

# Alloy 152-LAS Dilution Zone PWSCC Testing

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# Presentation Outline

## ► **Prior Testing at PNNL**

- Constant  $K$  CGR of  $\leq 3 \times 10^{-9}$  mm/s observed in a 20Cr dilution zone
- Unfavorable crack path that is  $\sim 60$  deg to the elongated weld grain boundaries

## ► **Prior Testing at ANL: N152-LAS-11 Specimen**

- $> 1 \times 10^{-8}$  mm/s constant load CGR observed, substantial cracking
- Test Specimen Examination at PNNL
  - 23-26 Cr measured near SCC region (similar measured at ANL)
  - Crack path appears to cut across long axis of weld grains
  - Closer inspection suggests cracking on an IG boundary

## ► **Two new ongoing SCC tests at PNNL**

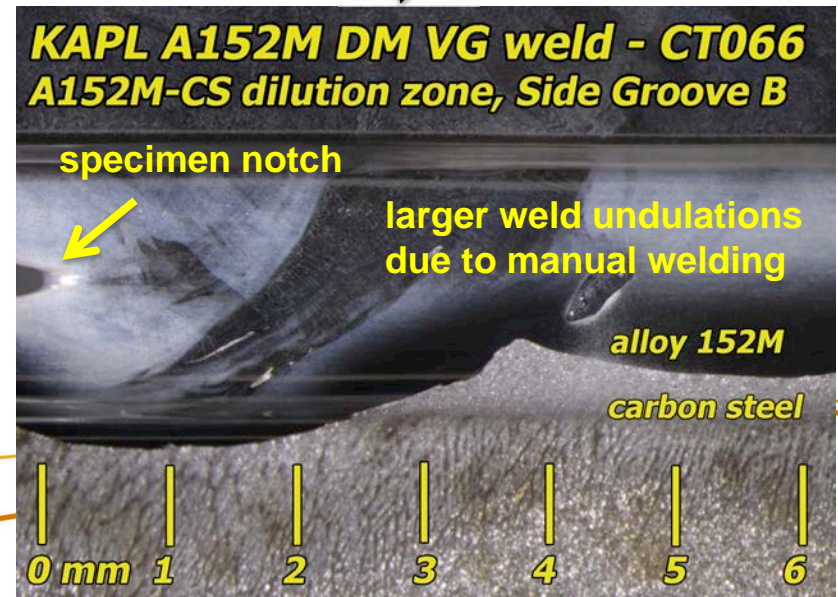
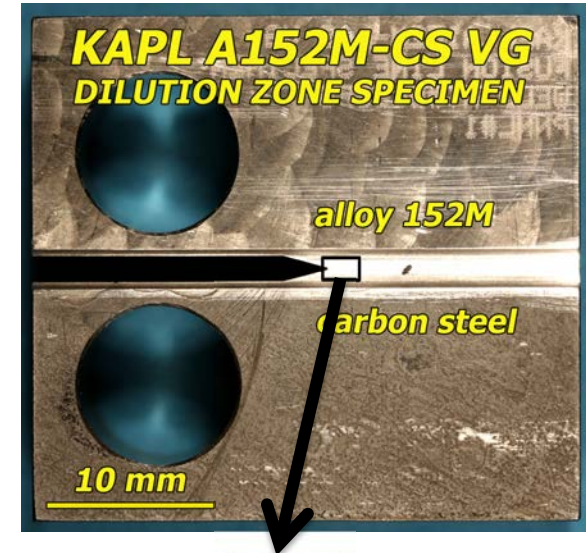
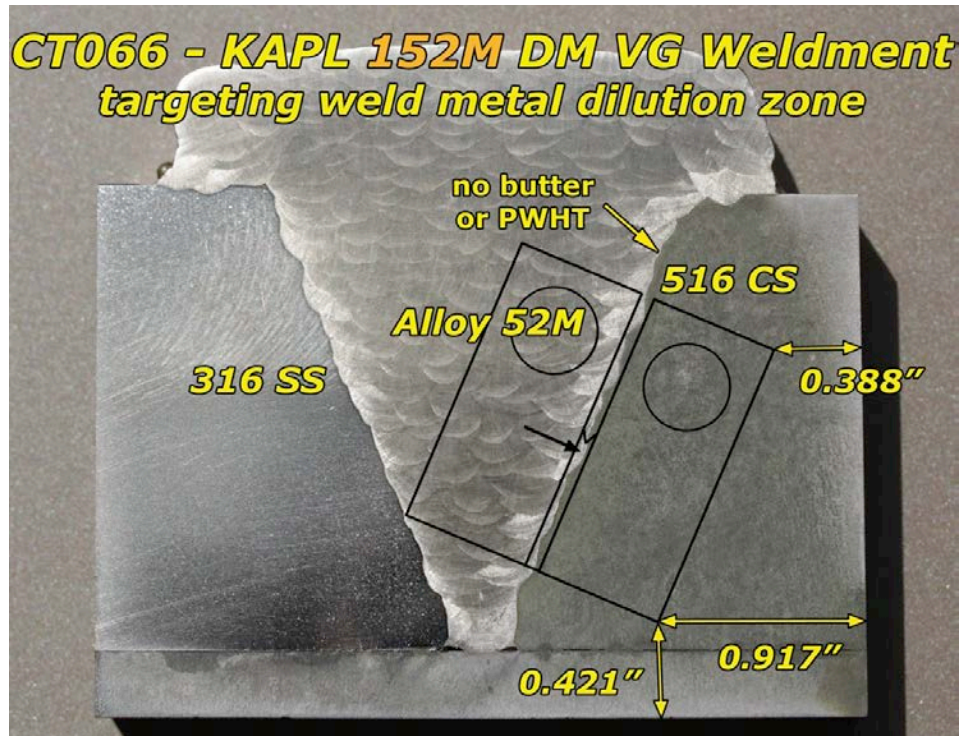
- Both tests assessing the same weldment as used for N152-LAS-11
- One specimen aligned to assess same region as N152-LAS-11
- Second specimen assessing a different region
- Indications of SCC susceptibility



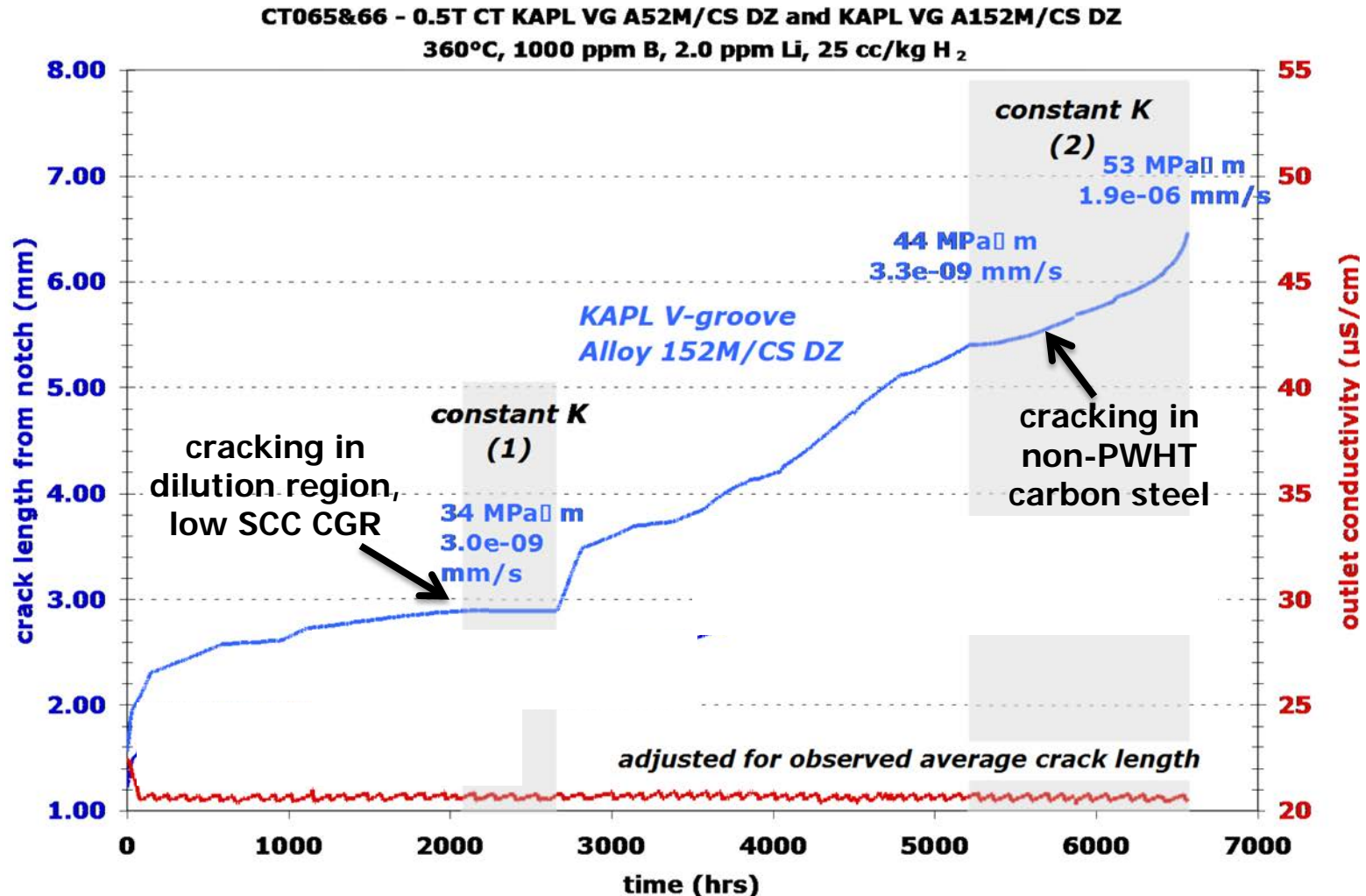
# KAPL Alloy 152M-CS (CT066) Dilution Zone Specimen

*Goal was to measure weld dilution zone response ~0.5-1 mm from fusion line.*

## KAPL Alloy 152M weldment



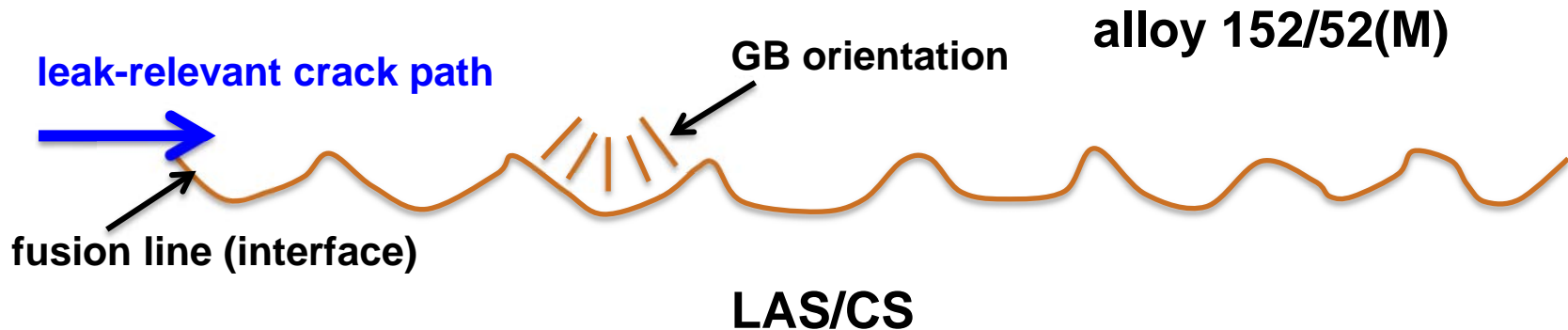
# Crack Growth Test on KAPL Alloy 152M-CS Dilution Zone Specimen



*Low SCC CGRs seen during constant K testing in a 20Cr dilution zone region. GBs were unfavorably aligned, a problem that is common to testing LAS/CS dilution zone regions.*

