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Alloy 690/52/152 PWSCC Testing

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EPRI Alloy 690 PWSCC Research

- Issue statement and objectives
- Overall testing results
- Fabrication/Characterization/Testing of Mockups
- PWSCC CGR data analysis and screening
- PWSCC initiation testing
- Examination of cold work

EPRI Alloy 690/52/152 PWSCC Program Issue Statement

- Alloys 690/52/152 very resistant to PWSCC; however, PWSCC-related issues remain:
  - PWSCC vulnerability for material with abnormal microstructure, specific product forms, and to thermo-mechanical processing that could be present in the HAZ
  - A52 fabrication defects could become a factor in initiation or growth of PWSCC cracks in welds or weld overlays.
  - Guidelines for material procurement specifications and weld quality are needed to minimize concerns for PWSCC

A690/52/152 PWSCC Research Objectives

- Consolidate knowledgebase on Alloy 690/52/152 PWSCC
  - Determine PWSCC initiation/growth improvement factors over Alloys 600/82/182
  - Develop crack growth rates curves and initiation models for Alloys 690/52/152
  - Inform regulatory consideration of inspection optimization for replacement components such as the reactor pressure vessel head with Alloy 690 penetrations

Overall Alloy 690/52/152 CGR Testing Results

- Relatively high CGRs measured in certain orientations after >20% levels of cold work; CGRs reduce at lower cold work levels
- Beneficial evidence of effect of hot versus cold forging on CGRs
- Tests to date do not show high CGR susceptibility in the weld HAZ, but testing of such specimens is still limited
- Weld and HAZ strains even after weld repair appear in the 10 to 15% range, limited testing shows very low CGRs; work continuing
- CGRs for A52/152 are generally low (≈5.0E-09 mm/s); need to address:
  - Effect of hot cracks and DDC
  - Higher CGRs reported at one lab
- Concern for dilution zone at interface with low-chrome material needs to be addressed

Isolated reports of high CGRs in A690 testing from labs; need review and cross-testing

Mockup Fabrication, Characterization and PWSCC Testing

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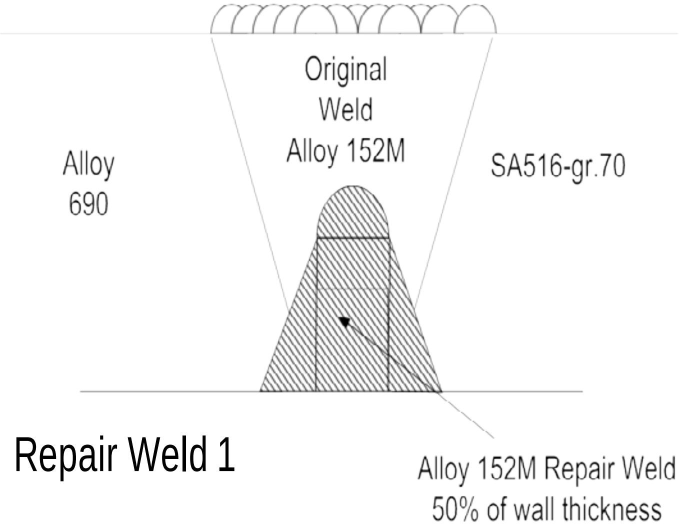
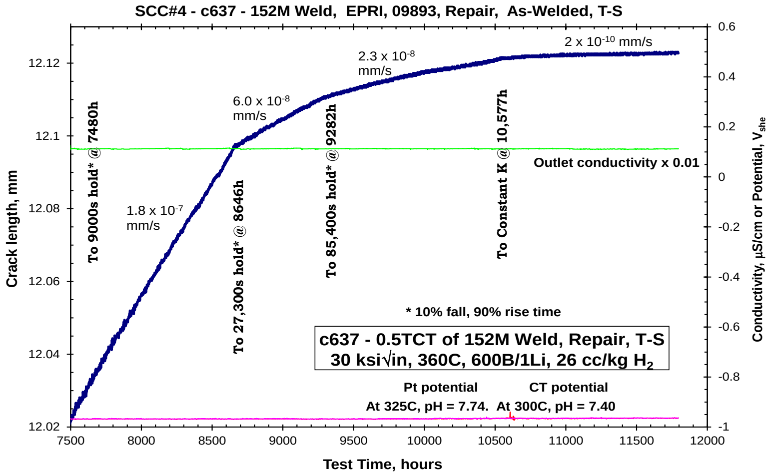
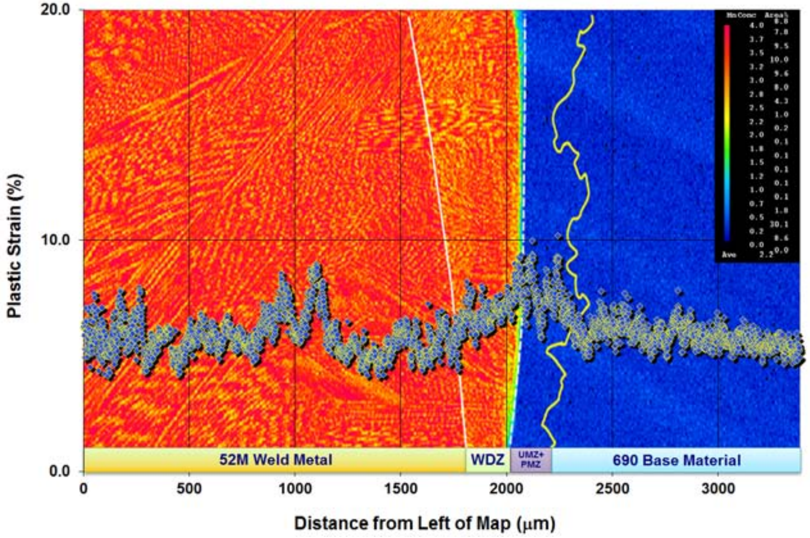
Low Residual Strains and CGR in 50% Repair Mockup







