

# **Stress Corrosion Crack Growth Response of Alloy 152/52-Carbon Steel Dissimilar Metal Welds in PWR Primary Water**

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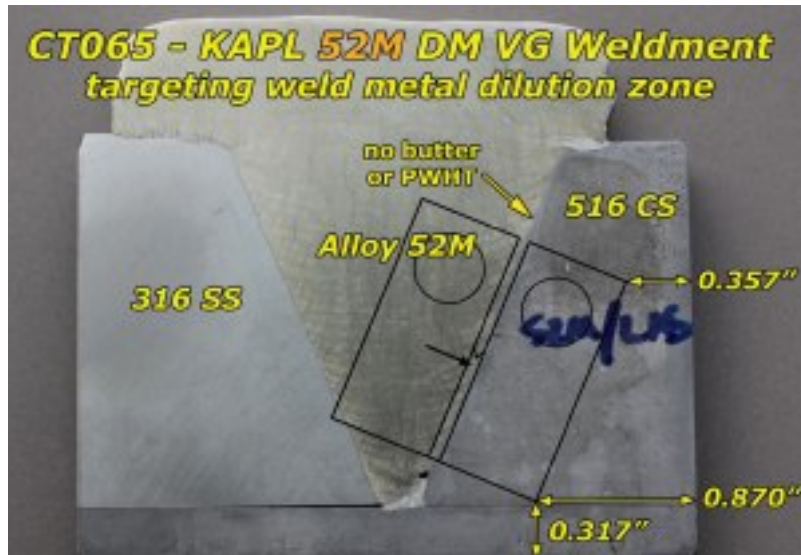
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# PNNL Crack-Growth Testing on CS Dissimilar Metal Welds

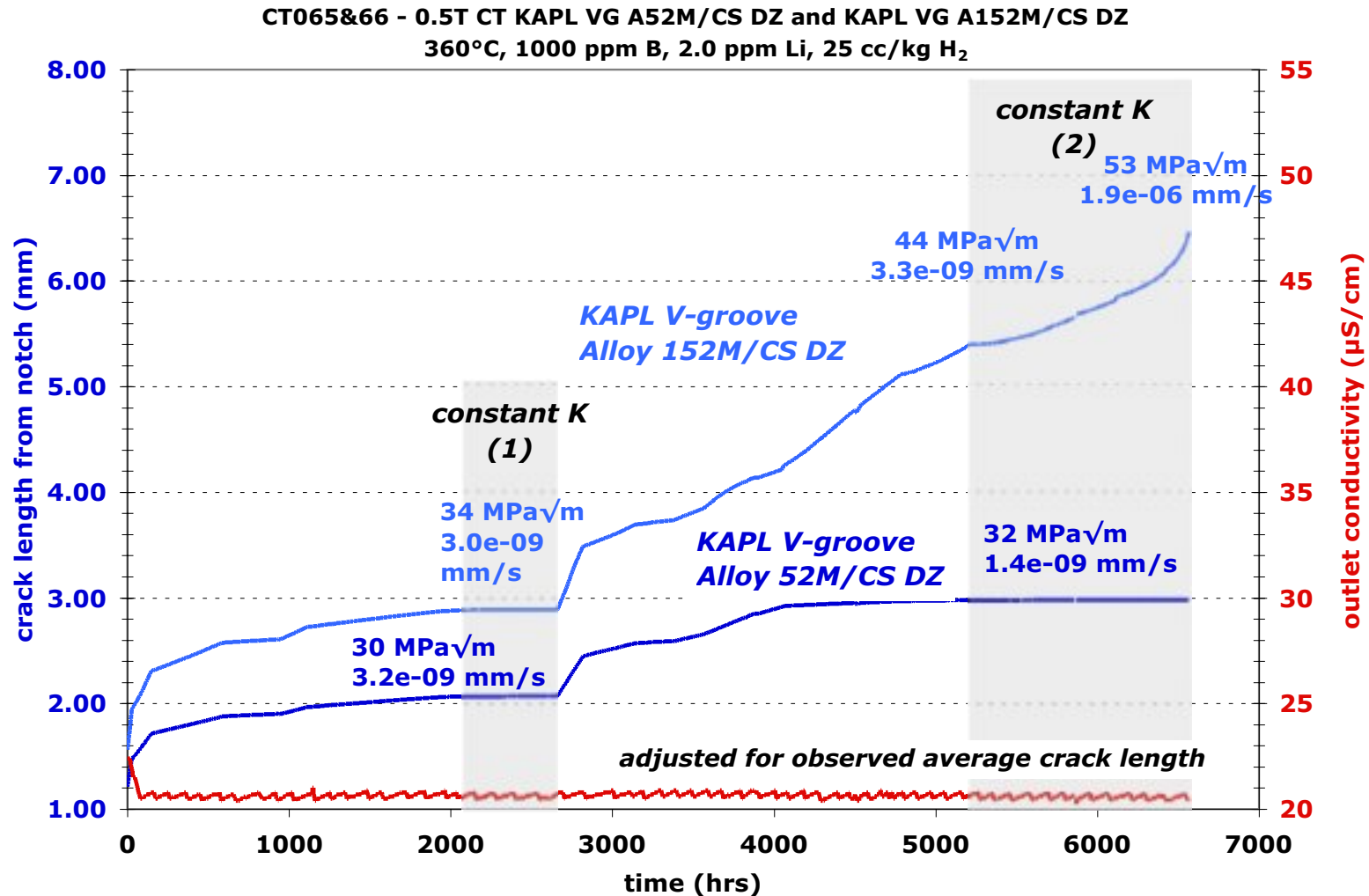
- ▶ *KAPL V-Groove Weld: Alloy 152M (WC83F8) to 516 Carbon Steel (CS) Plate. No butter or PWHT for CS.*
  - ***1 weld metal dilution zone to fusion line test recently completed (CT066)***
  - *1 fusion line test ongoing (CT082)*
- ▶ *KAPL V-Groove Weld: Alloy 52M (NX5285) to 516 Carbon Steel Plate. No butter or PWHT for CS.*
  - ***1 weld metal dilution zone test recently completed (CT065)***
  - *1 fusion line test ongoing (CT083)*

