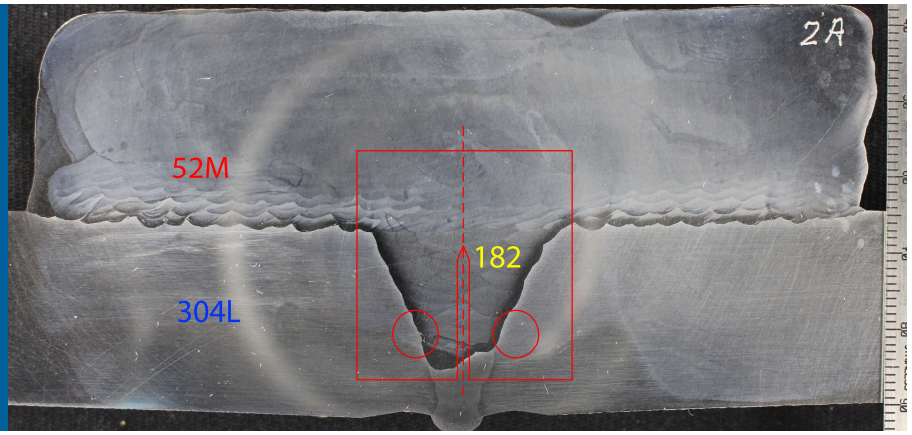
PRIMARY WATER SCC OF HIGH-CR NI-BASED WELDS AT OR NEAR INTERFACES



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NRC Project Manager: Margaret Audrain

Alloy 690 Collaboration Meeting – January 13-14, 2021

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PRESENTATION TOPICS

Focus on recently-completed testing:

SCC CGR response of Alloy 52M WOLs

- Alloy 52M WOL-182 by KAPL
- Alloy 52M WOL-182 by EWI

SCC CGR response of 1st layer Alloy 52M weld specimens from the “double-repair” Alloy 52M weld

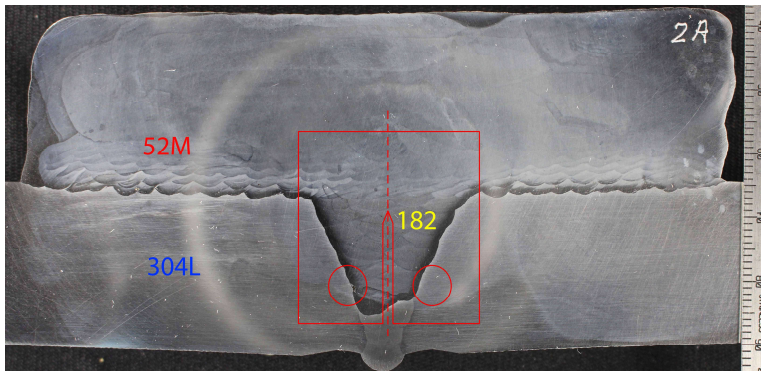
- Alloy 52M butter – 508 LAS interface

SCC CGR RESPONSE OF ALLOY 52M WOLS

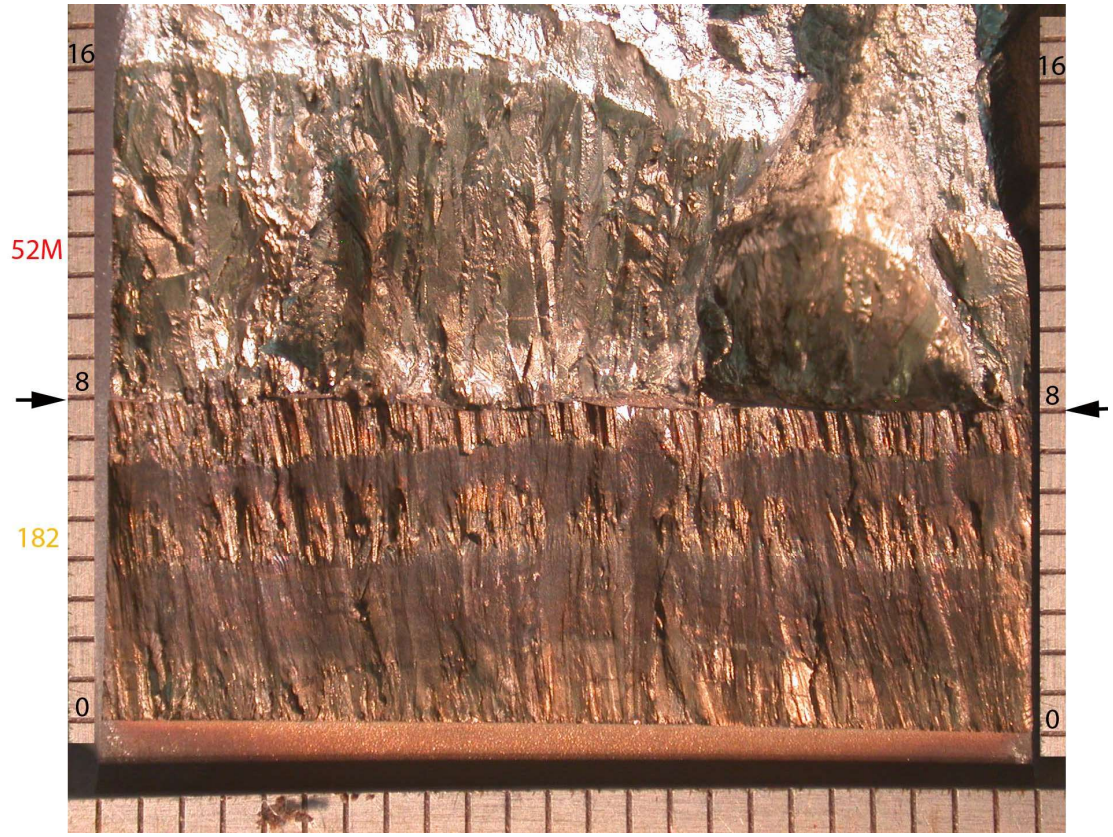
SCC CGR RESPONSE OF ALLOY 52M WOLS

- Earlier work involved an ANL-produced Alloy 52M-182 WOL (NUREG/CR-7226 2018)
- In addition to the typical TS orientations, ST orientations were tested to avoid crack deflection at the interface and have the ability to measure growth at the interface and 1st layer

- Key findings (ANL WOL): interface is the most susceptible, followed by the 1st 52M layer, followed by the Alloy 182 in compression under the WOL
- Additional testing in TS orientation on KAPL and EWI WOLs – test management is key:
- Location of the SCC CGR determinations is critical for the desired SCC CGR vs. distance info
- Objective: 1 mm of straight, continuous, free of ligaments IG SCC front ahead of the interface

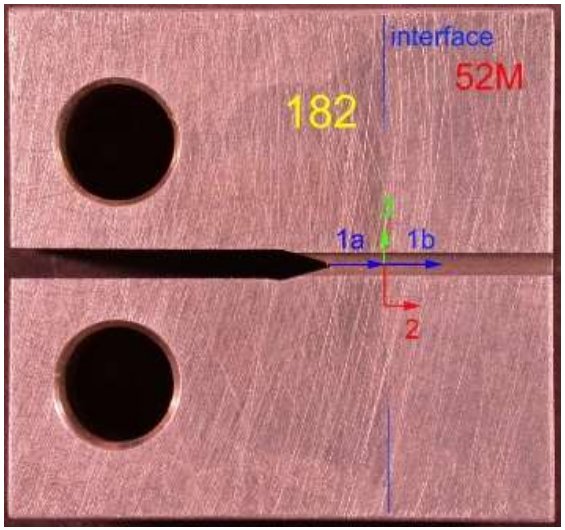


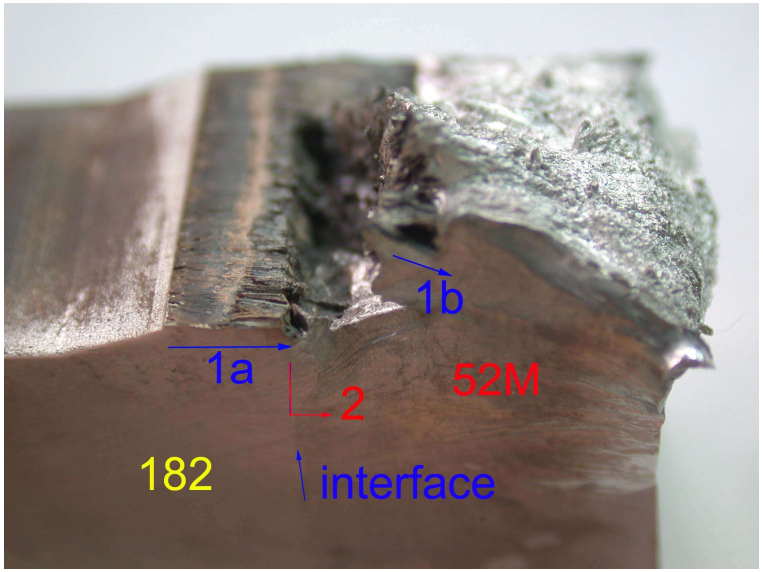
EARLY WOL TESTING: ANL ALLOY 52M-182 WOL



- Location is critical
- Requirement for sound results (SCC CGR vs distance): straight, fully-engaged SCC crack front in Alloy 182 ahead of WOL

EARLY WOL TESTING: ANL ALLOY 52M-182 WOL



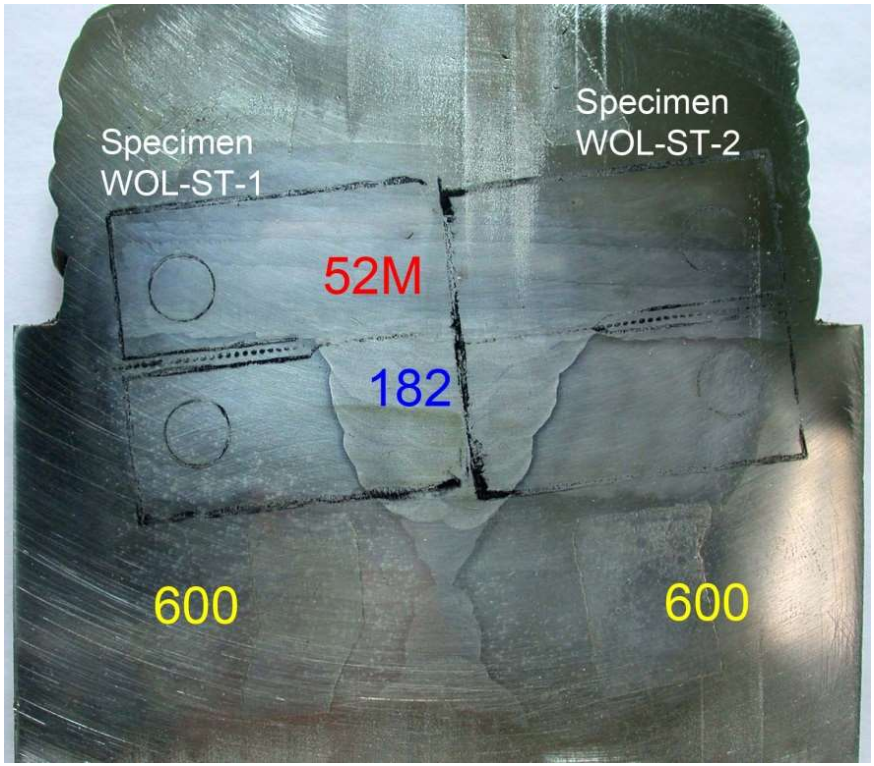


- Crack deflection at the interface, mm-size consistent with 10^{-10} m/s CGRs
- Consistent with other observations on the susceptible-to-resistant alloy transition [Seifert et al. in the Journal of Nuclear Materials (2008)]

EARLY WOL TESTING: ANL ALLOY 52M-182 WOL

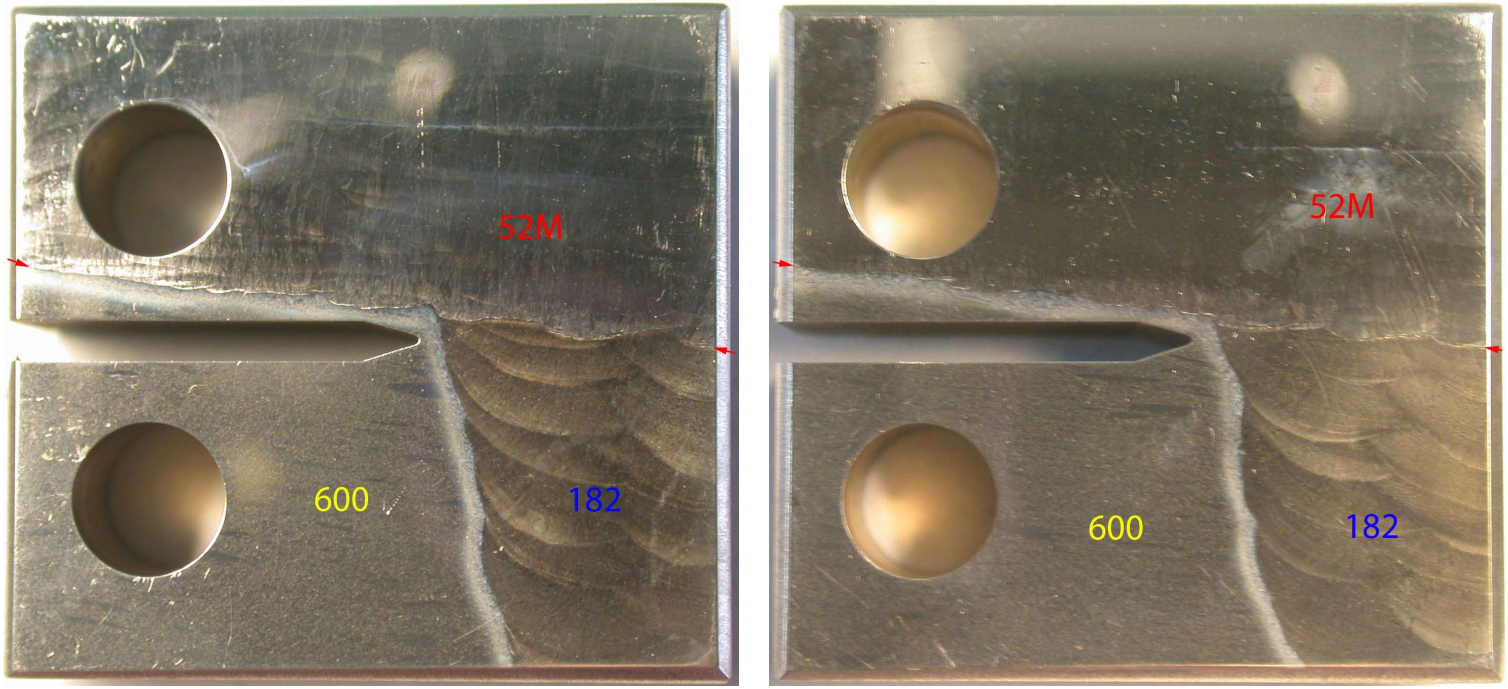
- Some SCC penetration of the WOL, some substantial, mm-size (consistent with 10^{-10} m/s CGRs)
- 25.4 wt. % Cr along crack path

ALLOY 52M-182 WOL ST SPECIMENS



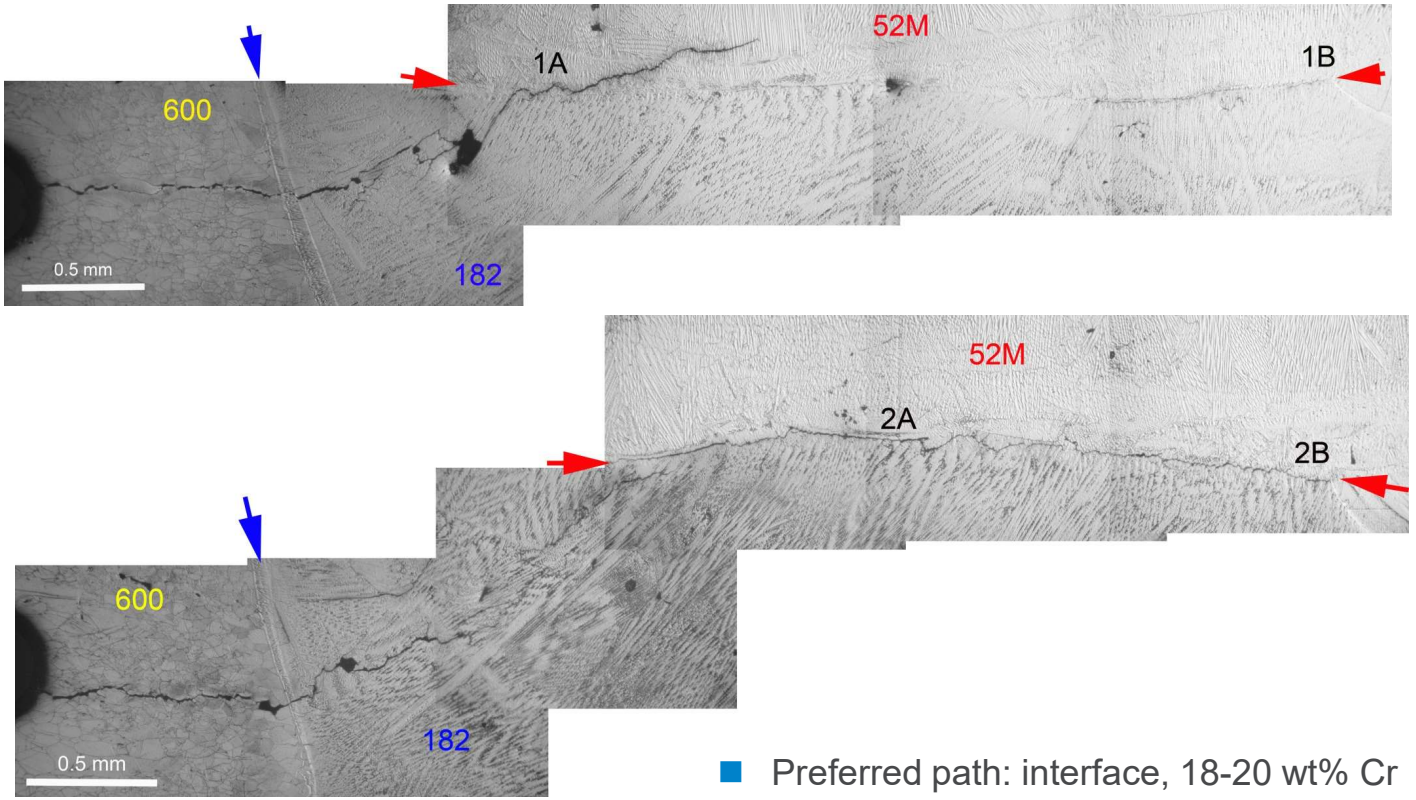
- Understood early on that the interface and 1st layer 52M have potential for 10^{-10} m/s CGRs
- ST orientation: obtain SCC CGRs in Alloy 52M and along the Alloy 52M-182 interface