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Alloy 690 Double Melt - VIM Heat D1-11747 then VAR Heat CX-2531

Forged pancake with simulated Alloy 690 PMZ+UMZ Microstructure

Six 0.5T CT blanks

C-R orientation

B-T1 - PNNL

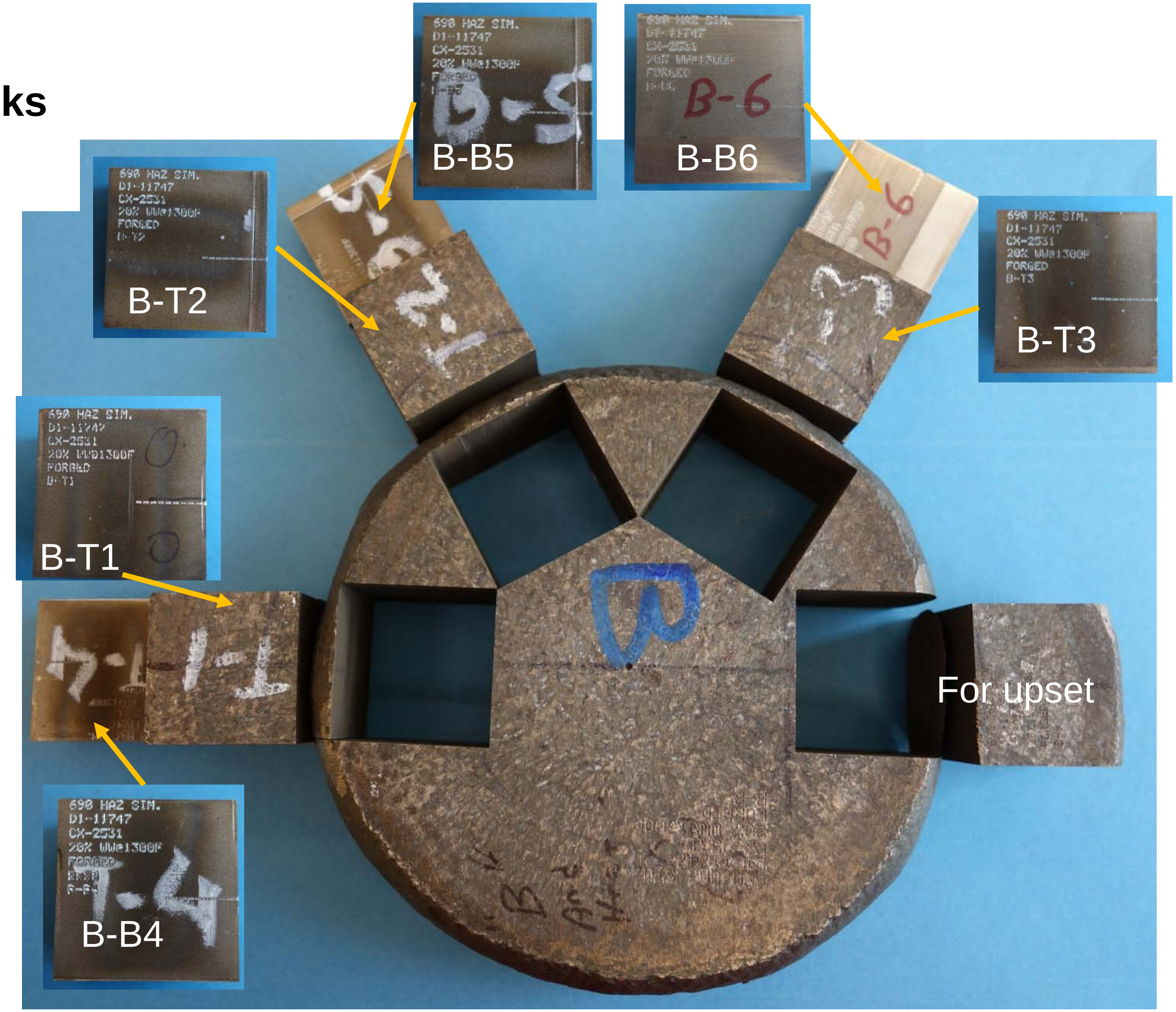
B-T2 - GEGR

B-T3 - PNNL

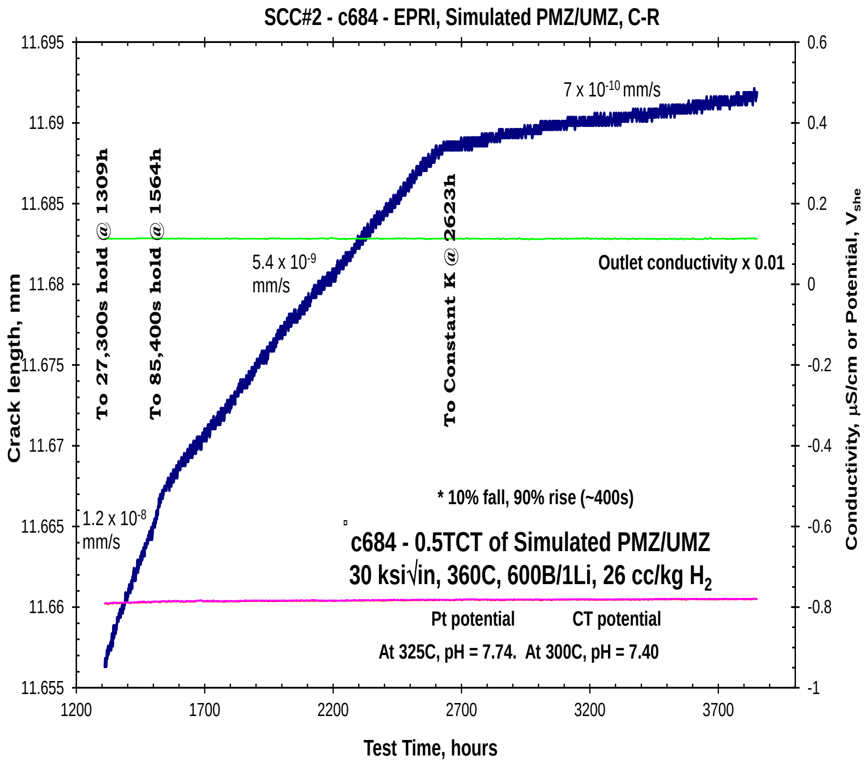
B-B4 -GEGR

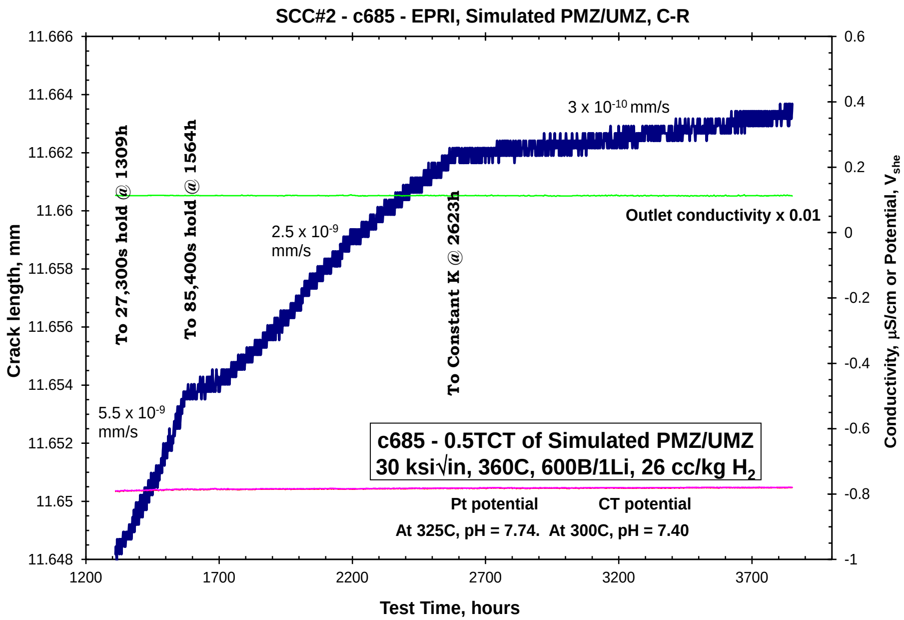
B-B5 - PNNL

B-B6 -GEGR



PMZ/UMZ CGR Testing: C-R Orientation





