

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

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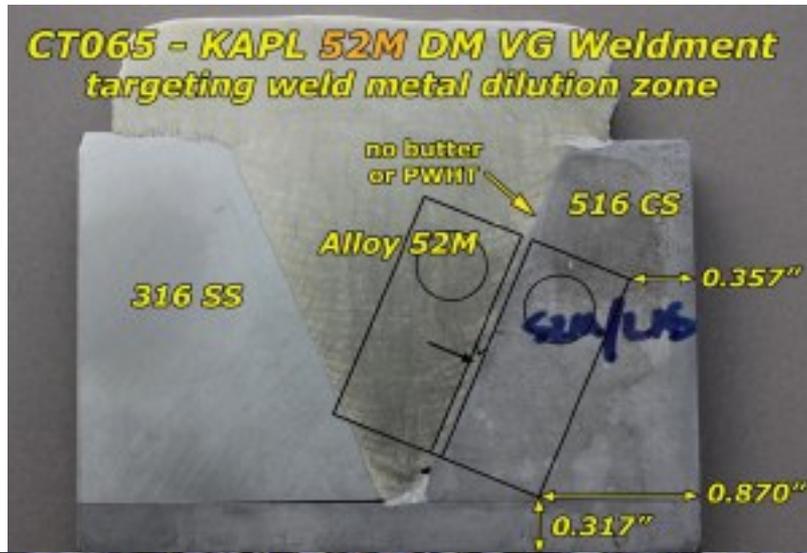
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PNNL Crack-Growth Testing on CS Dissimilar Metal Welds

- ▶ *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)*

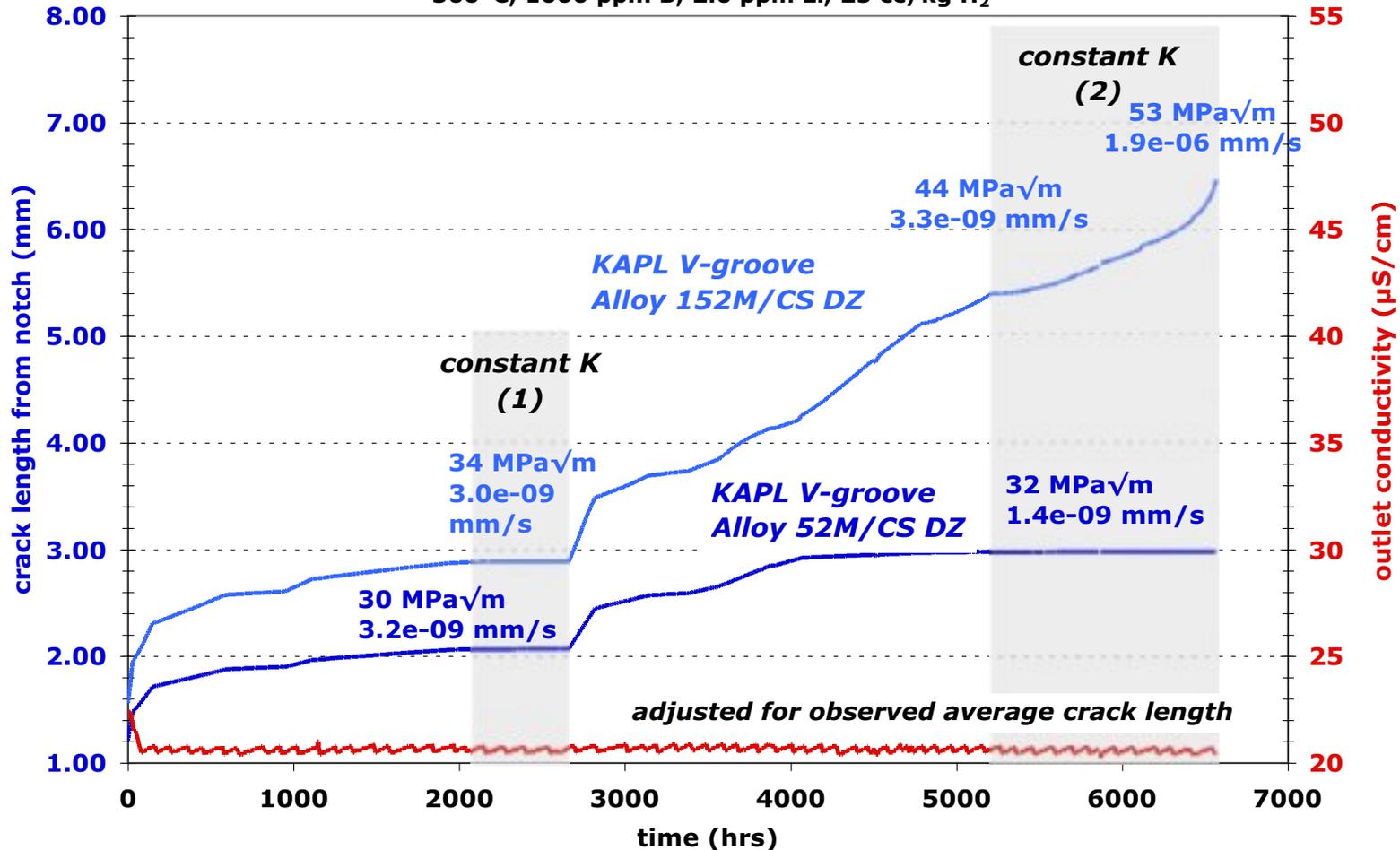
KAPL 52M/CS (CT065) and 152M/CS (CT066) Dilution Zone Specimens