# KAPL 52M/CS (CT065) and 152M/CS (CT066) Dilution Zone Specimens

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



# Overview of Crack Growth Test for KAPL 152M/CS and 52M/CS Specimens



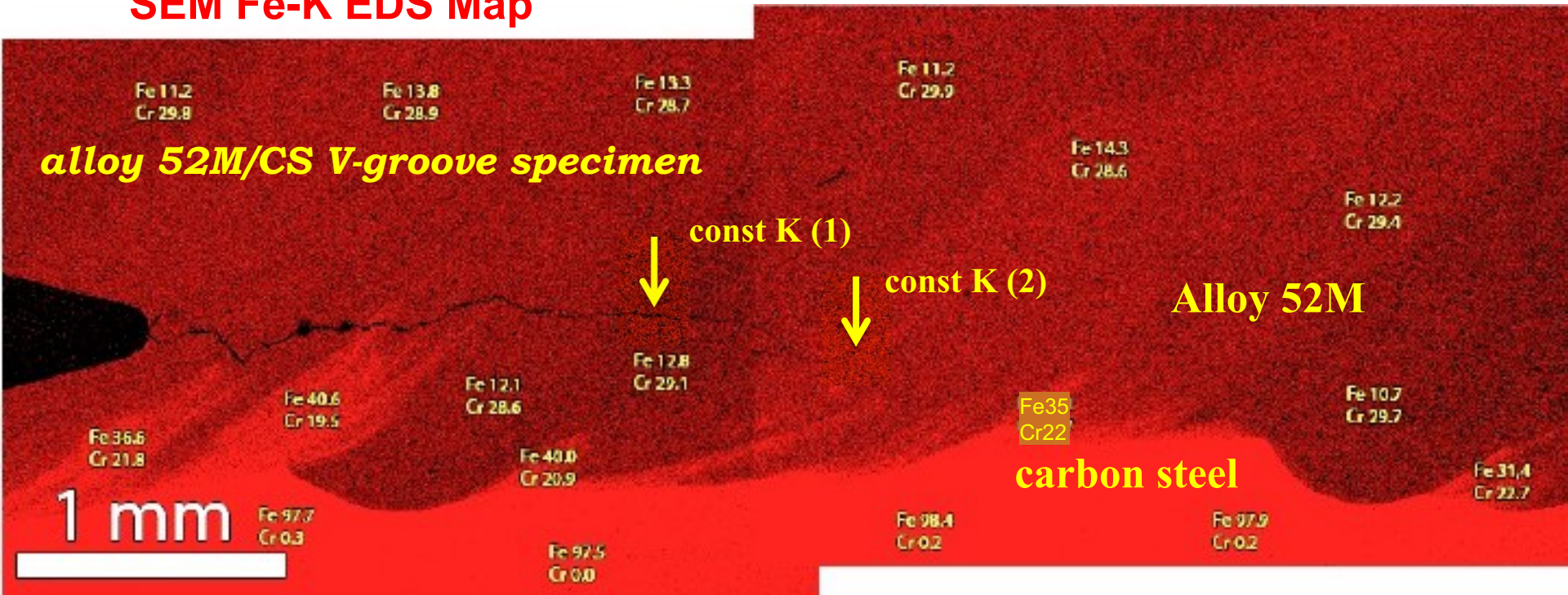
Constant  $K$  response measured twice for the dilution zone specimens with high SCC rates seen for the alloy 152M/CS specimen at high  $K$  levels.



# KAPL Alloy 52M/CS Dilution Zone Specimen CT065: Cross-Section

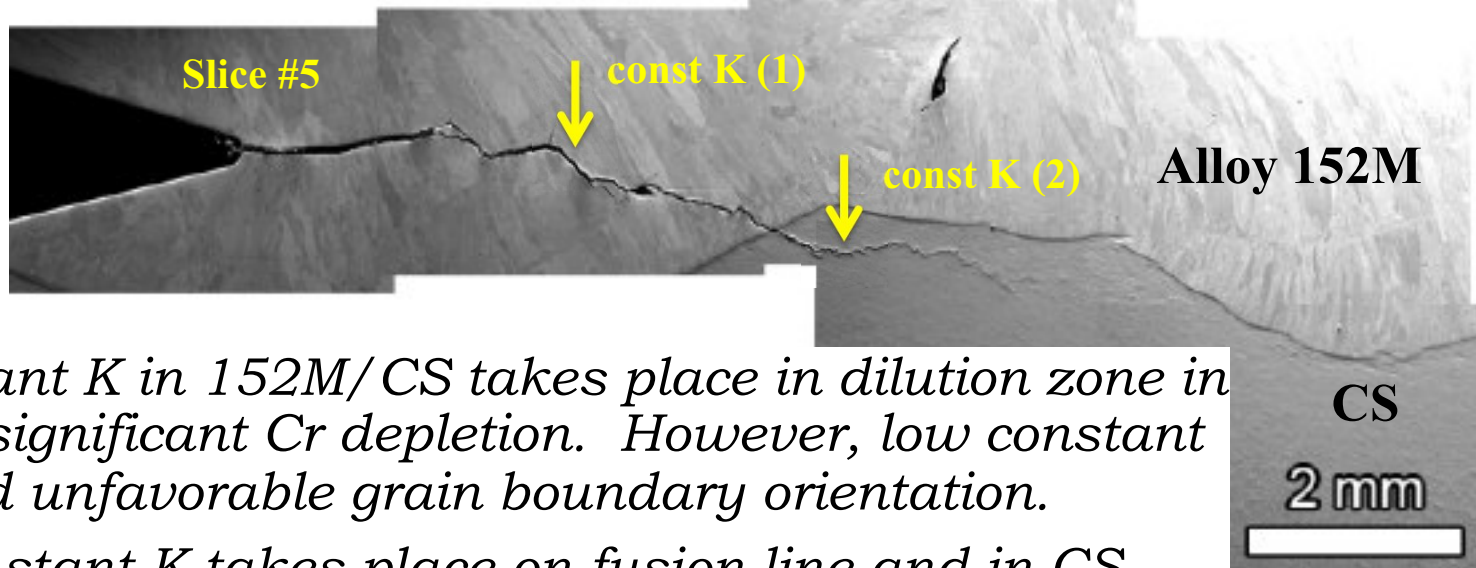
- **First** and **second** constant  $K$  in 52M/CS take place in regions of little or no chromium dilution.