Very low CGRs

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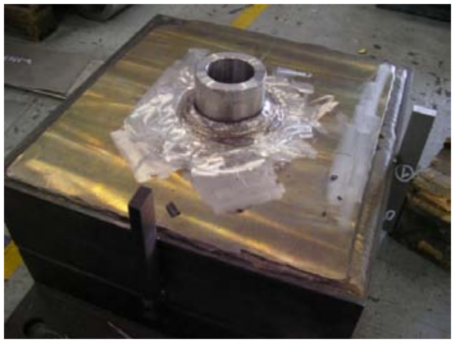
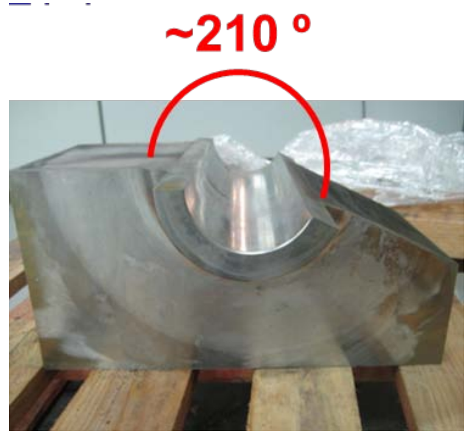
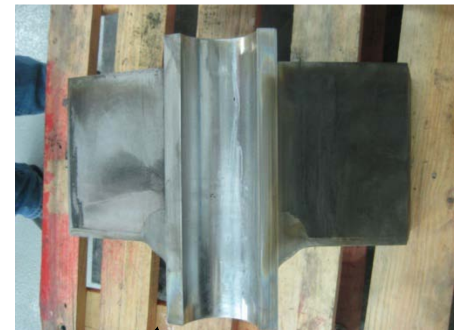
CIEMAT/CSN Alloy 690 CRDM Mockup