ALLOY 52M-182 WOL SPECIMEN WOL-ST-1
SIDE SURFACES



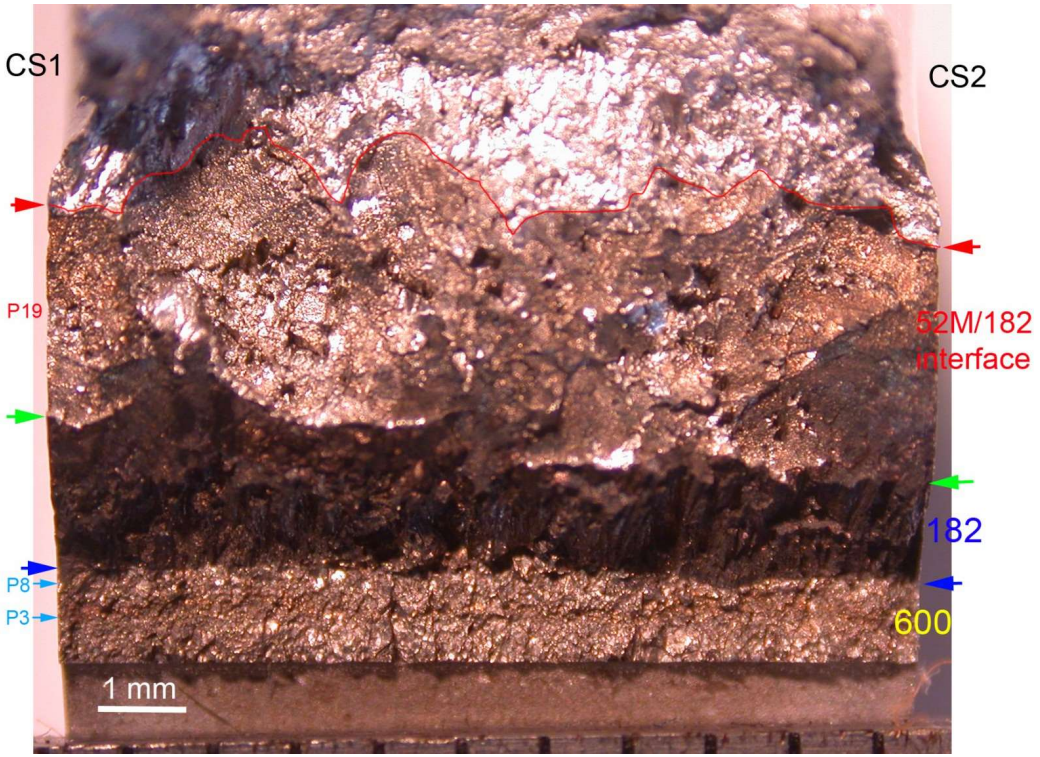
- Rationale: if interface if more susceptible than WOL and the compressed Alloy 182, then SCC will follow it
- Specimen alignment is critical

ALLOY 52M-182 WOL SPECIMEN WOL-ST-1
SIDE SURFACES



- Preferred path: interface, 18-20 wt% Cr

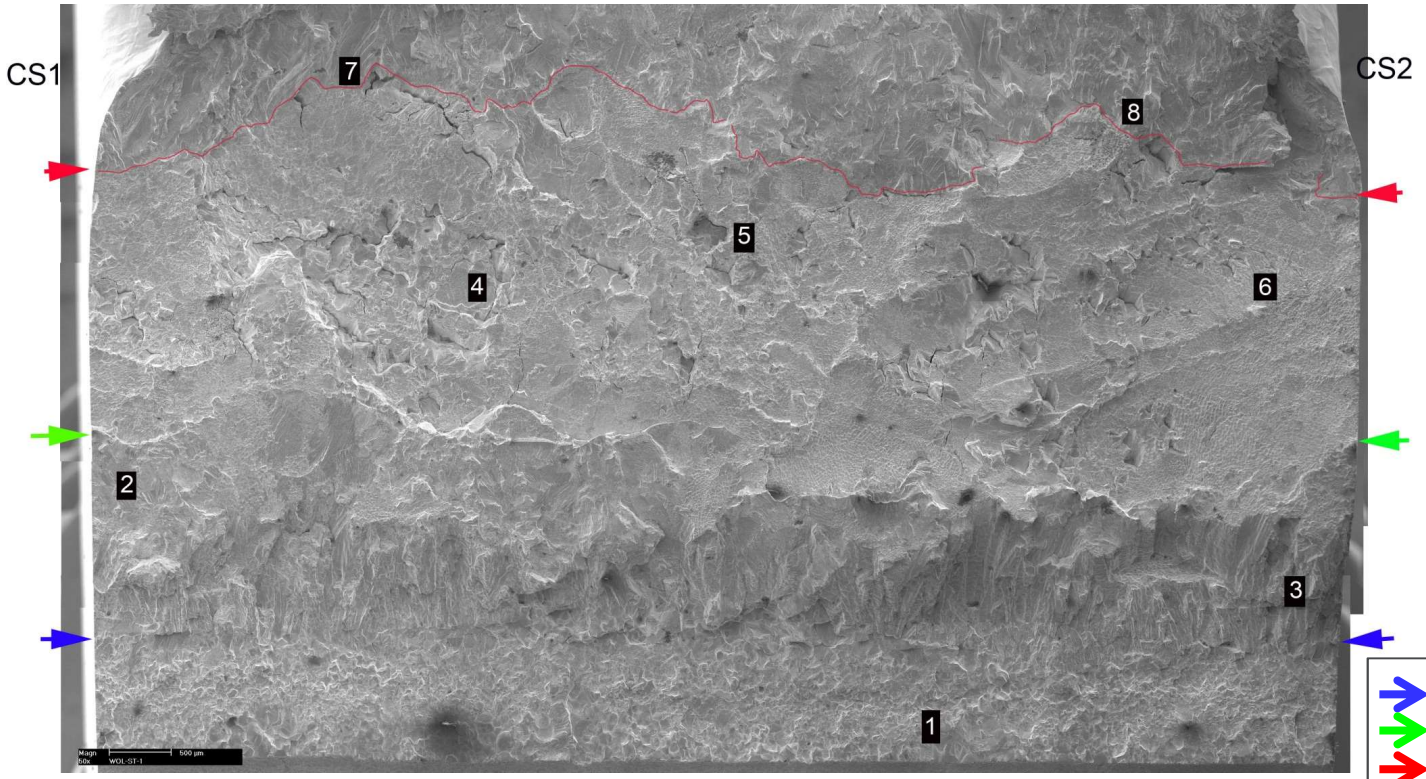
ALLOY 52M-182 WOL SPECIMEN WOL-ST-1
FRACTURE SURFACE



600/182 interface
182/52M interface
End of test

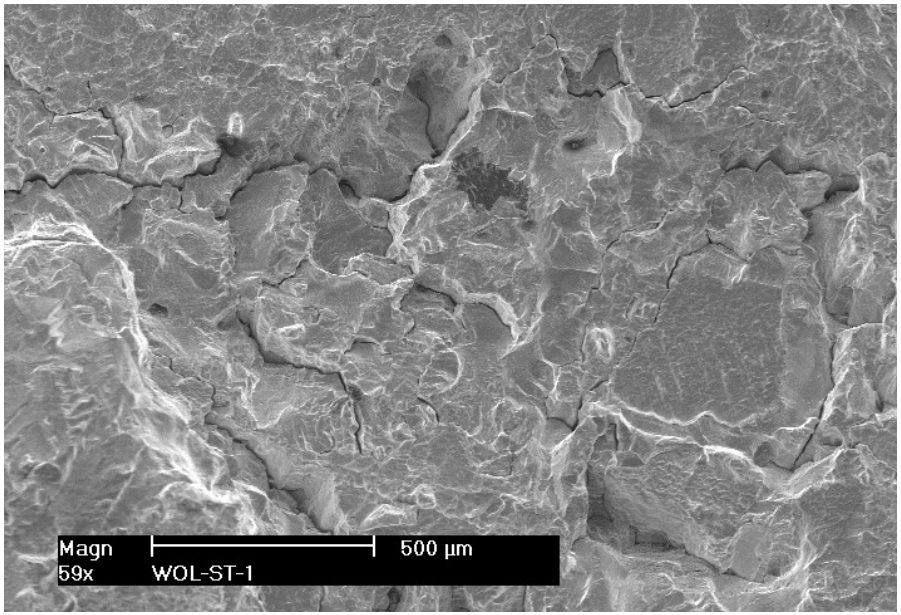
- Interface growth: 2.9 mm (8.2x higher than anticipated)

ALLOY 52M-182 WOL SPECIMEN WOL-ST-1
FRACTURE SURFACE

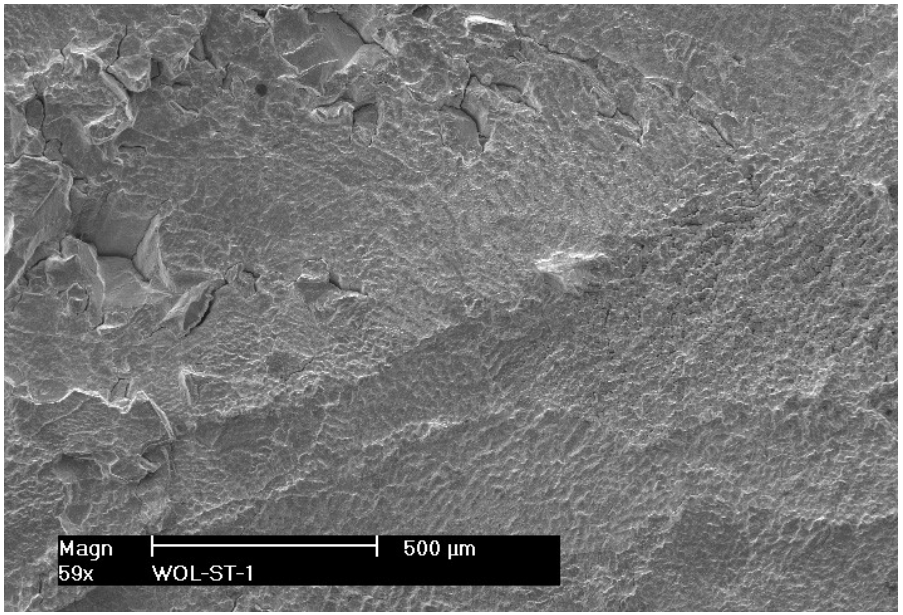


- Interface growth: 2.9 mm (8.2x higher than anticipated)

SPECIMEN WOL-ST-1 – FRACTURE



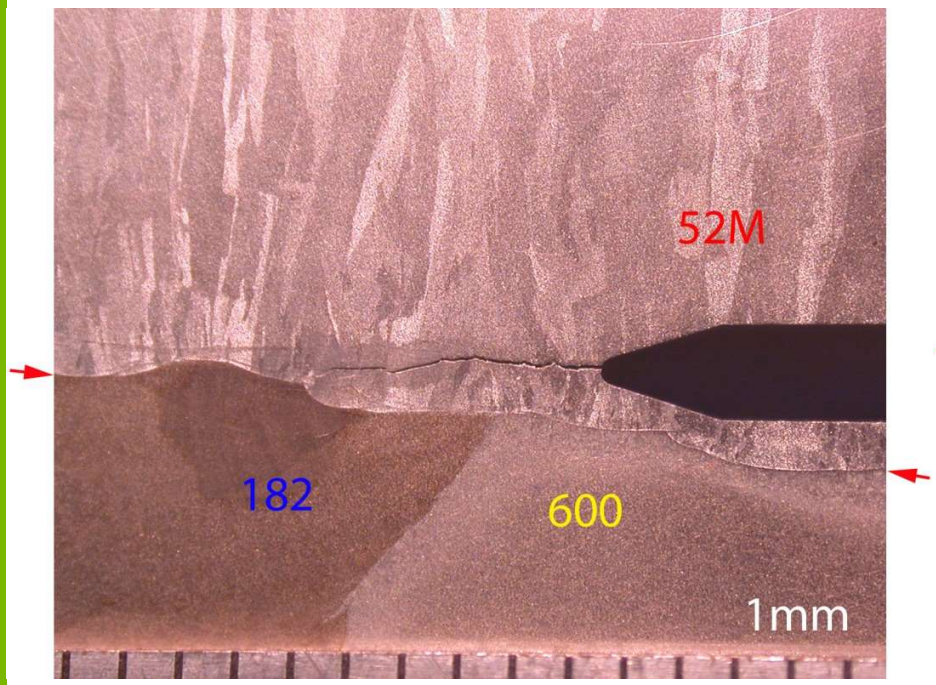
- Loc. 7

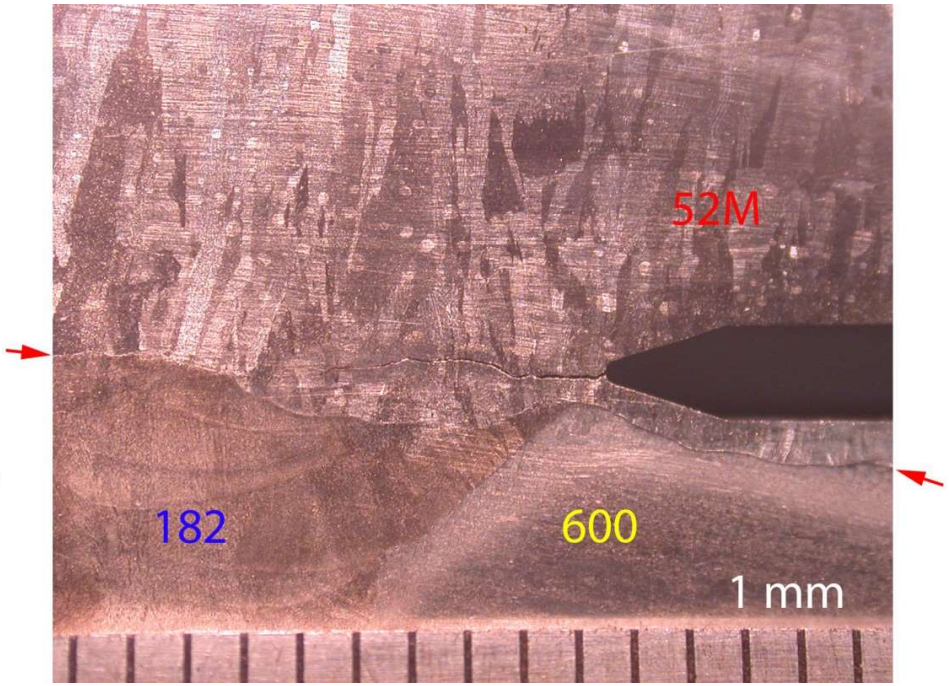


- Loc. 8

- IG interdendritic growth in ST orientation

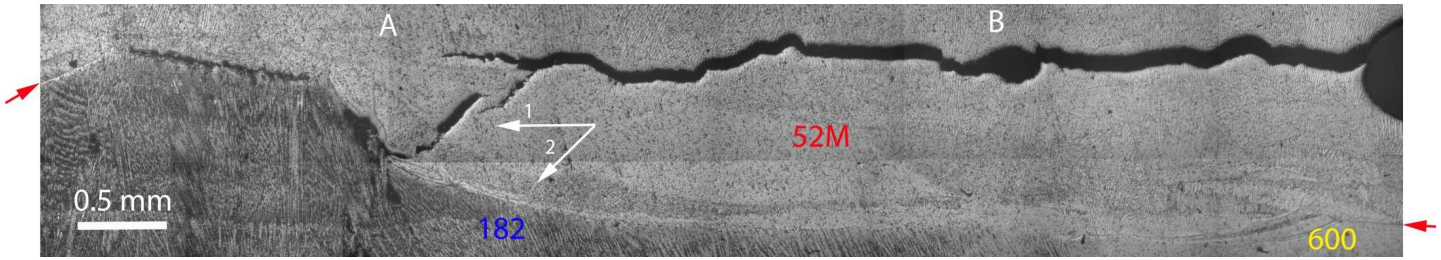
ALLOY 52M-182 WELD OVERLAY SPECIMEN WOL-ST-2
SIDE SURFACES

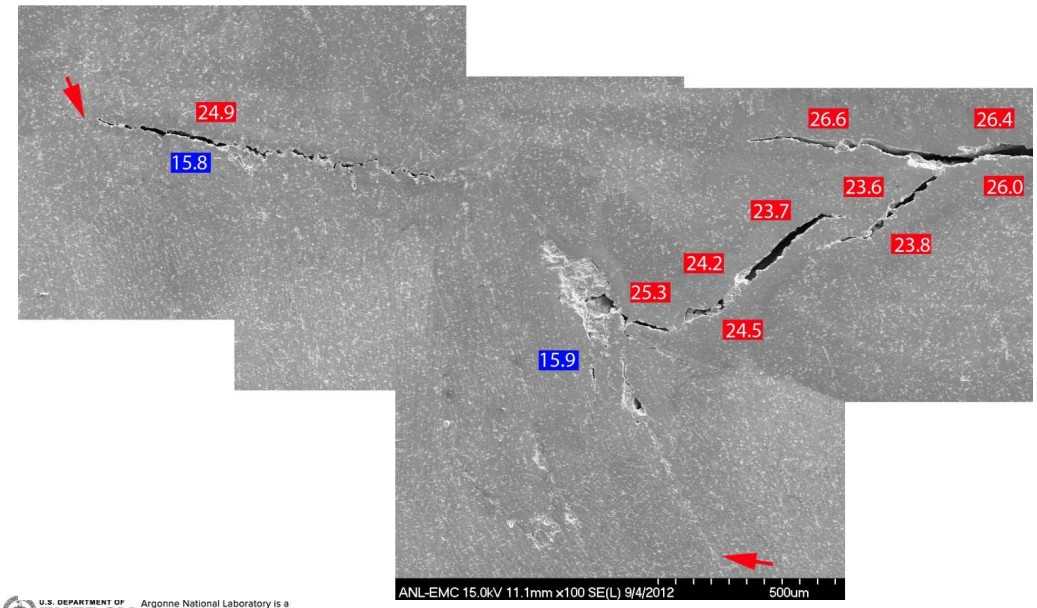




- Rationale: if 1st layer on Alloy 52M is so susceptible (10^{-10} m/s), then it would transition to IG SCC before the crack reached the interface. At the interface, it would follow it as the compressed Alloy 182 is relatively resistant (10^{-11} m/s) .

