Comments on SCC Crack-Growth-Rate Testing Issues

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Presentation Topics

- **Laboratory SCC Crack-Growth Testing**
- **Crack-Growth Rates for Alloy 690/152/52**
  - Current Alloy 690/152/52 Testing and Data Summary
  - Potential Issue for 1D-Rolled Alloy 690
  - Questions, Concerns, Issues and Research Needs
- **Crack-Growth Rates for Alloy 600/182/82**
  - Alloy 600 Data and Disposition Curve
  - Alloy 182/82 Data and Disposition Curves
  - Questions, Concerns, Issues and Research Needs
- **SCC Crack-Growth Testing Issues**
  - System Requirements and Test Approach
  - Problems/Issues for SCC-Resistant Materials

SCC Crack Growth Testing

Crack-growth-rate testing is the most effective and quantitative method to evaluate material and environment effects on SCC. Can be used to:

(1) define and quantify material-environment-stress dependencies on SCC

(2) generate data for mechanistic understanding and form the basis for engineering prediction

(3) resolve confusion and help elucidate service failures

(4) probe new phenomena and help confirm effectiveness of mitigation approaches.

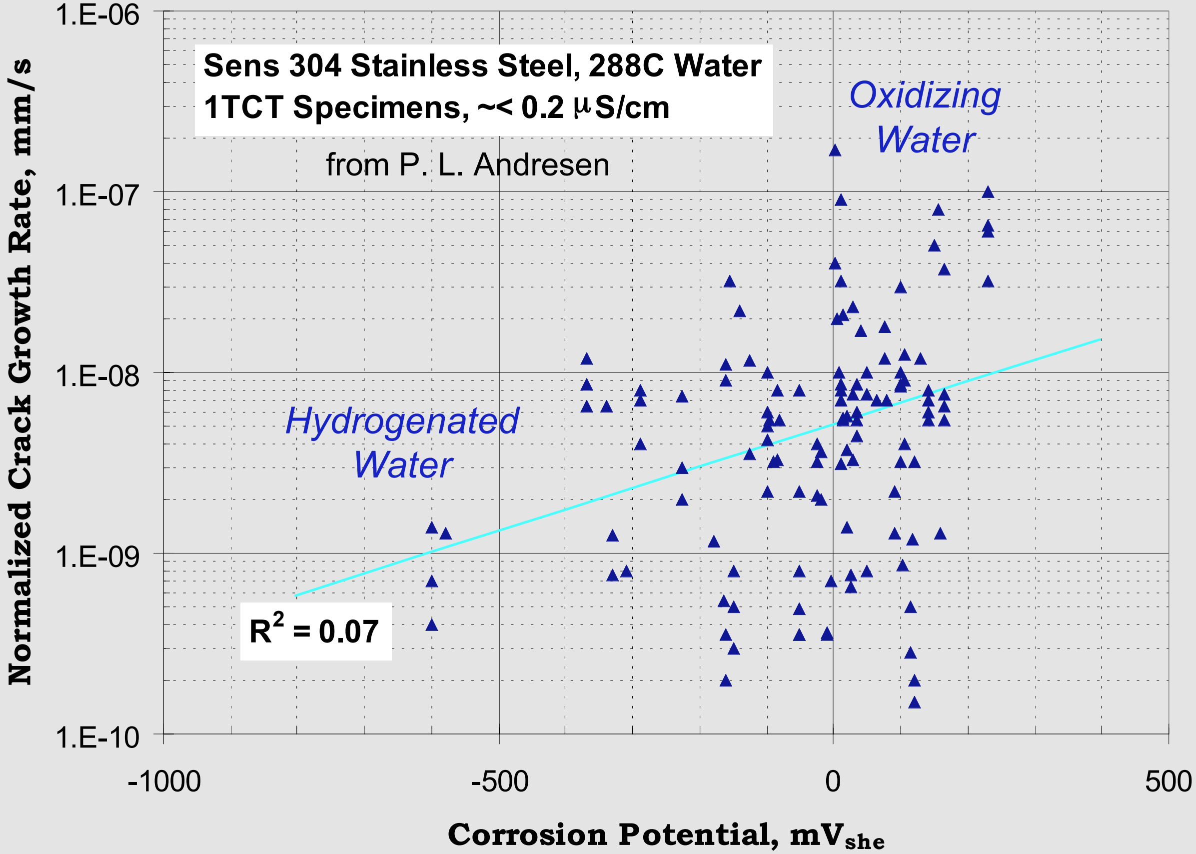
SCC Crack Growth Testing Issues

Many experimental, materials, enviromental and interpretation elements necessary for effective measurement/analysis of SCC:

1. *Successful SCC testing requires a broad knowledge of metallurgy, mechanics, chemistry, electrochemistry, and physical measurements - excellence not in a few areas, but in all*
2. *Test methodology important - transitioning, unloading, K/size, crack front evenness, dcpd resolution, test management*
3. *Material (heat, processing, homogeneity, heat treatment, inclusion/carbides, cold work/HAZ, orientation, …) and environment (temperature, pH, purity, …) variations important*
4. *Interpretation important – uneven crack fronts & data correction, use of avg vs. max CGR, K correction, data reproducibility…*

SCC Testing & Data Issues

*CGR data, even for "well behaved" material, often shows **large scatter** due to testing problems*



Even with best empirical model, scatter can produce a very poor statistical fit.