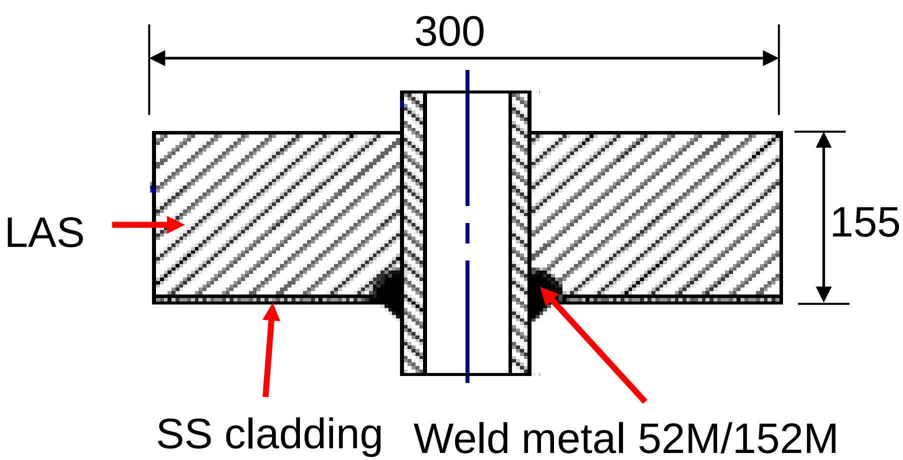


Original

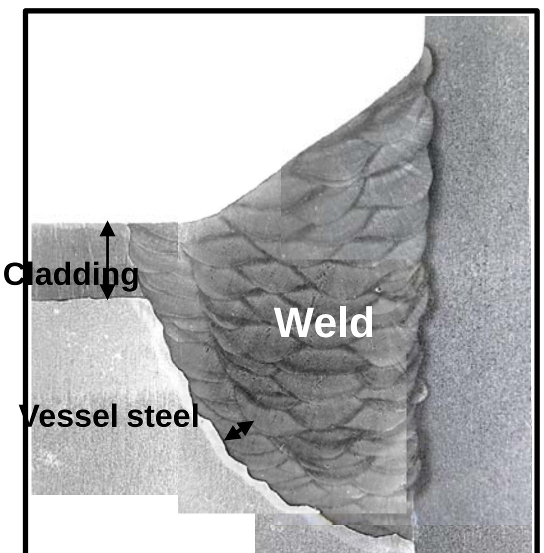




May 2014



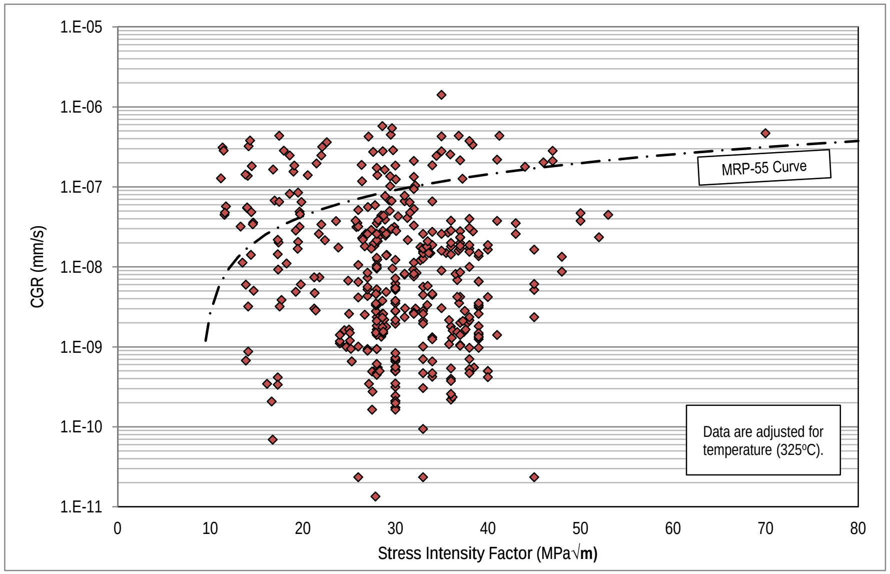
Alloy 690TT tube { Φ_e = 101.6 mm, Φ_i = 67.6 mm, Thickness =17 mm