## SEM Fe-K EDS Map



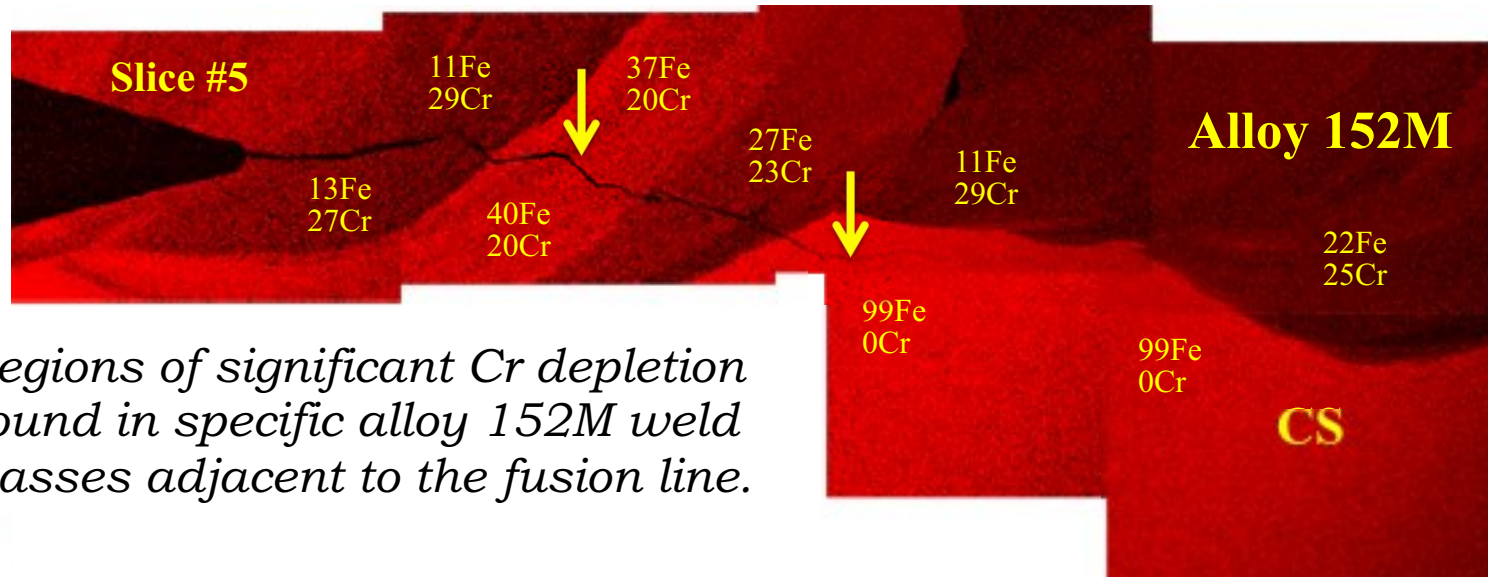
# KAPL Alloy 152M/CS Dilution Zone Specimen CT066: Cross-Section

SEM BSE  
Image



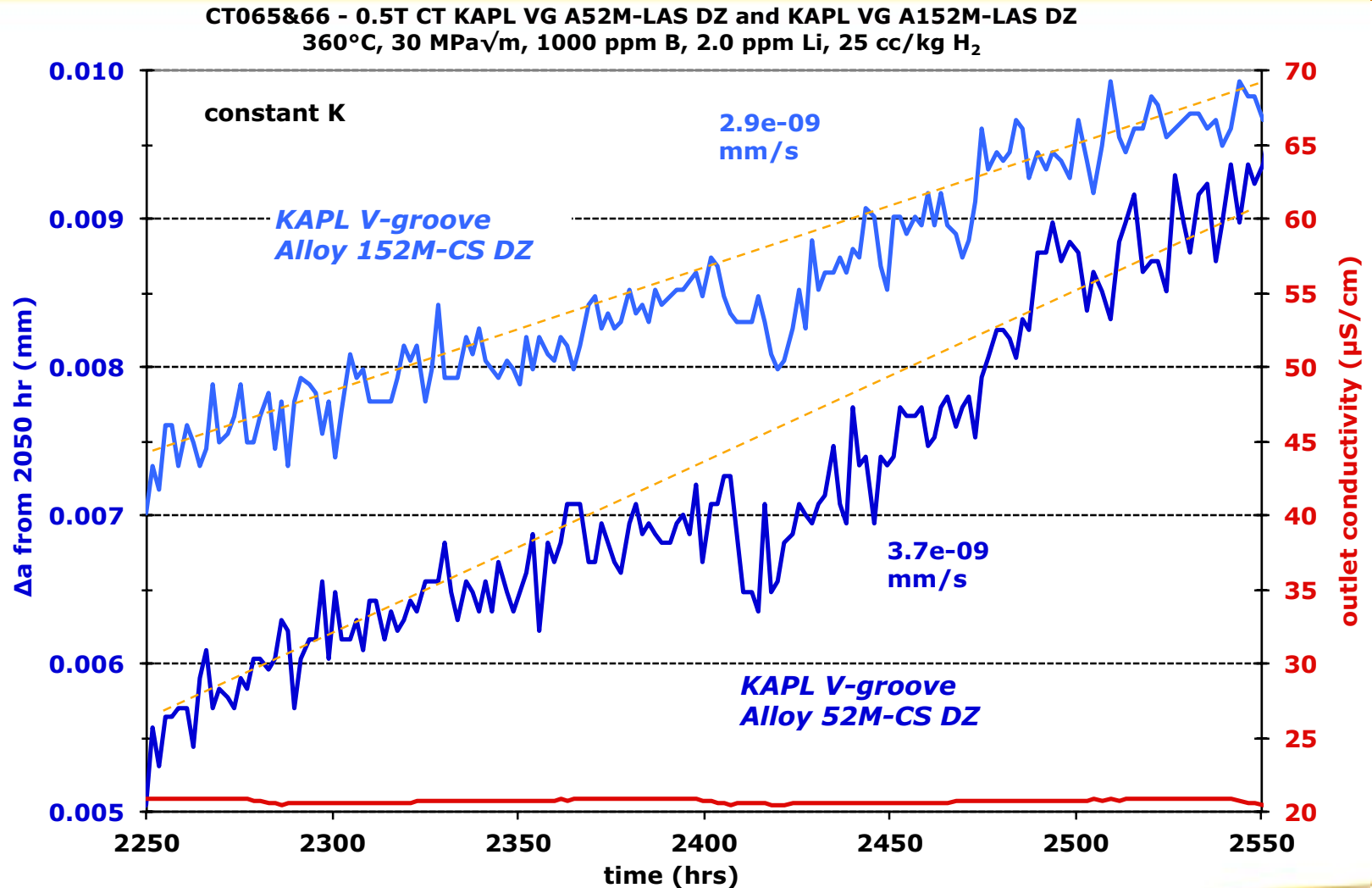
- ▶ **First** constant  $K$  in 152M/CS takes place in dilution zone in a region of significant Cr depletion. However, low constant  $K$  CGRs and unfavorable grain boundary orientation.
- ▶ **Second** constant  $K$  takes place on fusion line and in CS HAZ (depending on location in the specimen.)