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

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 H₂

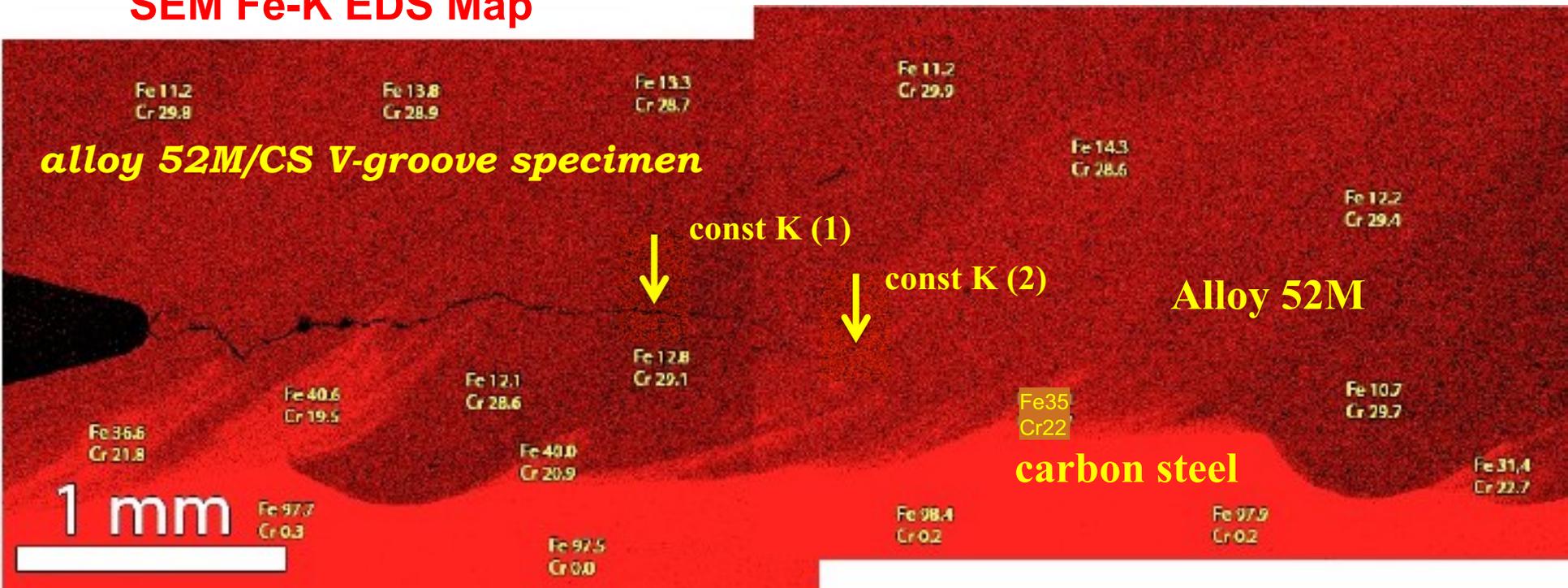


Constant *K* response measured twice for the dilution zone specimens with high SCC rates seen for the alloy 152M/CS specimen at high *K* levels.

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

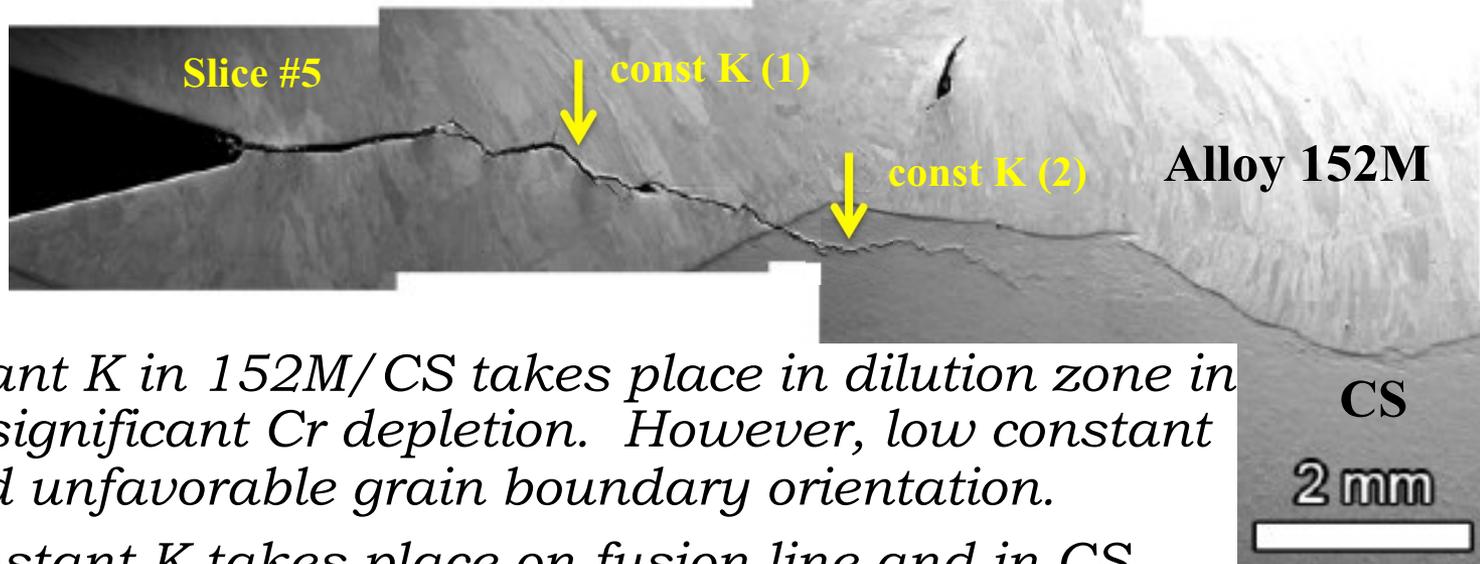
- **First** and **second** constant K in 52M/CS take place in regions of little or no chromium dilution.