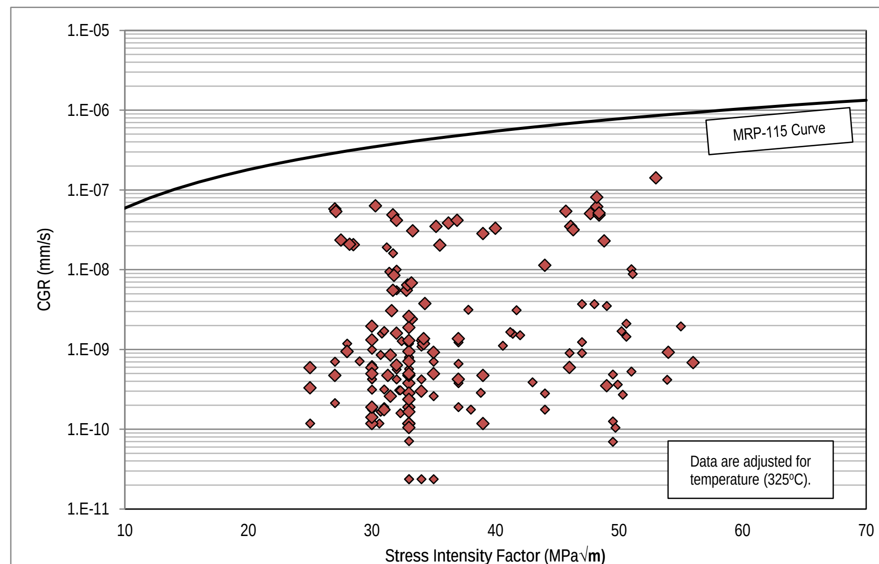
PWSCC CGR Data Analysis and Screening

PWSCC CGR Data Analysis/Screening (1/4)

Alloy 690: 6 laboratories, 450+ data points



Alloy 52/152: 5 laboratories, 150+ data points



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PWSCC CGR Data Analysis/Screening (2/4)

- Screening criteria based on several categories
  - Specimen preparation
  - Testing environment
  - Testing procedure
  - Crack growth
  - Data reporting
- Expert Panel ranks each data point from 1 (worst) to 5 (best)
- Only data with average ranking >2.5 is selected
- Selected data will be used to develop consensus crack growth rate curves

Data Analysis/Screening Expert Panel Being Assembled

PWSCC CGR Data Analysis/Screening (3/4)

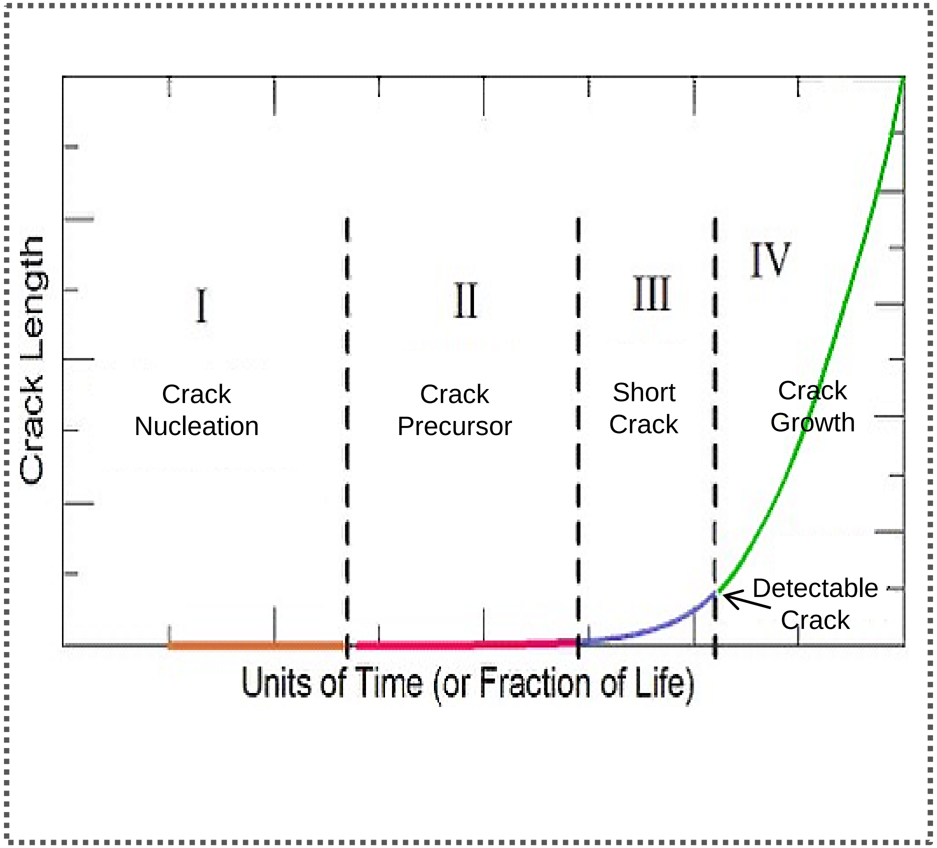
- Intergranular Engagement
  - Alloy 690 often shows little to no IG engagement
  - SCC may occur by both IG and TG propagation
- Partial Periodic Unloading (PPU)
  - PPU increases CGRs, but by what factor is unknown
  - Fatigue aspect plays an unknown role
- Post-Test Correction
  - DCPD errors must be corrected, especially for low CGRs
  - Correction for IG engagement is debatable