SEM Fe-K  
EDS Map



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

# First Constant K Evaluation of Alloy 52M/CS and 152M/CS Dilution Zone Test Specimens



52M/CS: Within weldment. Minor compositional change.

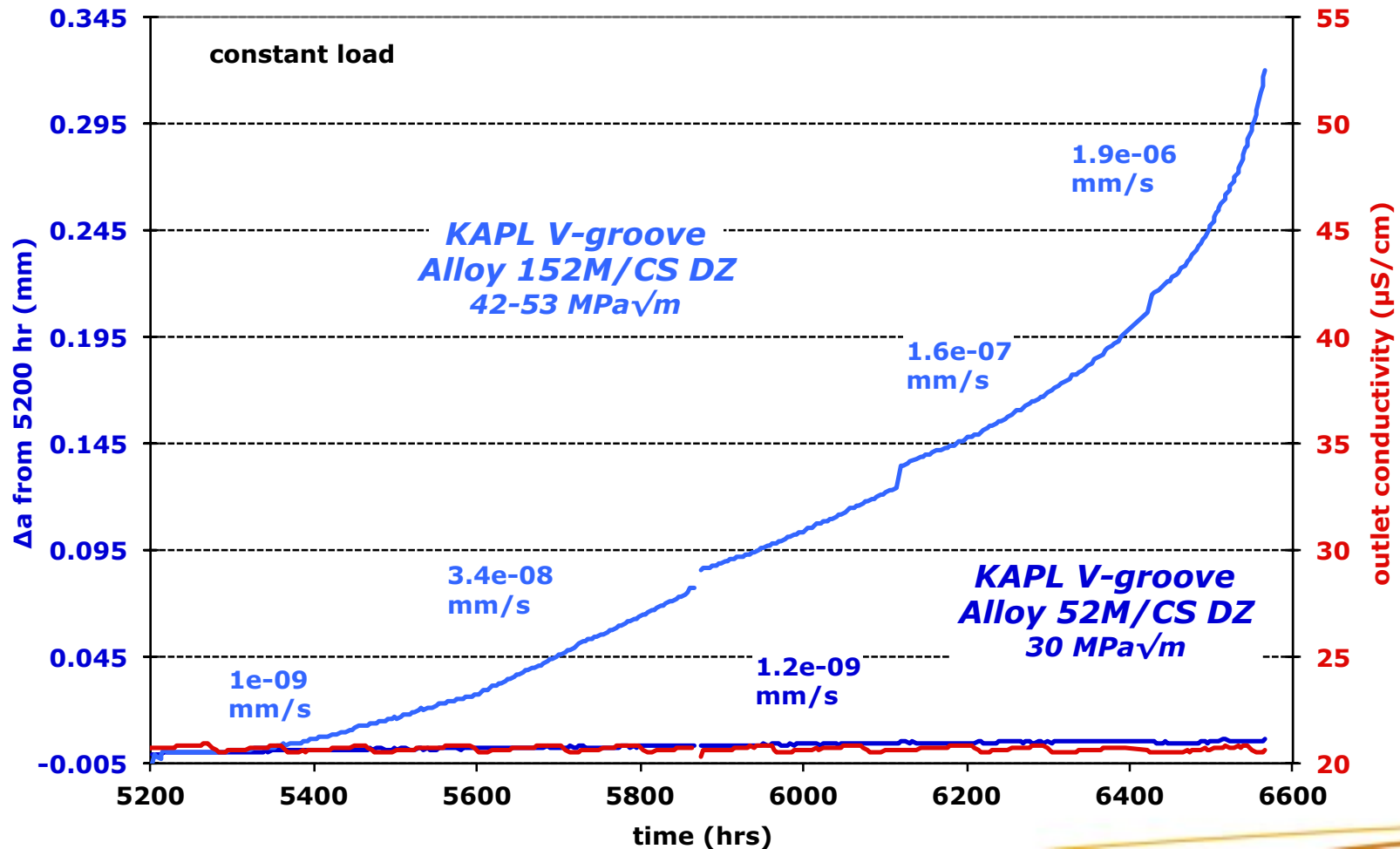
152M/CS: Within weldment. Significant Fe enrichment and Cr/Ni depletion.

For both specimens, weld GBs are strongly tilted relative to geometric crack path.



# Second Constant K Evaluation of Alloy 52M/CS and 152M/CS Dilution Zone Test Specimens

CT065&66 - 0.5T CT KAPL VG A52M/CS DZ and KAPL VG A152M/CS DZ  
360°C, 1000 ppm B, 2.0 ppm Li, 25 cc/kg H<sub>2</sub>



52M/CS: Crack is within the weld metal and at lower K, weld GBs tilted.  
152M/CS: Crack is either on fusion line or CS HAZ and at high K.