SEM Fe-K EDS Map



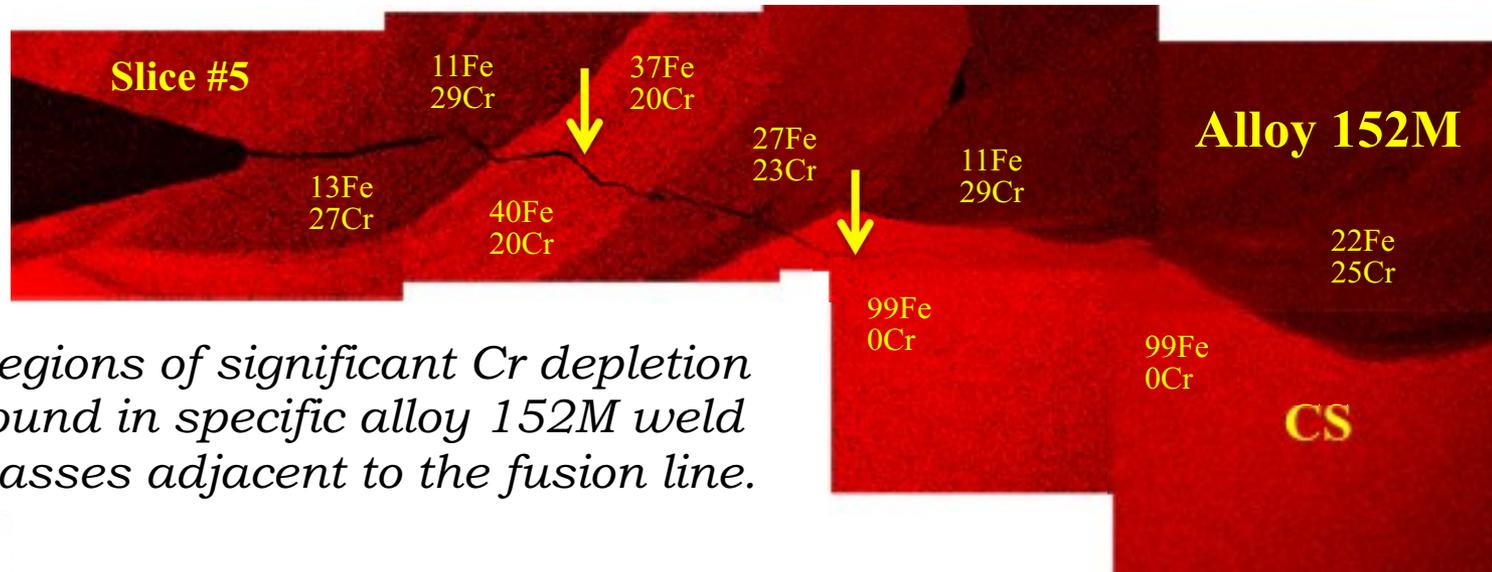
KAPL Alloy 152M/CS Dilution Zone Specimen CT066: Cross-Section

SEM BSE Image



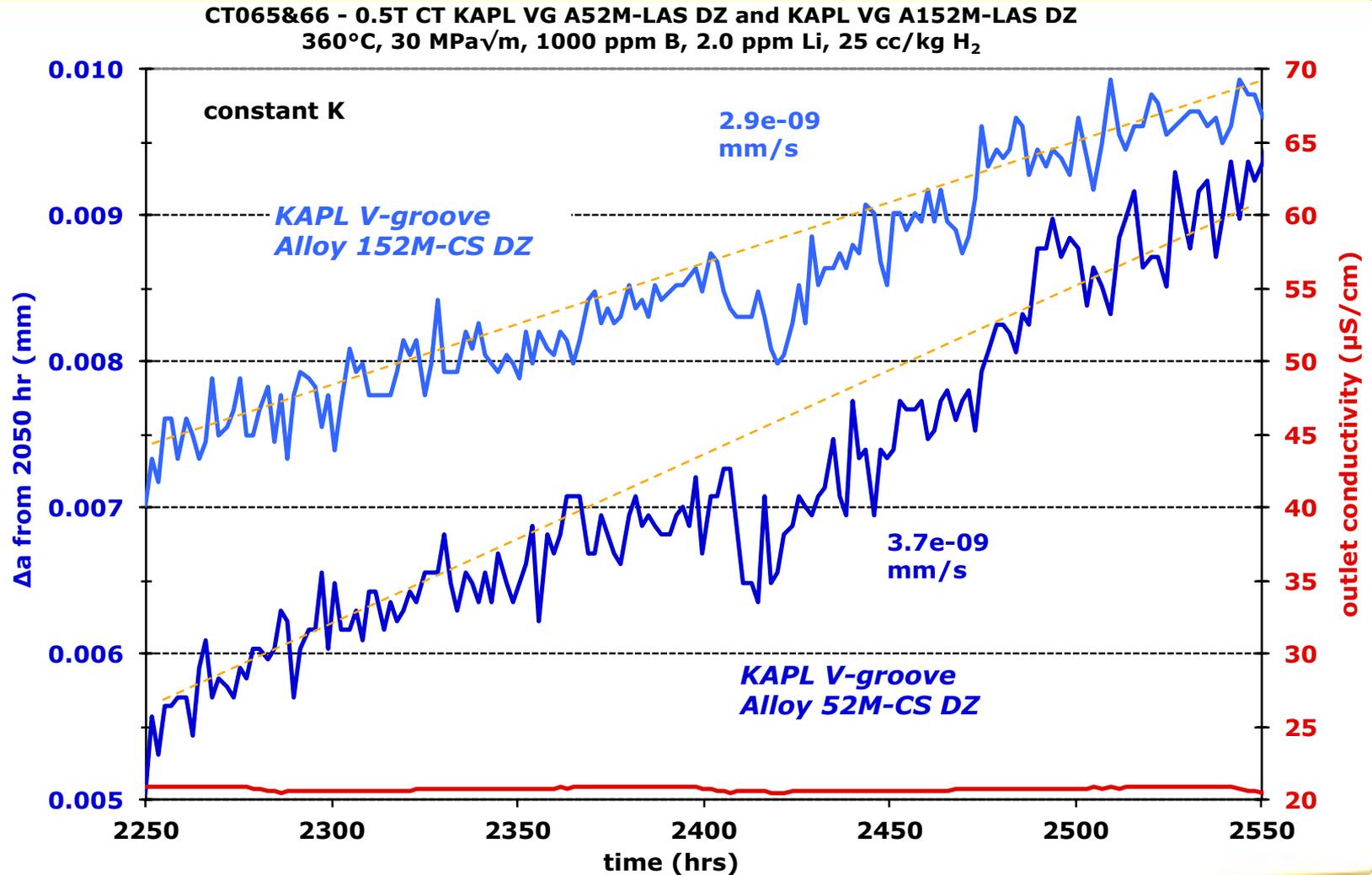
- ▶ **First** constant K in 152M/CS takes place in dilution zone in a region of significant Cr depletion. However, low constant K CGRs and unfavorable grain boundary orientation.
- ▶ **Second** constant K takes place on fusion line and in CS HAZ (depending on location in the specimen.)