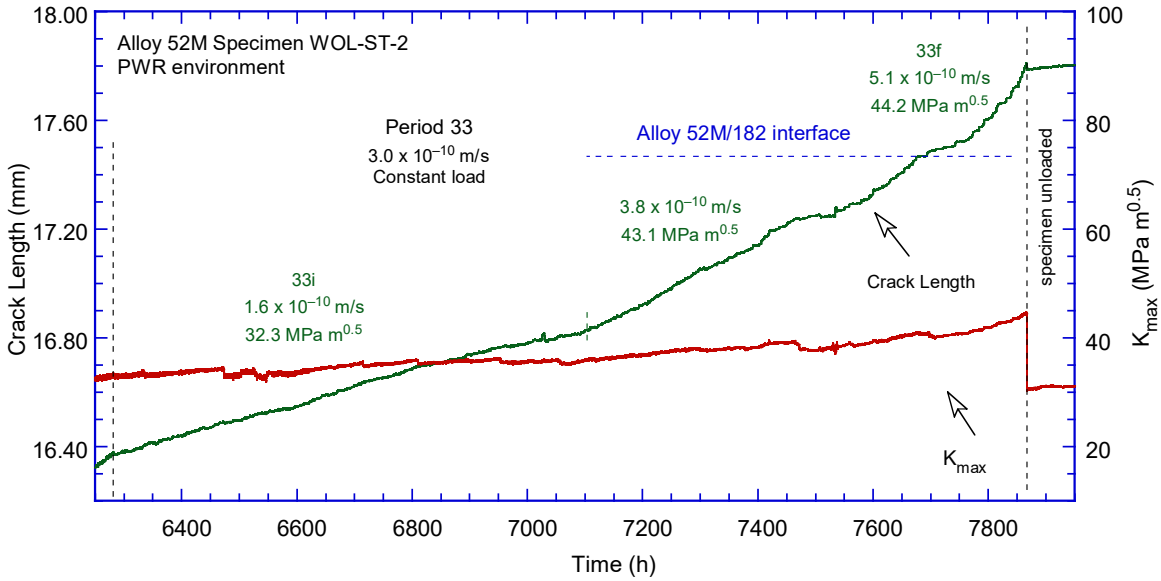
ALLOY 52M-182 WELD OVERLAY SPECIMEN WOL-ST-2
SIDE SURFACES





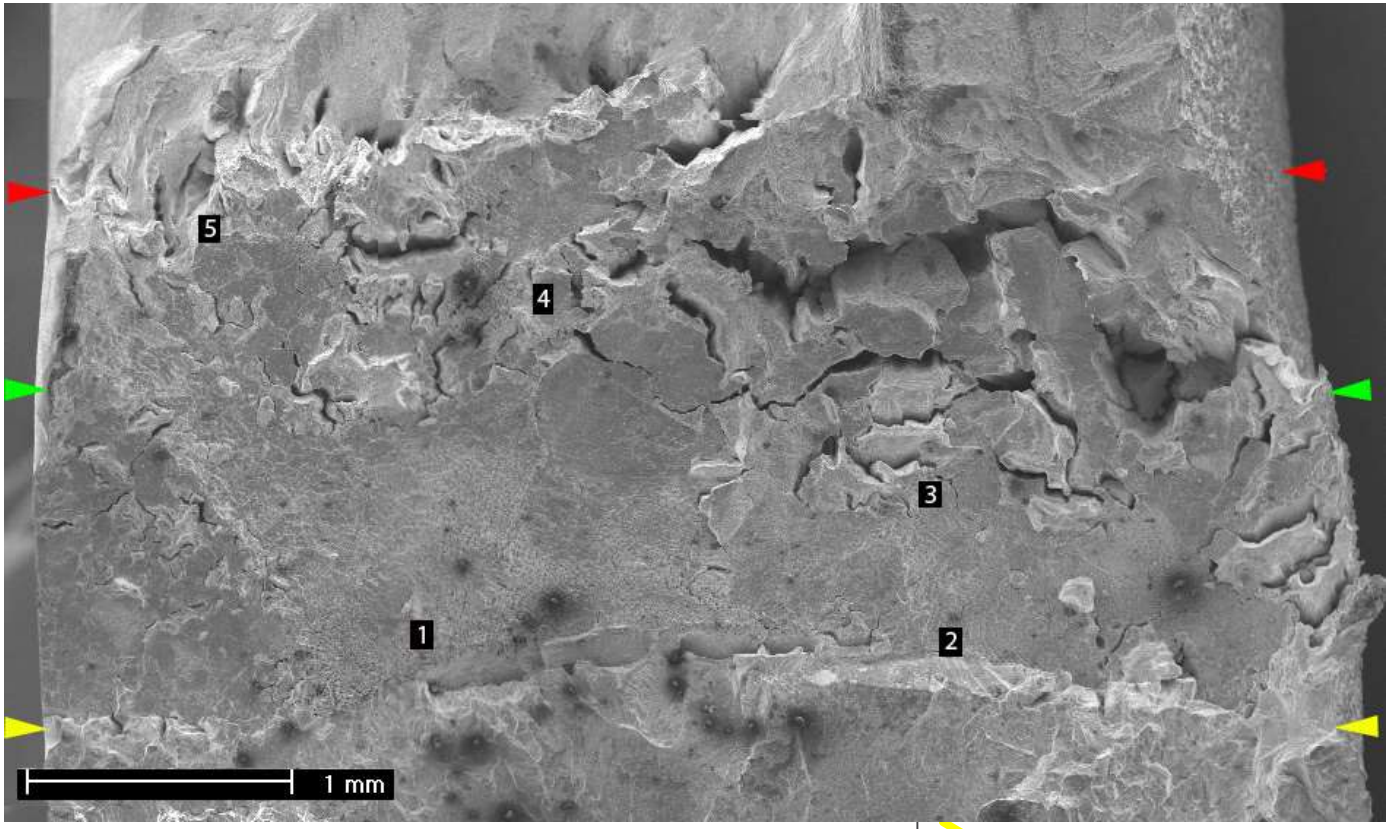
- Transitioned 1.0 mm from the interface
- MB Cr: 27.1%
- Avg. MA Cr: 24.2%
- “1” major crack direction

ALLOY 52M-182 WOL SPECIMEN WOL-ST-2



- Alloy 52M WOL SCC CGR = 1.6E-10 mm/s (calculated on the first 0.46 mm of growth, average distance to the interface is 1 mm)
- SCC CGR is 5X higher as it lands on the interface

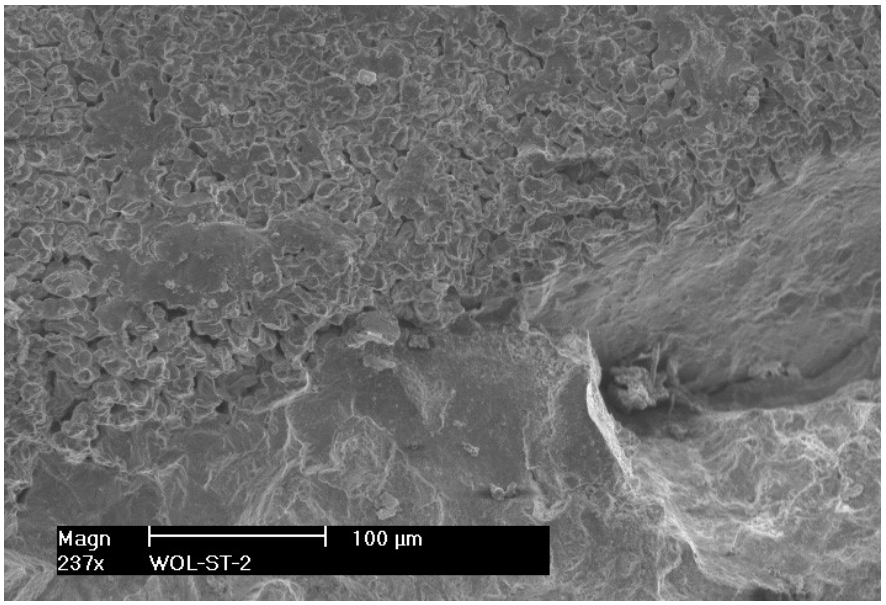
ALLOY 52M-182 WELD OVERLAY SPECIMEN WOL-ST-2
FRACTURE A



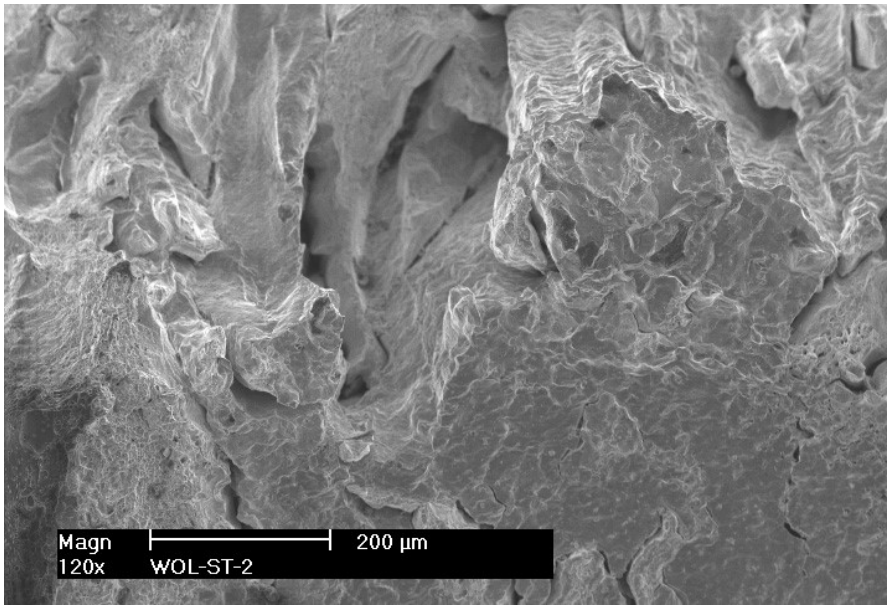
- SCC growth: 1.7 mm (4.2x higher than anticipated)

End precracking/transitioning
182/52M interface
End of test

ALLOY 52M-182 WELD OVERLAY SPECIMEN WOL-ST-2
FRACTURE A



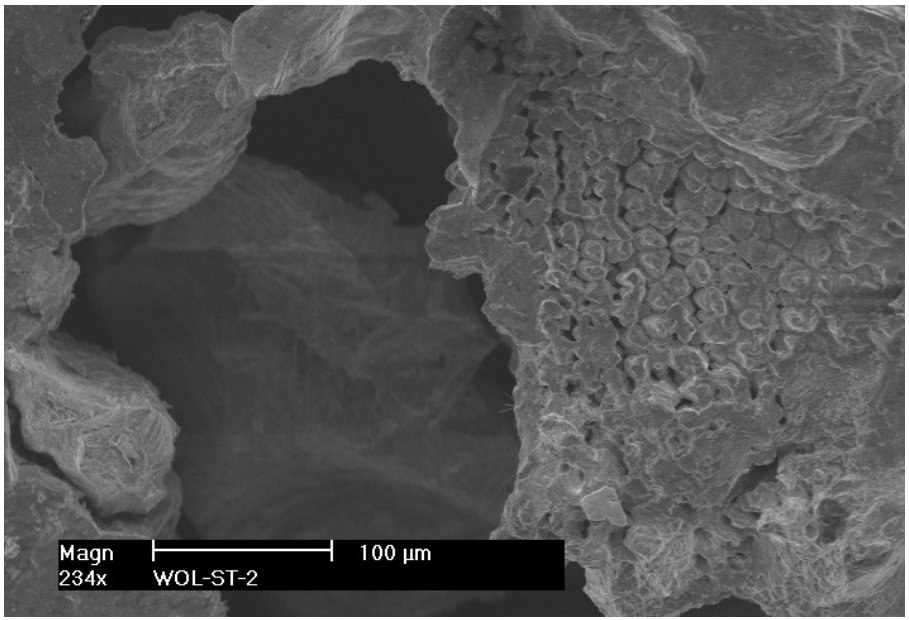
- Fracture A (loc. 1)



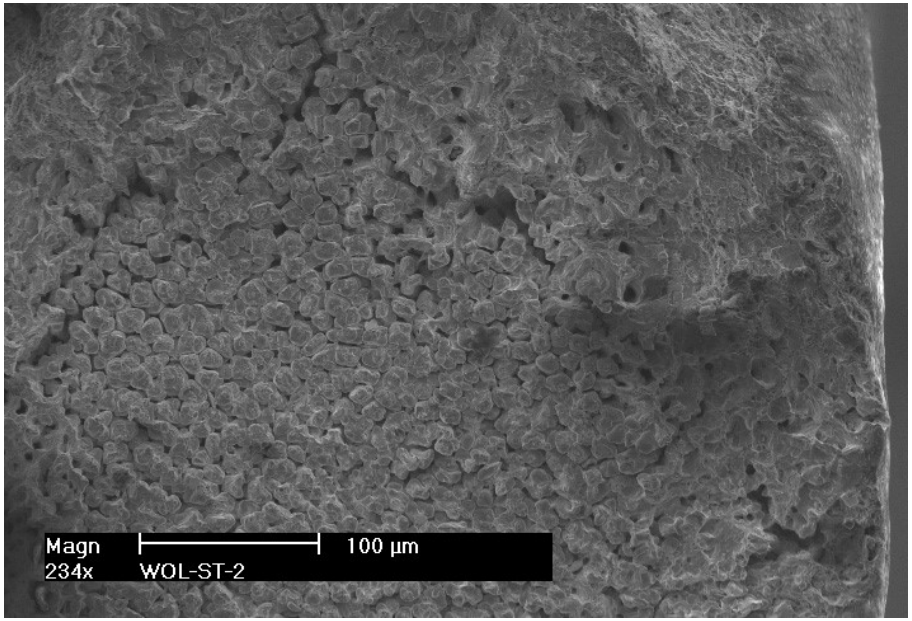
- Fracture A (loc. 5)

- IG interdendritic growth in ST orientation

ALLOY 52M-182 WELD OVERLAY SPECIMEN WOL-ST-2
FRACTURE B



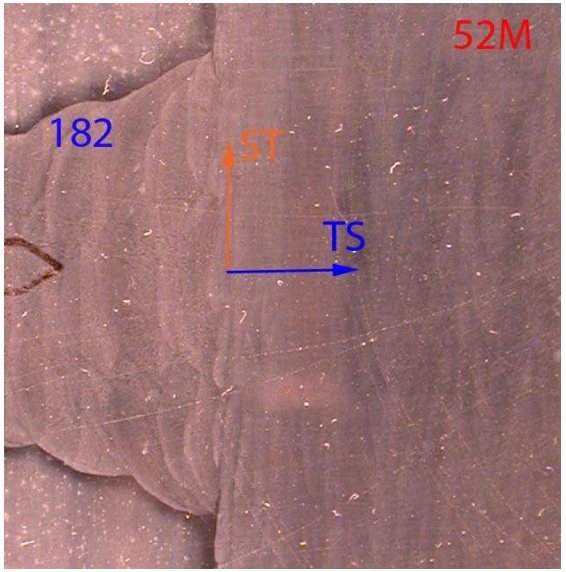
- Fracture B (loc. 2)

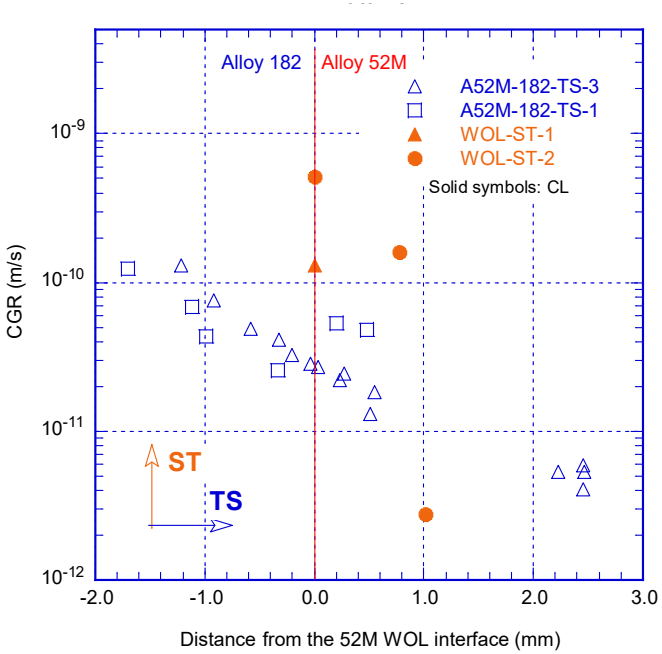


- Fracture B (loc. 3)

