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

- Status Update

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Alloy 690/52/152 PWSCC Research Collaboration Meeting
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EPRI ELECTRIC POWER RESEARCH INSTITUTE

Pacific Northwest NATIONAL LABORATORY

U.S.NRC United States Nuclear Regulatory Commission *Protecting People and the Environment*

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Outline

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- Material Selection
- Test Systems
- Program Status
  - Alloy 182
  - Alloy 600
  - Alloy 690 / 52 / 152
- Test Matrix and Timeline
- Summary

Objectives

- Obtain primary water stress corrosion cracking (PWSCC) initiation data for Alloy 182 to support the xLPR Code development project
  - Validate xLPR model parameters, including effects of temperature, stress, and yield strength
  - Understand uncertainties and accuracy of PWSCC initiation models

- Obtain PWSCC initiation data for Alloy 690/152/52 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

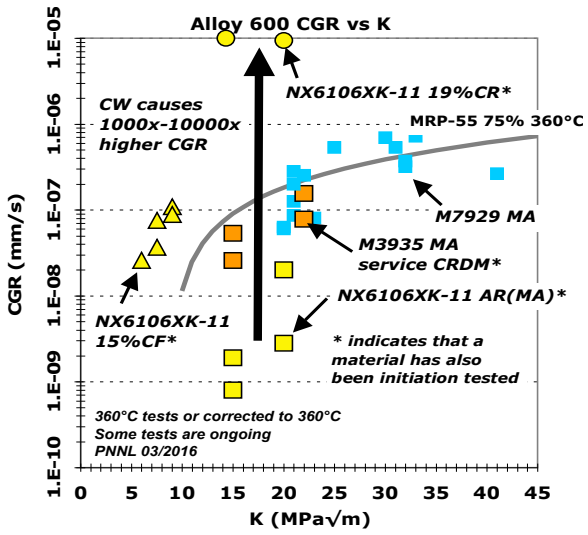
- The NRC and EPRI have entered into a memorandum of understanding (MOU) to conduct cooperative research on PWSCC initiation testing at PNNL, with a total estimated project duration of about five years

- Initiation testing will be performed 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 Alloy 182 results and for Alloy 690 FOI
  - Alloy 690/52/152, to obtain FOIs over Alloy 600/182

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 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 difference in CGR is consistent with strong reduction in SCC initiation time for CW Alloy 600
- Yield strength, hardness, and other characterizations are being performed on the 15% cold forged materials