# Grain Boundary Alignment

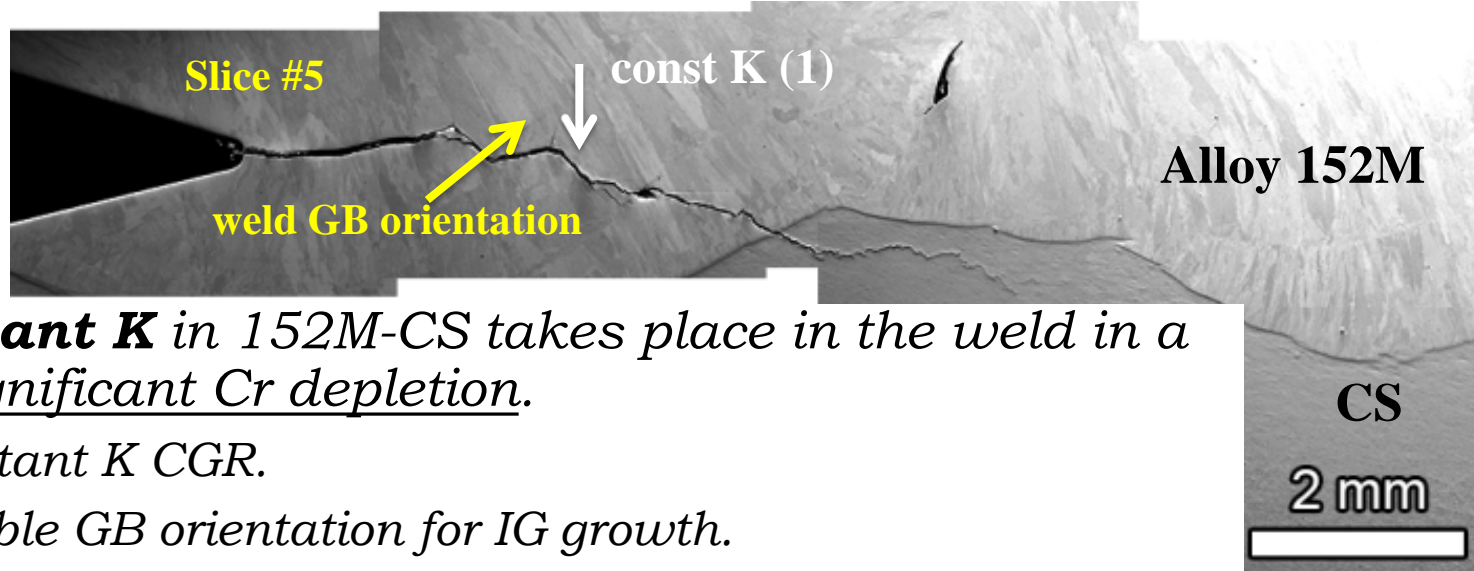
- ▶ *Weld grains are predominantly needle-shaped with long axis parallel to the weld-LAS interface normal.*
- ▶ *Leak-relevant crack path is parallel to interface and is roughly perpendicular to needle orientation.*
- ▶ *Leak-relevant crack path is unfavorable for IG cracking along these weld grain boundaries.*





# KAPL Alloy 152M-CS Dilution Zone Specimen CT066: Cross-Section

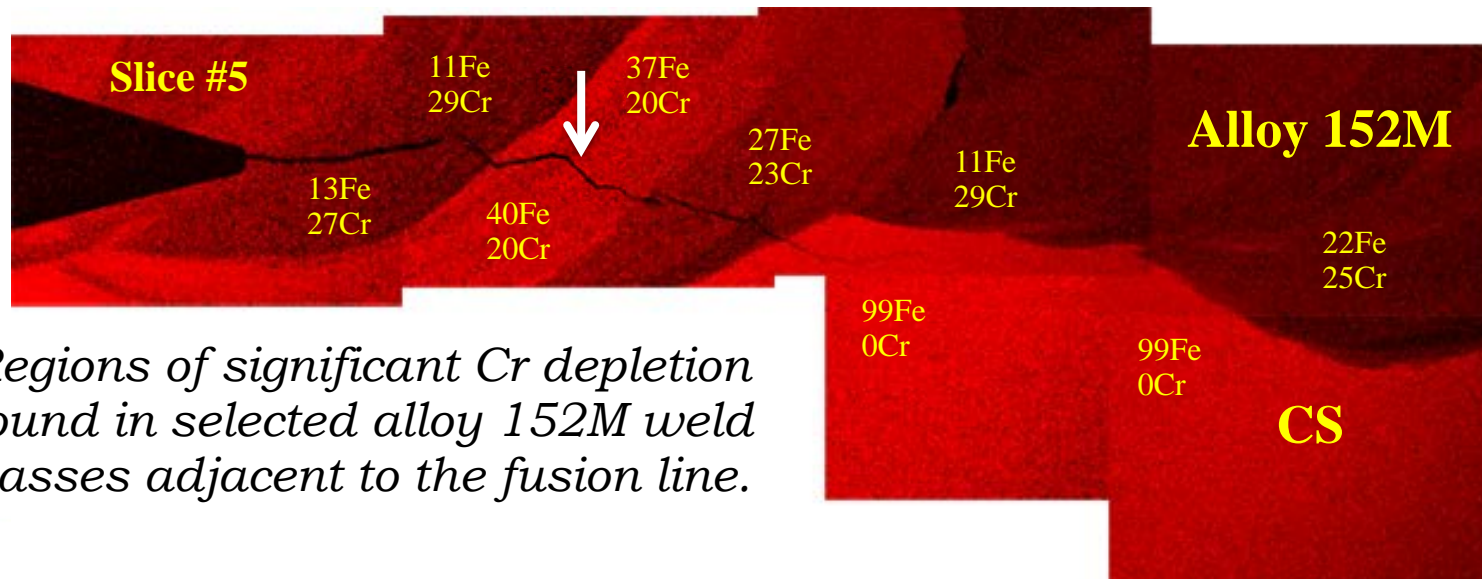
SEM BSE  
Image



► **First constant  $K$**  in 152M-CS takes place in the weld in a region of significant Cr depletion.

- Low constant  $K$  CGR.
- Unfavorable GB orientation for IG growth.
- Exams of crack surface showed predominately TG cracking.

Companion  
SEM Fe-K  
EDS Map



*Regions of significant Cr depletion found in selected alloy 152M weld passes adjacent to the fusion line.*

# Presentation Outline

## ▶ *Prior Testing at PNNL*

- *Constant K CGR of  $\leq 3 \times 10^{-9}$  mm/s observed in a 20Cr dilution zone*
- *Unfavorable crack path that is ~60 deg to the elongated weld grain boundaries*

## ▶ **Prior Testing at ANL: N152-LAS-11 Specimen**

- *$> 1 \times 10^{-8}$  mm/s constant load CGR observed, substantial cracking*
- *Recently examined at PNNL*
  - *23-26 Cr measured near SCC region (similar measured at ANL)*
  - *Crack path appears to cut across long axis of weld grains*
  - *Closer inspection suggests cracking on an IG boundary*

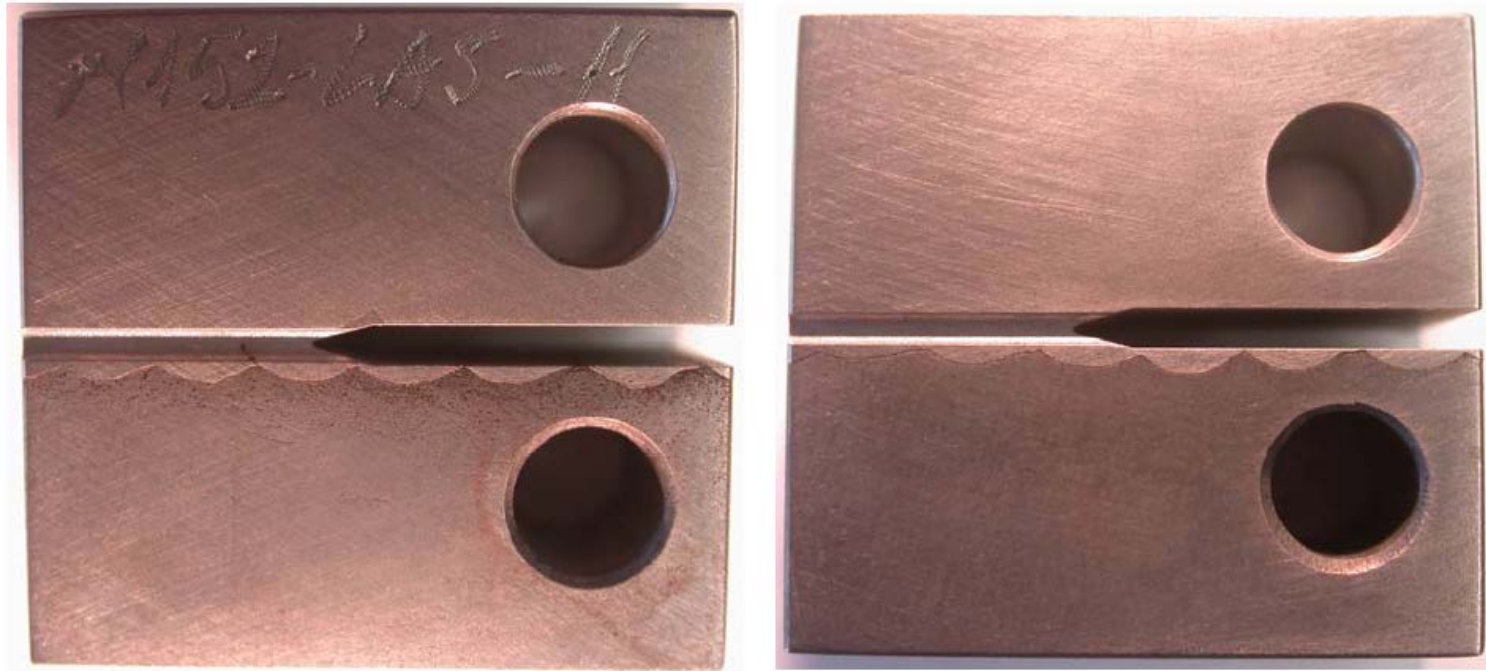
## ▶ *Two new ongoing SCC tests at PNNL*

- *Both tests assessing the same weldment as used for N152-LAS-11*
- *One specimen aligned to assess same region as N152-LAS-11*
- *Second specimen assessing a different region*
- *Indications of SCC susceptibility*