Reproducibility of SCC CGR Data Depends on Many Items Including Test System Capabilities:

1 – Loading stability, dK/da correction, high-to-low frequency cycling, cycle + hold, constant displacement control, …

***2 – DCPD crack length measurement** resolution & accuracy (need at least <10 μm, <2 μm for SCC resistant alloys)*

3 – Temperature (<0.2°C fluctuation), water pressure, seal friction and water chemistry (<0.1 μS/cm outlet) control

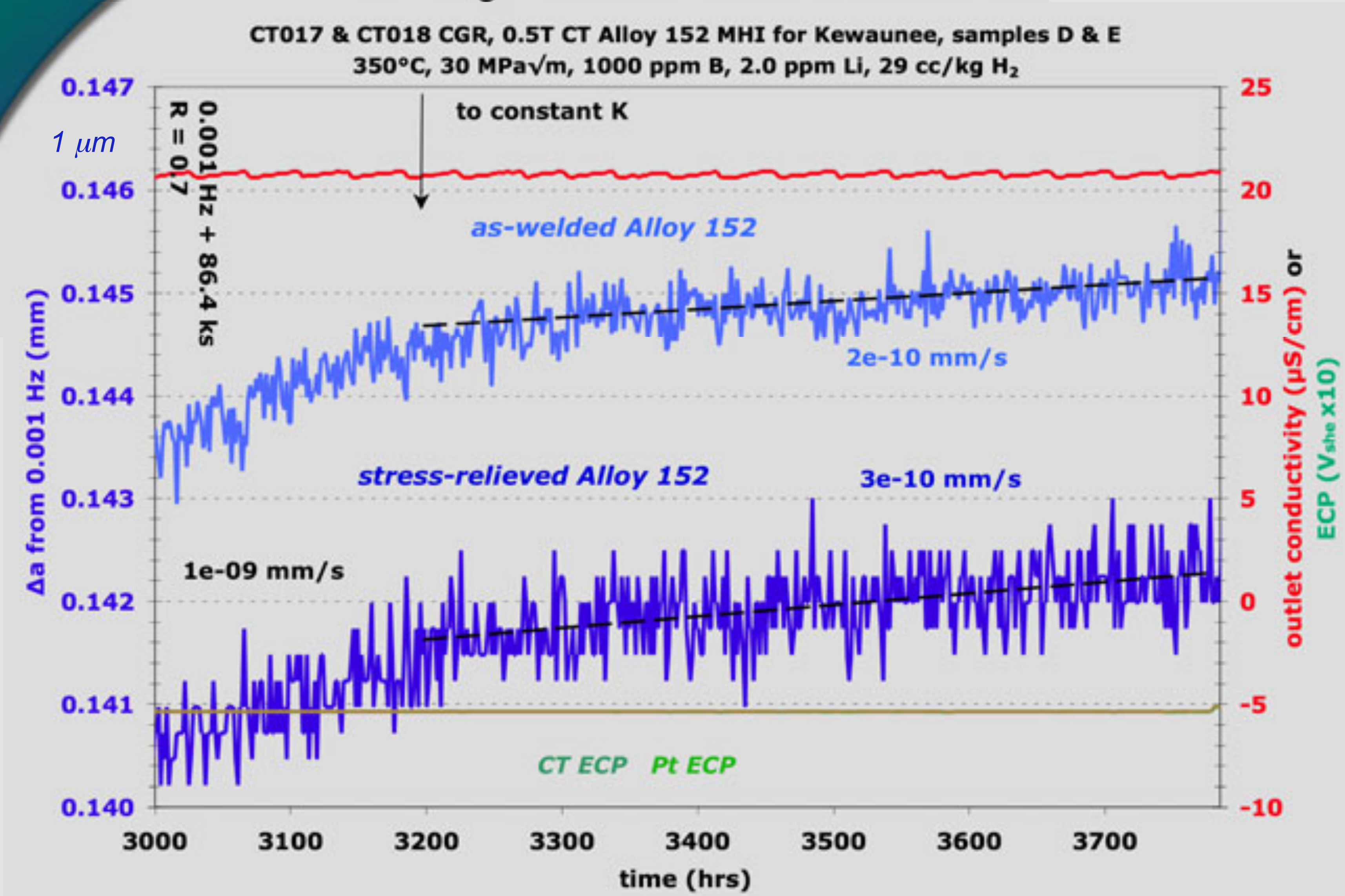
4 – Reference electrode accuracy & reliability