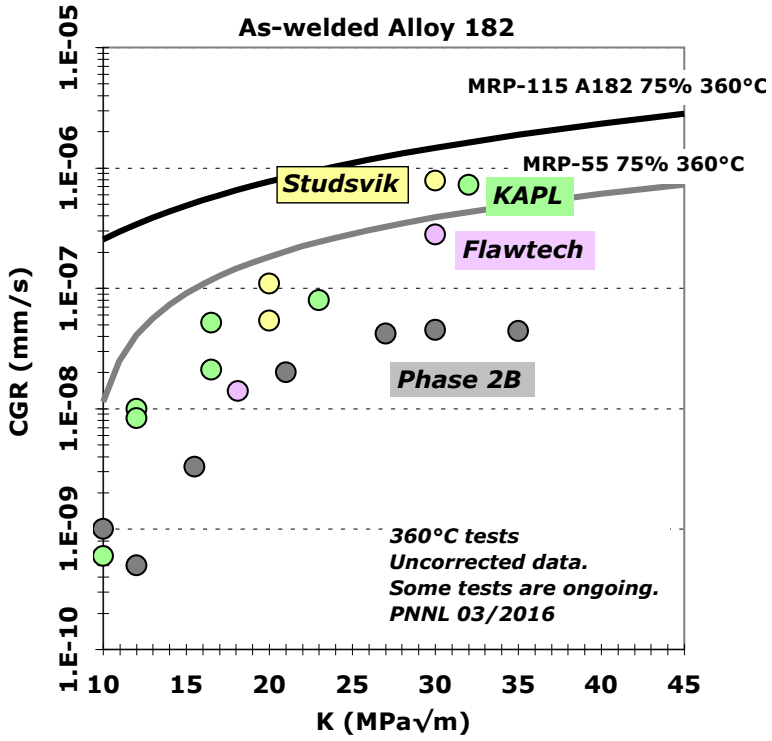
15% Cold Forged Material

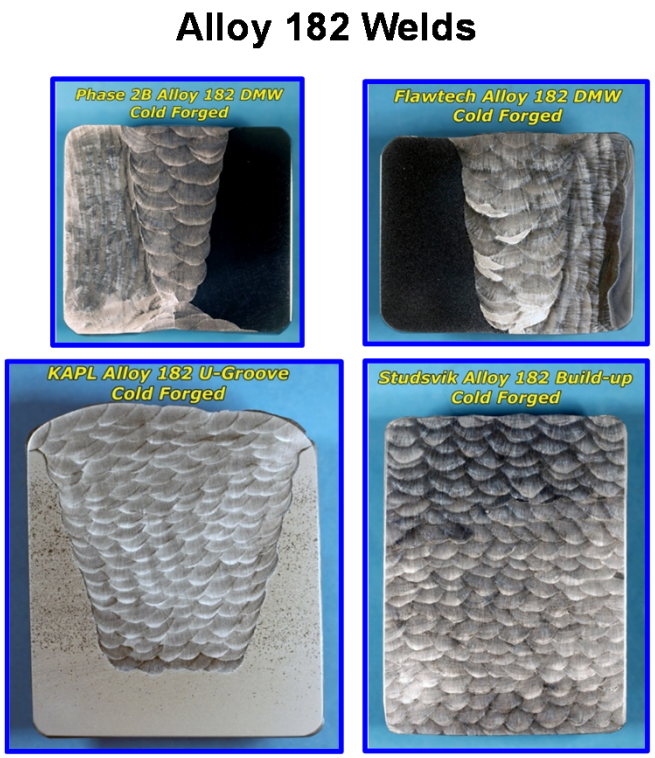
Material	ID	YS@360°C (MPa)	Hardness (kg/mm²)
Alloy 182 Build-up	Studsvik 8001231	550	240-345
Alloy 182 DMW	Flawtech 844305	515, 525	225-345
Alloy 182 DMW	Phase 2B	460, 500	225-330
Alloy 182 U-Groove	KAPL 823030	580, 590	250-350
Alloy 600 Plate	NX6106XK-11	575	270
Alloy 600 Plate	522068	450	240
Alloy 600 Plate	33375-2B	540	in-progress
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	in-progress
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 MPa√m
- Studsvik and KAPL welds exhibited highest SCC susceptibility
- Flawtech was midrange
- Phase 2B lowest
- *High SCC CGRs in Studsvik and KAPL suggest possibility of very low SCC initiation times*



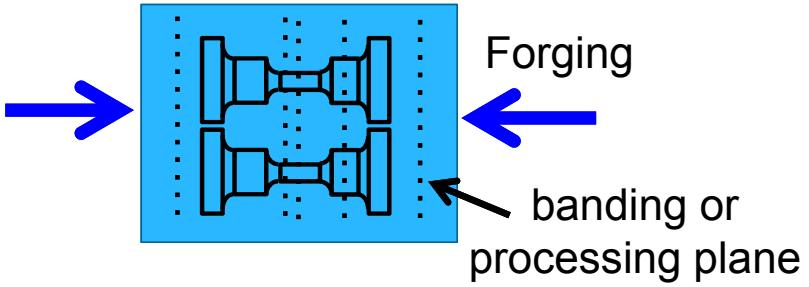


Material Selection

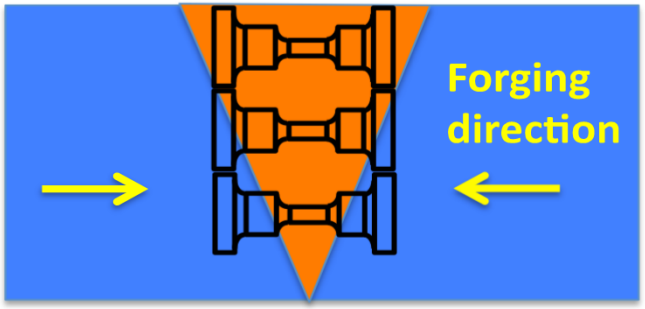
Specimen Fabrication

- For base metal specimens
  - Forging plane is aligned with processing plane
  - Specimen cracking plane is aligned with forging plane (and processing plane)
- For weld metal specimens
  - Gauge and fillet are always made entirely of the weld metal
  - Forging plane is aligned to T-S orientation of weld
  - Specimen cracking plane is aligned to forging plane (and T-S orientation)
- Same orientations have been used for SCC CGR testing of these materials