# ANL N152-LAS-11 Specimen

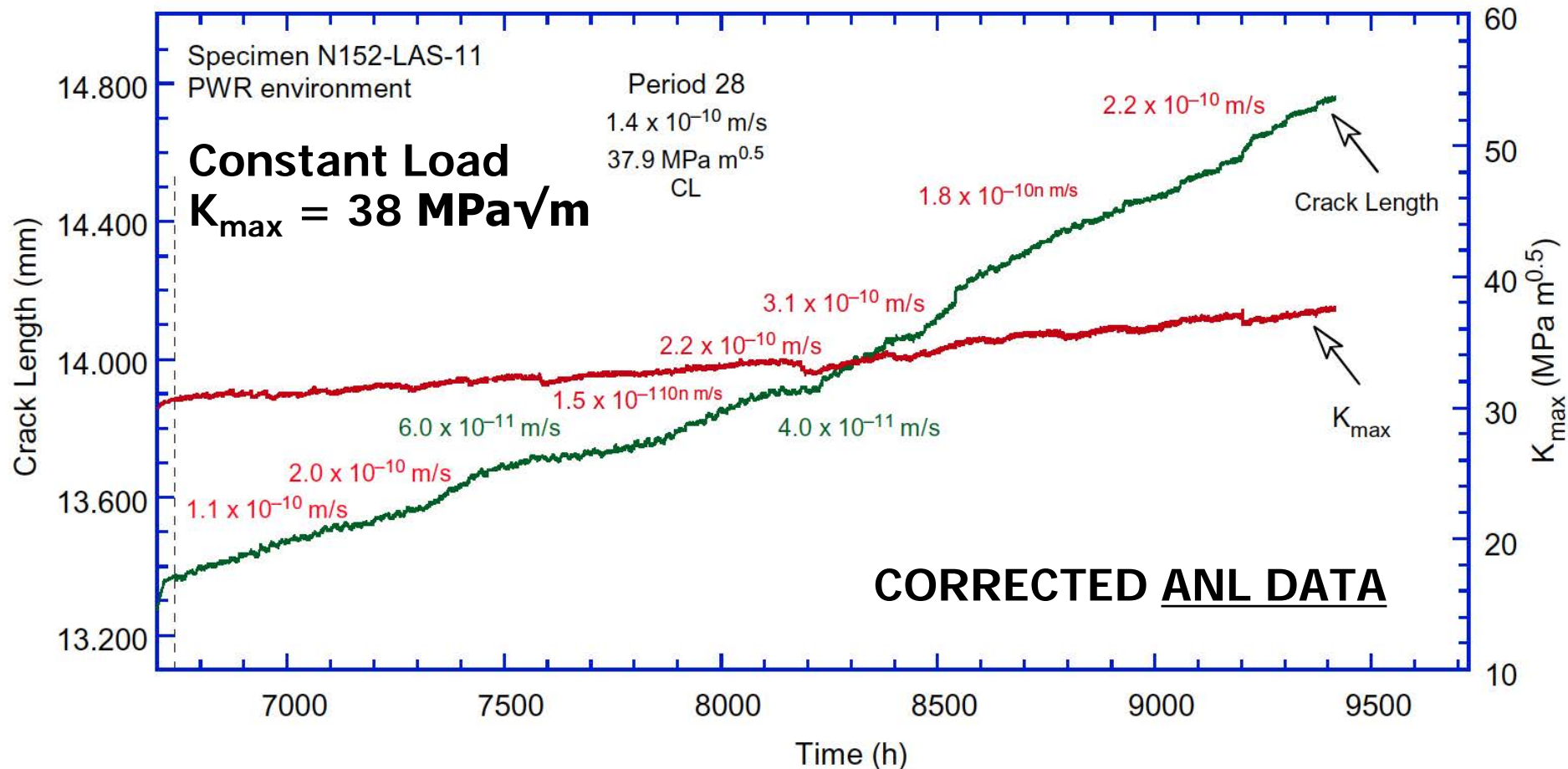
- ▶ *N152-LAS-11 specimen has roughly similar alignment relative to the fusion line as the KAPL alloy 152M-CS dilution zone specimen tested at PNNL.*

Both sides of the specimen





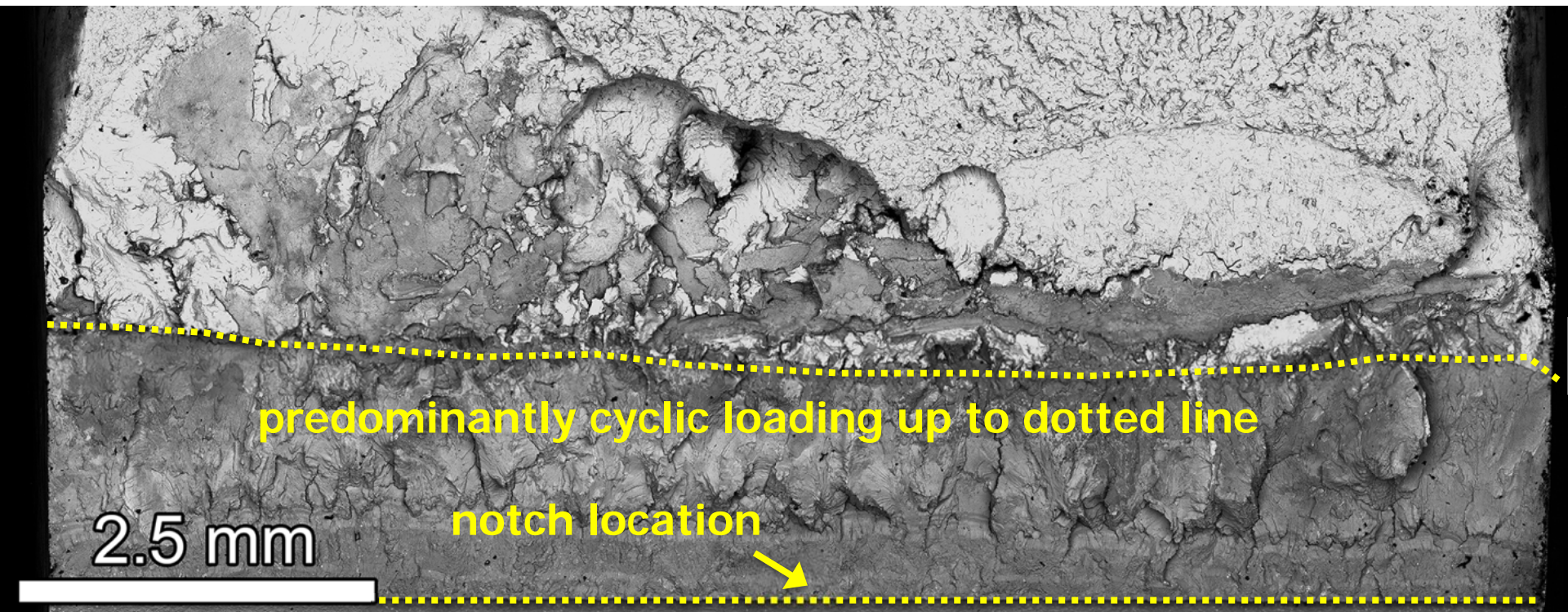
# ANL Constant Load Response for N152-LAS-11 Specimen



*Post-test corrected average constant load CGRs is  $>1 \times 10^{-7} \text{ mm/s}$ .*

# ANL N152-LAS-11 Specimen Crack Surface Observations

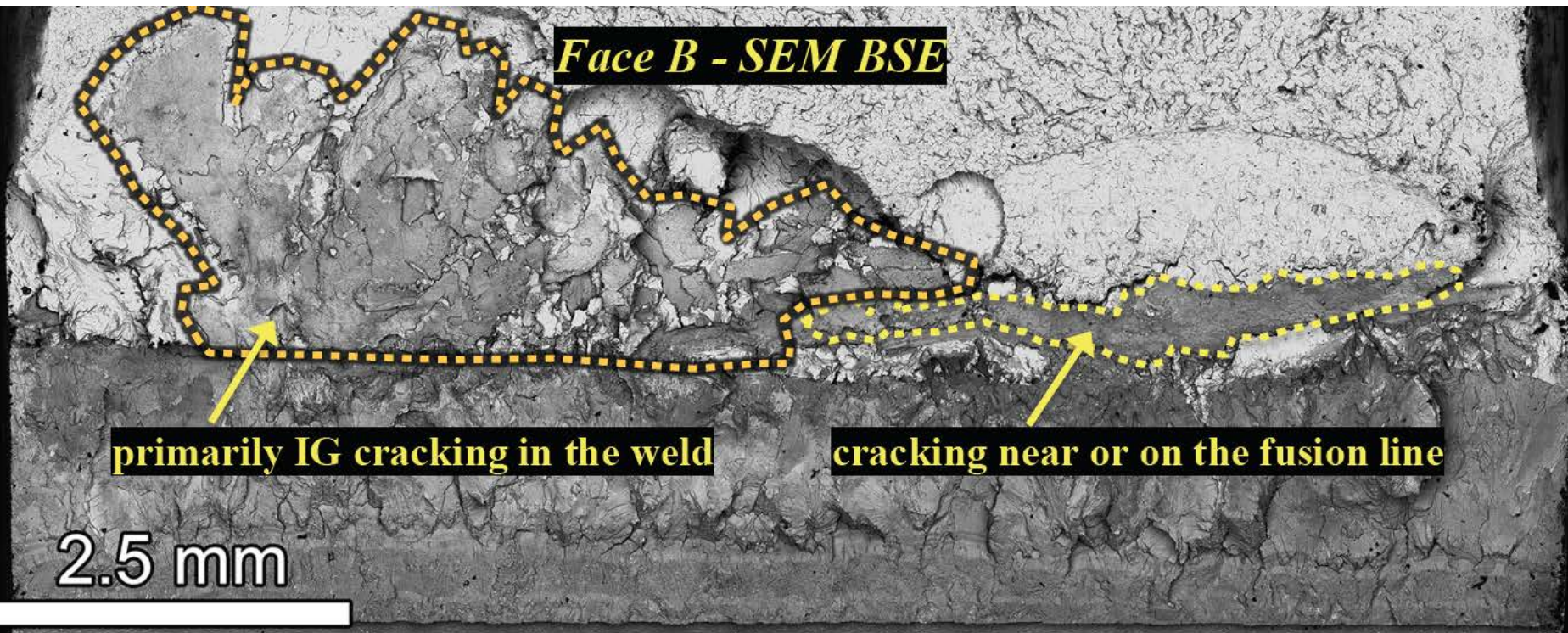
- *Predominantly cyclic loading prior to constant load SCC response that was shown in the previous slide.*





# ANL N152-LAS-11 Specimen Crack Surface Observations

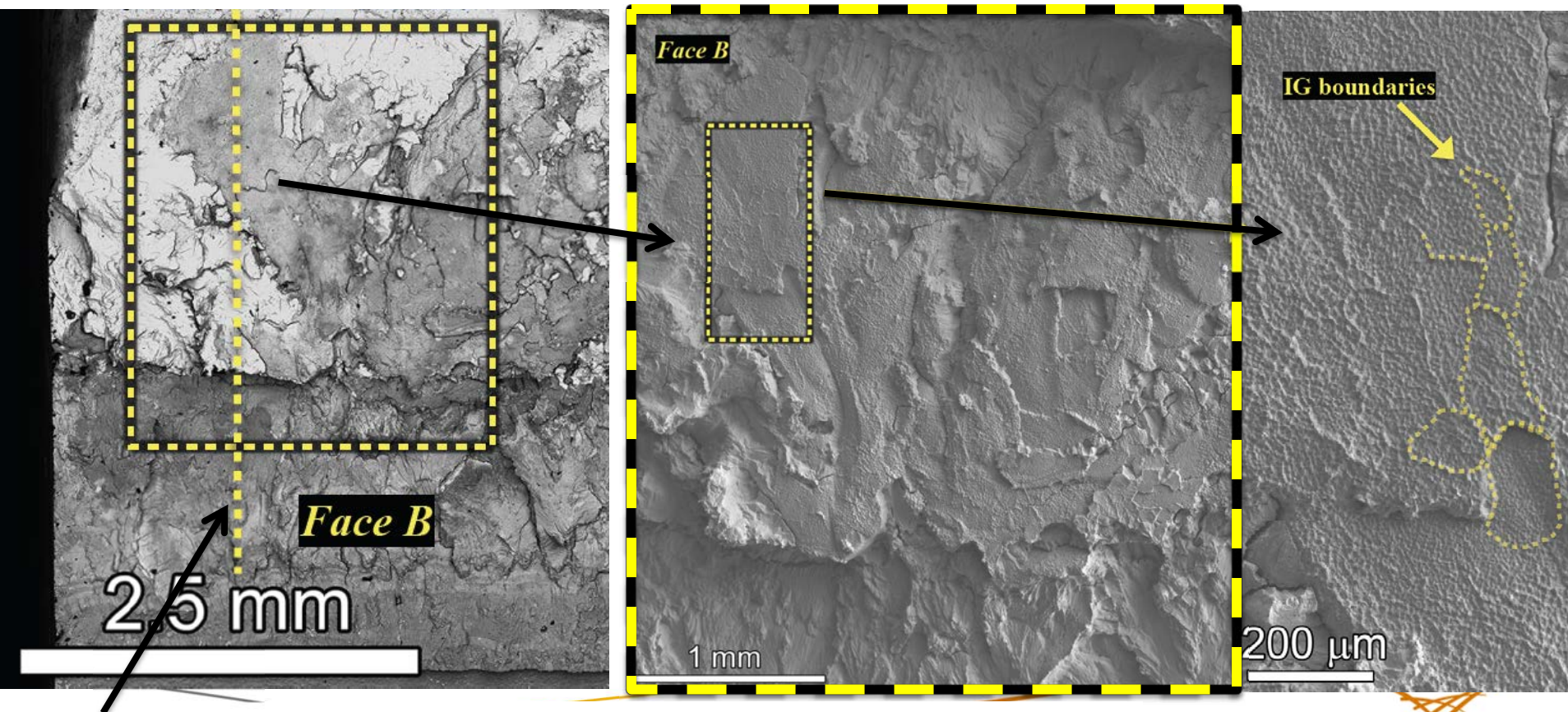
- ▶ Region on left is main area of interest. Cracking is in the weld and appears to be responsible for high SCC CGRs.
- ▶ Region on the right is cracking on or near the fusion line.