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



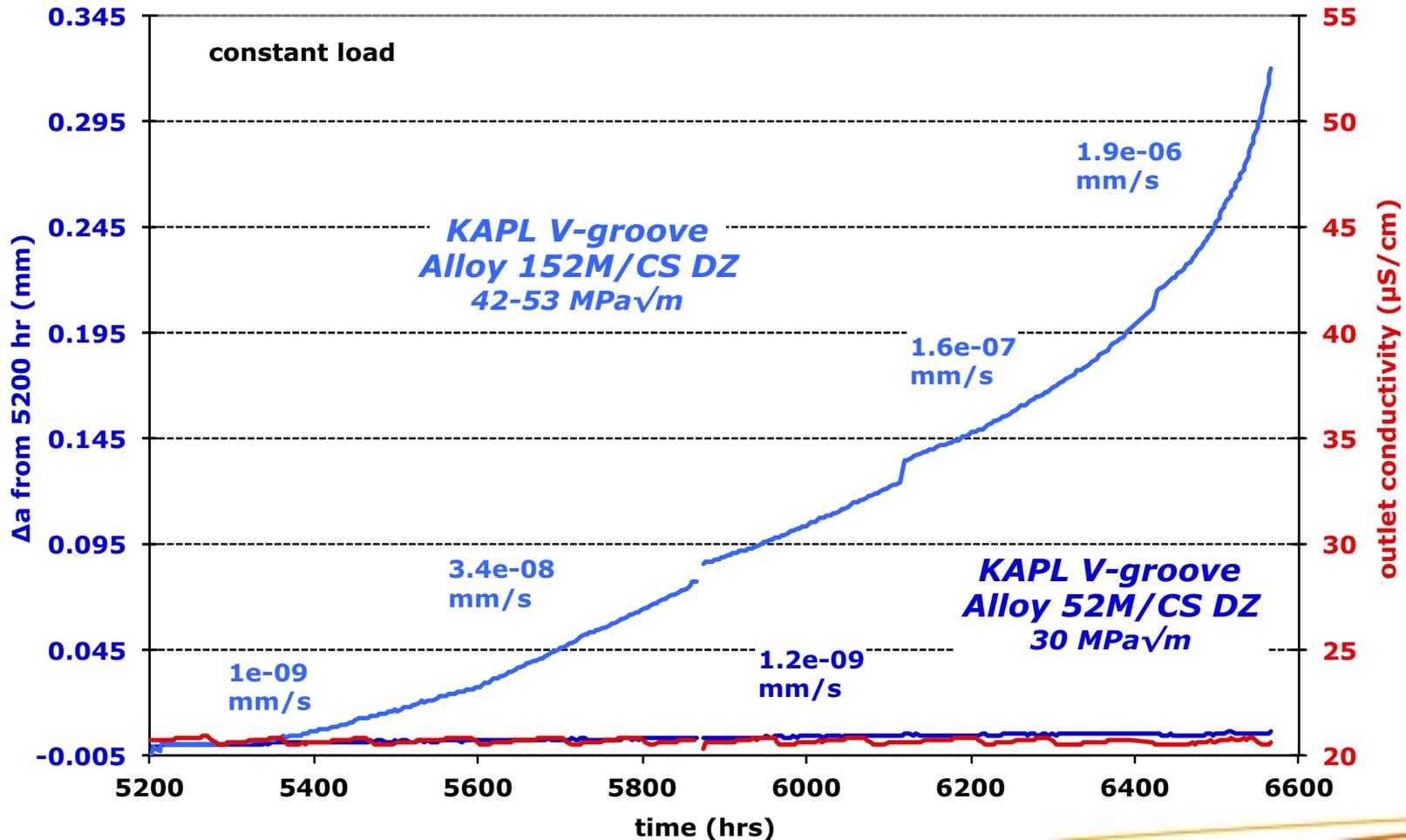
52M/CS: Within weldment. Minor compositional change.

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 H2



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.