- IG interdendritic growth in ST orientation

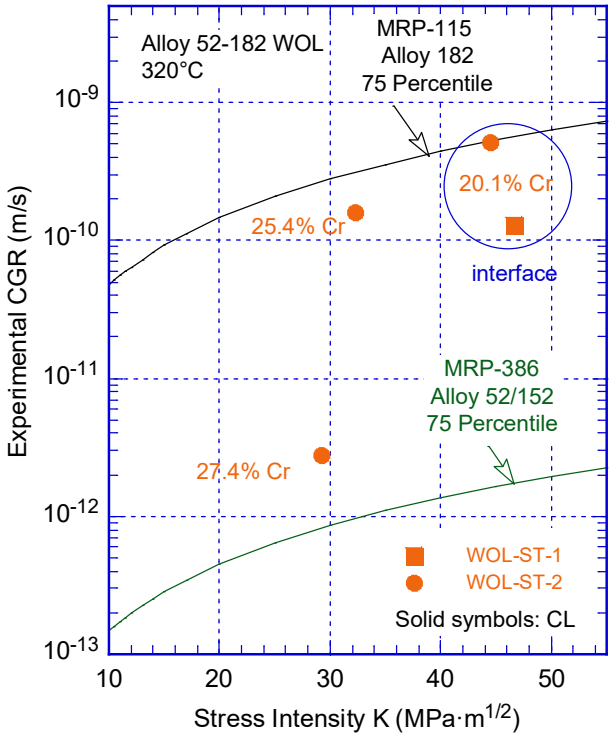
EARLY WOL TESTING: CGR





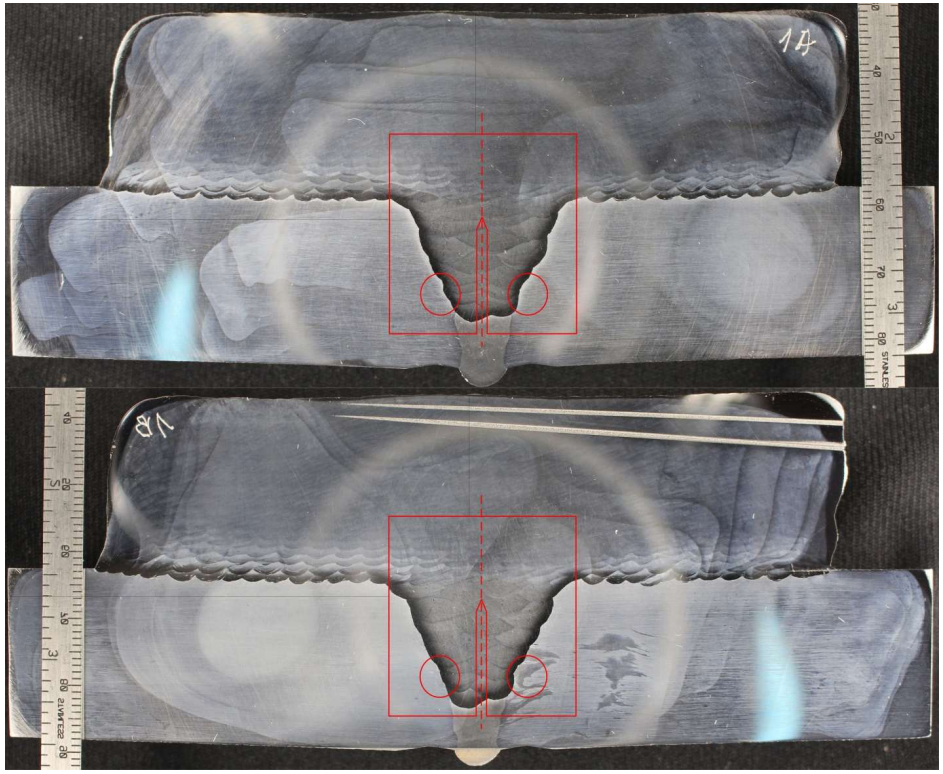
- Factor 10x decrease in SCC CGR in 1 mm ahead of the interface (response reproduced on two specimens); the existence of a compressive stress was demonstrated (PVP 2011)
- Fast (10^{-10} m/s) SCC CGRs in the first layer and along the interface [NUREG/CR-7226]

EARLY WOL TESTING: SCC CGR DATA



- Fast (10^{-10} m/s) SCC CGRs in the first layer and along the interface [NUREG/CR-7226]
- Good correlation with Cr level

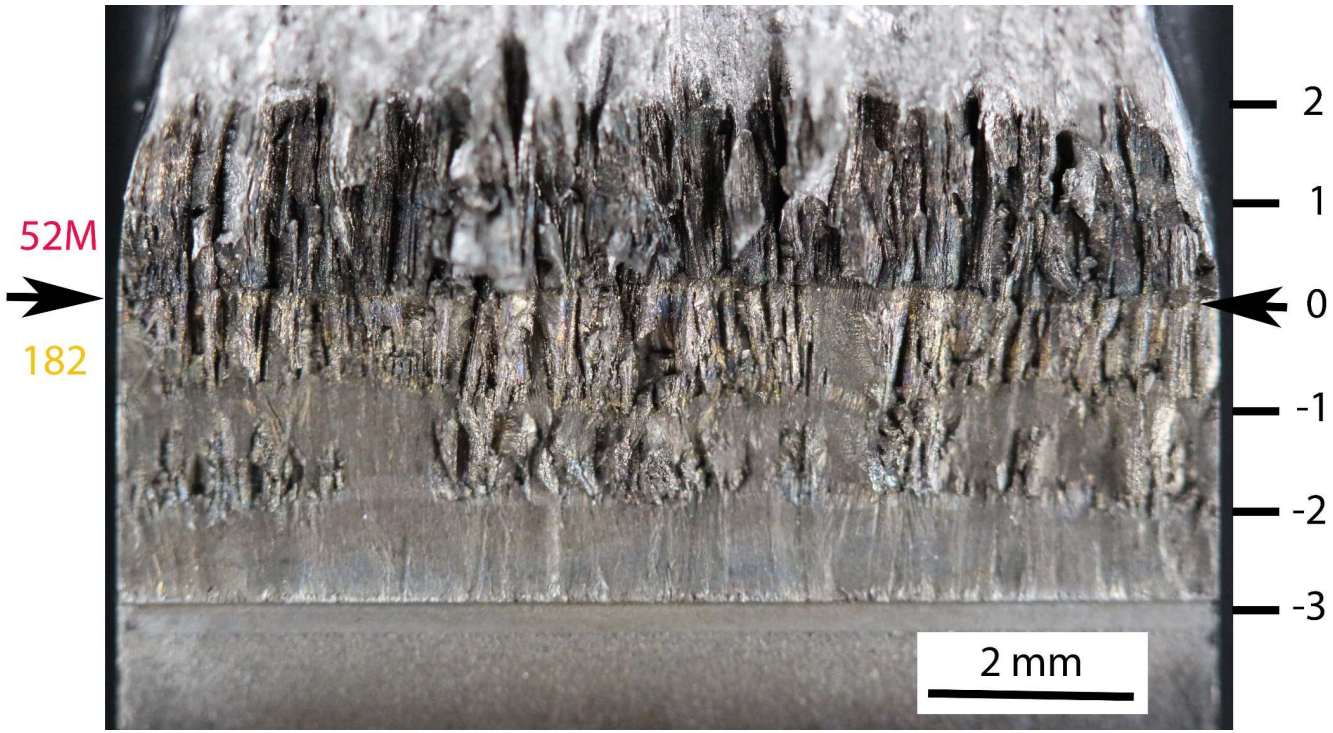
KAPL ALLOY 52M-182 WOL: K52M-ST-1



- TS orientation: propagate a crack from Alloy 182 into Alloy 52M WOL

KAPL ALLOY 52M-182 WOL: K52M-TS-1

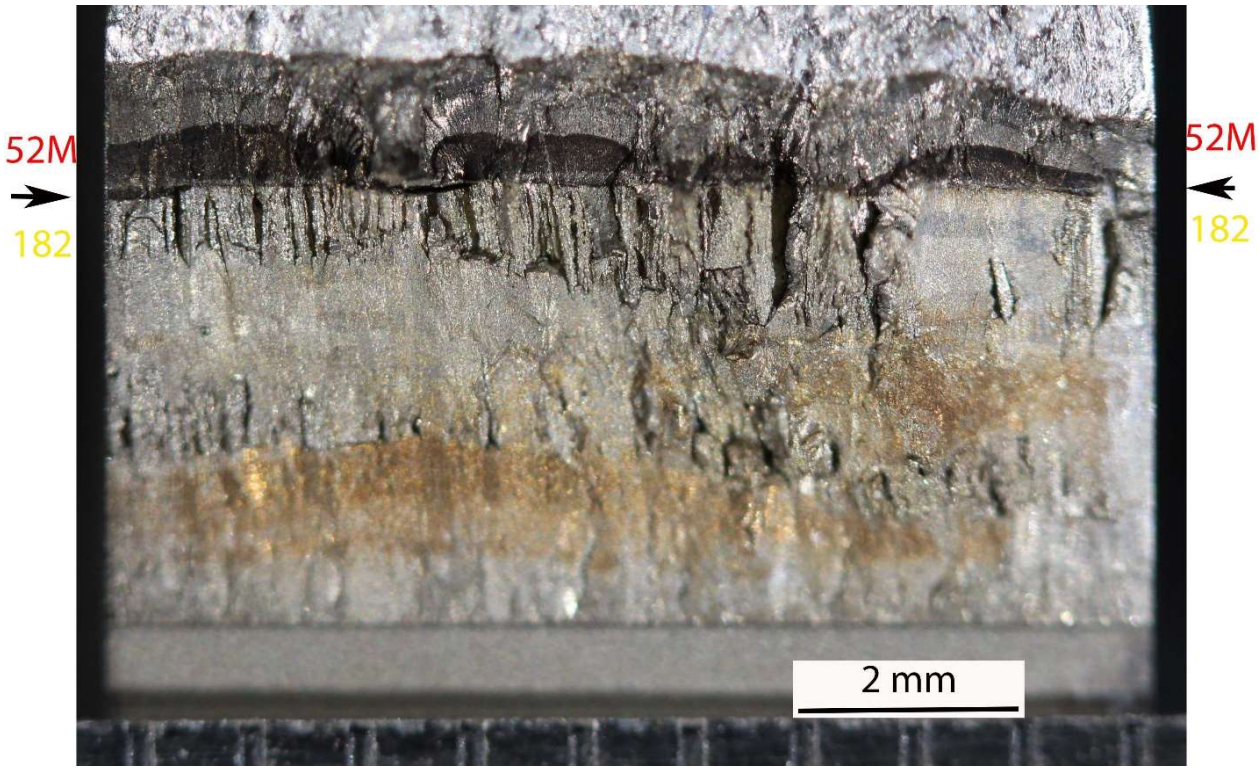
FRACTURE SURFACE



- 1.8 mm extension – 2 layers - into the WOL (10x the DCPD measurement) over 4,300 hrs at CL
- 22 wt. % Cr measured along crack path, however, the crack also clearly extended into the 2nd layer (22 wt. % Cr)

EWI ALLOY 52M-182 WOL: E52M-TS-1

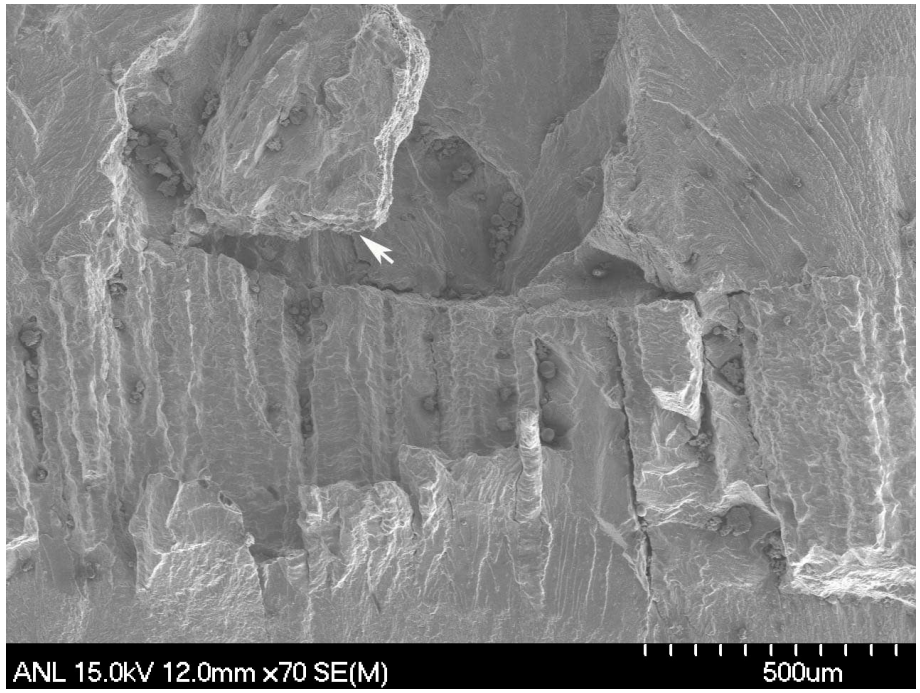
FRACTURE SURFACE

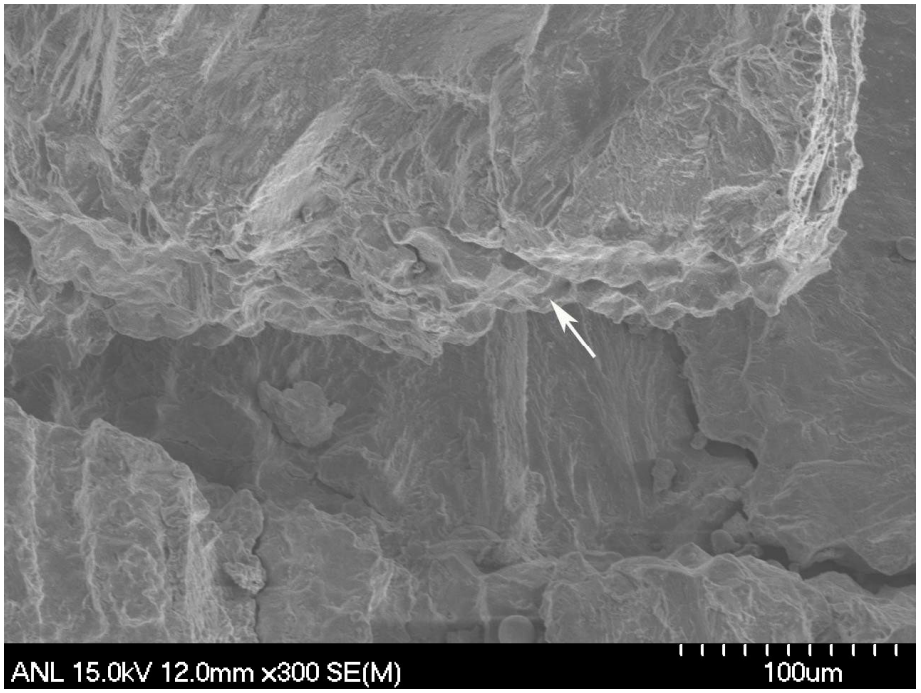


- There is crack advance past the interface, but there is no IG SCC crack advance
- 24 wt. % Cr along crack path

EWI ALLOY 52M-182 WOL: E52M-TS-1

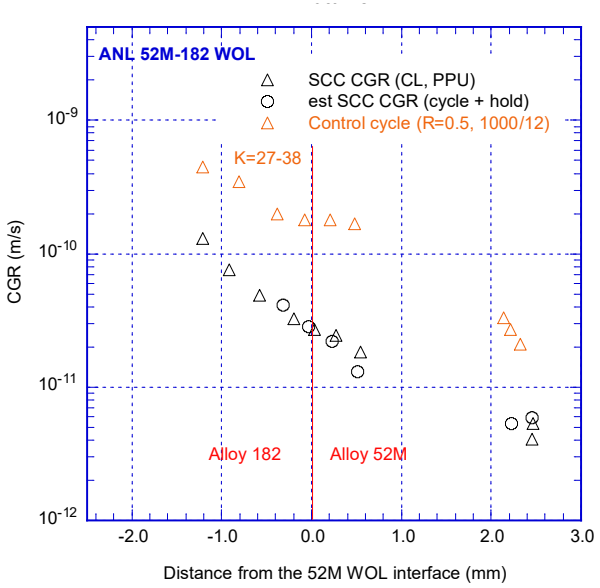
FRACTURE SURFACE

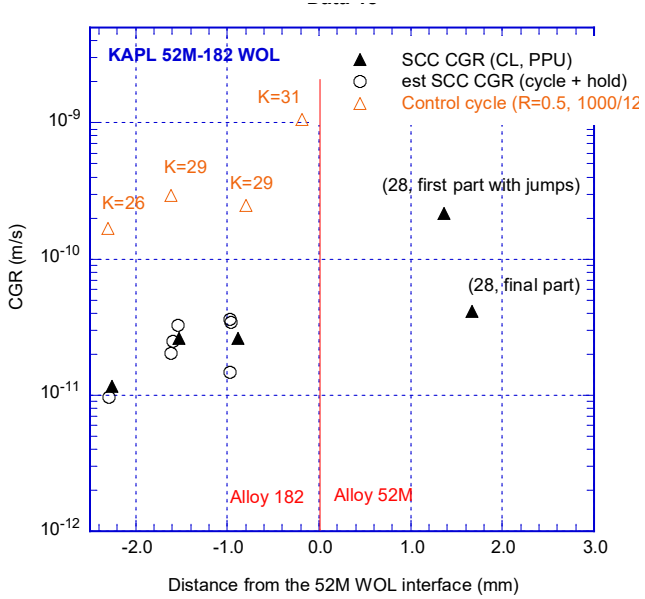




- Example of crack deflection at the interface

ANL AND KAPL ALLOY 52M-182 WOL

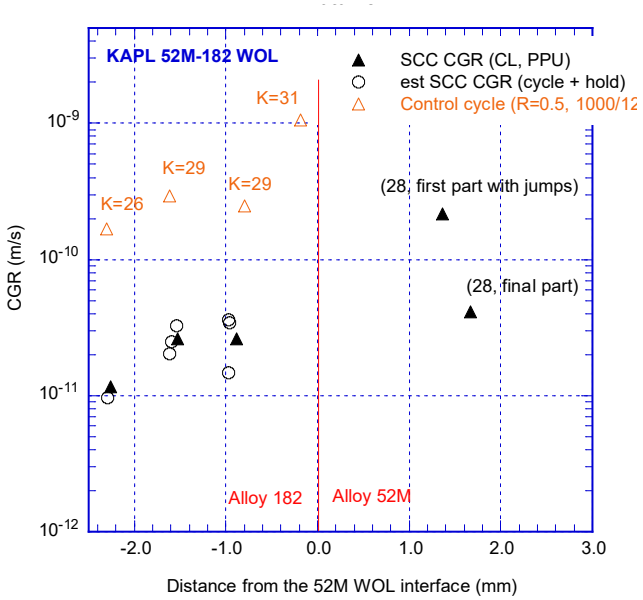


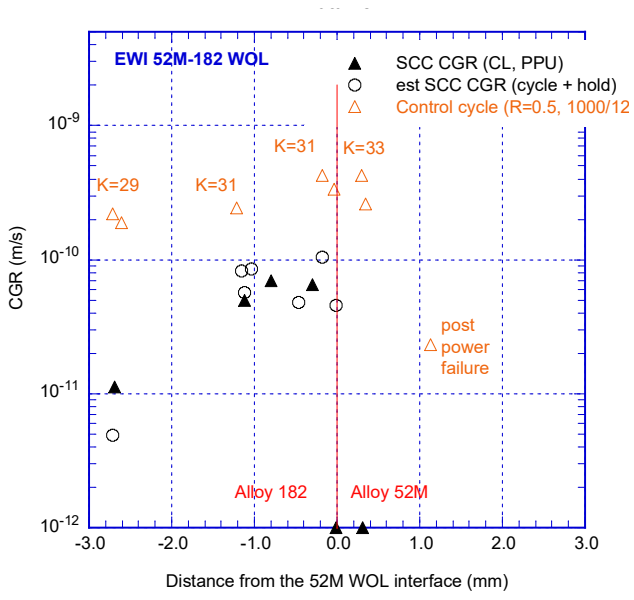


[NUREG/CR-7226]