# ANL N152-LAS-11 Specimen Crack Surface Observations

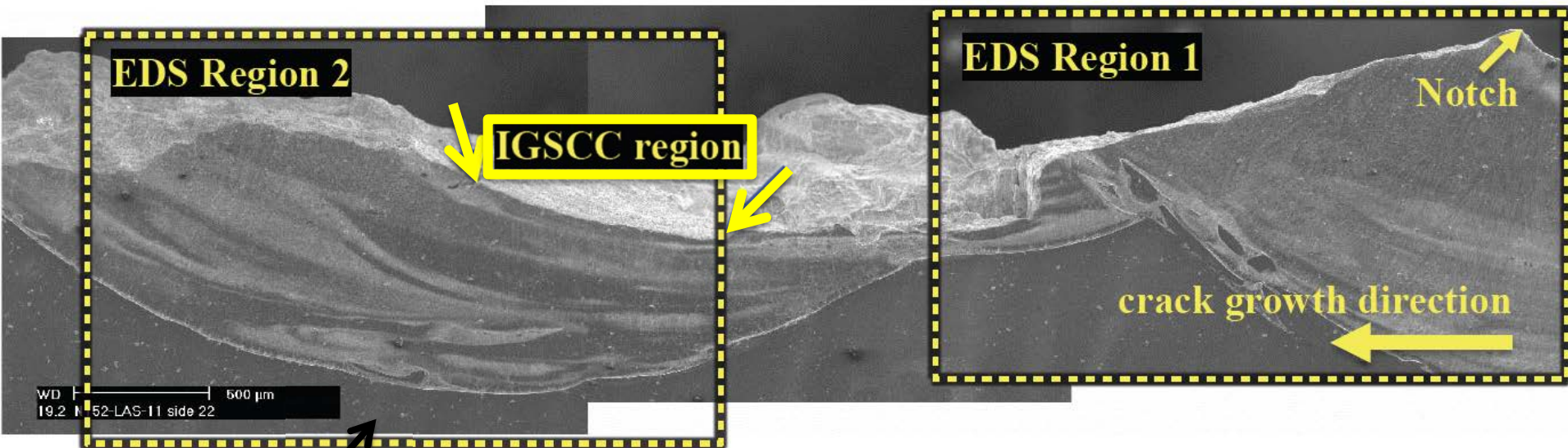
- Crack surface in the weld does not appear transgranular. Has an unusual intergranular appearance. Very flat surface.



Cut for cross section observation on opposite half of specimen

# ANL N152-LAS-11 Specimen Cross-Section Observations

- Specimen was fractured - one side of the specimen was cross-sectioned after fracture.



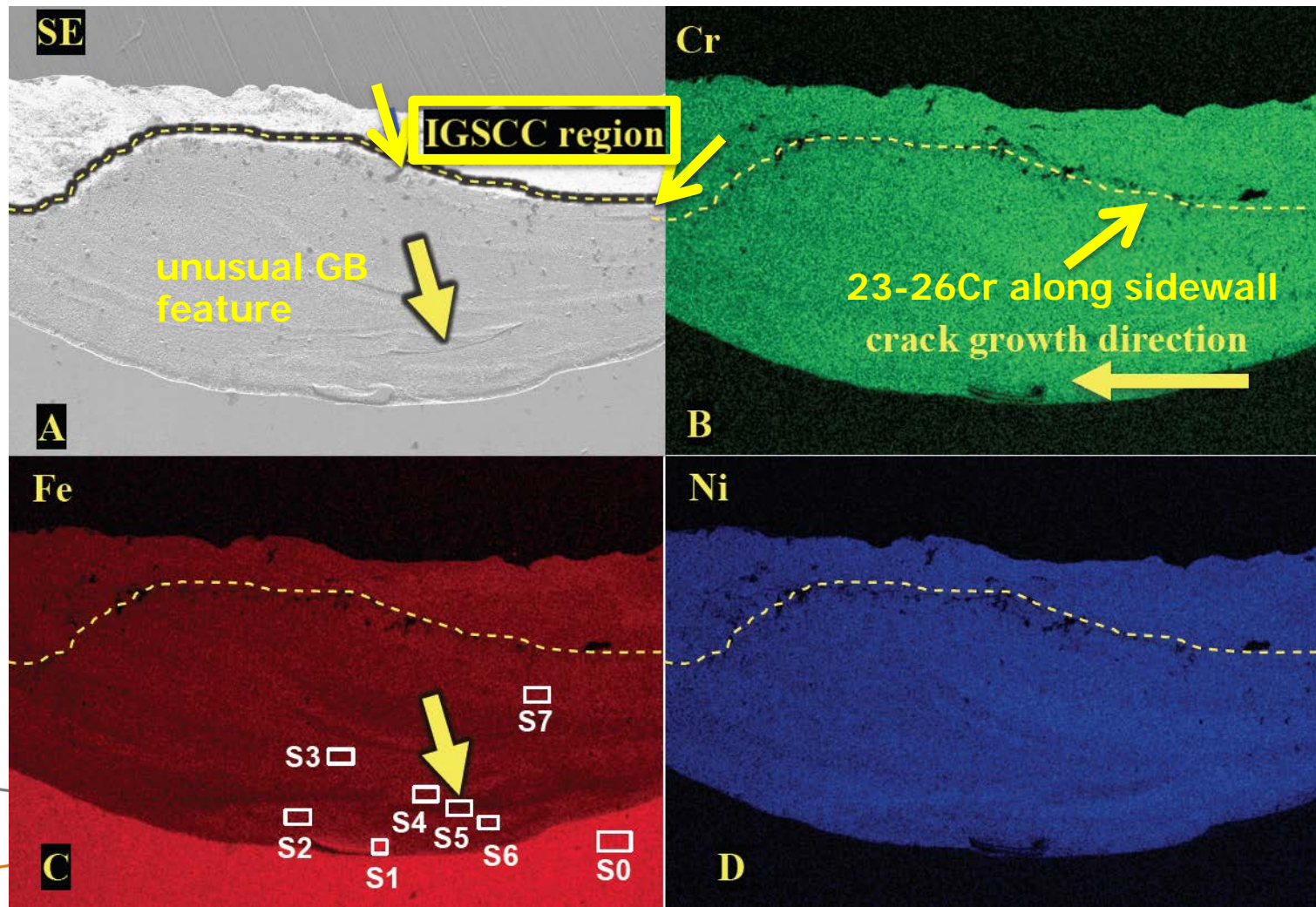
Region of interest near that contains constant load crack extension



# ANL N152-LAS-11 Specimen

## Cross-Section Observations EDS Region 2

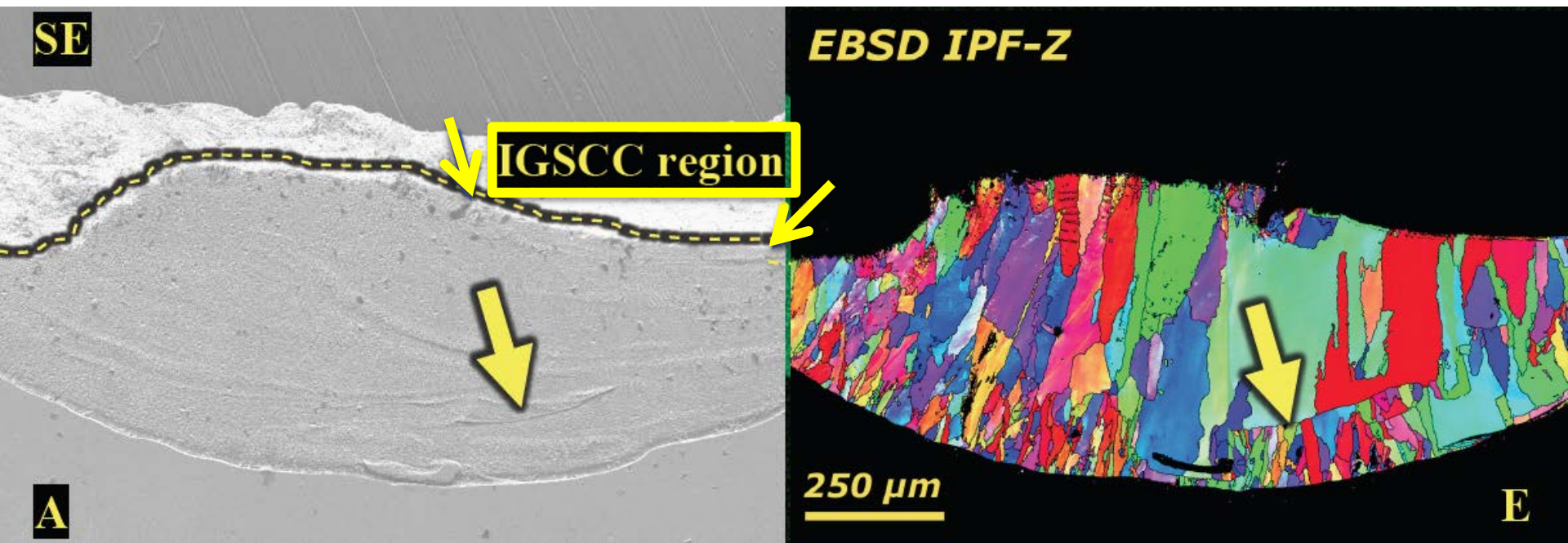
- ▶ *SEM-EDS exams indicate that Cr levels near SCC region are 23-26% on this side of the crack.*





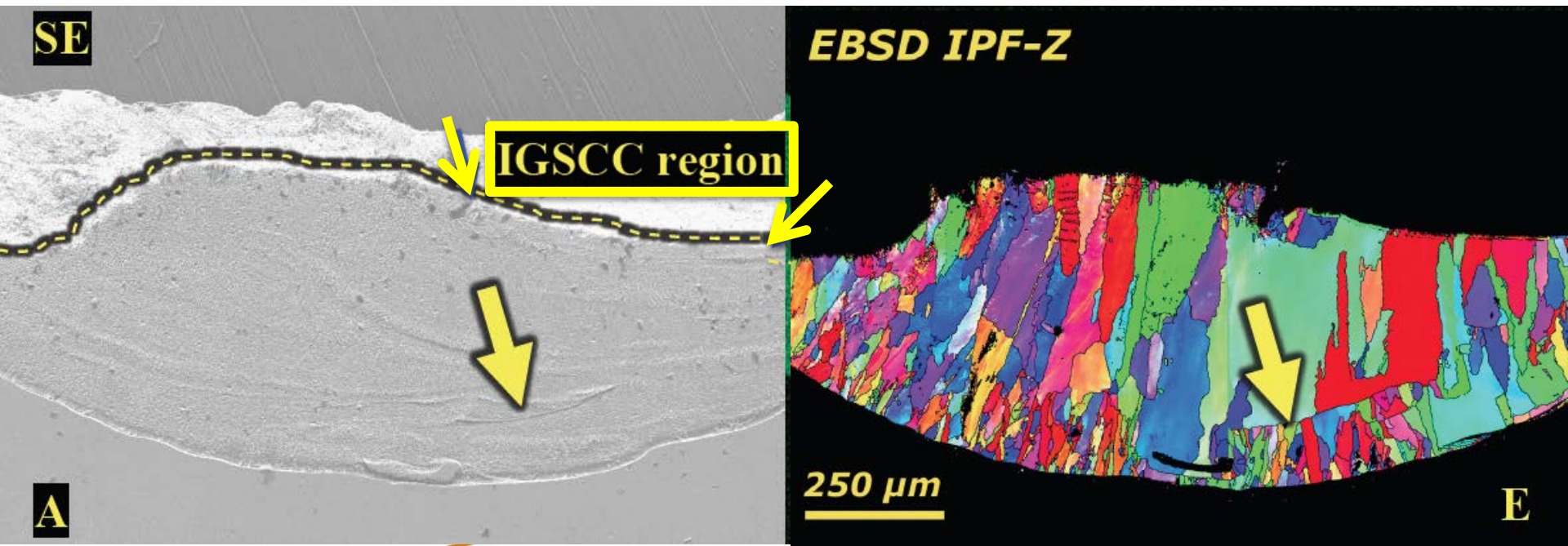
# ANL N152-LAS-11 Specimen Cross-Section Observations