5 – Ability to make changes "on-the-fly", e.g., in temperature, H_2 concentration, pH/B/Li/impurities, …

***6 – Maintain continuous operation and stability** of all test conditions **over long times** (e.g., >12 months)*

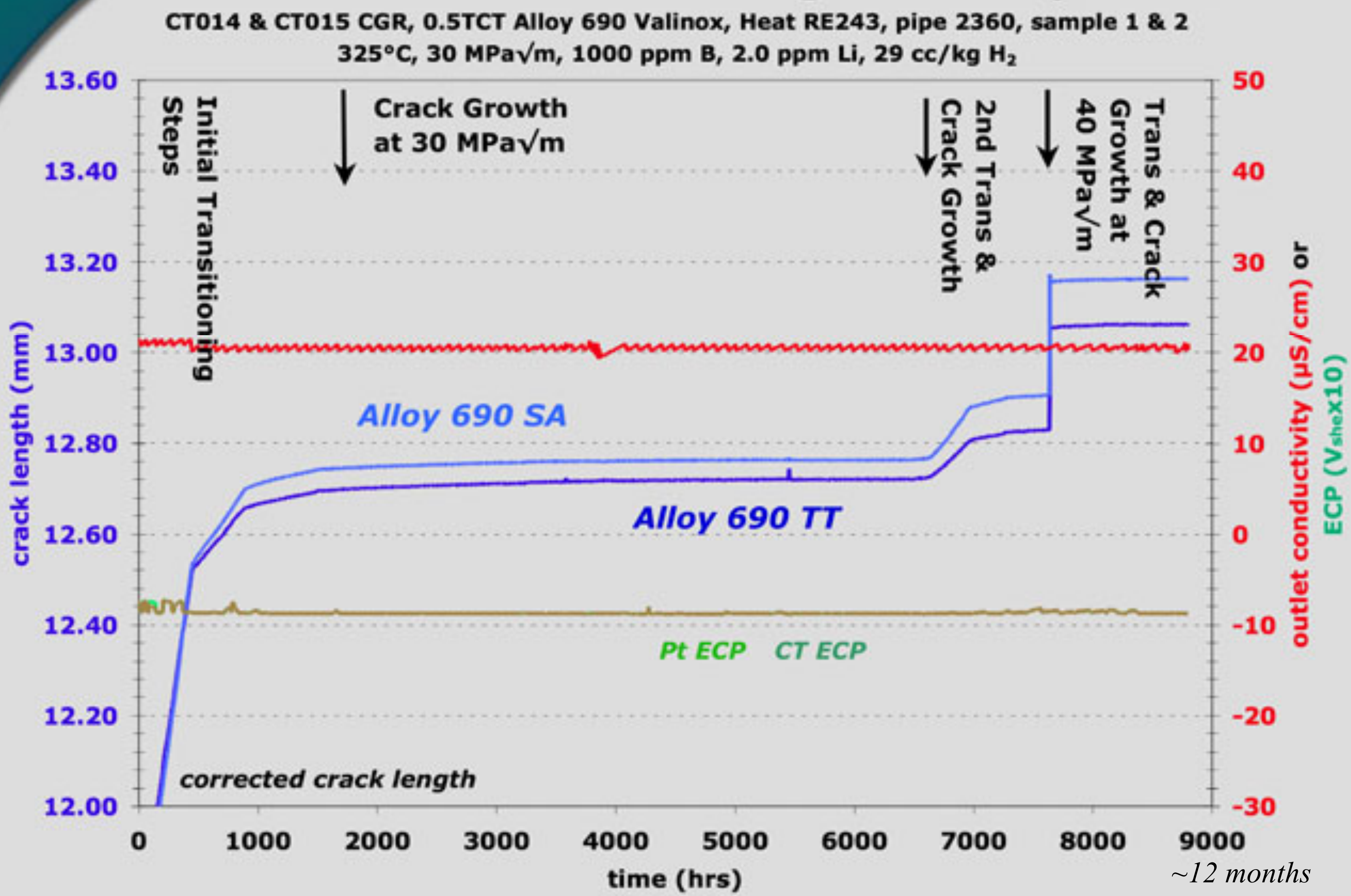
Based in part on material presented by Peter Andresen, GE Global

Alloy 152: Constant K



Stable system and high-resolution DCPD capable of measuring extremely slow, stable crack growth (μm dimensions) at constant K over many months

Crack Growth Testing of Alloy 690



~12 months

Several cycle and cycle + hold steps employed to evaluate different microstructural regions and help transition crack front to SCC

Reproducibility of SCC CGR Data Depends on Many Items Including Test Approach Aspects:

1 – Wise management of testing and specimen response

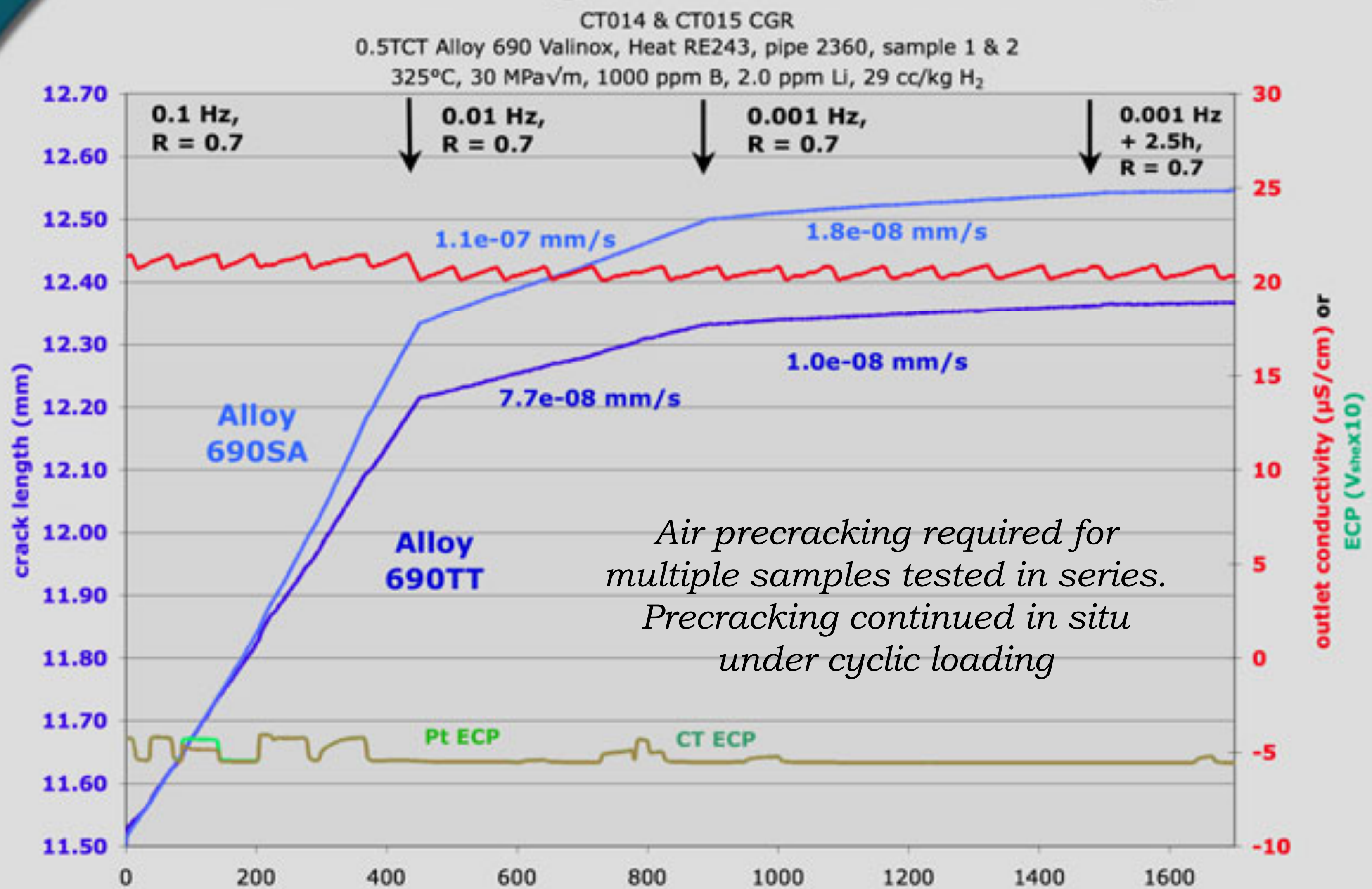
2 – Transition from TG fatigue precrack to corrosion fatigue to IGSCC, *e.g., use decreasing cyclic frequencies, increasing R values and increasing hold times at* K_{max}

3 – Maintain straight crack front and minimize "fingers" of SCC growth as possible

4 – Repeat crack growth rate measurements for key conditions after different crack extensions to sample different microstructural regions