PWSCC CGR Data Analysis/Screening (4/4)

- Manufacturing defects
  - e.g., hot cracks, lack of fusion
- Cold worked Alloy 690
- High residual plastic strains
  - e.g., in and adjacent to welds
- Alloy 690 HAZ
- Alloy 52/152 dilution zones
  - interfaces with Alloys 600/82/182, SS, CS, LAS
- Surface layers abused by grinding and machining

Alloy 690/52/152 PWSCC Initiation Testing

Alloy 690 PWSCC Initiation: Background



- No PWSCC in Alloy 690 detected to date and long initiation times are expected
- Quantification of PWSCC initiation time desired to provide input for:
  - decisions on mitigation measures such as peening
  - determining appropriate risk-based ISI (e.g. xLPR)

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Alloy 690 PWSCC Initiation: Objectives

- Determine Factor of Improvement (FOI) for Alloys 690/52/152 over 600/82/182
  - PWSCC initiation in thick wall Alloy 600/82/182 assumed to have occurred in periods of ~ 1 year (uncertain since small flaws not seen by UT)
  - FOI of at least 60 desired to help show that PWSCC initiation not likely for >60 years
- Account for time to crack initiation for inspection intervals

Long testing times for both Alloy 600 and Alloy 690 (and weld metals) require ways to accelerate cracking in laboratory testing

Alloy 690 PWSCC Initiation: Test Parameters

- Material Condition:
  - Presence of fabrication defects including weld defects
  - Cold work from material processing prior to welding
  - Residual stresses and strains introduced by welding
  - Heat affected zone of Alloy 690 base metal
  - Dilution Alloy 52/152 weld metal at interfaces with lower Cr metals
  - Surface layers abused by grinding
- Application:
  - Alloy 690 nozzles with Alloy 52/152 J-groove welds
  - Alloy 82/182 piping dissimilar metal butt welds (DMWs) mitigated using Alloy 52/152 inlays/onlays
  - DMWs fabricated using Alloys 52 and 152

Examination of Cold Work

Issue

- SCC testing for RCS materials such as Ni-based alloys and stainless steels has clearly shown that susceptibility to SCC initiation and growth increases with surface and bulk cold work
  - That is why cold work is widely used as an SCC accelerant
  - Alloy 690 and stainless steels are especially degraded by cold work
- While cold work plays such an important role in material degradation, levels of cold work present in our plants remain unknown
- Lack of knowledge of levels (and causes) of bulk and surface cold work has two undesirable consequences:
  - Use of (assumed) overly conservative levels of bulk and surface cold work in test specimens. This in turn causes significant conservatism in life prediction.
  - Continuation of fabrication and installation practices for replacement components and for new plants without any meaningful attempt to address cold work

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Planned Work

- Review fabrication/installation practices used in existing plants and, if necessary, fabricate mockups, to assess levels of surface and bulk cold work in key components that could be expected realistically

- Investigate how different fabrication/installation procedures (and subsequent finishing, e.g., grinding) affect surface and bulk cold work in finished components

Alloy 690 and Stainless Steel will be the focus

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