- Moderate SCC CGRs ahead of the WOL
- KAPL: fast (10^{-10} m/s) SCC CGRs beyond the first layer

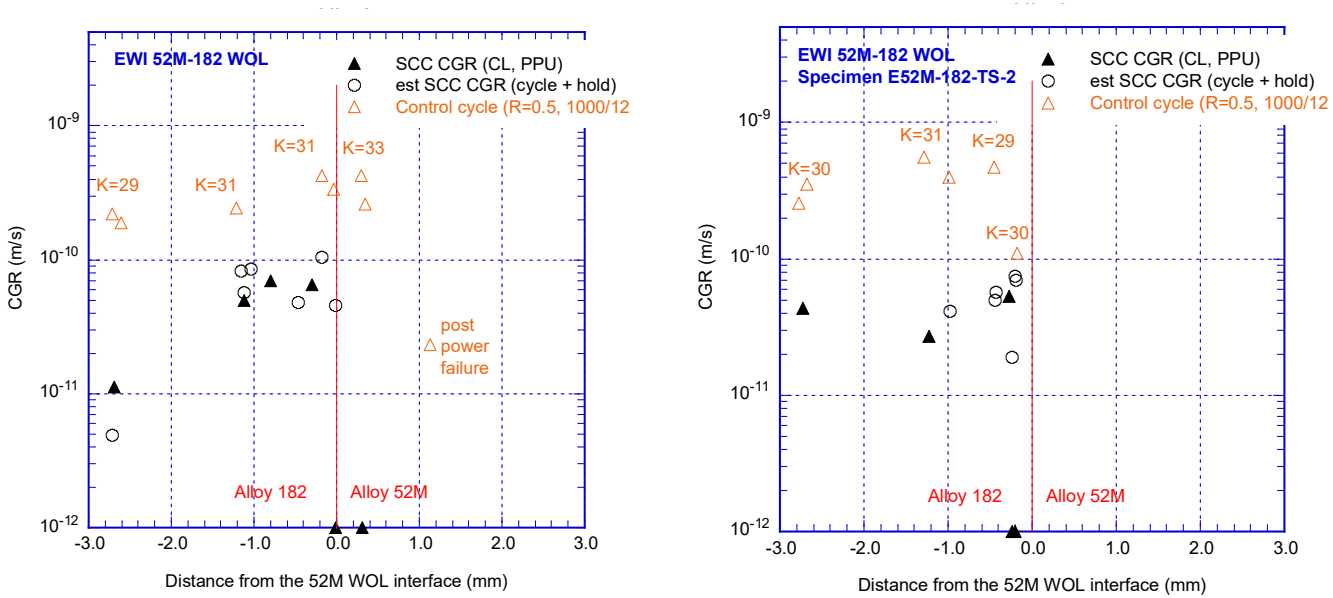
KAPL AND EWI ALLOY 52M-182 WOL





- Similar evolution as the to the KAPL WOL until the interface
- No SCC growth past the WOL interface

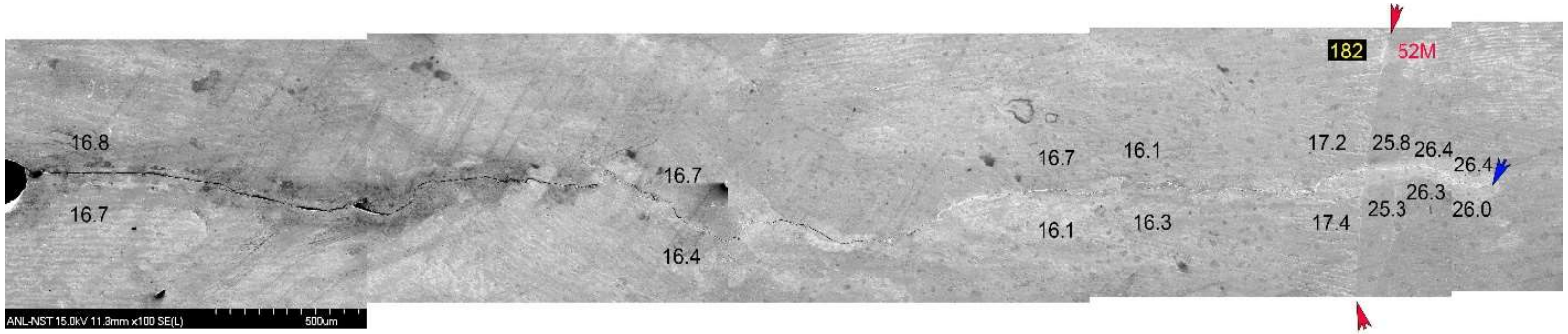
EWI – ORIGINAL AND REPEAT TEST- ALLOY 52M-182 WOL

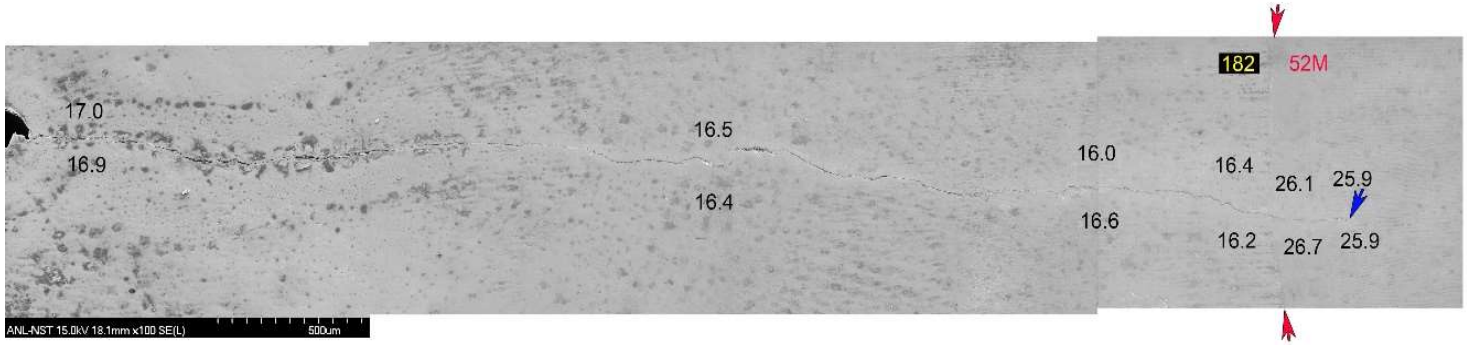


- Similar evolution as the prior specimen until the interface
- Maintained at the interface with CL and gentle cyclic for 4,336 hrs

EWI ALLOY 52M-182 WOL: E52M-TS-2

SIDE SURFACES

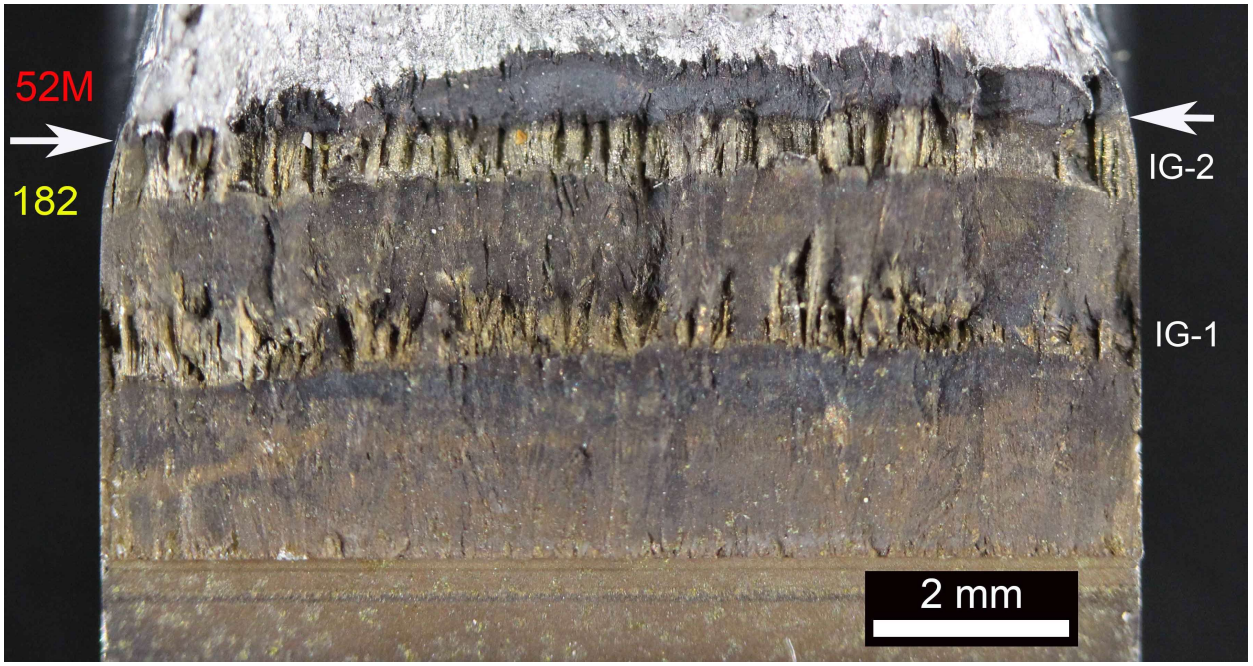




- There seems to be some advance (0.4 mm) past the interface advance
- 26.1 wt. % Cr along crack path

EWI ALLOY 52M-182 WOL: E52M-TS-2

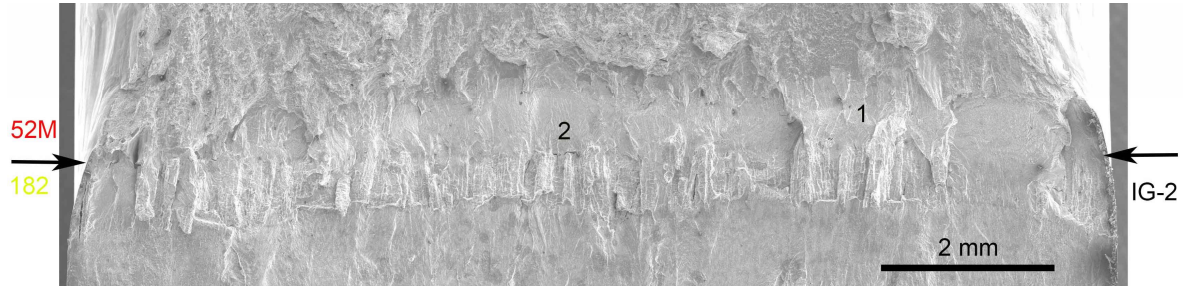
FRACTURE SURFACE

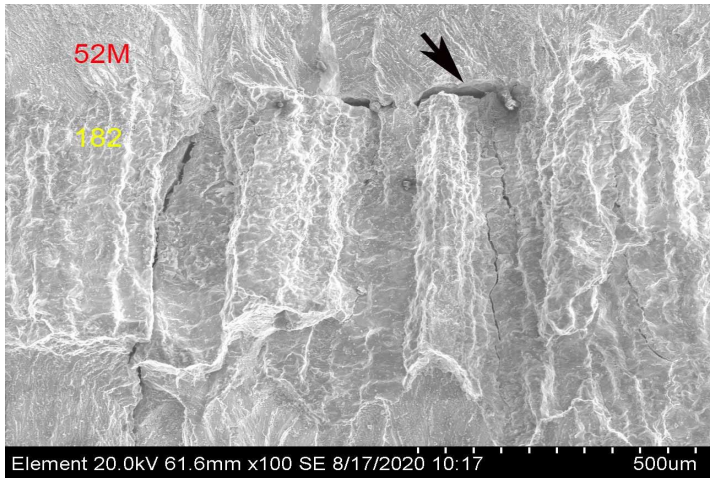


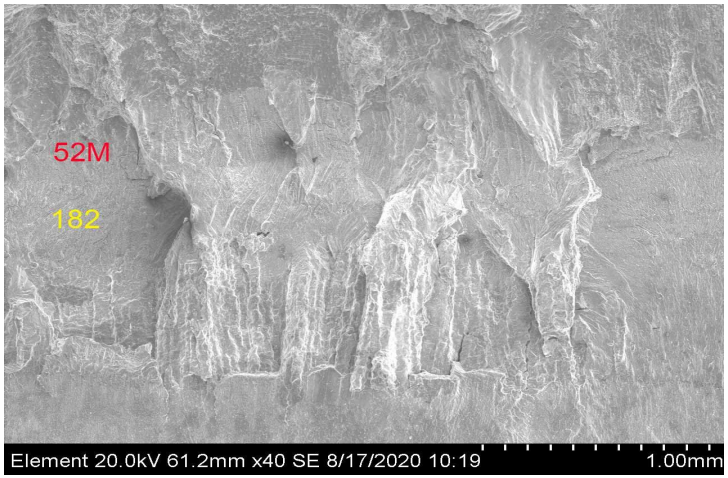
- There is crack advance past the interface, but there is no IG SCC crack advance
- 26.1 wt. % Cr along crack path

EWI ALLOY 52M-182 WOL: E52M-TS-2

FRACTURE SURFACE





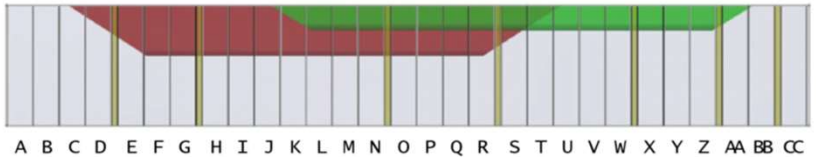


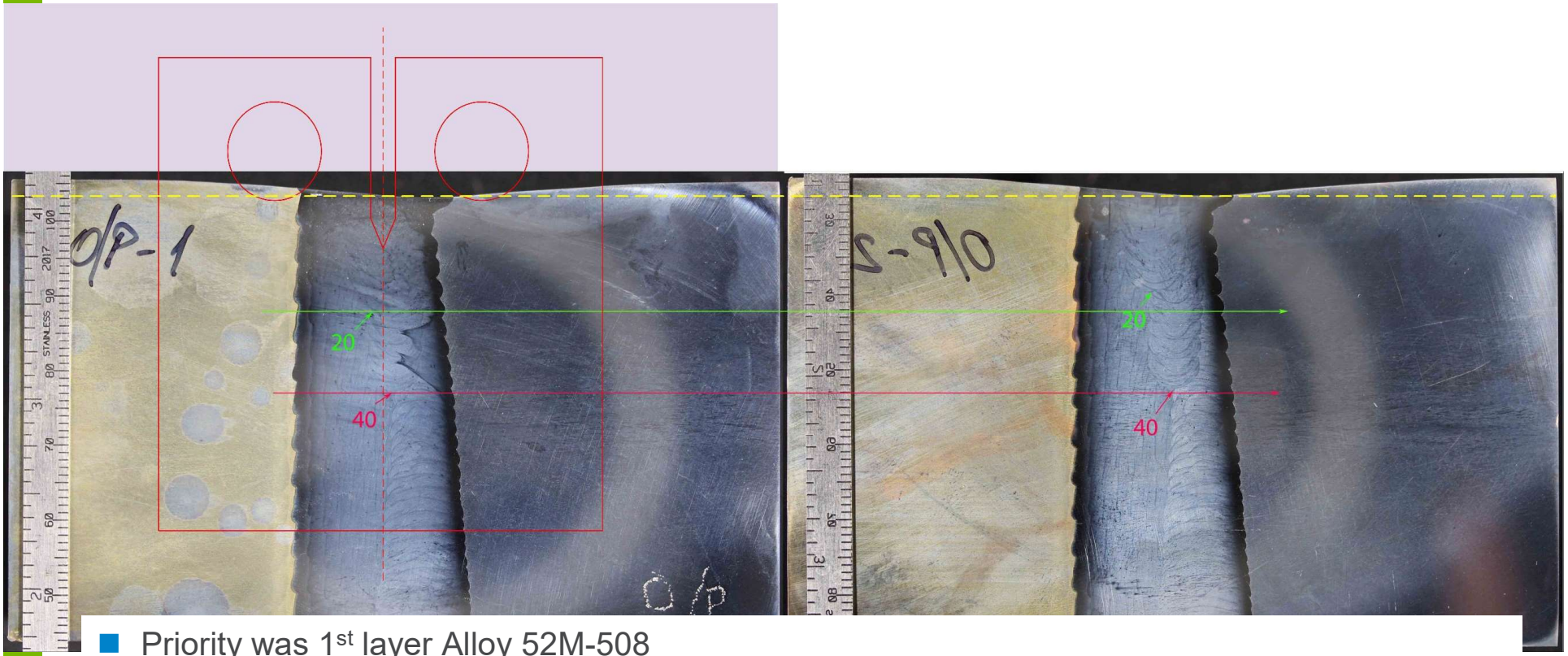
- There is crack advance past the interface, but there is no IG SCC crack advance