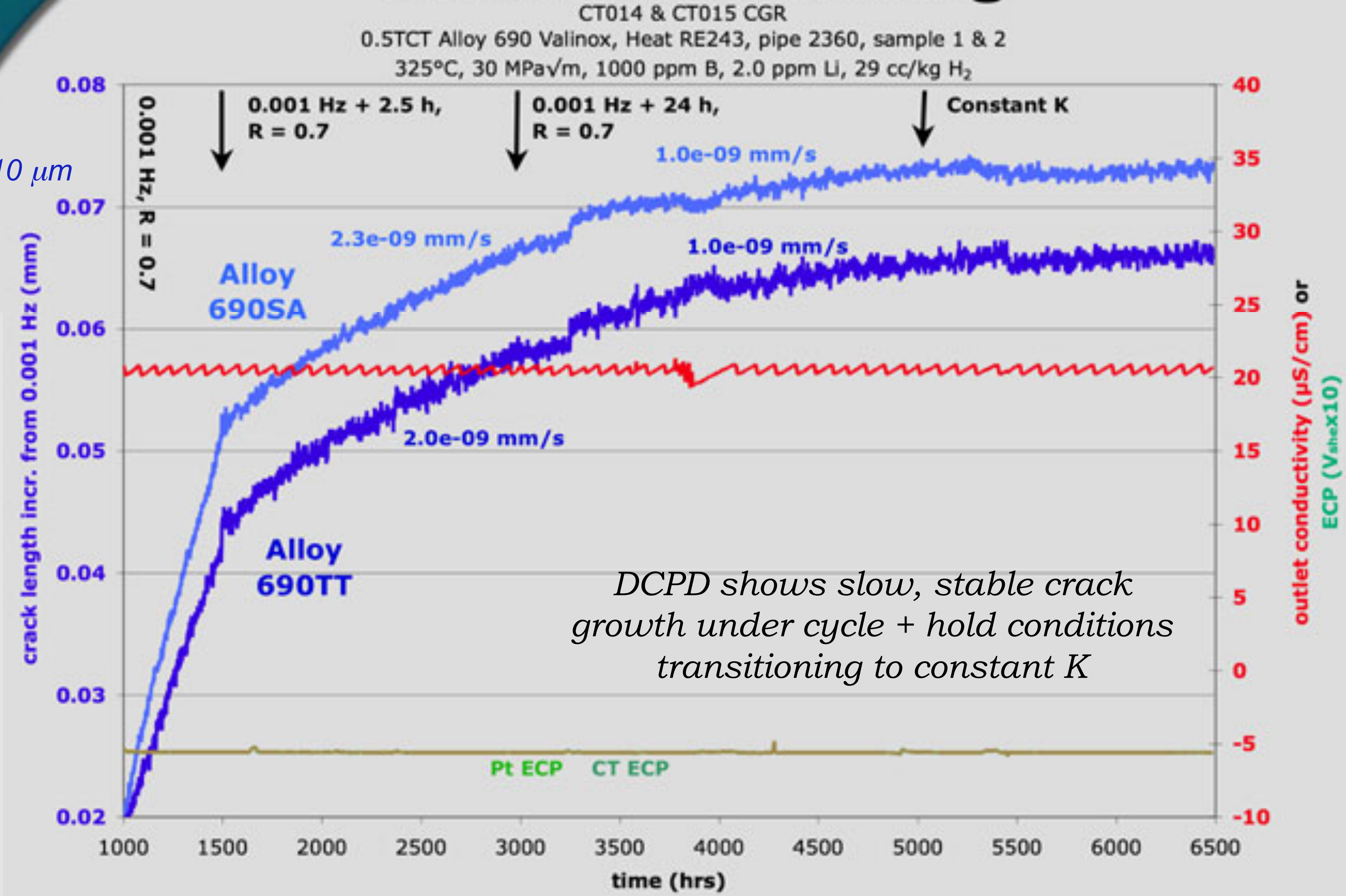
5 – Post-test crack length correction to obtain accurate K levels and best assessment of average/maximum growth rates

Alloy 690 (TT/SA) Precracking and Transitioning



Precracking can be done in water or air. If in air, crack should be extended under similar conditions after test started in high-temperature water.

Alloy 690 (TT/SA) Crack Transitioning



Many options for transitioning steps reaching low frequency cycling (to 0.001 Hz) and higher R values (0.5 to 0.7), then adding hold time at K_{max}