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

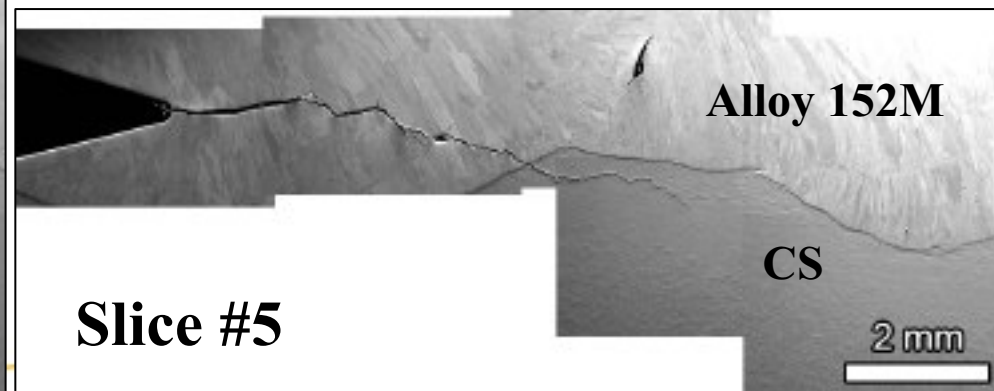
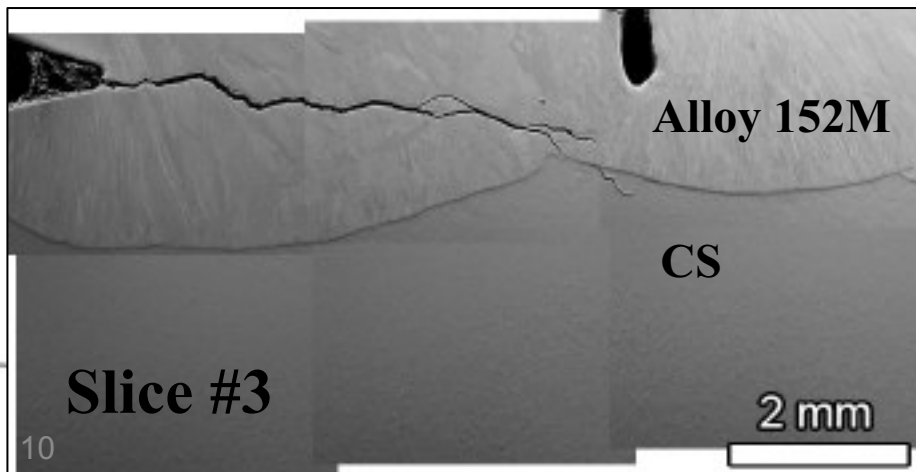
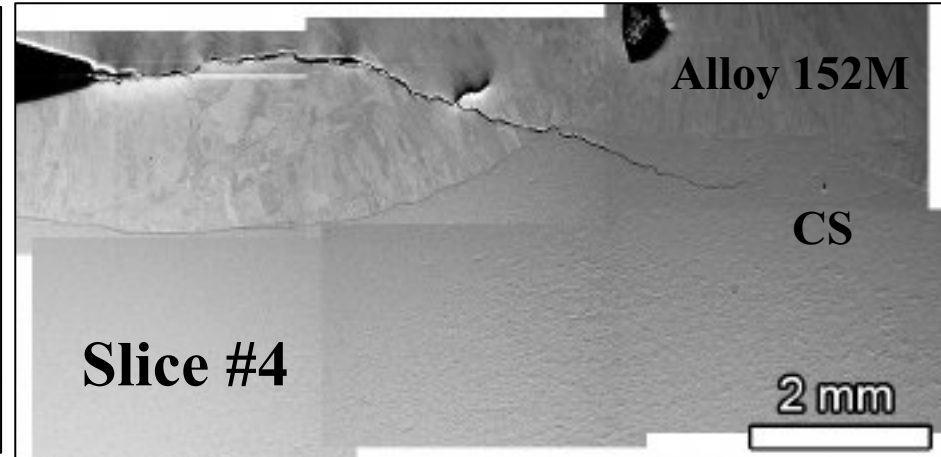
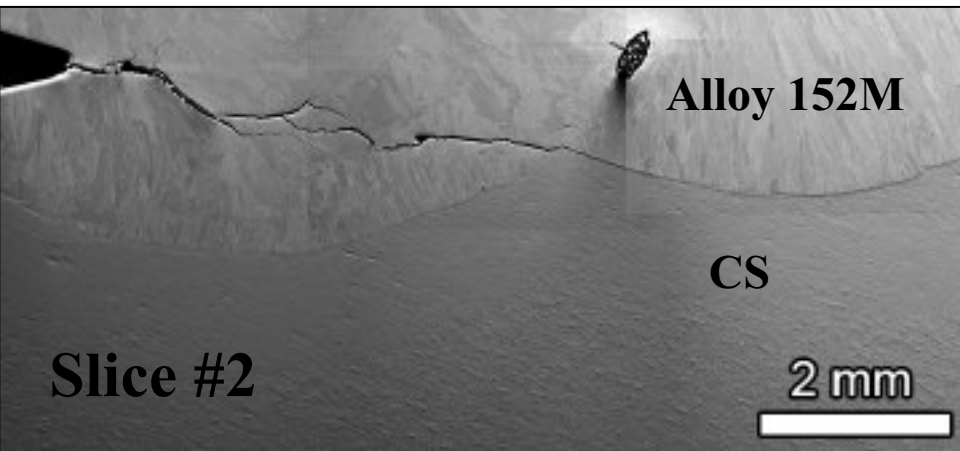


- *High crack growth rate observed in 152M/CS specimen.*
- *Section half of the width of specimen into 5 slices. Slice #1 is nearest to the sidegroove while slice #5 is at the center of the specimen.*