Orientation of Specimens from Plate



Orientation of Specimens from Welds



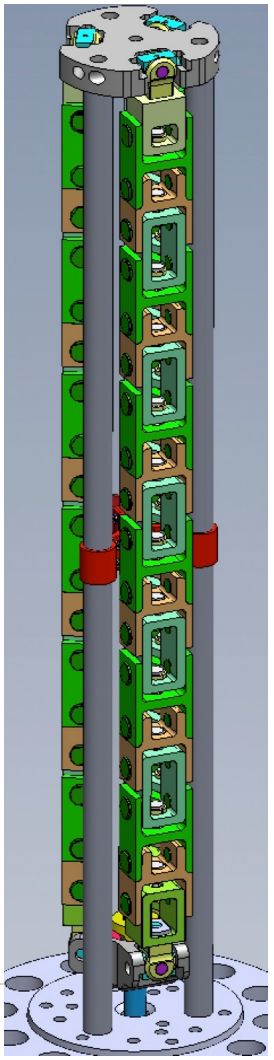
Test Systems

- Available systems
  - Two 36-specimen testing systems (developed for NRC/EPRI program)
  - Two 6-specimen testing systems (modified/shared with LWRS program)
  - Two 3-specimen testing systems (owned by PNNL)
- Measurements of servo load, tare load, and autoclave temperature are performed every ~48 seconds
  - Variations in each represent <0.5% changes in these key environmental variables
- DCPD data acquisition software was completely rewritten for NRC/EPRI program with optimization of interaction with hardware and measurement parameters
- 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
- Direct current potential drop (DCPD) is used to detect crack initiation; gauge voltage increases strongly at the point of initiation

6-Specimen SCC Initiation System

30 mm (1.2“) Tall Specimen

36-Specimen Initiation System



Program Status

Alloy 600/182 – 15% Cold Forged Results

Alloy 182 (15% CF) Heat ID	Material	Total Specimens	# Tested	# Cracked	Uncracked Total Hours
Studsvik 8001231	Alloy 182 Build-up	6	3	2	>3020
Flawtech 844305	Alloy 182 DMW	6	3	0	>250
Phase 2B	Alloy 182 DMW	6	3	2	>430
KAPL 823030	Alloy 182 U-Groove	6	3	3	---

Alloy 600 (15% CF) Heat ID	Material	Total Specimens	# Tested	# Cracked	Uncracked Total Hours
NX6106XK-11	Alloy 600 Plate	6	6	0	>2500
33375-2B	Alloy 600 Plate	6	6	4	>2500
WNP5	Alloy 600 CRDM	6	---	---	---
522068	Alloy 600 Plate	6	---	---	---

Program Status

Alloy 690/52/152 – 15% Cold Forged Results

Alloy 690 (15% CF) Heat ID	Material	Total Specimens	# Tested	# Cracked	Uncracked Total Hours
RE243	Alloy 690 CRDM	3	3	0	>5600
WP142	Alloy 690 CRDM	3	3	0	>5600
114092	Alloy 690 Plate	3	3	0	>5600
B25K-2	Alloy 690 Plate	3	3	0	>5600

Alloy 52/152 (15% CF) Heat ID	Material	Total Specimens	# Tested	# Cracked	Uncracked Total Hours
MHI 307380	Alloy 152 U-groove	6	6	0	>5600
IHI 444537/WC83F8	Alloy 152M U-groove	6	6	0	>5600
MHI NX2686JK	Alloy 52 U-groove	6	6	0	>5600
ENSA DPM Butter	Alloy 52M Butter	6	6	0	>5600