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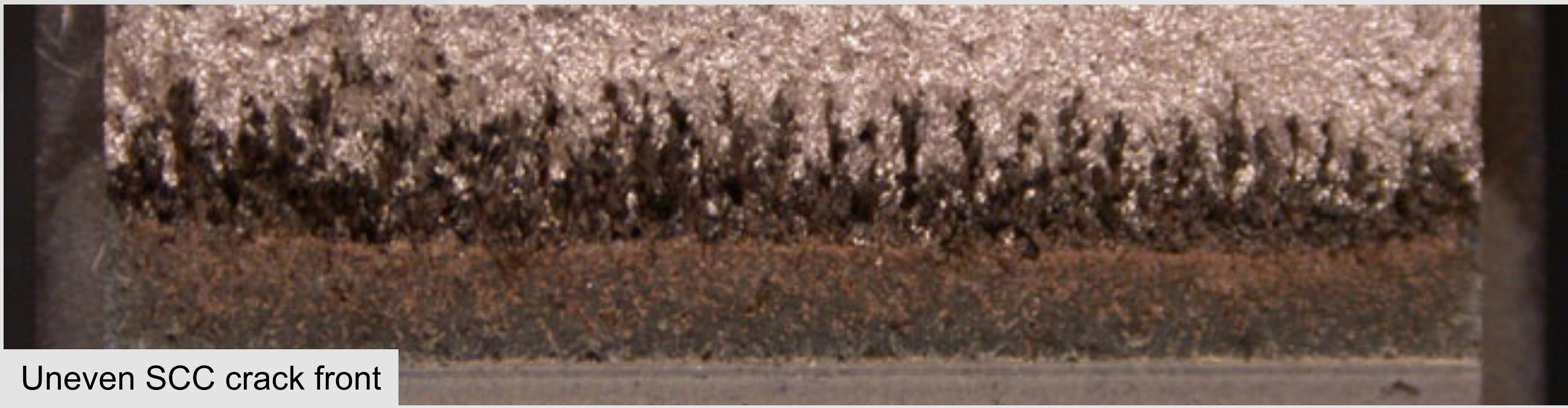
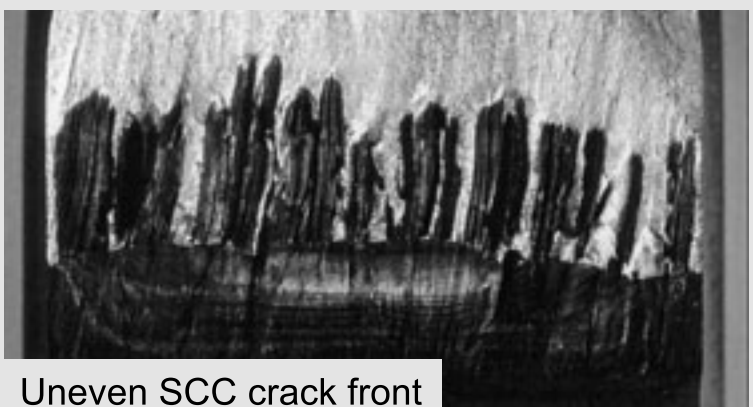
TG Fatigue Precracking and IGSCC Transitioning

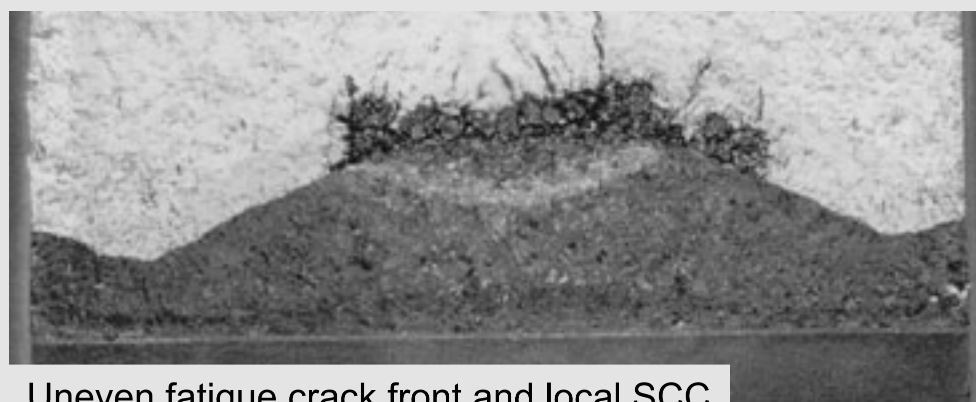
TG fatigue cracks poorly simulate lab or field IGSCC. Morphology change, plastic zone, crack front pinning issues. Attempt to transition to IGSCC during low frequency cycling + hold times.