- ▶ *SEM-EBSD exam shows the crack plane to be perpendicular to the long axis of the grain boundaries.*
- ▶ *Did it crack on a weld interpass boundary?*
- ▶ *An unexpected interface was seen that is aligned similar to that of the SCC crack path.*
- ▶ *Could this be the source of the crack path?*



# ANL N152-LAS-11 Specimen Summary

- ▶ SCC tested at ANL. Additional exams performed at PNNL.
- ▶ High constant load crack growth rates were observed.
- ▶ 23-26Cr near SCC region in cross-section.
- ▶ Not well aligned to grain boundaries, but IG appearance.
- ▶ Origin of crack path possibly an interpass boundary or this "unexpected" boundary.
- ▶ Additional exams needed to better understand this.



# Presentation Outline

## ▶ *Prior Testing at PNNL*

- *Constant K CGR of  $\leq 3 \times 10^{-9}$  mm/s observed in a 20Cr dilution zone*
- *Unfavorable crack path that is ~60 deg to the elongated weld grain boundaries*

## ▶ *Prior Testing at ANL: N152-LAS-11 Specimen*

- *$> 1 \times 10^{-8}$  mm/s constant load CGR observed, substantial cracking*
- *Recently examined at PNNL, observations presented here*
  - *23-26 Cr measured near SCC region (similar measured at ANL)*
  - *Crack path appears to cut across long axis of weld grains*
  - *Closer inspection suggests cracking on an IG boundary*

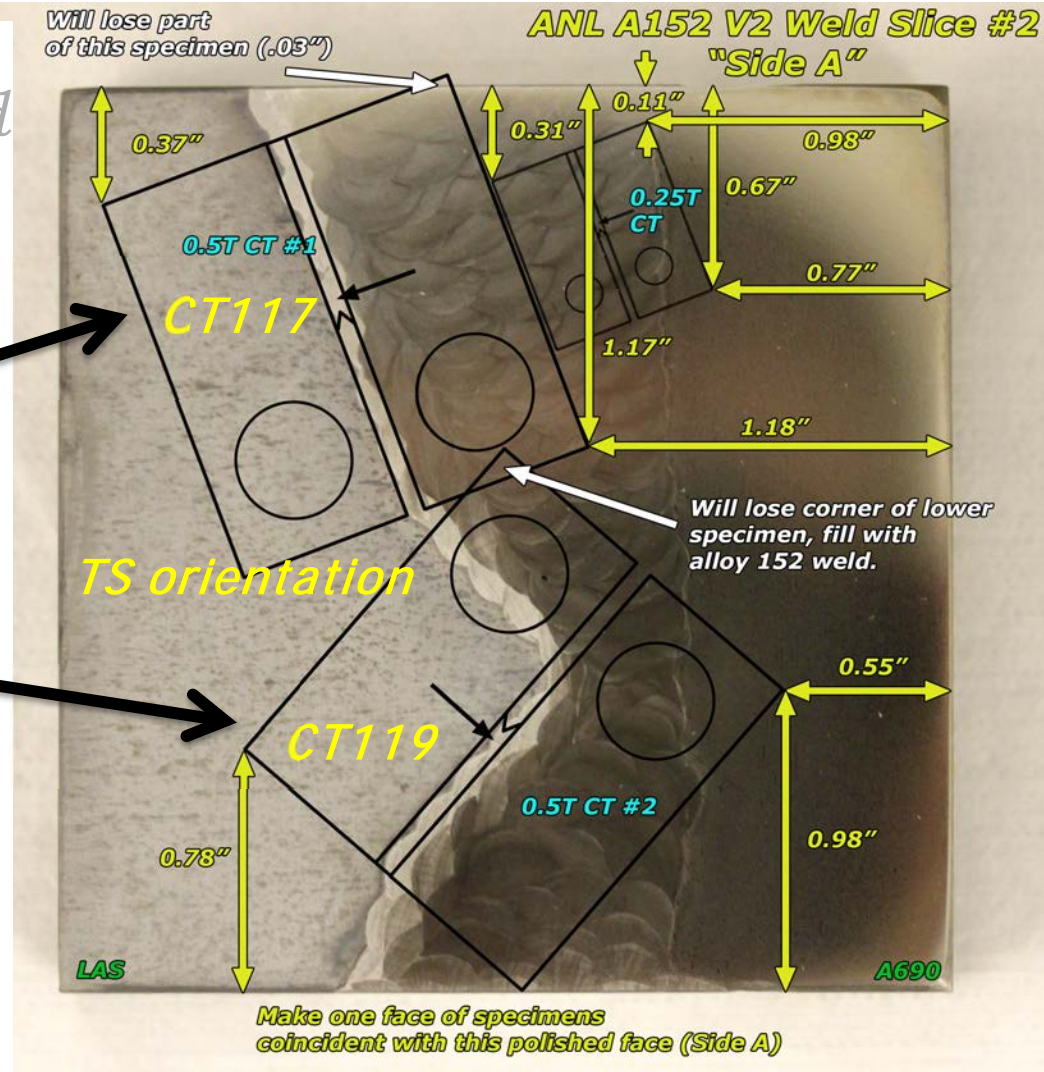
## ▶ ***Two new ongoing SCC tests at PNNL***

- *Both tests assessing the same weldment as used for N152-LAS-11*
- *One specimen aligned to assess same region as N152-LAS-11*
- *Second specimen assessing a different region*
- *Indications of SCC susceptibility*



# A152v2-LAS PNNL #1 (CT117) and #2 (CT119)

- ▶ Cut from same weldment as ANL N152-LAS-11 and N152-LAS-1 specimens.
- ▶ **CT117** aligned to same region of weld as ANL N152-LAS-11 specimen tested at ANL.
- ▶ CT119 does not correspond to any ANL tests.
- ▶ CT117 and CT119 tested separately.
- ▶ Tested in 360° C PWR primary water with 25 cc/kg dissolve H<sub>2</sub>.

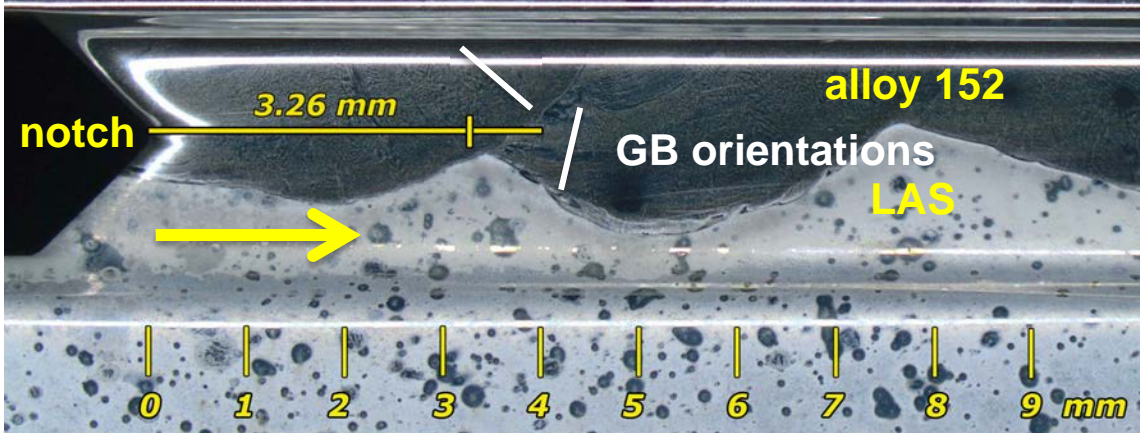


# A152v2-LAS PNNL #1 (CT117)

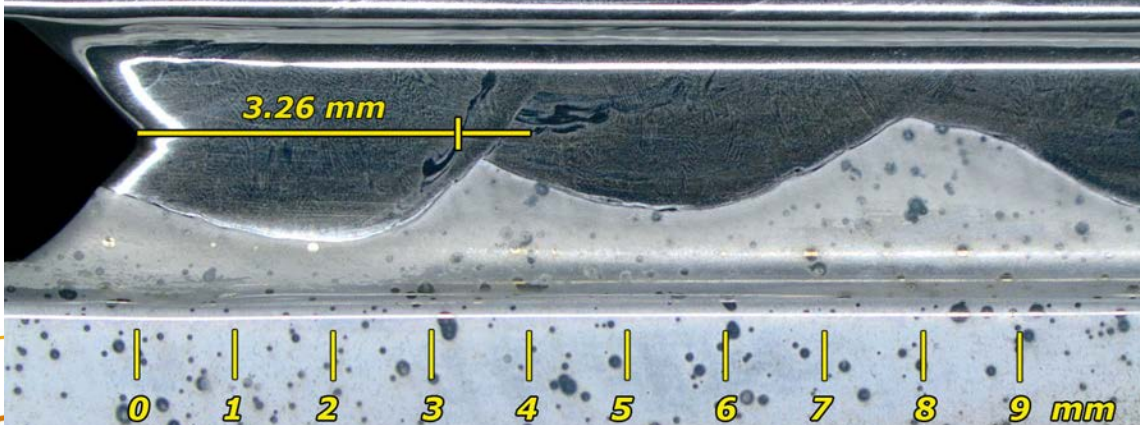
## Side Groove Images

- ▶ Same region as ANL N152-LAS-11 specimen.
- ▶ First weld pass has dilution near interpass boundary as indicated by etching contrast.
- ▶ Second pass also has dilution near the same interpass boundary.
- ▶ Poor orientation to typical weld GBs.
- ▶ Crack front is currently in the second weld pass.

