load; applied stress is controlled by adjusting gauge diameter
- Load train carries the load of a failed specimen through a catch mechanism (6, 12, and 36-specimen systems)

1.2" Tall Specimen



36-Specimen SCC Initiation System



etc.

6-Specimen SCC Initiation System



Program Status

	2016	2017	2018	2019	2020	2021
36-Spec. System #1	<u>Alloy 690/52/152 @ YS</u> 6 each of 4 welds @ 15% CF + 3 each of four base metals @ 15% CF (F1, F2)			→		
36-Spec. System #2		<u>15% CF A600 @ YS</u> 6 each of 2 heats (F1)	<u>AW A182 @ YS</u> 3 each of 4 welds (X3)	→	<u>15% CF A182 @ 330°C</u> 9 each of 2 welds (X4)	
36-Spec. System #3			<u>15% CF A182 @ 0.90YS</u> 6 Spec. – KAPL (X2)	→	<u>15% CF A182 @ 345°C</u> 9 each of 2 welds (X4)	
3-Spec. System #1		<u>15% CF A182 @ YS</u> All but 3 KAPL spec. (X1, F2)	<u>7.5% CF A182 @ YS</u> 3 Spec. – Studsvik Stopped @ 7734 hrs	<u>15% CF A182 @ YS</u> 3 Spec. – KAPL (X1, F2)	→	<u>15% CF A182 vs Dissolved Hydrogen</u> (X6)
3-Spec. System #2 – (Relinquished)			<u>7.5% CF A182 @ YS</u> 3 Spec. – KAPL Stopped @ 732 hrs (X3)	} To be restarted in April/May		<u>15% CF A182 vs Surface Condition</u> (X7)
6-Spec. System #1			<u>15% CF A182 @ 0.90YS</u> 6 Spec. – Studsvik (X2)	→	<u>7.5% CF A182 @ 0.80 YS</u> 6 each of 2 welds (X3)	Other Materials (Interfaces, weld defects)
6-Spec. System #2			<u>15% CF A600 @ YS</u> 6 each of 2 heats 132 hrs (F1)	→	<u>15% CF A182 @ 0.80YS</u> 6 each of 2 welds (X2)	



Program Status

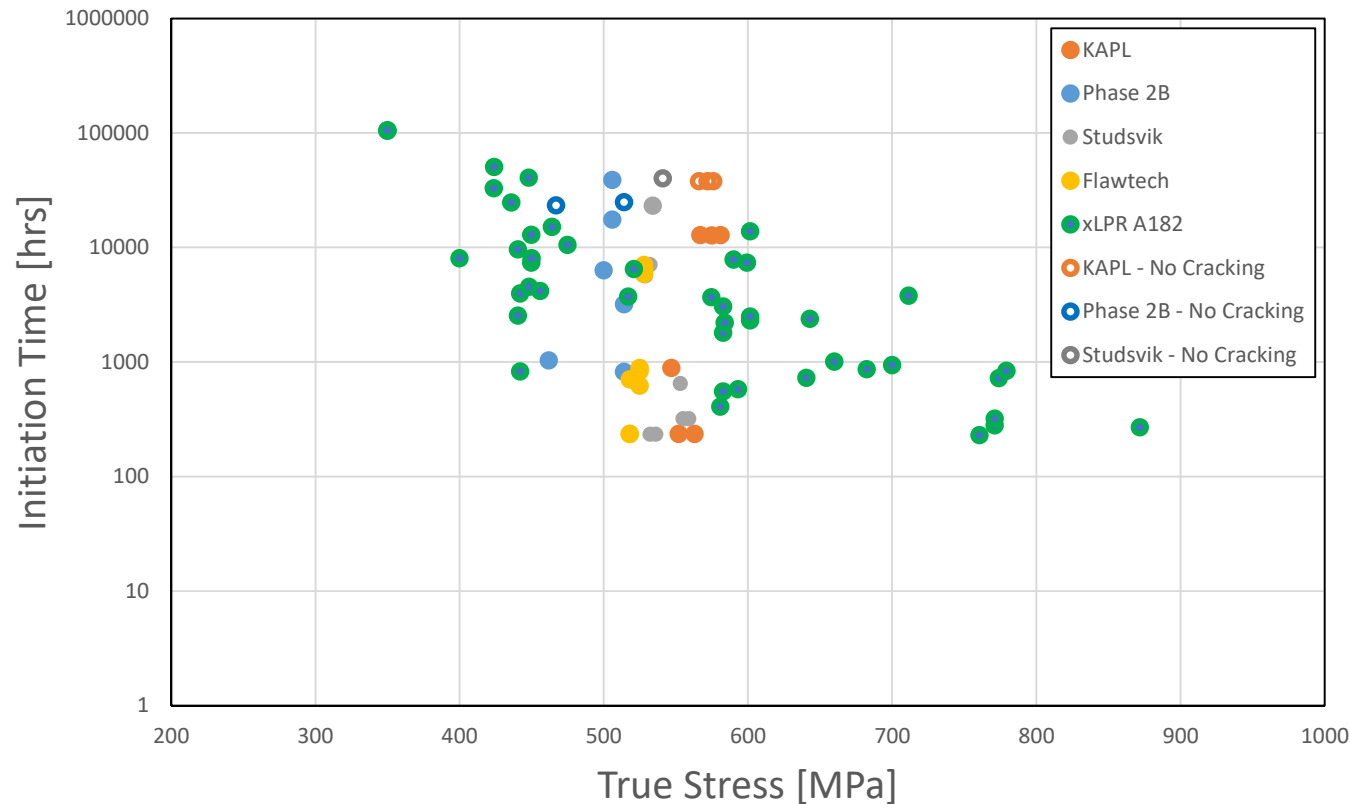
Selected temperature-adjusted initiation times