# KAPL Alloy 152M/CS Dilution Zone

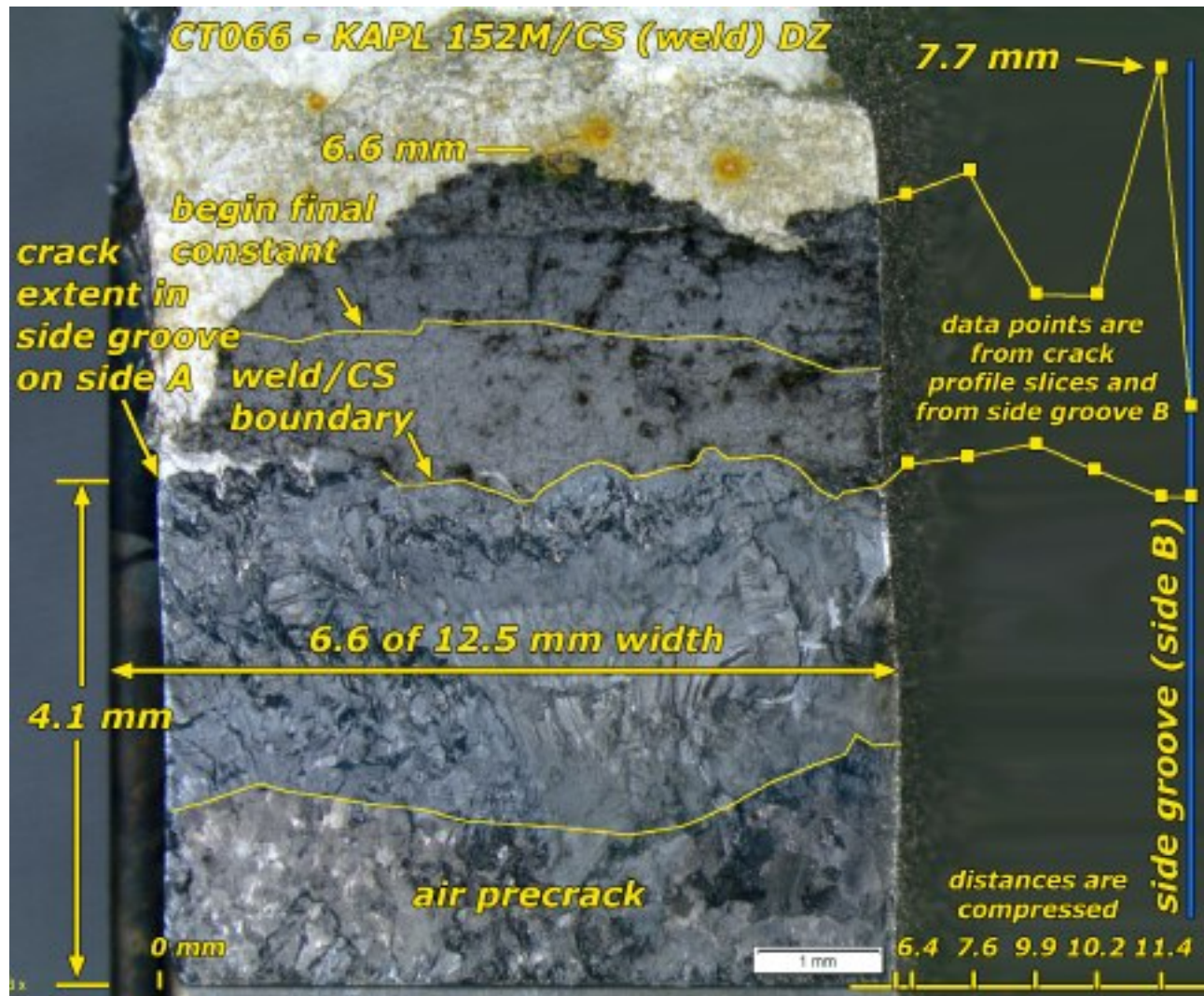
## Specimen CT066: Cross-Sectioning

- Slice #2 is nearest to sidegroove, and slice #5 is at the center of the specimen.
- Crack starts in alloy 152M weld and propagates toward and into the CS.



# KAPL Alloy 152M/CS CT Specimen

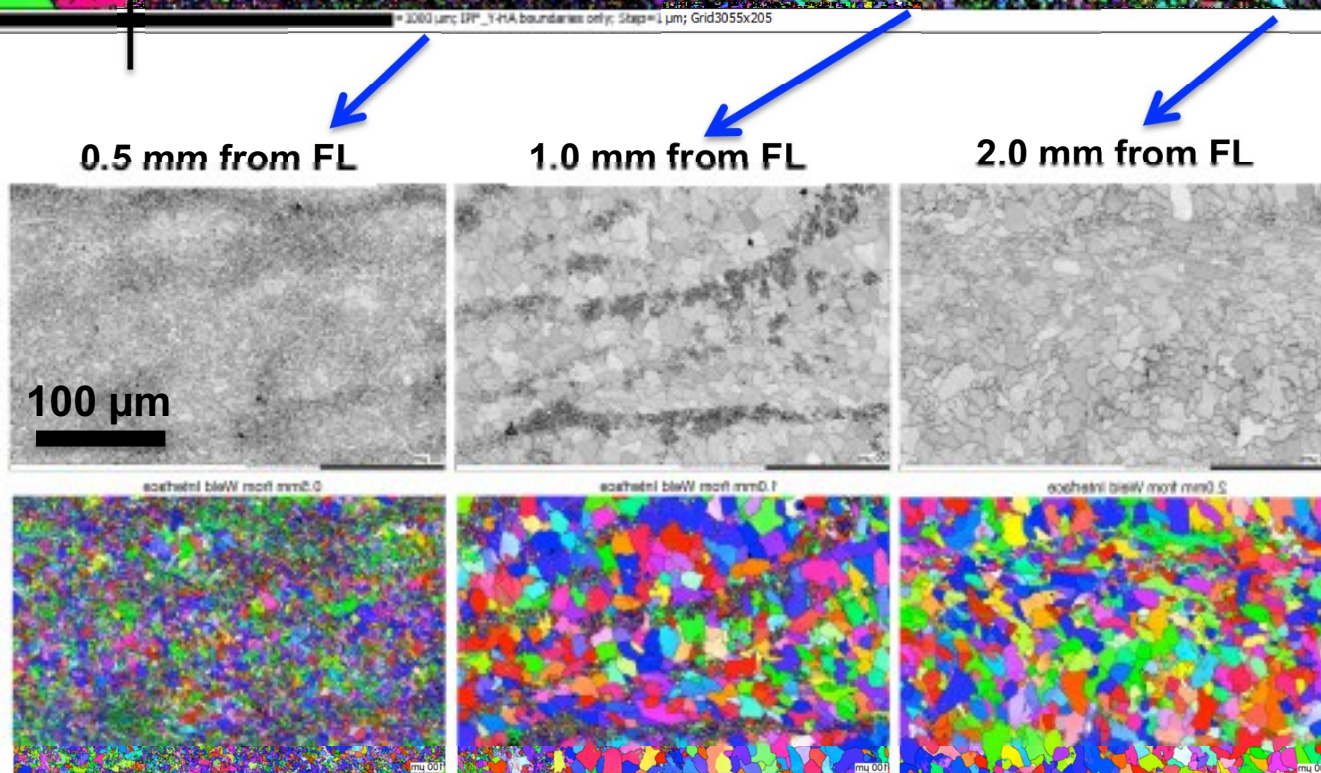
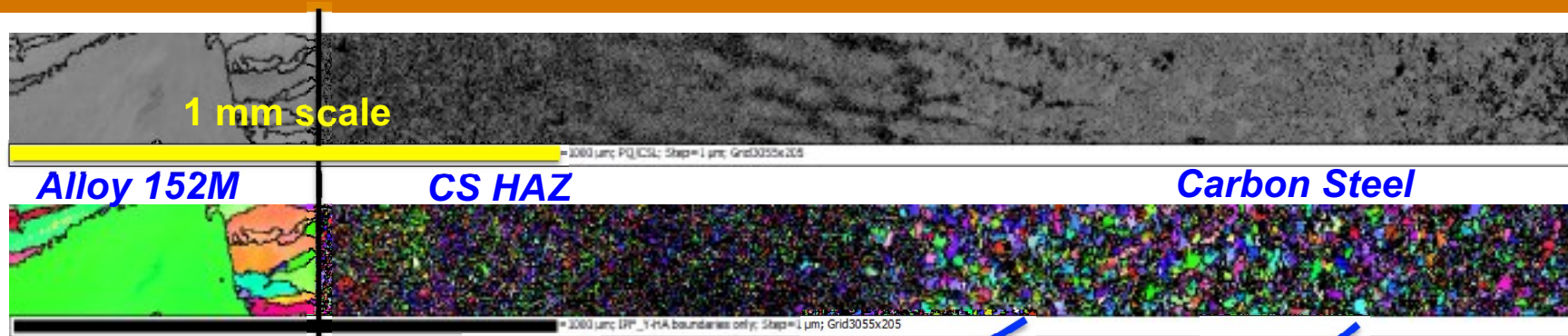
## CT066: Crack Growth Surface