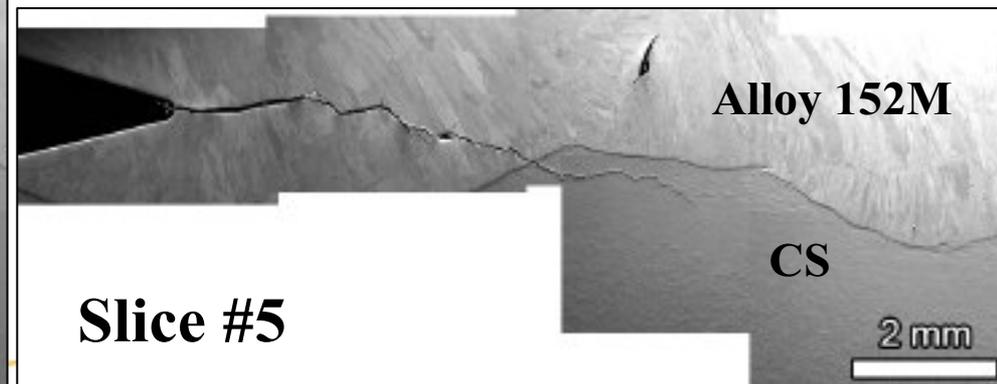
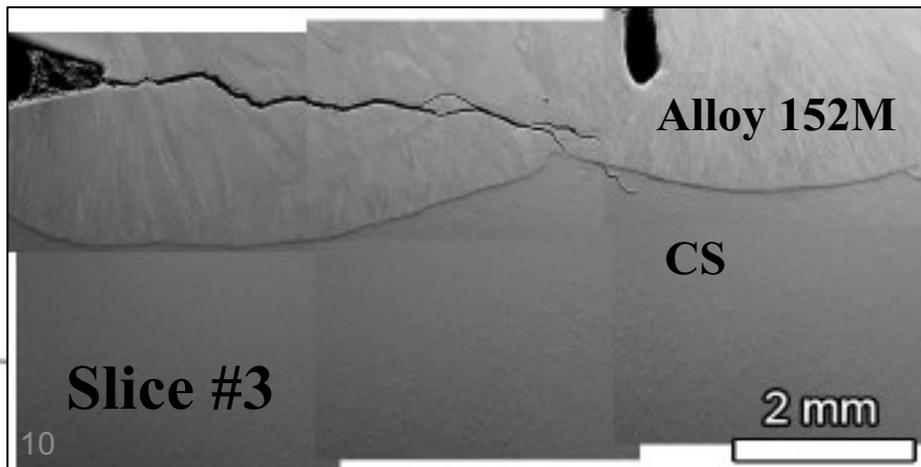
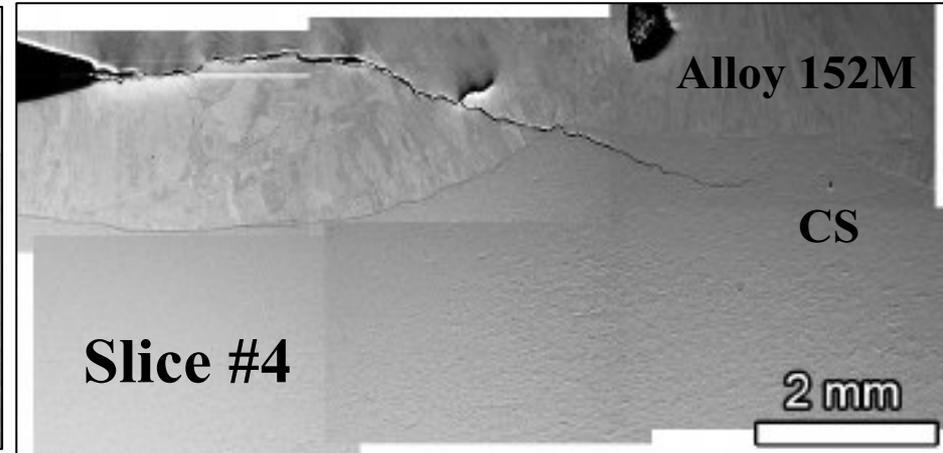
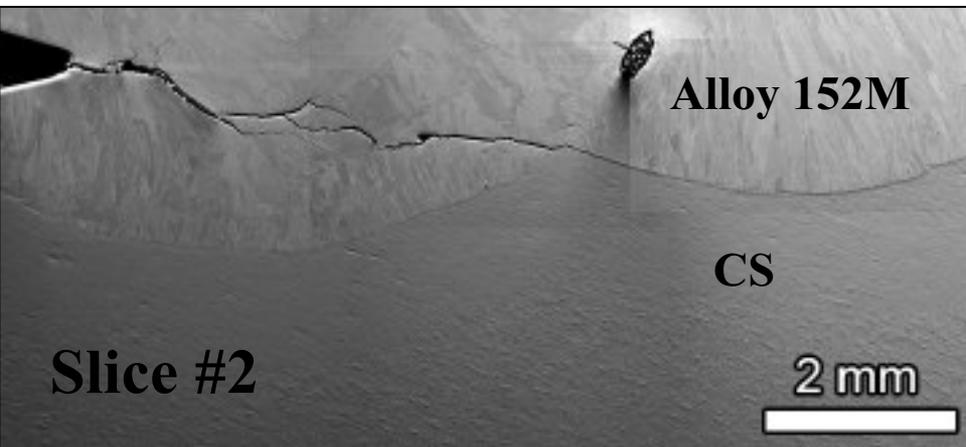
KAPL Alloy 152M/CS Dilution Zone Specimen CT066: Cross-Sectioning



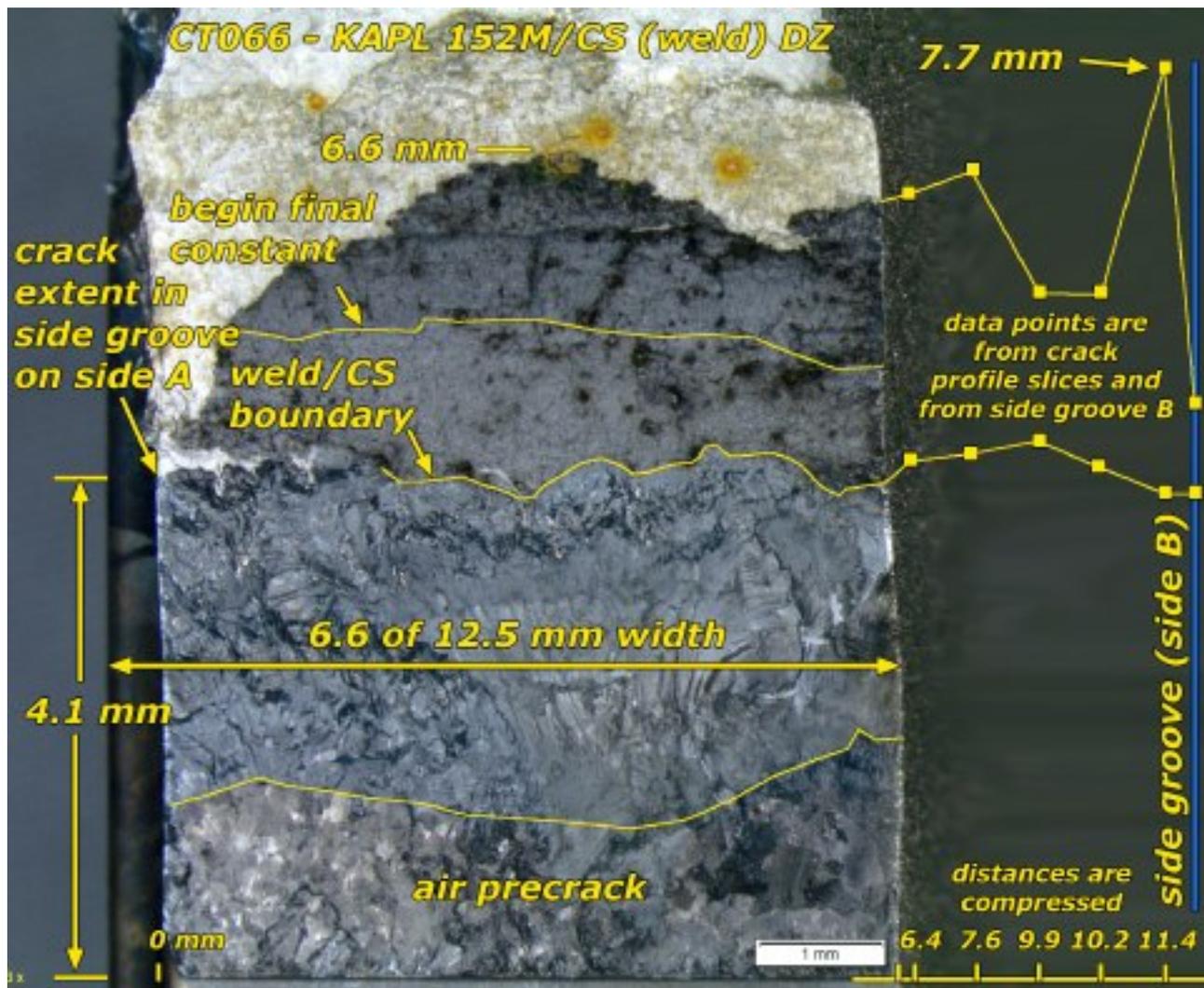
- *High crack growth rate observed in 152M/CS specimen.*
- *Section half of the width of specimen into 5 slices. Slice #1 is nearest to the sidegroove while slice #5 is at the center of the specimen.*