Material (tested @ YS)	Median Initiation Time [hrs]*	
	Test Temp. 360 °C	Adjusted Temp.** 325 °C
15% CF A182 Studsvik	83	650
15% CF A182 Flawtech	106	830
15% CF A182 Phase 2B	2,238	17,514
15% CF A182 KAPL	1,025	8,021
As-welded A182	>14,334	>112,174
15% CF A600 NX6106XK-11	1,903	14,892
15% CF A600 33375-2B	1,044	8,170
15% CF A600 522068	880	6,887
15% CF A690/52/152	>23,225	>181,752
* 1 yr = 8,760 hrs		
** Q = 185 kJ/mol		

Results

15% CF Alloy 182 @ YS loading Adjusted to 325°C

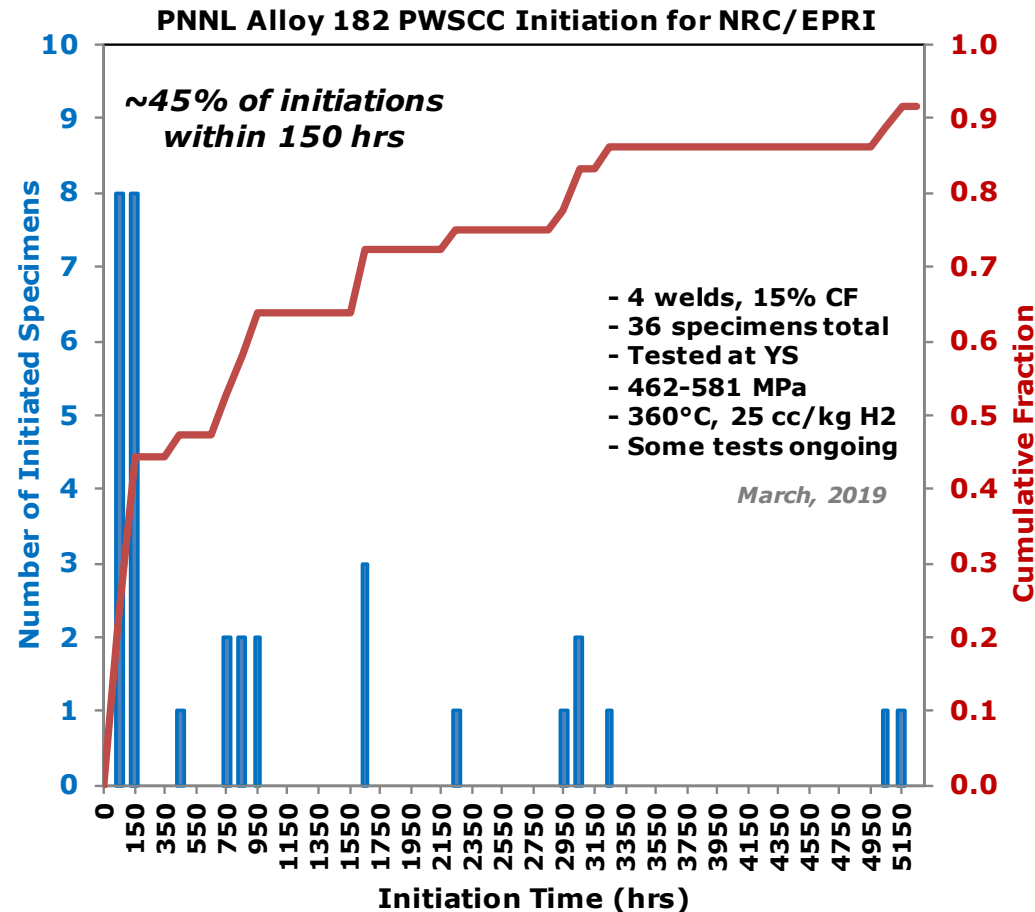
- 9 specimens each from four welds.
- Distinct grouping of data at < 1000 hours.
- Data appears to be consistent with xLPR Alloy 182 data.
- Not all specimens have initiated:
 - 3 KAPL specimens at > 40,694 hrs. (5200 hrs. of testing)
 - 2 Phase 2B at ≥ 24,831 hrs. (3173 hrs. of testing)
 - 1 Studsvik at ≥ 40115 hrs. (5126 hrs. of testing)



Results

15% CF Alloy 182 Initiation Testing (360 °C)