**ANL 152 V2 Weldment**  
**PNNL DZ Specimen #1, Side A**  
**Corresponds to ANL N152-LAS-11 Specimen**  
**Side A**



**ANL 152 V2 Weldment**  
**PNNL DZ Specimen #1, Side B**  
**Corresponds to ANL N152-LAS-11 Specimen**  
**Side B**

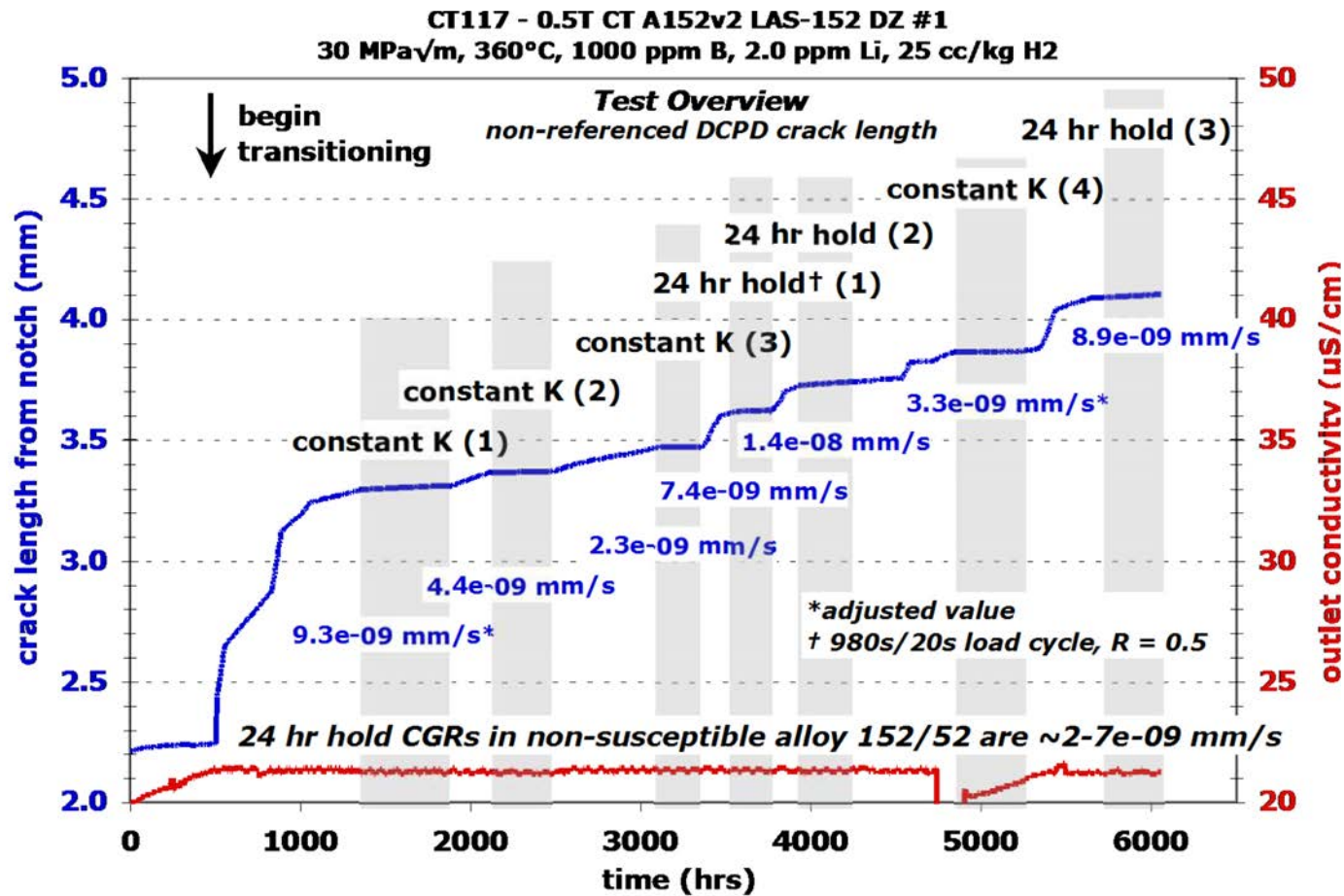




# A152v2-LAS PNNL #1 (CT117)

## Test Overview

- ▶ Sidegrooves indicate possible dilutions over the range of 3.25 mm to 4.5 mm from the crack notch.
  - Have been assessing carefully starting at 3.3 mm.
- ▶ Using constant  $K$  and 24 hr hold loading.

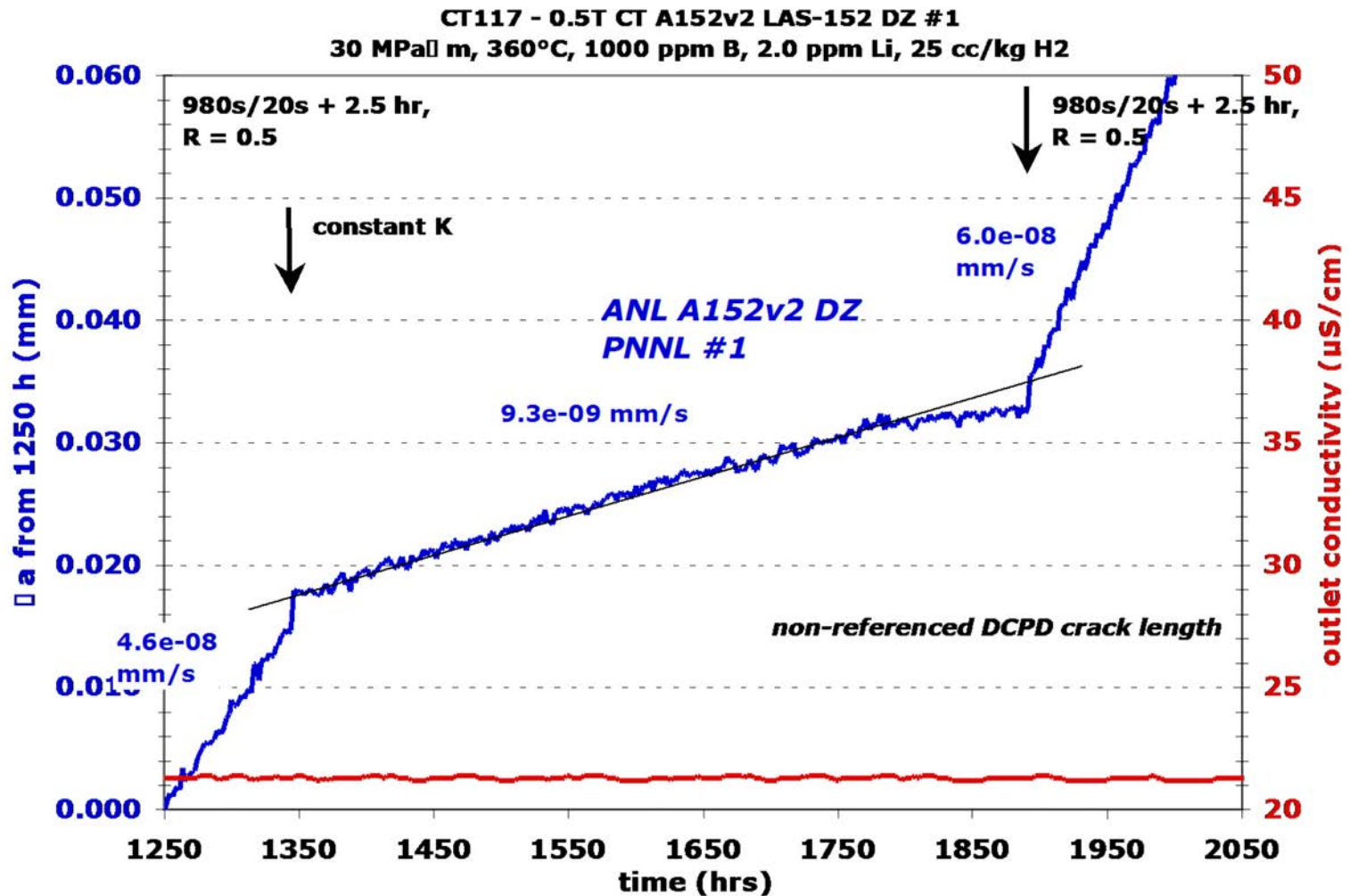




# A152v2-LAS PNNL #1 (CT117)

## Constant K Response

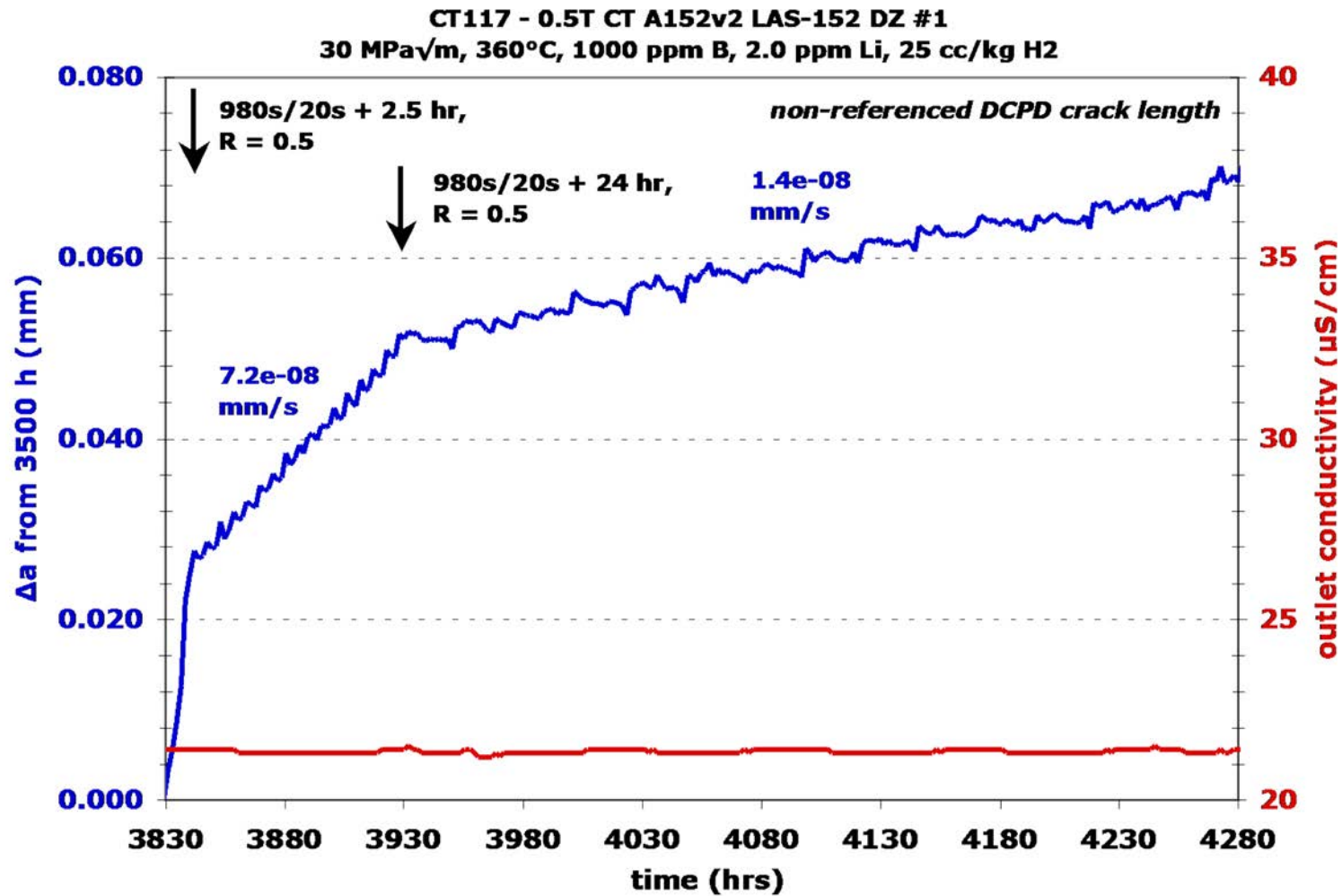
- ▶  $\sim 1 \times 10^{-8}$  mm/s observed during first constant K.
- ▶ Some indication of ligaments.
- ▶ Decreasing CGR in later observations to  $\sim 3 \times 10^{-9}$  mm/s.