SCC CGR RESPONSE OF ALLOY 52-508 IN THE DOUBLE REPAIR WELD

EPRI DOUBLE REPAIR WELD

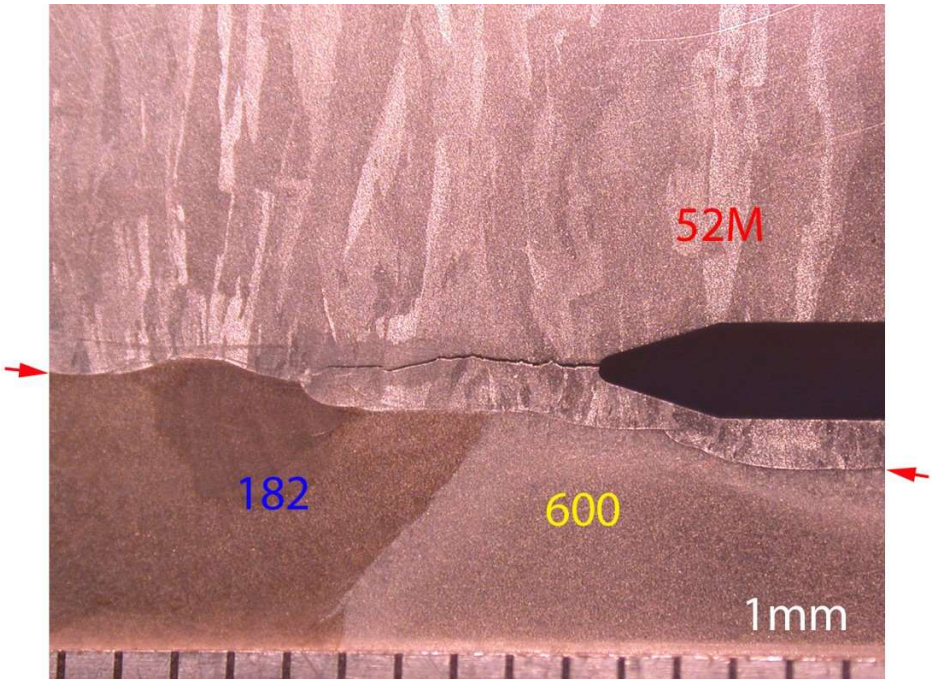
The double-repair weld – slice OP (40%+20% repair)

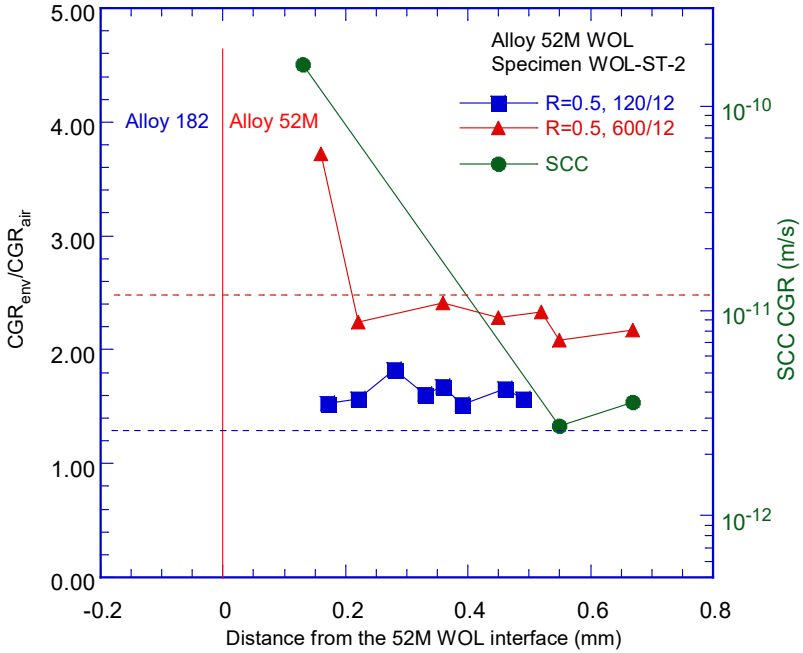




- Priority was 1st layer Alloy 52M-508

TEST MANAGEMENT

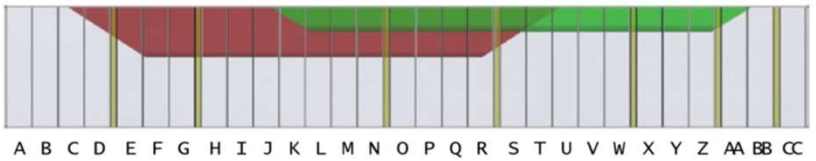


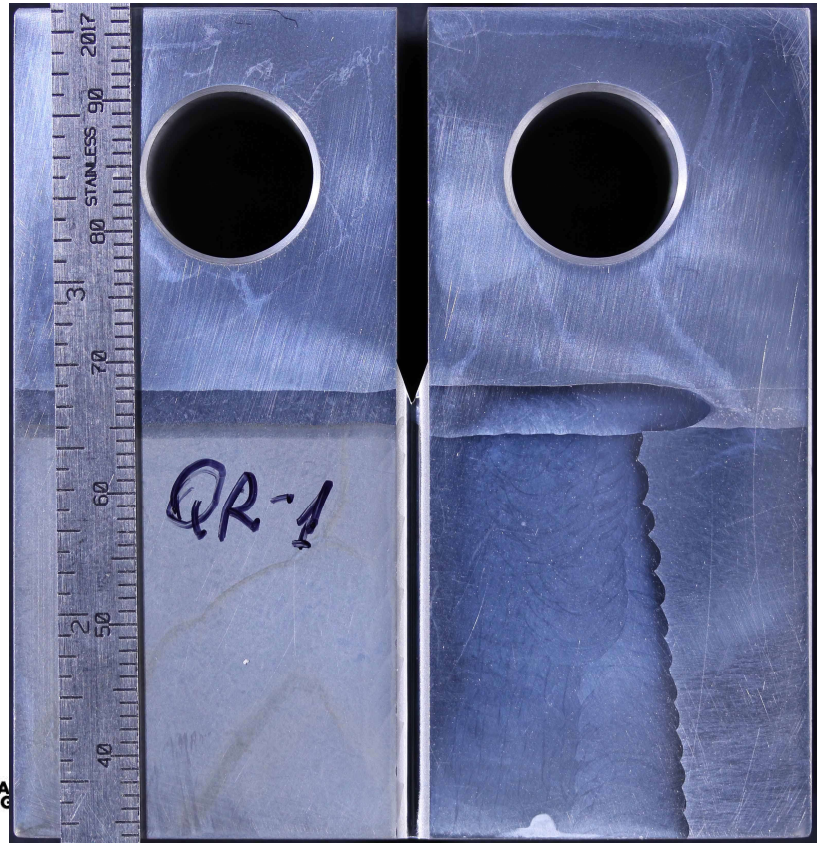


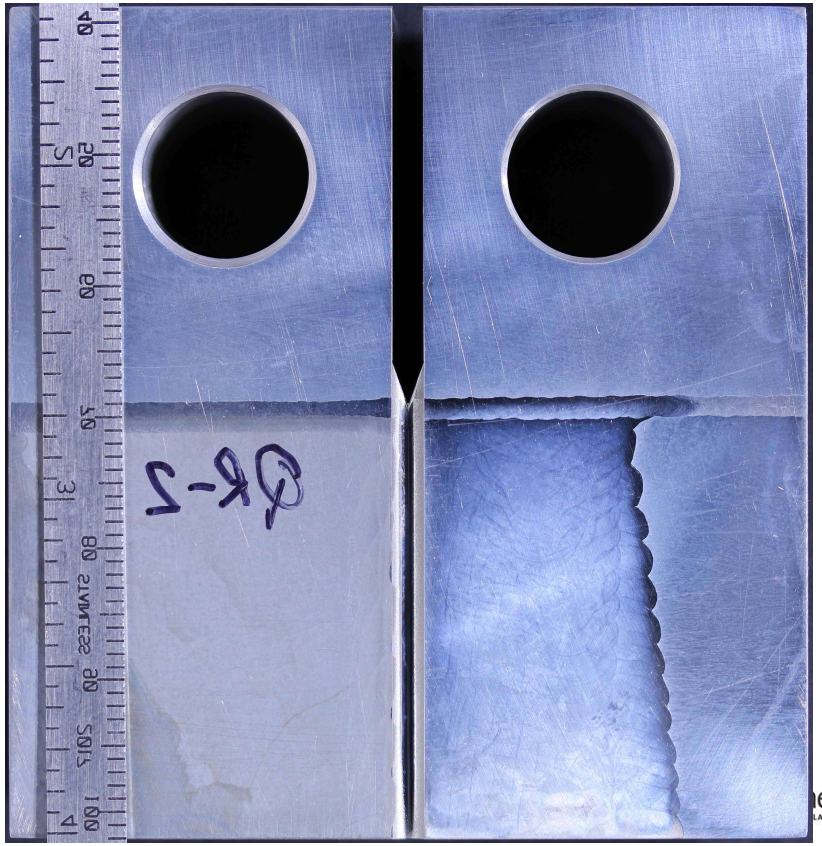
- Test management based on specimen response: crack is advanced with “known” conditions, response is compared with that of known “IG, forward propagation”, then is set at constant load when that comparison is favorable

EPRI DOUBLE REPAIR WELD

The double-repair weld – slice QR (40%+20% repair)

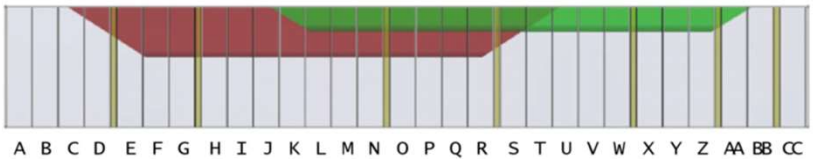


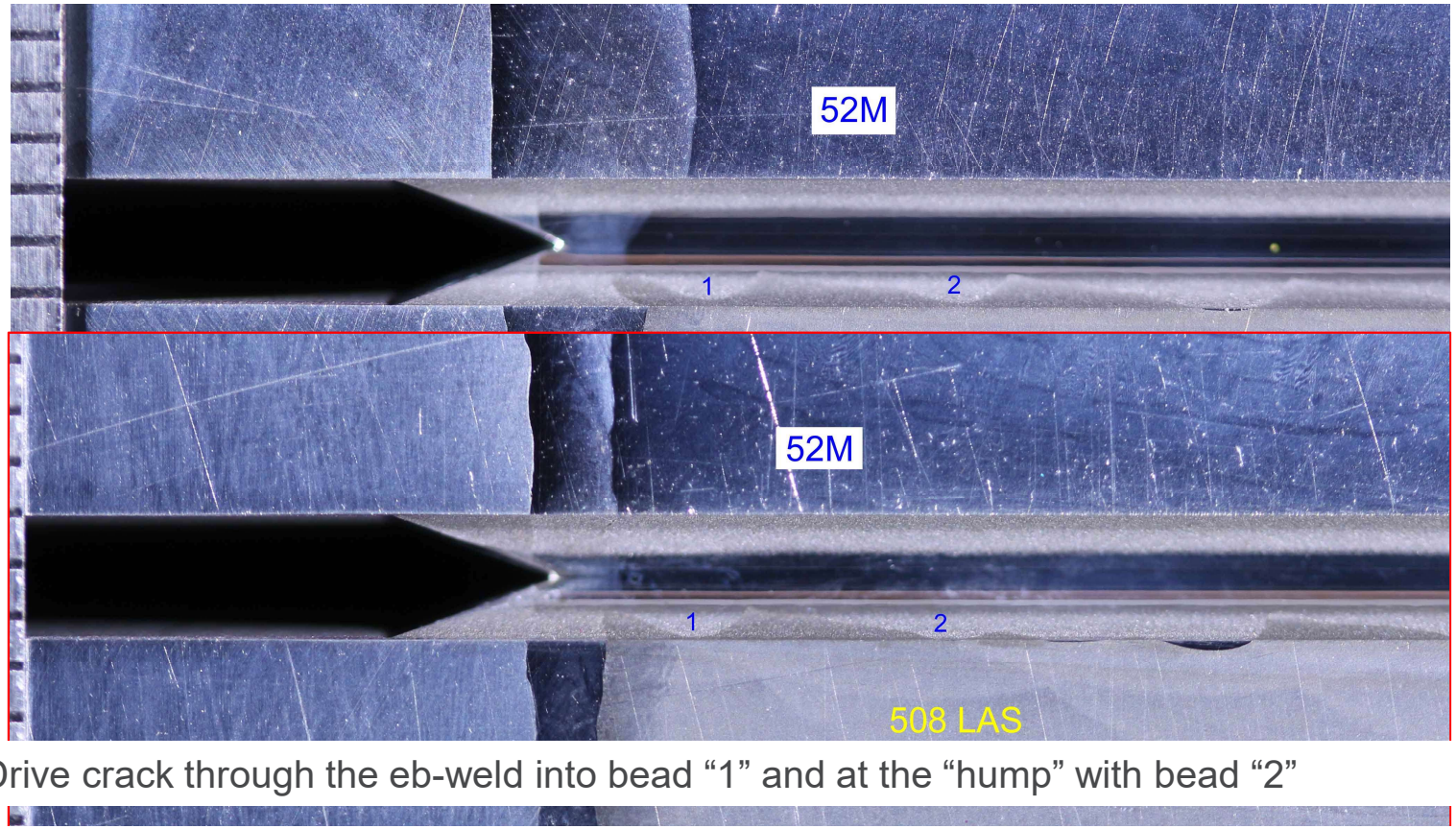




EPRI DOUBLE REPAIR WELD

The double-repair weld – slice QR (40-20% repair)

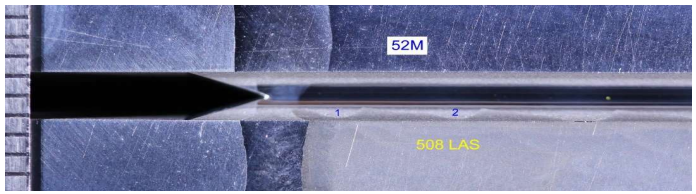


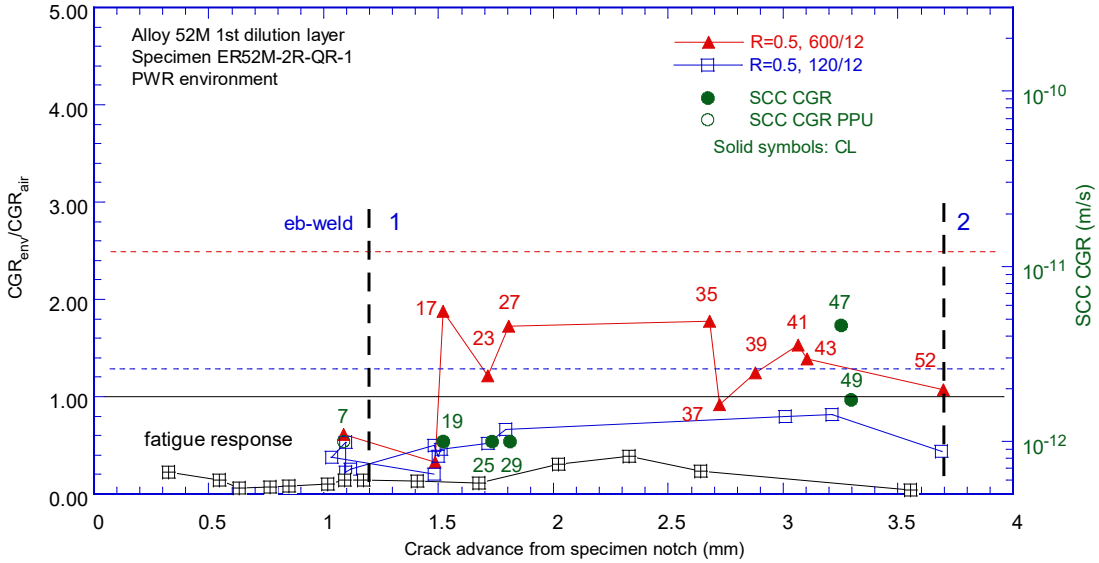


- Drive crack through the eb-weld into bead “1” and at the “hump” with bead “2”

EPRI DOUBLE REPAIR WELD

The double-repair weld – slice QR (40-20% repair)

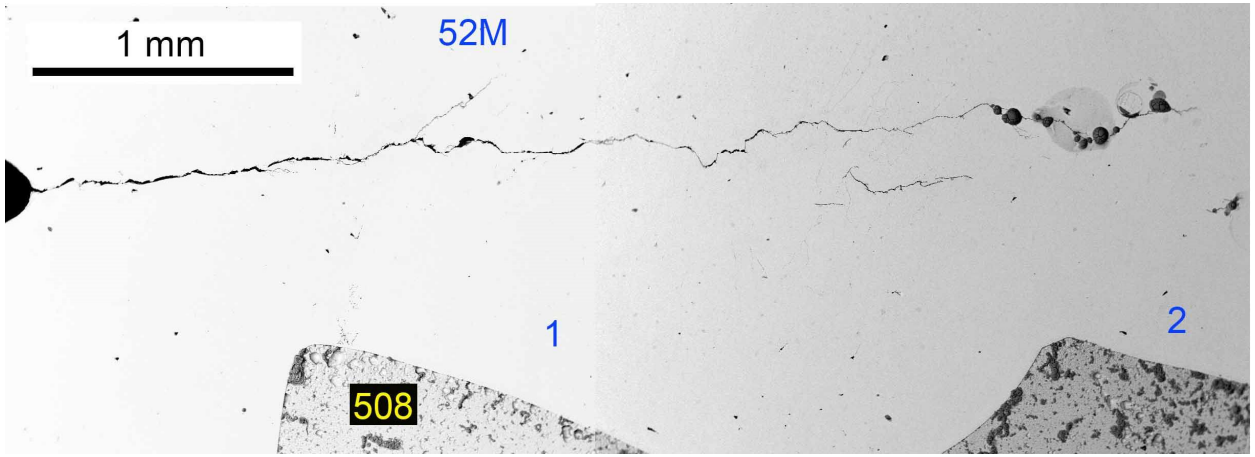


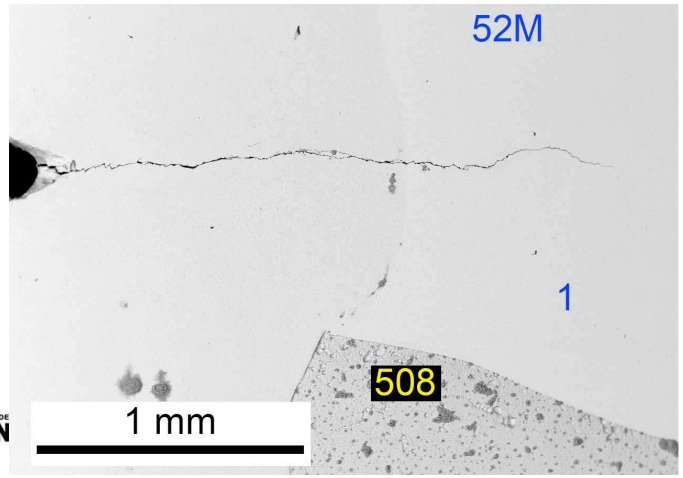


- Took 1.5 mm to obtain a reasonable “Ni-based weld” response
- Cyclic and SCC CGRs are low