Uneven SCC crack front



Uneven SCC crack front

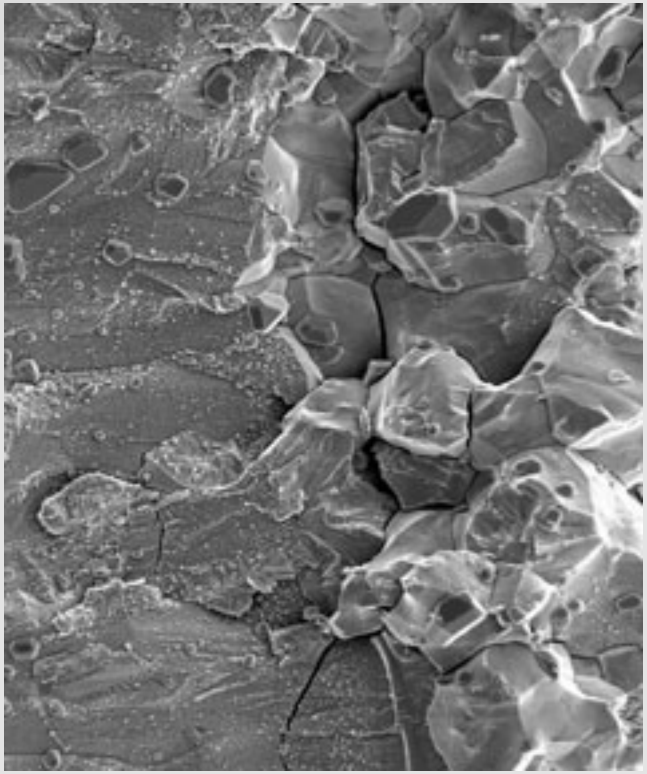


Uneven fatigue crack front and local SCC

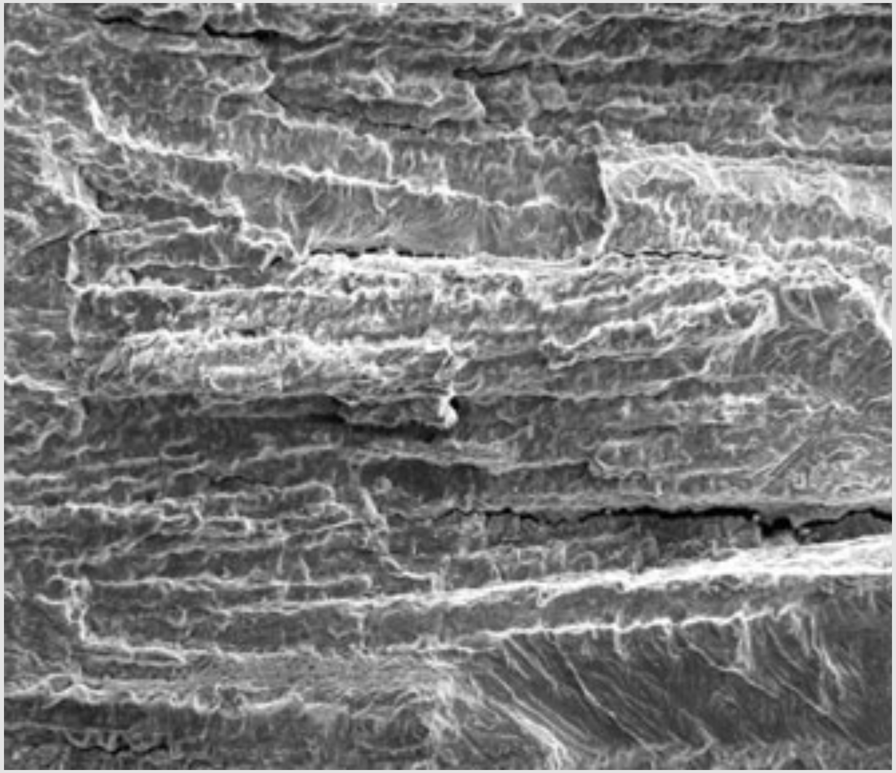
Figures from P. L. Andresen

IGSCC Transitioning and Reproducible Crack Growth Data

Best results obtained for crack front fully engaged and transitioned to IGSCC. Complex microstructures such as for weld metals can make fully engagement difficult.