# A152v2-LAS PNNL #1 (CT117)

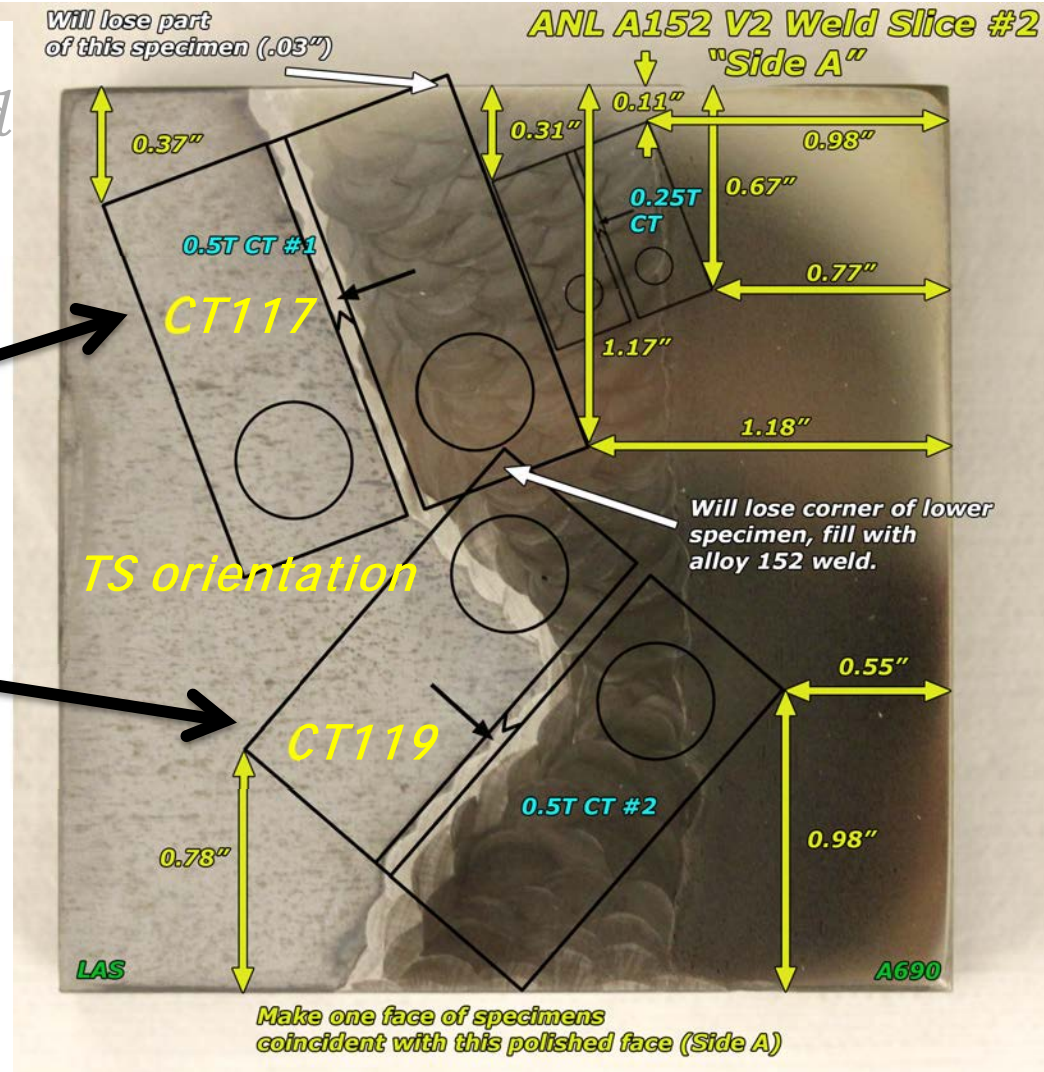
## 24 Hour Hold Response

- ▶  $2\text{--}7 \times 10^{-9}$  mm/s CGRs for non-engaged alloy 152/52.
- ▶  $0.8\text{--}1.4 \times 10^{-8}$  mm/s observed for this specimen.
- ▶ Serrated response suggests ligament breakage.



# A152v2-LAS PNNL #1 (CT117) and #2 (CT119)

- ▶ Cut from same weldment as ANL N152-LAS-11 and N152-LAS-1 specimens.
- ▶ CT117 aligned to same region of weld as ANL N152-LAS-11 specimen tested at ANL.
- ▶ **CT119** does not correspond to any ANL test specimens.
- ▶ CT117 and CT119 tested separately.
- ▶ Tested in 360° C PWR primary water with 25 cc/kg dissolve H<sub>2</sub>.

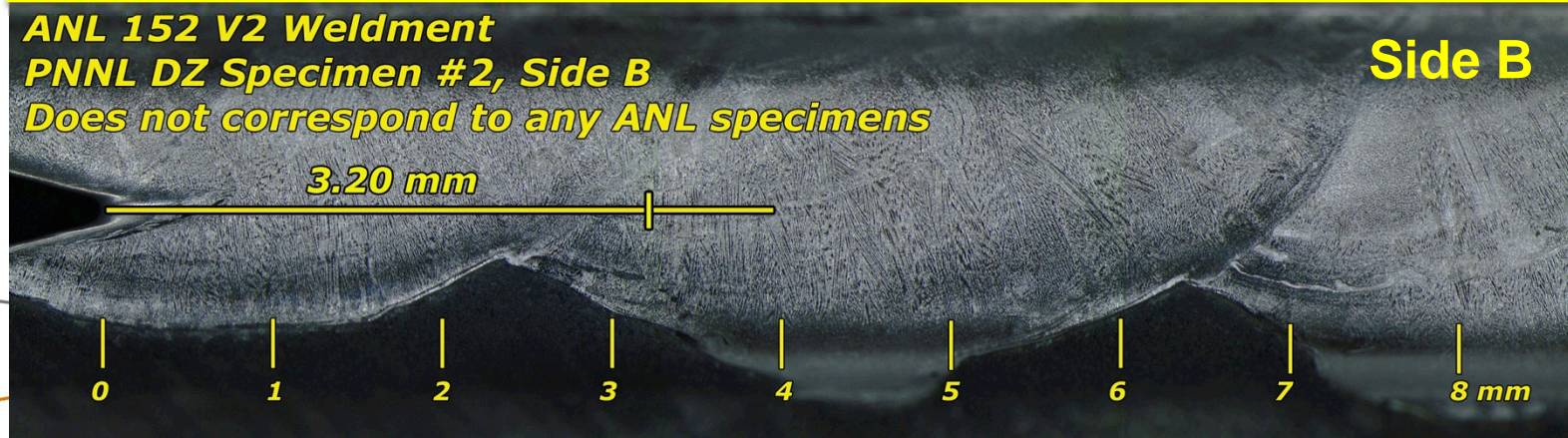
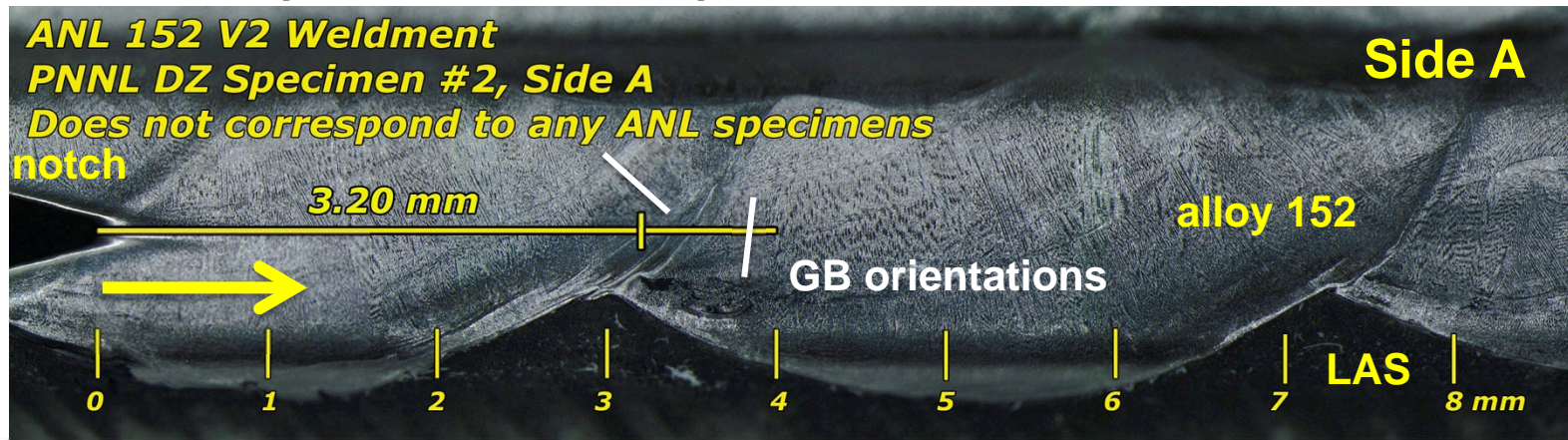




# A152v2-LAS PNNL #2 (CT119)

## Side Groove Images

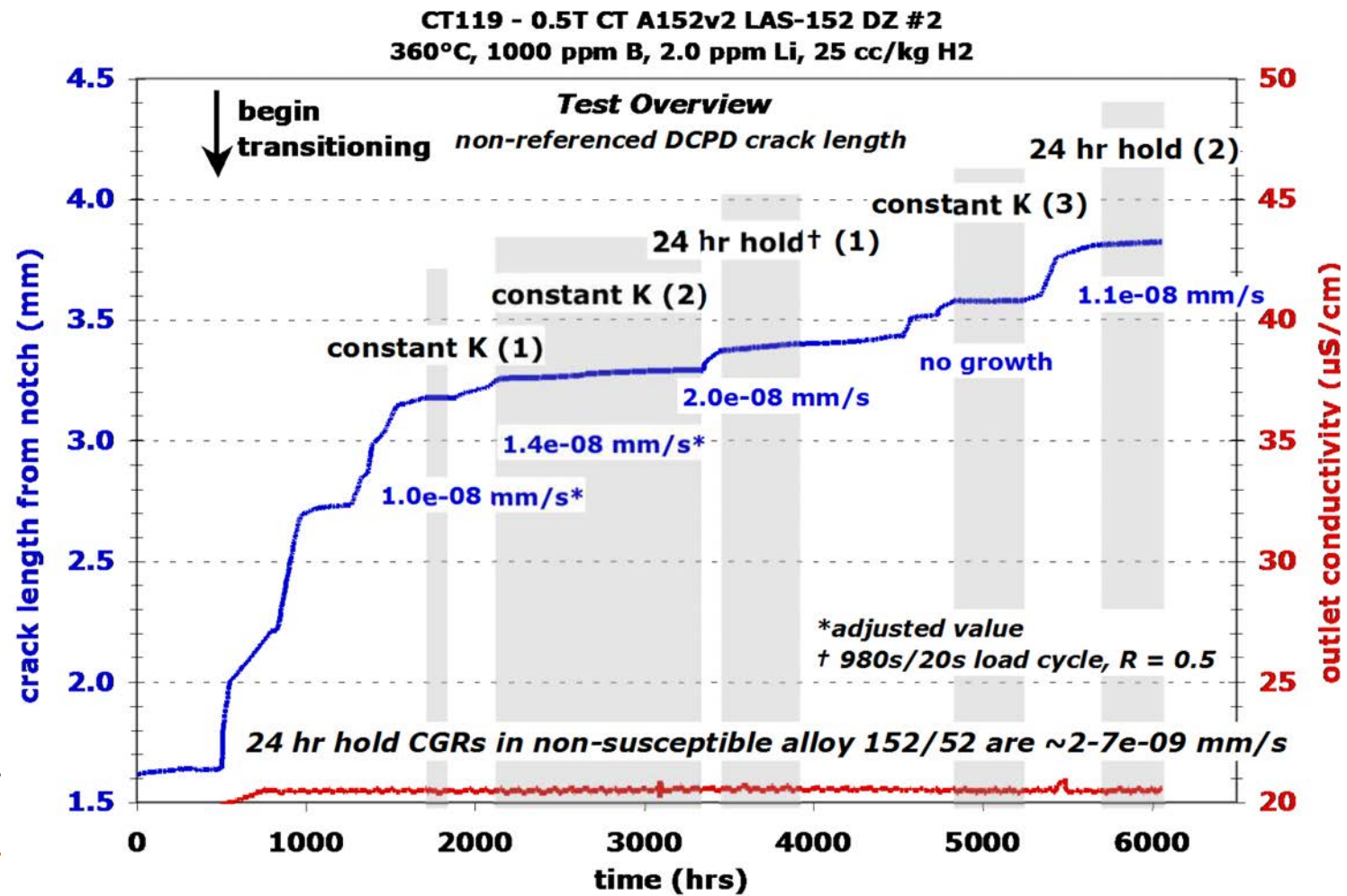
- ▶ Crack in this specimen also currently positioned to assess dilution zone near interpass boundary.
- ▶ Crack front on Side A is in the first pass while on Side B it is in the second pass.
- ▶ Not well aligned to weld grain boundaries.