EPRI DOUBLE REPAIR WELD

The double-repair weld – slice QR (40-20% repair)





- Took 1.5 mm to obtain a reasonable,

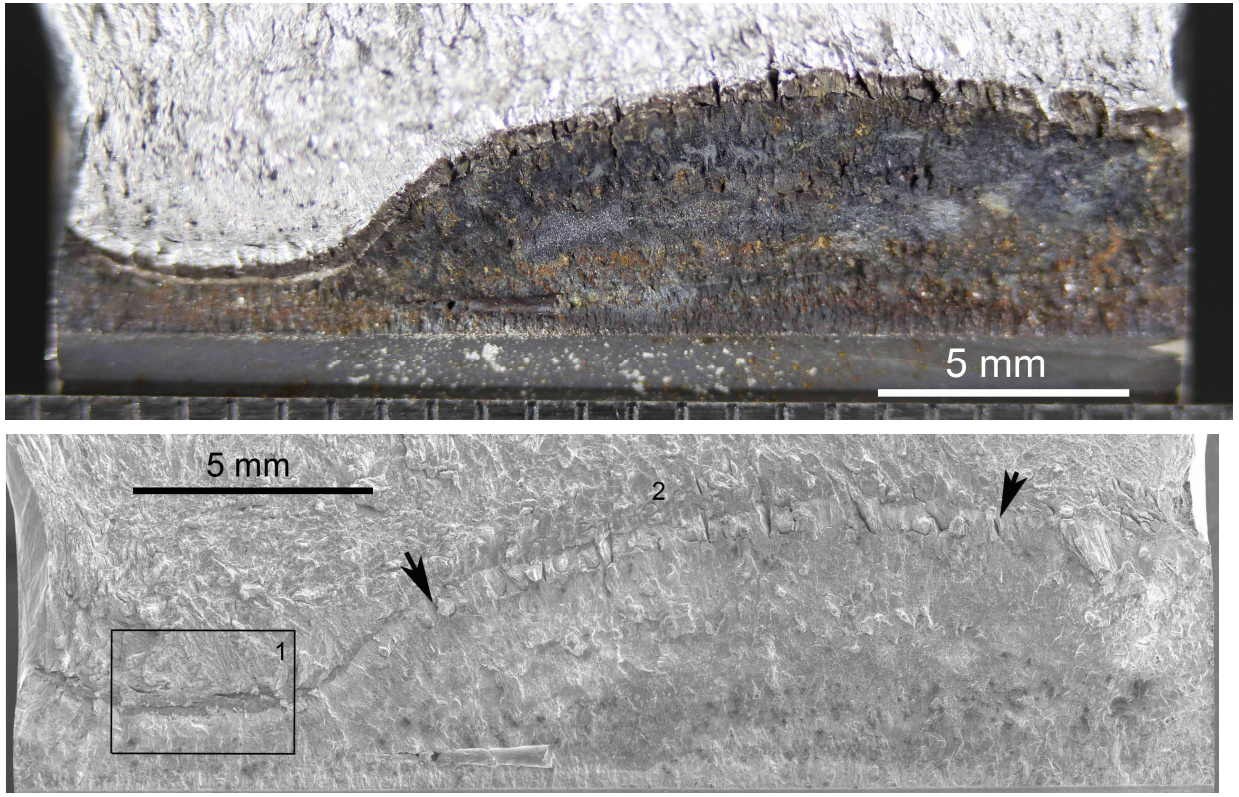
"Ni-based weld" response because the eb-weld

more than expected

- Short crack on side 2

EPRI DOUBLE REPAIR WELD

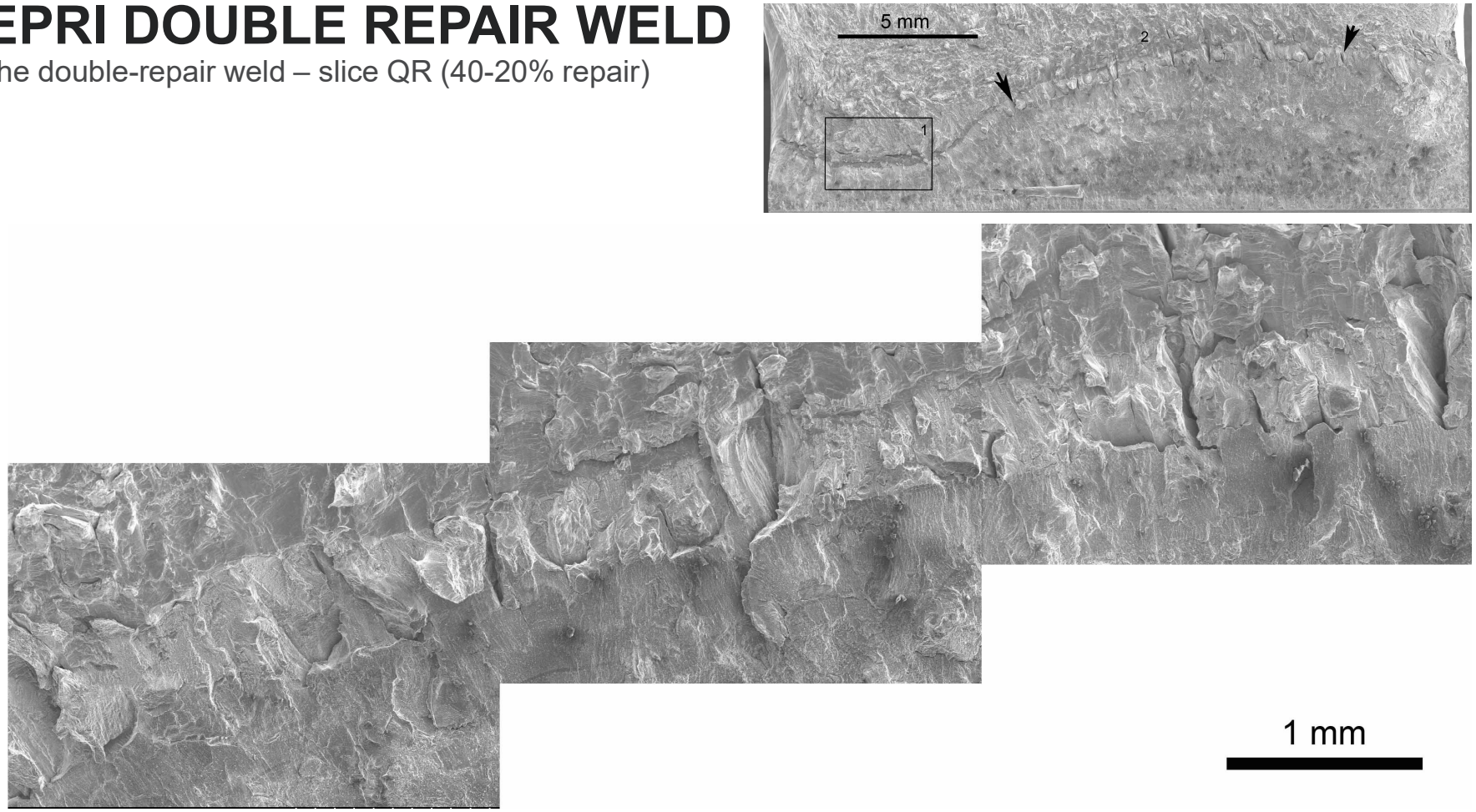
The double-repair weld – slice QR (40-20% repair)



- Crack pinned at the eb-weld
- Despite the unfavorable loading, transitioning to IG SCC appears to have occurred

EPRI DOUBLE REPAIR WELD

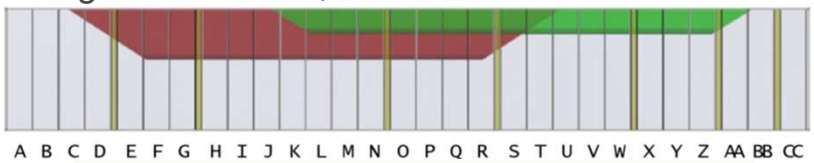
The double-repair weld – slice QR (40-20% repair)

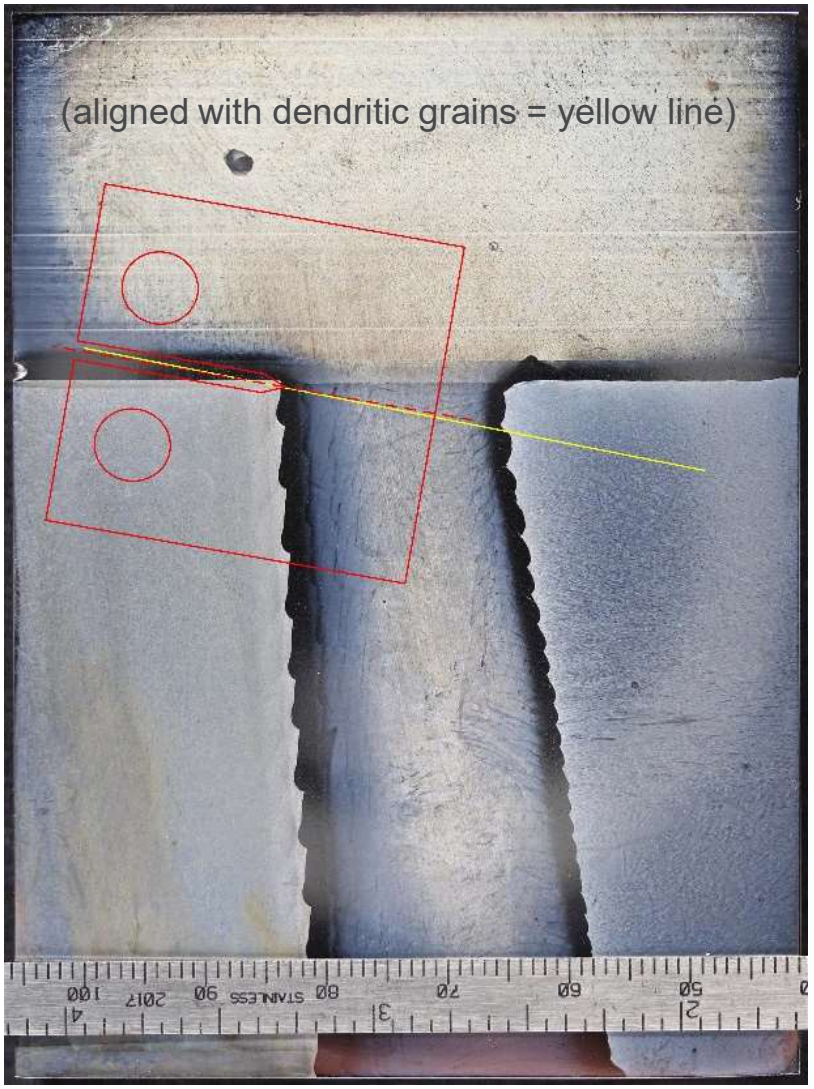


- Substantial IG SCC on the fracture surface

EPRI DOUBLE REPAIR WELD

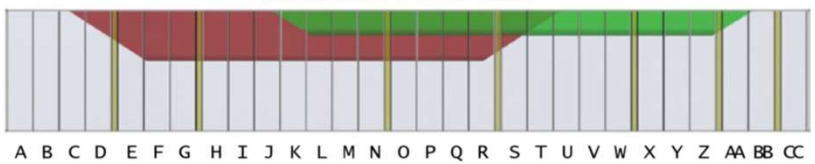
The double-repair weld – slice G (40% repair), in area with high deformation, blank received from PNNL

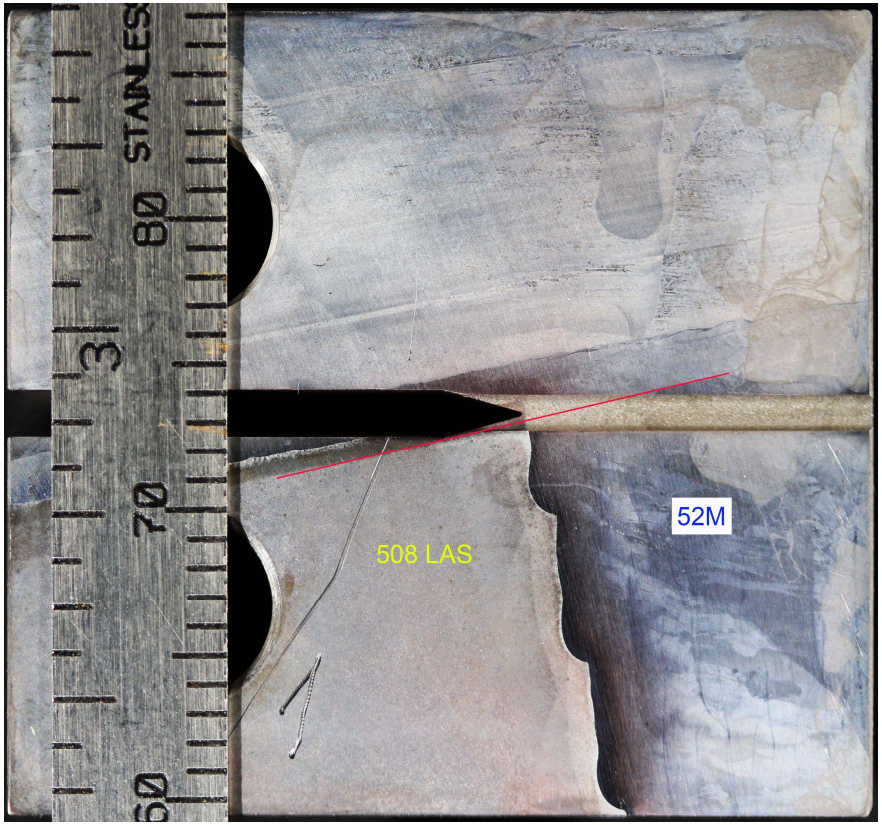


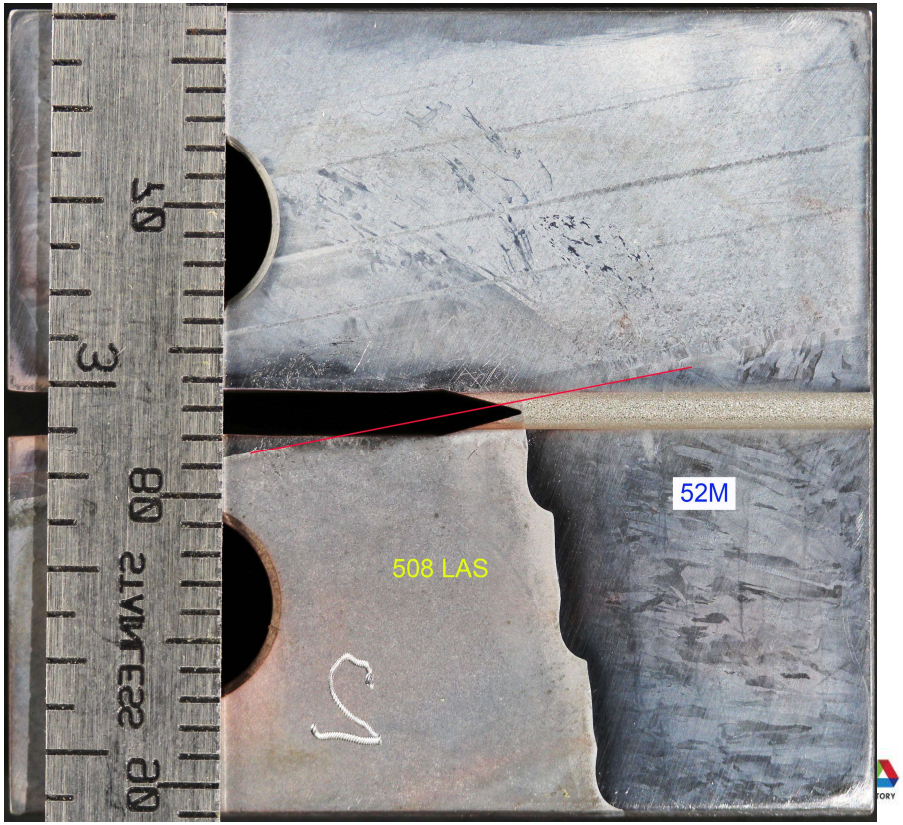


EPRI DOUBLE REPAIR WELD

The double-repair weld – slice G (40% repair)