TG fatigue crack - IGSCC in wrought 304SS



IGSCC along dendritic boundaries in alloy 182 weld metal

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3 – Maintain straight crack front and minimize "fingers" of SCC growth as possible
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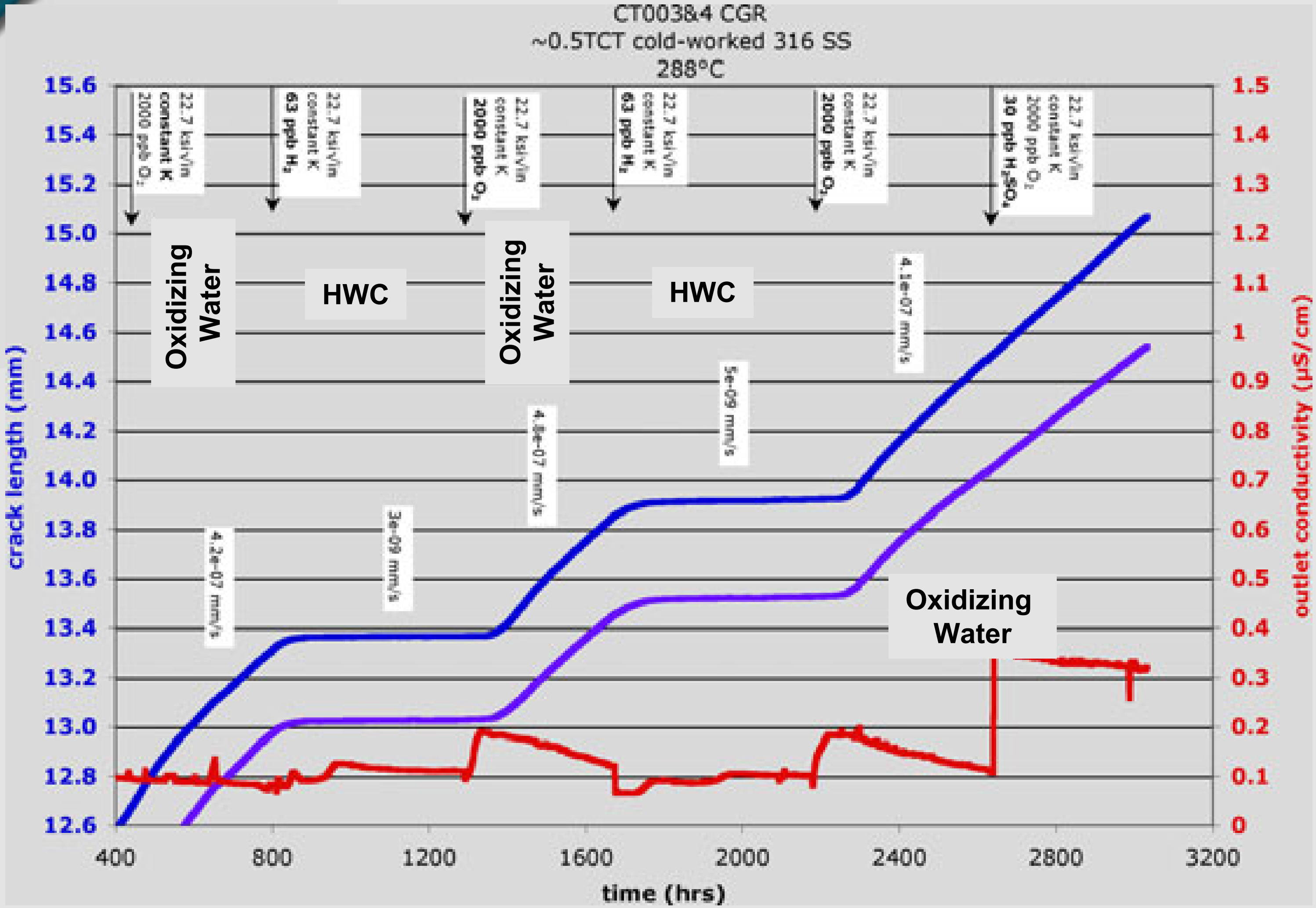
General CGR Test Approach



Demonstrate data reproducibility by repeating key conditions during single test, e.g., O_2 (4-5x10^{-7} mm/s) versus H_2 (3-5x10^{-9} mm/s)

IG Transitioning and SCC Test Management

Criterion for success is pragmatic: Does it work?

SCC resistant materials are much harder to transition, often when IG path has low susceptibility.

1 – Use higher R (typically 0.5 to 0.7) during low frequency cycling to promote IGSCC
2 – Add hold time at K_{max} to assist change to constant K
3 – Must monitor material response on-line for real-time assessment of transitioning; a fixed formula of loading and time rarely works for SCC resistant materials.
4 – Often necessary to repeat/modify transitioning steps when extremely low rates identified at constant K.

Chemistry Disconnects in Comparing Data

Large number of variables to monitor and control during a test, often not reported, creates data uncertainties.

1 – Test temperature; H_2 control and stability; H_2 vs. test temperature; activation energies and normalizing data.
2 – Impurities in water and H_3BO_3 , esp. in static autoclaves.
3 – Possible concern for autoclave system materials and transport of metal cations to the specimen.
4 – Test start up, interruptions and condition (temperature or chemistry) changes may perturbate SCC response.

Lab control of PWR primary water chemistry is a smaller issue than BWR due to much higher conductivity, but some concerns remain.

Material Issues in Comparing Data

1 – Heat-to-heat variability, bulk composition, melt practice, general homogenization (inclusions, banding), …

2 – Mill anneal & thermal treatment (e.g., grain size, grain boundary segregation and precipitation)

3 – Residual or intentional cold/warm work: 1-D, 2-D, 3-D deformation, work per pass, interpass temperature, …

4 – Welding procedures: constraint, heat input, interpass temperature, dilution, residual stress & strain, …

4 – Specimen orientation after rolling, welding, HAZ alignment, …

Detailed background info on materials must be reported and selected characterization (OM, SEM, EBSD, TEM) performed. Test materials should be exchanged among laboratories, esp. when unusual behavior is observed

Interpretation Issues in Comparing Data

1 – Material differences/ variability/ orientation unknowns

2 – Test management including initial pre-cracking, transitioning, constant K versus load testing, effect of periodic unloading, test duration and Δa, crack re-activation ….

3 – Active test management always better than "load-and-hold"

4 – Crack growth non-uniformity posts interpretation challenges:

· recalcitrant areas can retard overall SCC along crack front

· rapid growth along dendrites increases K & allow 2D growth

5 – Post-test correction: effect on CGR and K (avg vs max…), can be difficult to accurately correct for test stages

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