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.

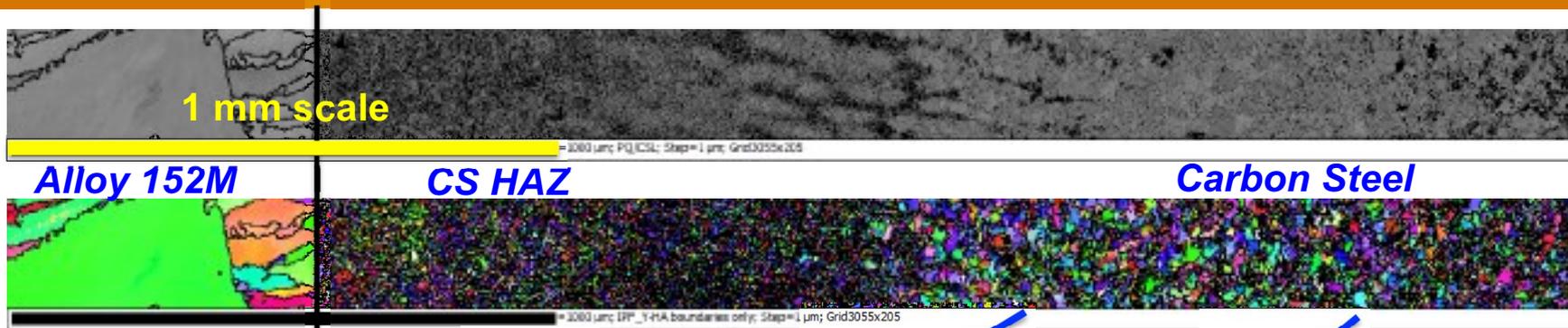


KAPL Alloy 152M/CS CT Specimen CT066: Crack Growth Surface



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

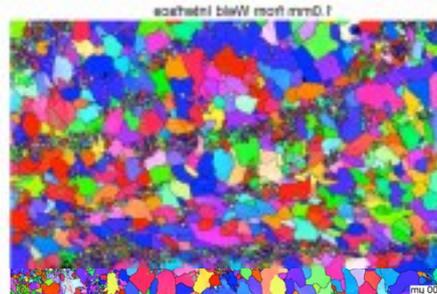
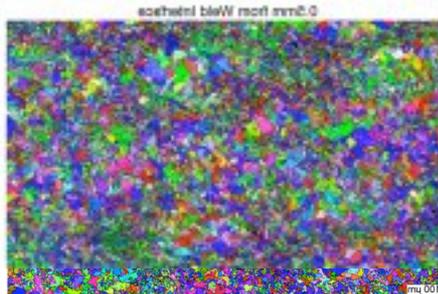
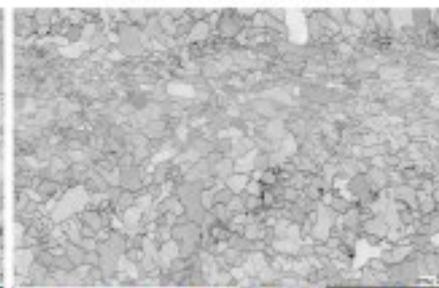
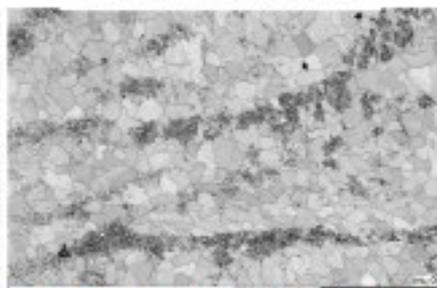
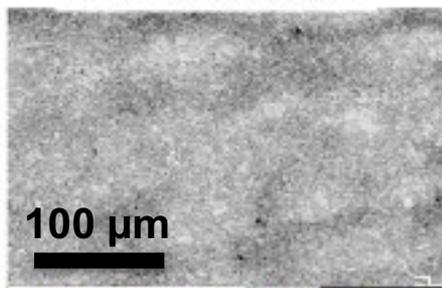
KAPL Alloy 152M/CS Dilution Zone Specimen CT066: EBSD Cross-Section #5