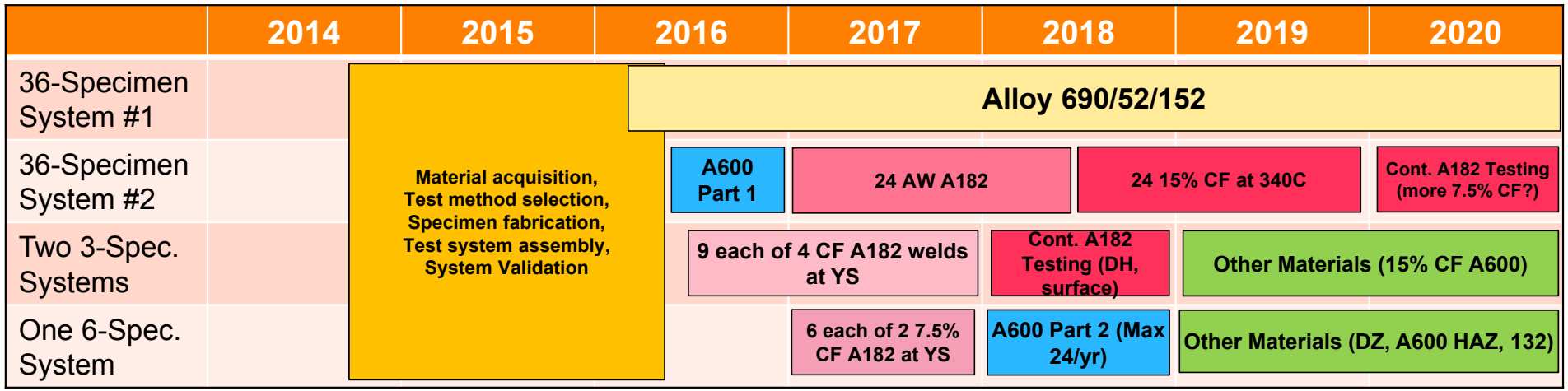
Test Matrix and Timeline

Alloy 182 Test Matrix Potential Modifications

- A greater number of tests of Alloy 182 are needed to characterize the distribution of initiation times and to provide results that can be applied to xLPR:
  - 15% CF material at YS – to make better sense of the range of times currently observed and to improve the confidence in the FOI for Alloy 52/152
    - Use all 4 welds, if sufficient amount of material
  - As-welded material at YS – to investigate the yield strength dependency
    - Use only 1-2 most susceptible welds
  - 15% CF material below YS – to investigate the stress / stress ratio dependency
    - Use only 1-2 most susceptible welds
  - 15% CF material at YS, multiple temperatures – to investigate activation energy
    - Use only 1 most susceptible weld

Test Matrix and Timeline

Proposed Timeline



- 15% CF Alloy 182 – 9 specimens per weldment, all four weldments, test in small autoclave systems
- As-welded Alloy 182 – 6 specimens per weld, all four weldments, and test in 36-specimen system
- Include 7.5% CF for stress dependence, 6 specimens per weldment, 2 or possibly 3 weldments
- Include 340°C for temperature dependence, 9-12 specimens per weldment, 2 or possibly 3 weldments
- Key milestones
  - Preliminary stress dependence data obtained by January 2018
  - Complete stress dependence data obtained by July 2018
  - Temperature dependence data obtained by January 2019
  - Alloy 600 data by January 2019

Test Matrix and Timeline

Mapping Testing Objectives to Test Matrix

Testing Objectives

- xLPR Initiation Model Parameter Objectives (X)
  1. Alloy 182 microstructure / material variability
  2. Stress (or stress ratio = stress/YS)
  3. Yield strength
  4. Temperature
  5. Hydrogen
  6. Specimen geometry (tensile vs. bent beam)
  7. Surface condition (bent beam specimens)
- Factors of Improvement Objectives (F)
  1. Ratio of time to initiation for A690 vs. A600
  2. Ratio of time to initiation for A52/152 vs. A182

Test Matrix – Estimated Objective Testing Date

Test Specimens	2016	2017	2018	2019*	2020*
15%CF A182 @ YS 4 welds	X1, F2	X1, F2			
AW A182 @ YS 4 welds		X3	X3		
7.5%CF A182 @ YS 2 welds		X3			
15%CF A182 @ 340°C 4 welds			X4	X4	
15%CF A182 @ DH_{var}			X5		
15%CF A600 @ YS 4 heats	F1				
A600 TBD					
15%CF A182 @ 0.9YS (X2, when?)					
15%CF A690 @ YS 4 heats	F1	F1	F1	F1	F1
15%CF A52/152 @ YS 4 welds	F2	F2	F2	F2	F2

* - Optional

- End