*Extensive SCC growth in carbon steel during final constant load exposure at high K in CT066.*



# KAPL Alloy 152M/CS Dilution Zone Specimen CT066: EBSD Cross-Section #5



*EBSD reveals extremely fine grained microstructure  
in CS HAZ within ~1 mm of weld fusion line*



# Summary of Preliminary Results on 152M/CS and 52M/CS Dilution Zone Tests

- ▶ *Weldments have no butter or PWHT and are not representative of PWR dissimilar metal welds.*
- ▶ *Goal was to evaluate SCC response of weld dilution zone. Specimens were cut so that the geometric crack path was offset about 0.5-1.5 mm from fusion line into the weld.*
- ▶ *Elongated grains in weldment are at ~45 degree angle to geometric crack path.*
- ▶ *Crack in alloy 52M/CS specimen stayed in weldment with no indication of enhanced SCC susceptibility.*
- ▶ *Crack in alloy 152M/CS turned grew towards fusion line.*
  - *First SCC assessment was in region of 20% chromium in dilution zone. Low SCC CGRs observed, no indication of IG cracking.*
  - *Second SCC assessment was partially on fusion line and partially in CS HAZ. Very high crack growth rates observed at high  $K$  of 44-53 MPa $\sqrt{m}$ .*

# PNNL Crack-Growth Testing on CS Dissimilar Metal Welds

- ▶ *KAPL V-Groove Weld: Alloy 152M (WC83F8) to 516 Carbon Steel Plate. No butter or PWHT for CS.*
  - *1 weld metal dilution zone to fusion line test recently completed (CT066)*
  - **1 fusion line test ongoing (CT082)**
- ▶ *KAPL V-Groove Weld: Alloy 52M (NX5285) to 516 Carbon Steel Plate. No butter or PWHT for CS.*
  - *1 weld metal dilution zone test recently completed (CT065)*
  - **1 fusion line test ongoing (CT083)**

# KAPL 152M/CS (CT082) and 52M/CS (CT083) Fusion Line Specimens

## CT082 - KAPL A152M/CS Fusion Line

### Side A

specimen notch

constant K (1)

constant K (2)

carbon steel

alloy 152M

0 1 2 3 4 5 mm

1) Notch positions selected to produce precrack at **weld fusion line or slightly within CS HAZ.**

2) Arrows show location of first constant K evaluation.

3)  $K$  levels are being increased by  $dK/da$  in an attempt to duplicate high growth rates seen previously.

4) Follow by removing specimens, apply PWHT, and reevaluate crack growth response.

## CT083 - KAPL A52M/CS Fusion Line

### Side A

specimen notch

constant K (1)

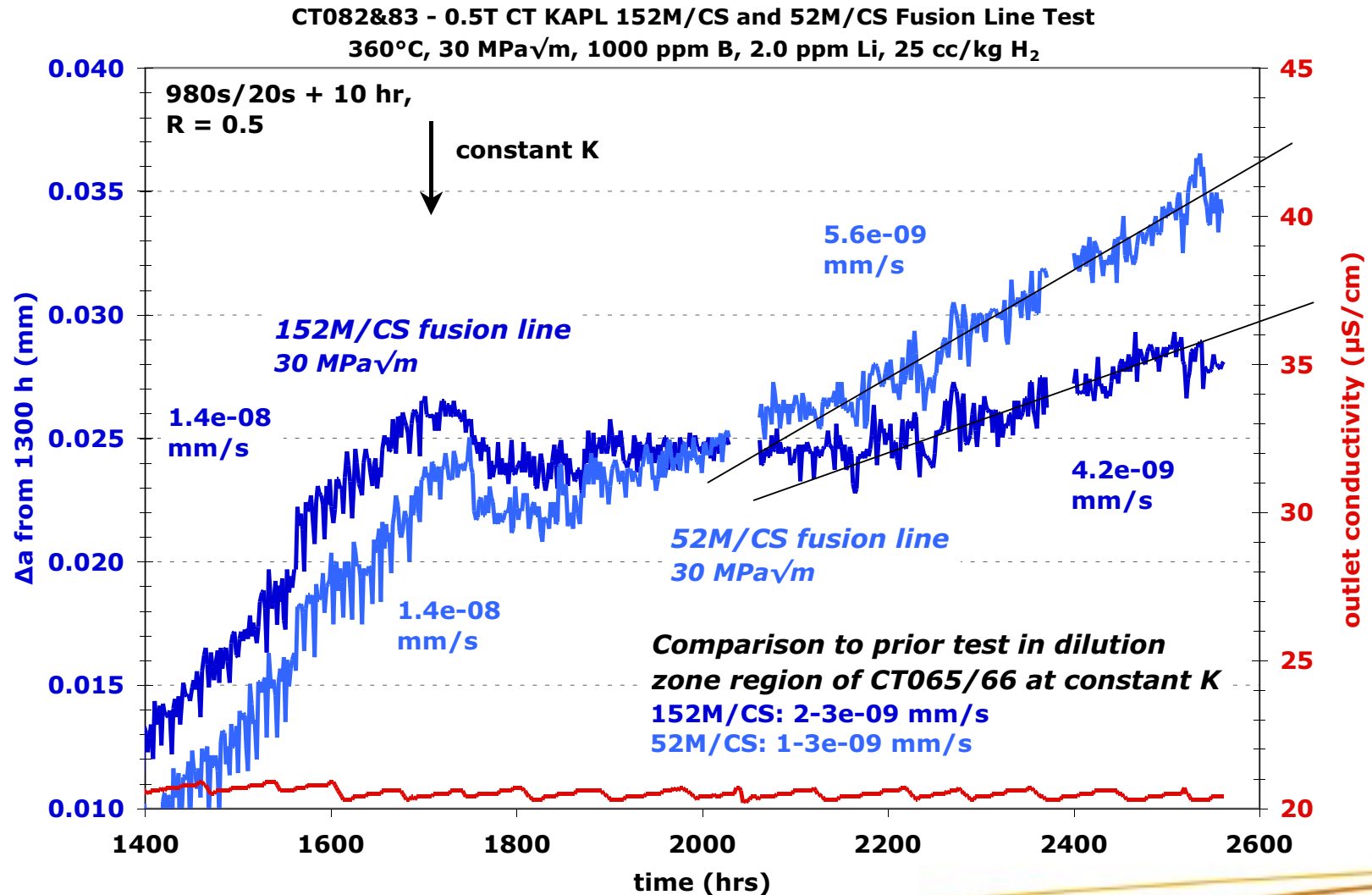
constant K (2)