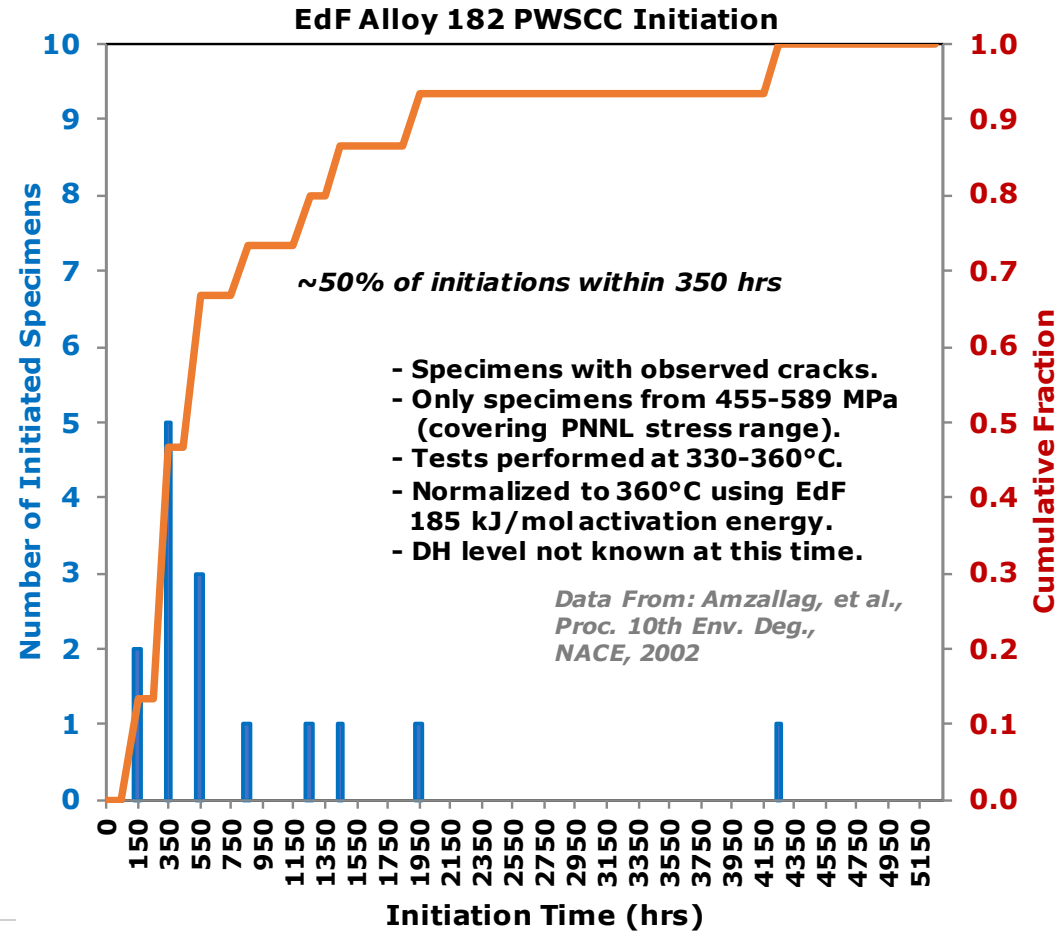
- Approx 45% of initiations at <150 hours when grouping all four welds together.
 - Many of these appear to be SCC initiations occurring upon reaching full load.
 - These are below the PNNL Alloy 600 trend band.
- Decreasing distribution all the way out to ~5000 hours.
- All specimens shown, including non-initiated.
 - 3 KAPL specimens at > 5200 hrs.
 - 2 Phase 2B at ≥ 2971 hrs.
 - 1 Studsvik at ≥ 5126 hrs.



Results

Alloy 182: Comparison to Other Labs – EdF Histogram (360 °C)

- EdF data at similar stresses and test temperature to PNNL tests.
- Only specimens with observed cracks.
- Approx 50% of initiations at <350 hours, similar to PNNL observation of many low SCC initiation times.
- Decreasing distribution all the way out to ~4500 hours. Distribution tail goes out to >5650 hours when including exposure times for EdF specimens that have not cracked.
- Trend in distribution matches PNNL test results.



Results

Developing Trends

- Alloy 182
 - 15% CF material has a wide range of initiation times, but most are at very low times.
 - Wide range of initiation times suggests large microstructural variability in Alloy 182.
 - Initiation times of 15% CF material consistent with EdF results.
 - Much longer initiation times for lower strength conditions (7.5% CF and as-welded).
 - Much longer initiation times for 15% CF material tested at 90% YS.
- Alloy 600
 - Results thus far are consistent with values from PNNL LWRS program and other labs.
- Alloy 690/152/52
 - As expected, no initiations after ~2.6 years.
 - Observations from PNNL LWRS program that is testing more highly CW Alloy 690 indicate 15% CF material tests are expected to continue for 5 years without initiations. (5 years at 360C corresponds to 48 years at 320C.)

Path Forward

Remainder of 2019

- Continue on-going testing.
- Investigate possible metallurgical factors that lead to early initiations and data scatter.
- Reassess testing plan to ensure that testing/data will achieve the goals of the project.
- Draft report on results to date.