0.5 mm from FL

1.0 mm from FL

2.0 mm from FL



*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

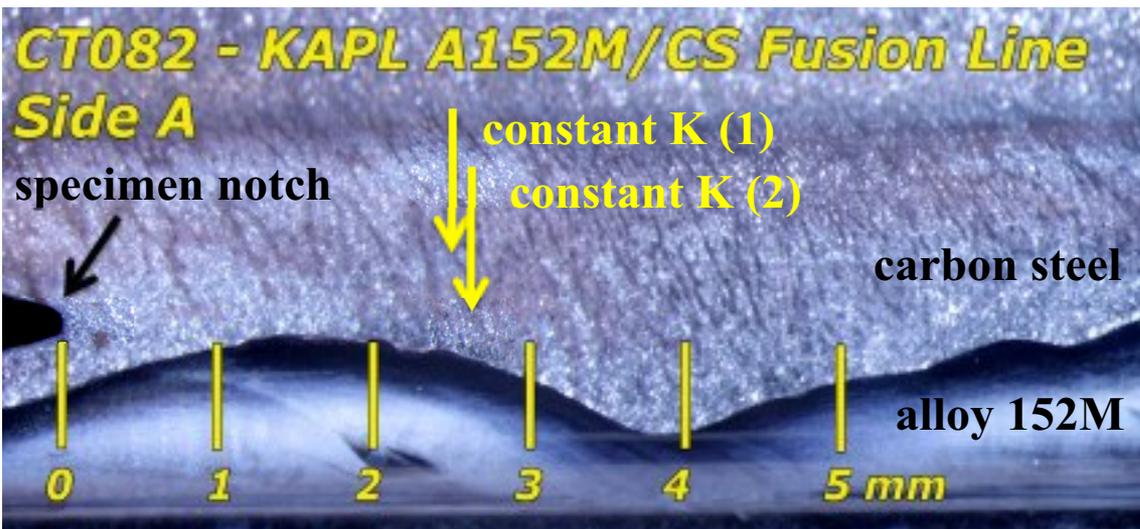
- ▶ *Weldments have no butter or PWHT and are not representative of PWR dissimilar metal welds.*
- ▶ *Goal was to evaluate SCC response of weld dilution zone. Specimens were cut so that the geometric crack path was offset about 0.5-1.5 mm from fusion line into the weld.*
- ▶ *Elongated grains in weldment 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

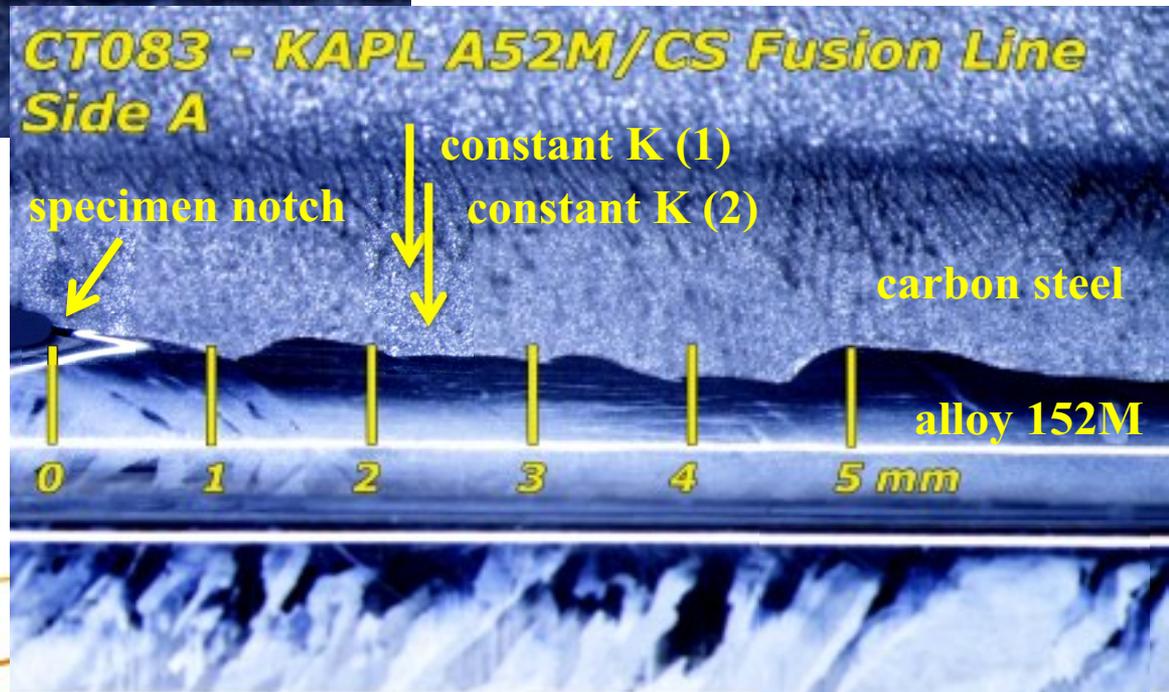
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KAPL 152M/CS (CT082) and 52M/CS (CT083) Fusion Line Specimens