# A152v2-LAS PNNL #2 (CT119)

## Test Overview

- ▶ Fewer indications of dilutions in the sidegrooves but have been assessing carefully starting at 3.2 mm.
- ▶ Using constant  $K$  and 24 hr hold loading.

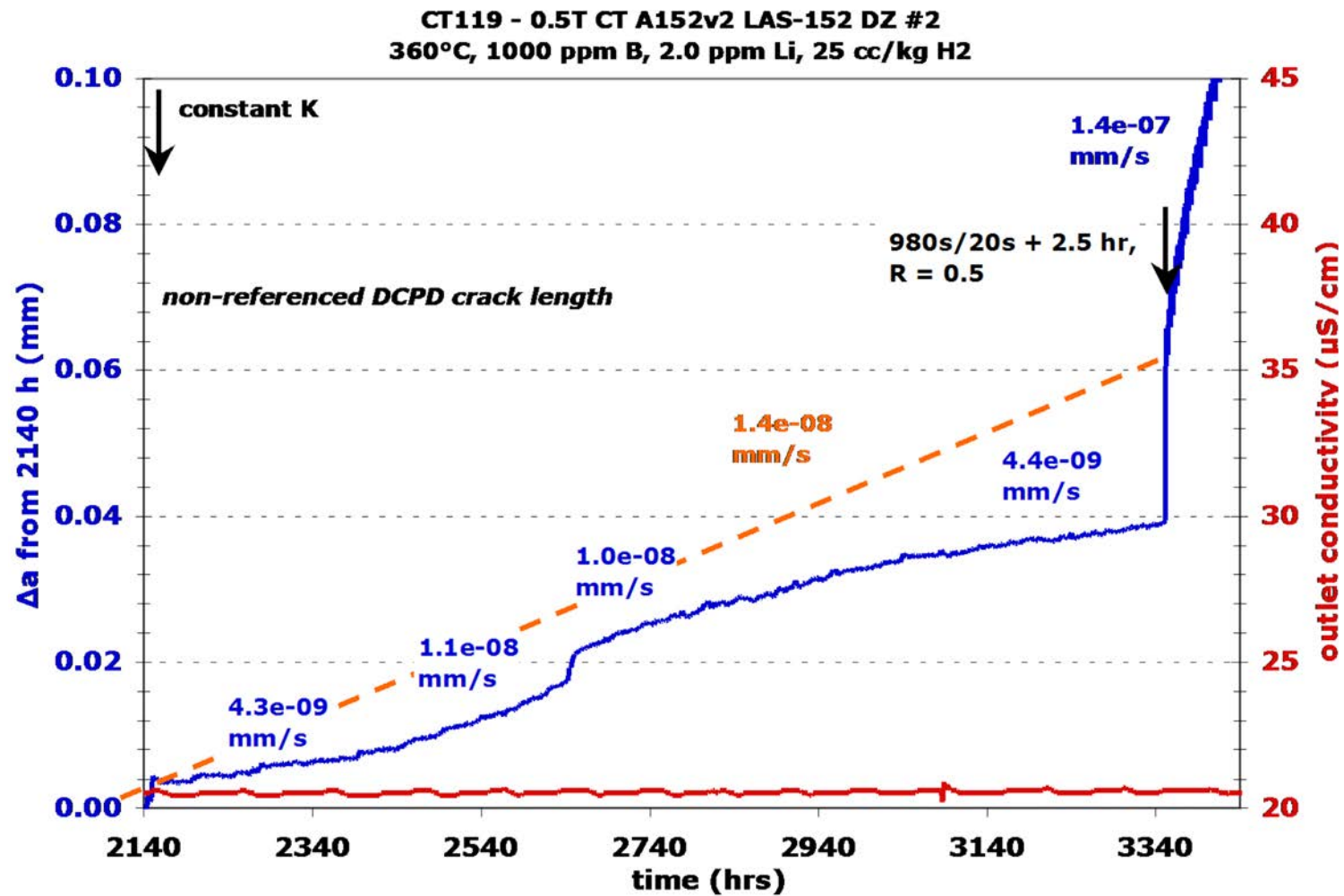




# A152v2-LAS PNNL #2 (CT119)

## Constant K CGR

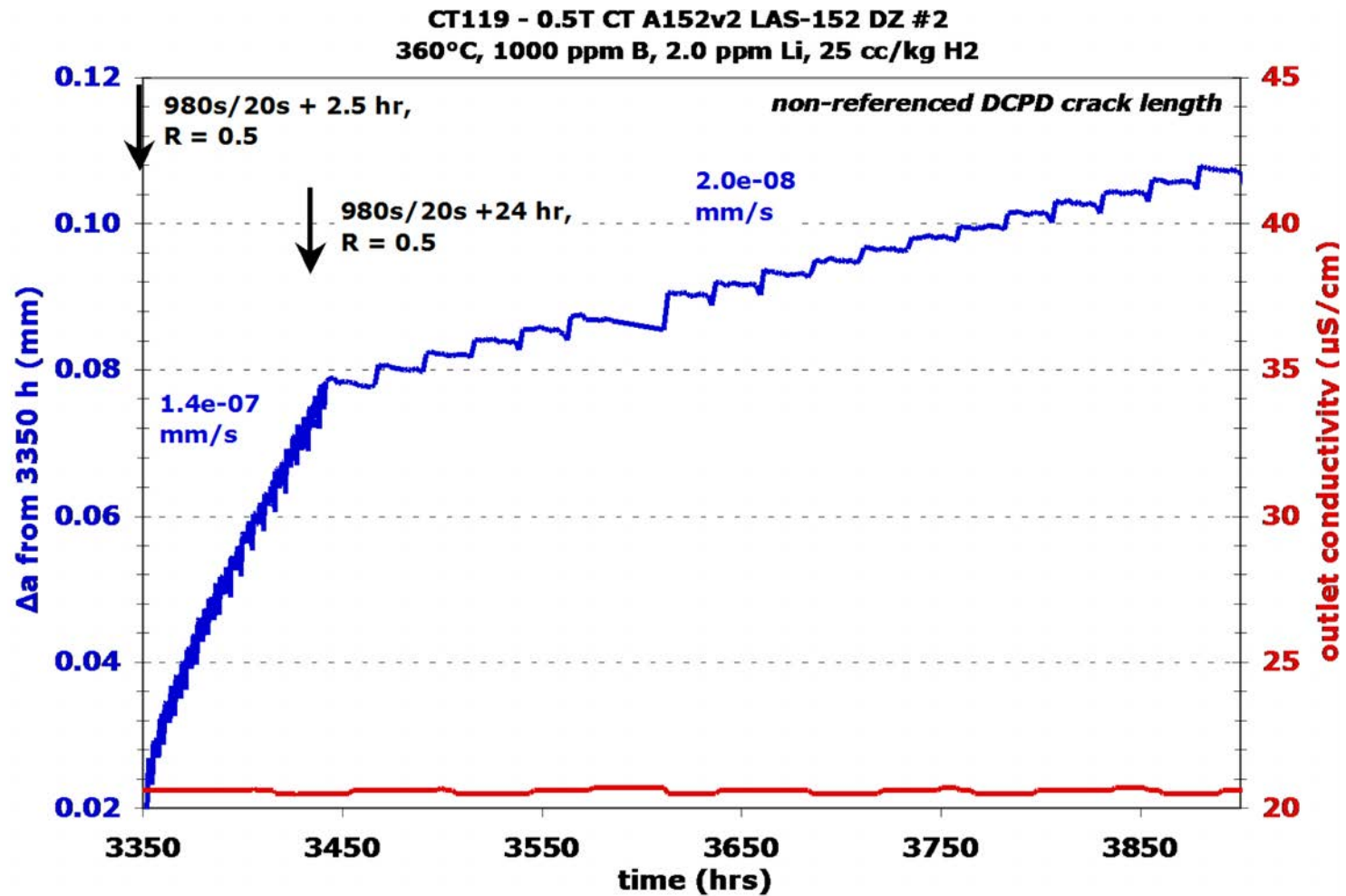
- ▶ Variable response at constant  $K$ . Some no growth by DCPD.
- ▶ Strong indication of ligament or partial engagement. Estimated CGR is  $\sim 1.4 \times 10^{-8}$  mm/s for this observation.



# A152v2-LAS PNNL #2 (CT119)

## 24 Hour Hold Response

- ▶  $2-7 \times 10^{-9}$  mm/s CGRs for non-engaged alloy 152/52.
- ▶  $1.1-2.0 \times 10^{-8}$  mm/s observed for this specimen.
- ▶ Serrated response suggests ligament/contact breakage.





# Alloy 152/52-LAS Dilution Zone Summary

## ► Prior PNNL Test

- One specimen (CT066) with a region of ~20Cr was assessed.
- Geometric crack plane was not well aligned to weld GBs.
- Low SCC CGRs were observed with transgranular cracking.

## ► Analysis of ANL N152-LAS-11 Specimen at PNNL

- Also not well aligned to weld grain boundaries, but high SCC CGR.
- 23-26Cr on one side of crack that was observed in cross-section.
- Crack surface had an intergranular appearance.
- Possibly cracking on interpass boundary or unexpected boundary.

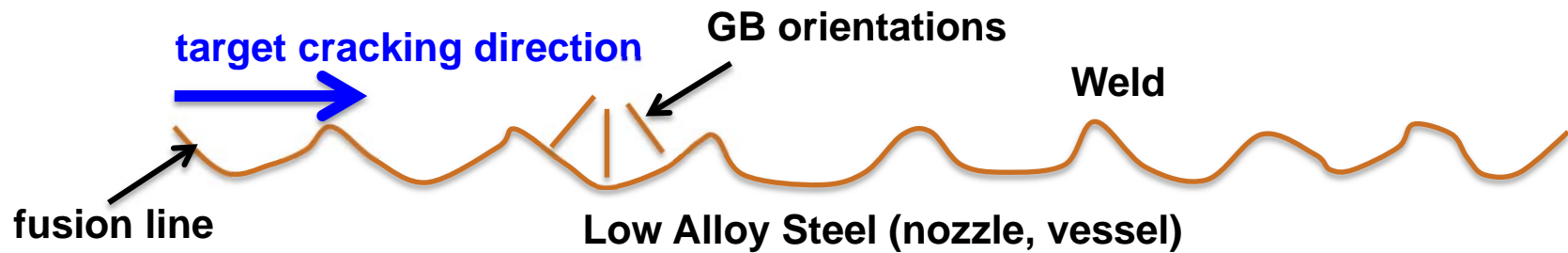
## ► New tests at PNNL are assessing the same weldment as tested at ANL. Some indication of susceptibility. Testing will continue.

## ► For cracking parallel to weld-LAS interface in dilution zones...

- Non-continuous dilutions suggest challenge to sustained cracking.
- SCC has been observed on an undetermined IG crack path.
- Additional testing and material exams are needed.

# Additional Comments on Weld-LAS Dilution Zone Susceptibility

- ▶ *Leak path is parallel to the fusion line.*
- ▶ *Dilution zones within the weld may be a challenging crack path.*
  - *Grain boundaries typically misaligned to target crack path.*
  - *Dilution regions appear to be discontinuous.*
  - *Strong dilutions appear to be more common in manual welds.*
- ▶ *Is the fusion line between the weld and LAS a likely path?*
  - *Curved path of fusion line is not ideal but...*
  - *Must be dilution in close vicinity of the fusion line.*
  - *Needs to be a continuous dilution from wetted surface to exterior.*





# Cracking Through Inlay/Onlay Dilutions

- ▶ *Target crack path can be aligned to weld grain boundaries.*
- ▶ *Concern for SCC susceptibility if dilutions can exist in thin inlay/onlay welds.*