carbon steel

alloy 152M

0 1 2 3 4 5 mm

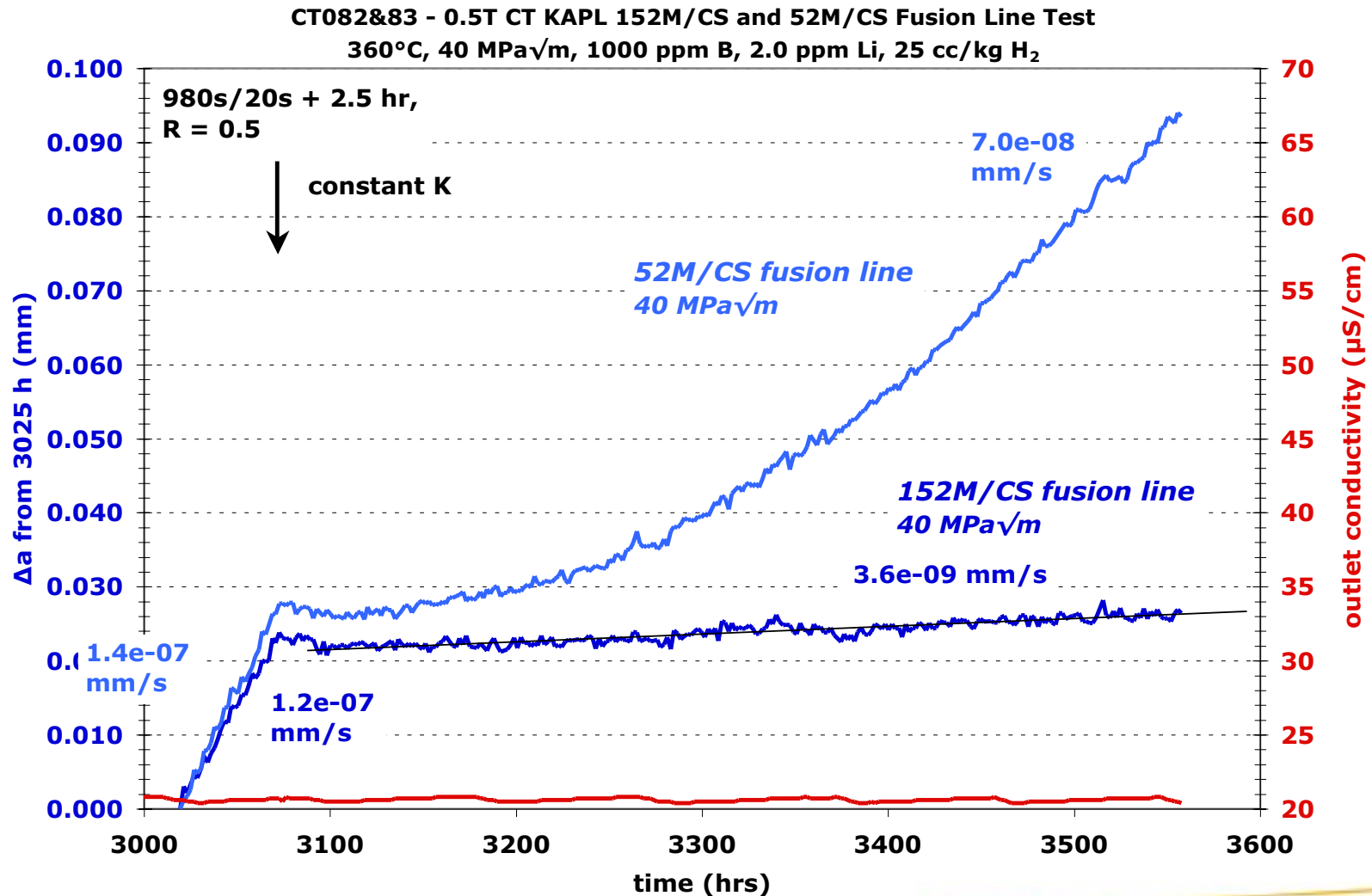
# Ongoing Results on Alloy 152M/CS and 52M/CS Fusion Line Test – $30 \text{ MPa}\sqrt{m}$



*Slightly higher CGRs than in dilution zone evaluation of previous test but lower than fusion line/HAZ response in previous test.  $K$  only  $30 \text{ MPa}\sqrt{m}$ .*



# Ongoing Results on Alloy 152M/CS and 52M/CS Fusion Line Test – $40 \text{ MPa}\sqrt{m}$



- 52M/CS fusion line CGR is 10x higher than at 30 MPa√m, and still increasing.
- 152M/CS specimen CGR is similar to 30 MPa√m. Crack in this specimen is further from the fusion line.

# Summary of Ongoing Test on 152M/CS and 52M/CS Fusion Line Specimens

- ▶ *Weldments have no butter or PWHT and are not representative of PWR dissimilar metal welds.*
- ▶ *Plan is to reproduce high SCC crack growth rates on fusion line/HAZ, apply PWHT, and reexamine SCC response. Purpose is to obtain a general indication of effect of PWHT on SCC response on fusion line and in CS HAZ.*
- ▶ *52M/CS is exhibiting high crack growth rates suggestive of SCC growth on fusion line.*
- ▶ *152M/CS is within CS, but not as well aligned to fusion line and exhibiting low SCC CGRs.*
- ▶ *Will remove both specimens, examine crack front location, apply PWHT, and reinsert to reevaluate PWSCC response.*



# Overall Summary of Ongoing Dissimilar Metal Weld Studies

- ▶ *First test on alloy 52M/CS and 152M/CS materials focused on weld dilution zone region.*
  - *Both constant K evaluations of 52M/CS specimen were entirely within weld in a region of minor dilution while first constant K evaluation of 152M/CS specimen was within a 20% Cr region. GBs tilted at  $\sim 45^\circ$  to geometric crack path. Cracking was TG with low CGRs for both materials.*
  - *Crack in 152M/CS specimen ran off plane to fusion line and partially into the HAZ, reaching high SCC CGRs. Cracking appears mixed IG/TG.*
- ▶ *Second (ongoing) test on alloy 52M/CS and 152M/CS specimens is focusing on fusion line and CS HAZ region in order to evaluate the influence of PWHT on SCC susceptibility.*