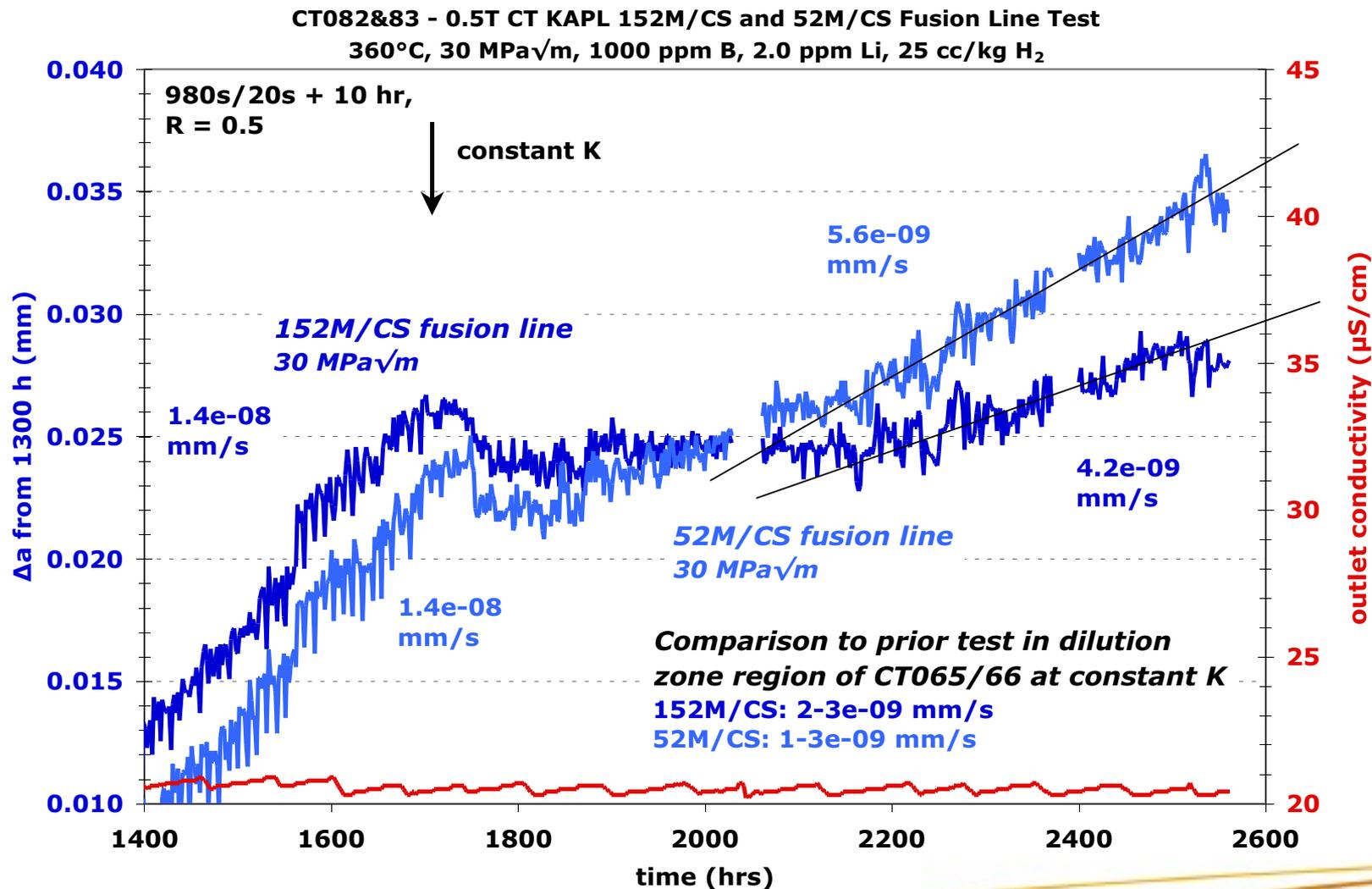


- 1) Notch positions selected to produce precrack at **weld fusion line or slightly within CS HAZ.**
- 2) Arrows show location of first constant *K* evaluation.



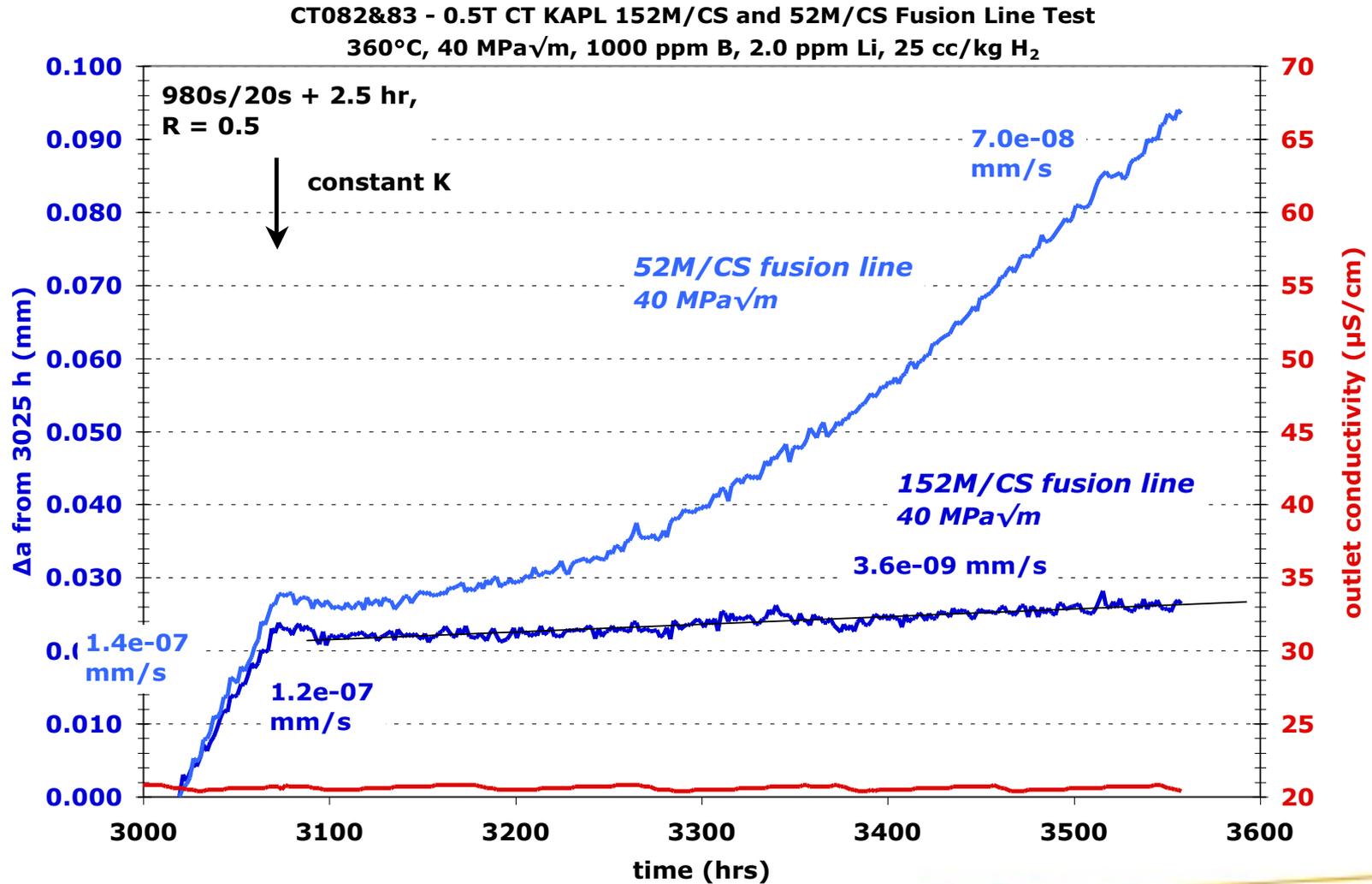
- 3) *K* levels are being increased by dK/da in an attempt to duplicate high growth rates seen previously.
- 4) Follow by removing specimens, apply PWHT, and reevaluate crack growth response.

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.*