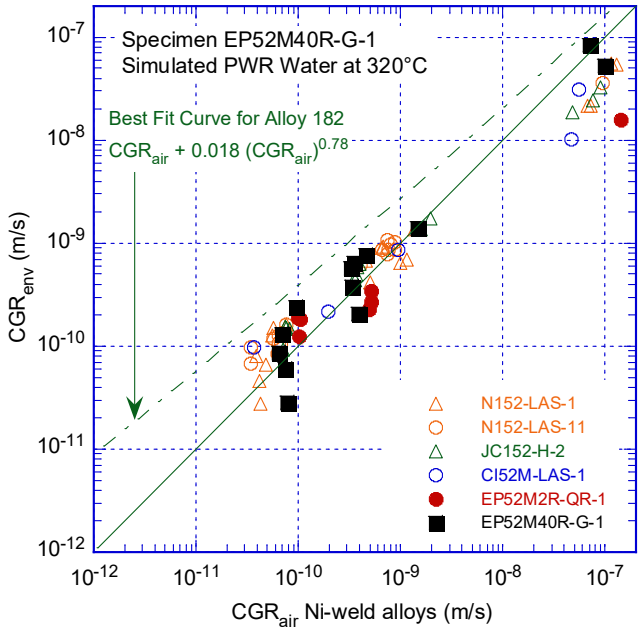






EPRI DOUBLE REPAIR WELD

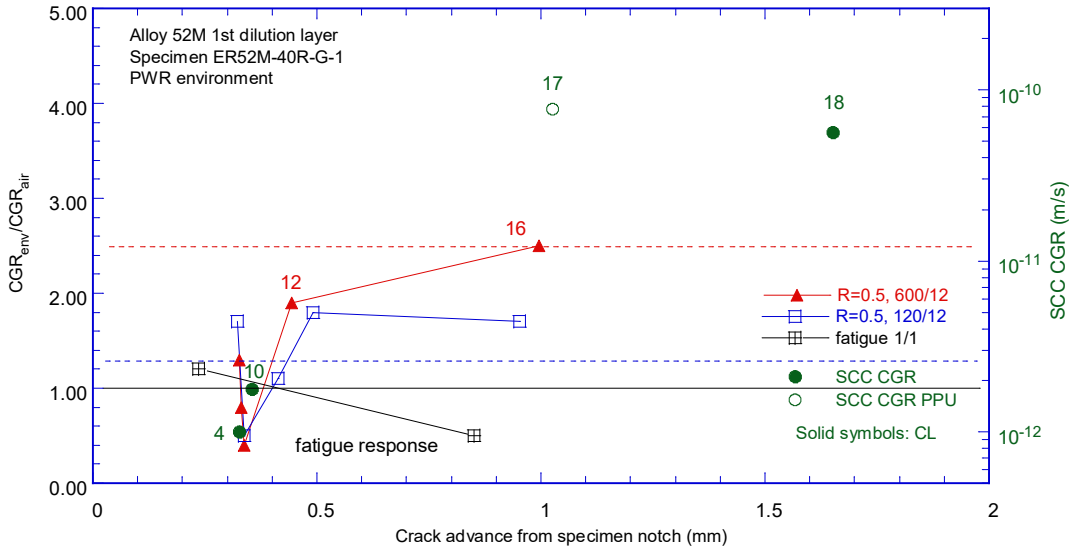
The double-repair weld – slice G (40% repair)



- Cyclic response similar to that of previous 1st layer weldments – no apparent effect of repair

EPRI DOUBLE REPAIR WELD

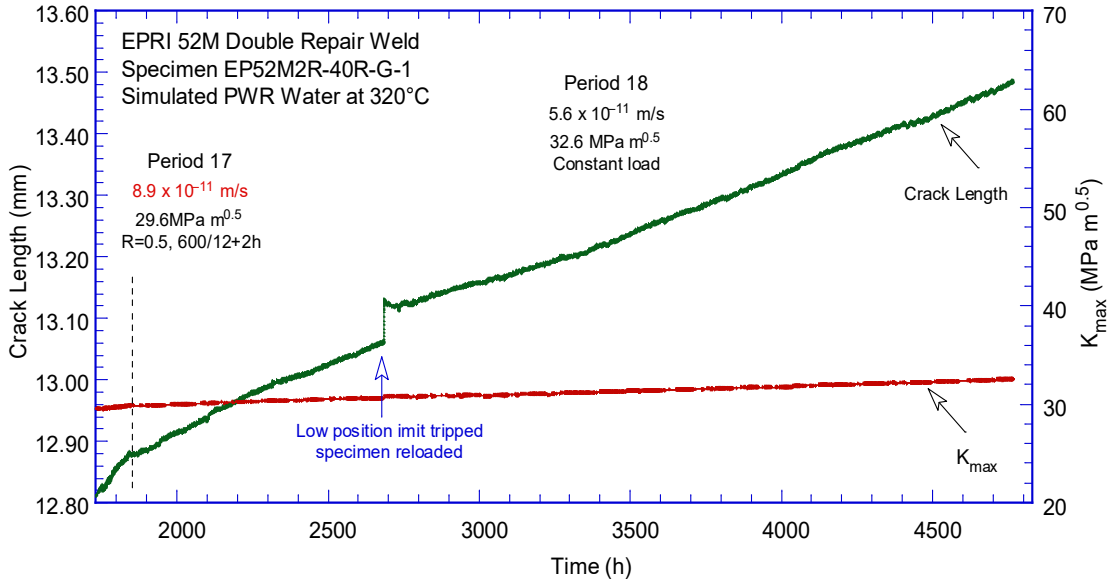
The double-repair weld – slice G (40% repair)



- Test period 12, response seems consistent with that of a Ni-based weld
- Test period 17 response suggests IG SCC – followed by PPU and CL

EPRI DOUBLE REPAIR WELD

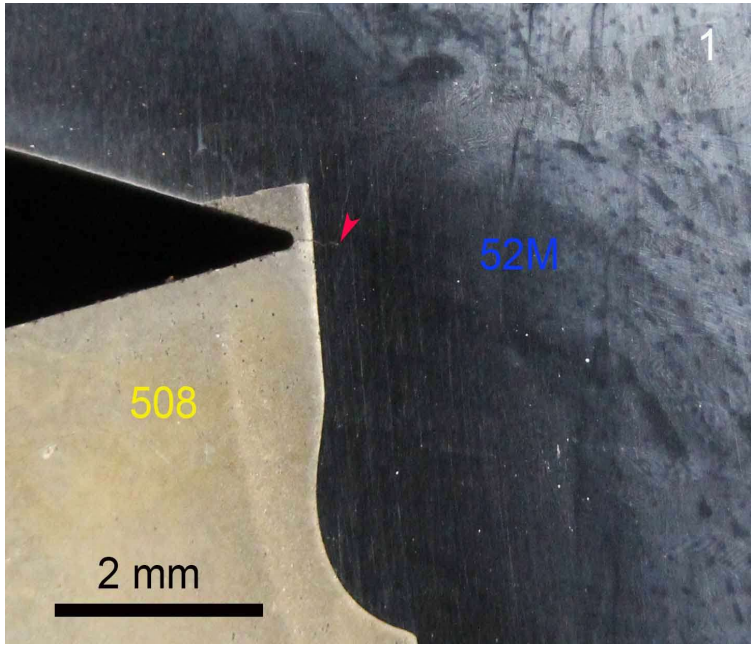
The double-repair weld – slice G (40% repair)

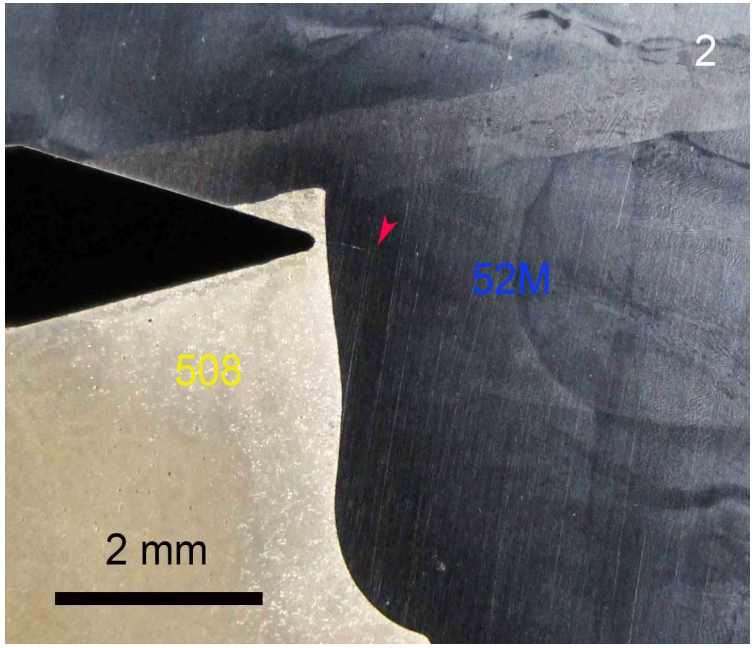


- At CL for 3,000
- Growth is well-behaved, no evolution to the response

EPRI DOUBLE REPAIR WELD

The double-repair weld – slice G (40% repair)

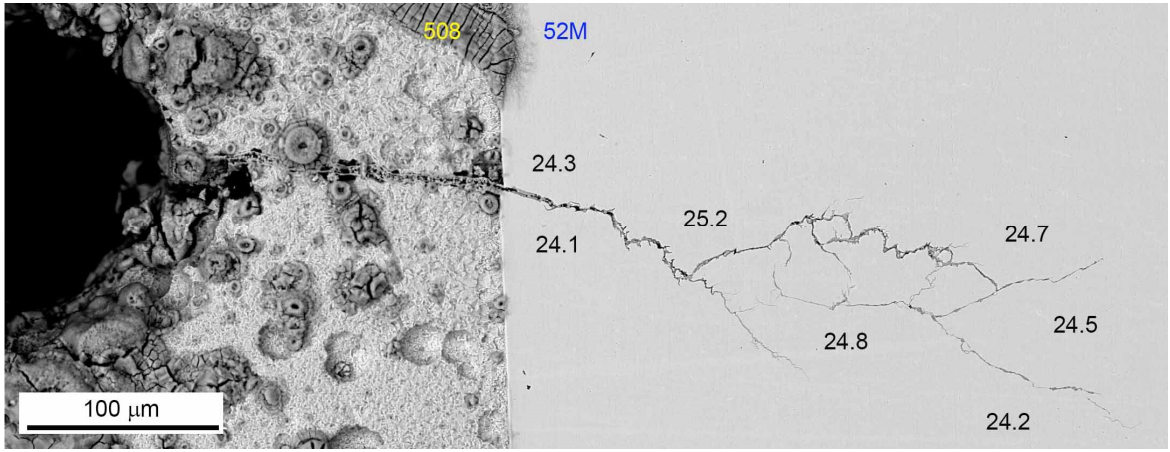


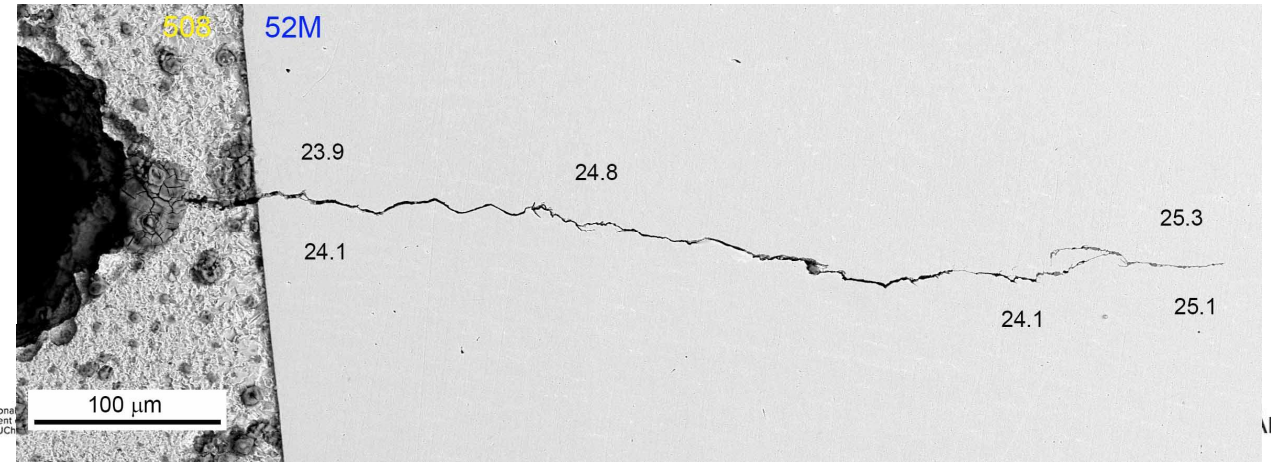


- Side surfaces suggest the test took place in the desired region

EPRI DOUBLE REPAIR WELD

The double-repair weld – slice G (40% repair)

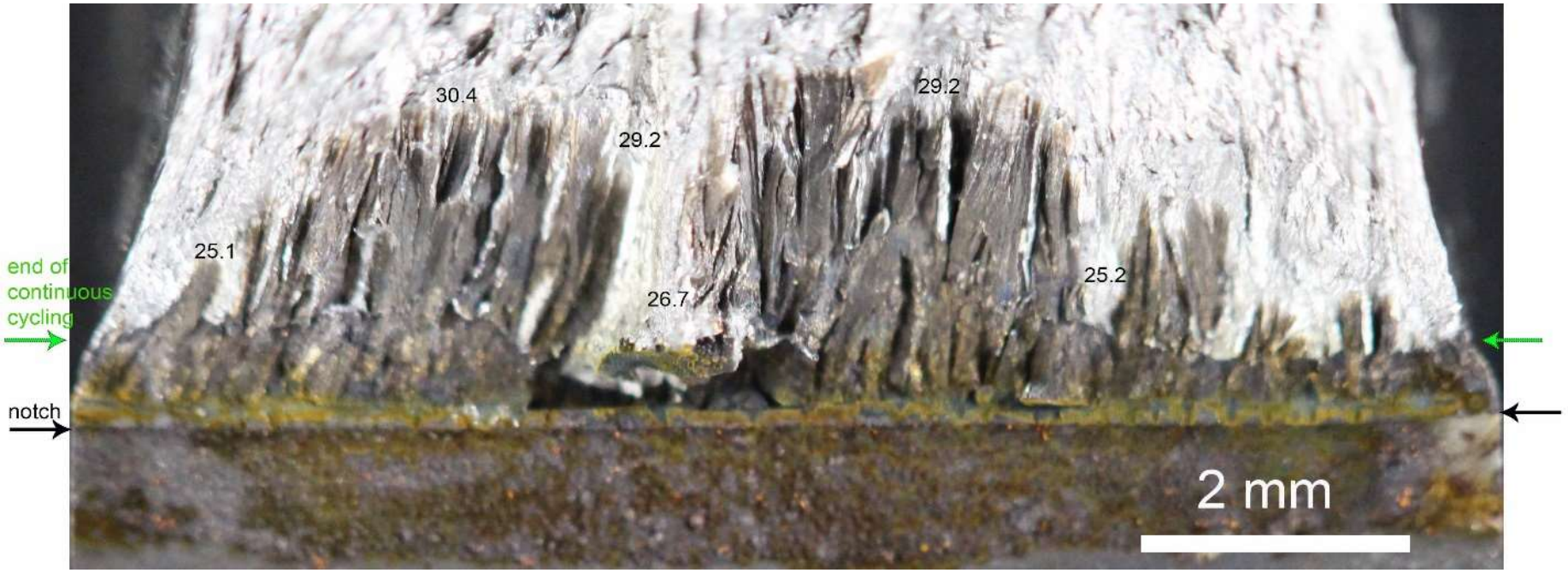




- Crack took 0.35 mm to meet the expected response
- Appears to be in the “dilution” zone

EPRI DOUBLE REPAIR WELD

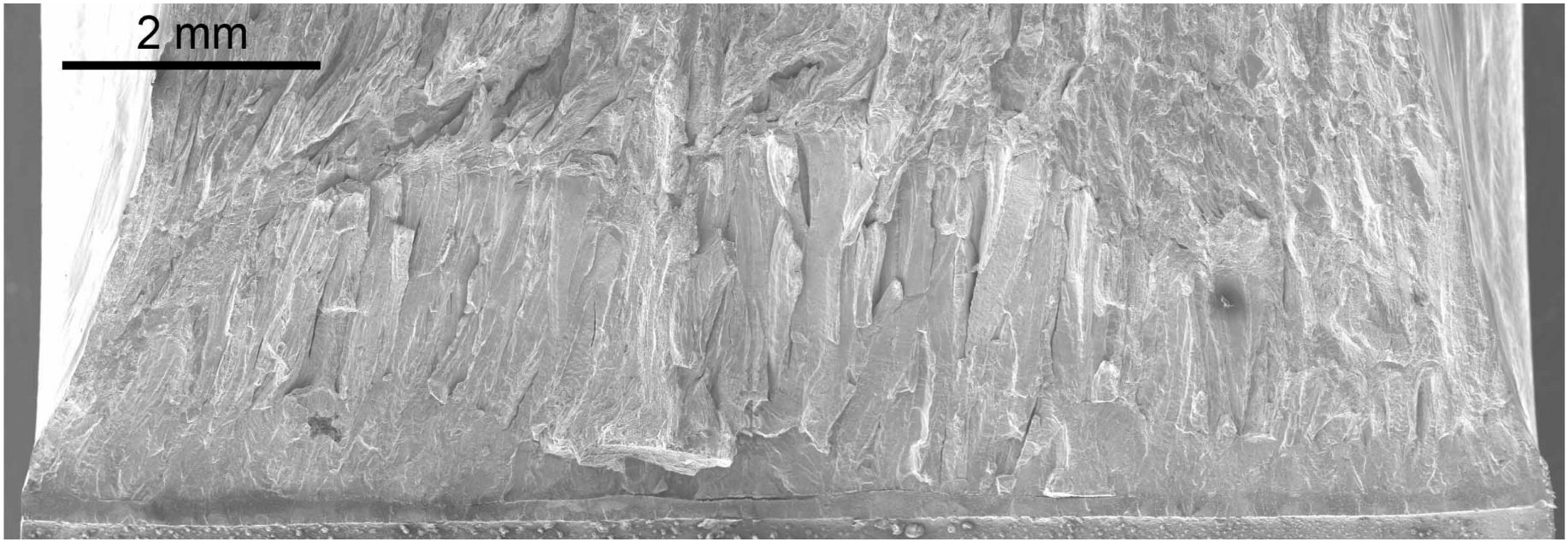
The double-repair weld – slice G (40% repair)



- Extensive IG SCC starting in diluted zone but ending in the second pass with 20-30 wt. % Cr; no effect on CGR response
- Extension (0.65 mm) much larger than expected

EPRI DOUBLE REPAIR WELD

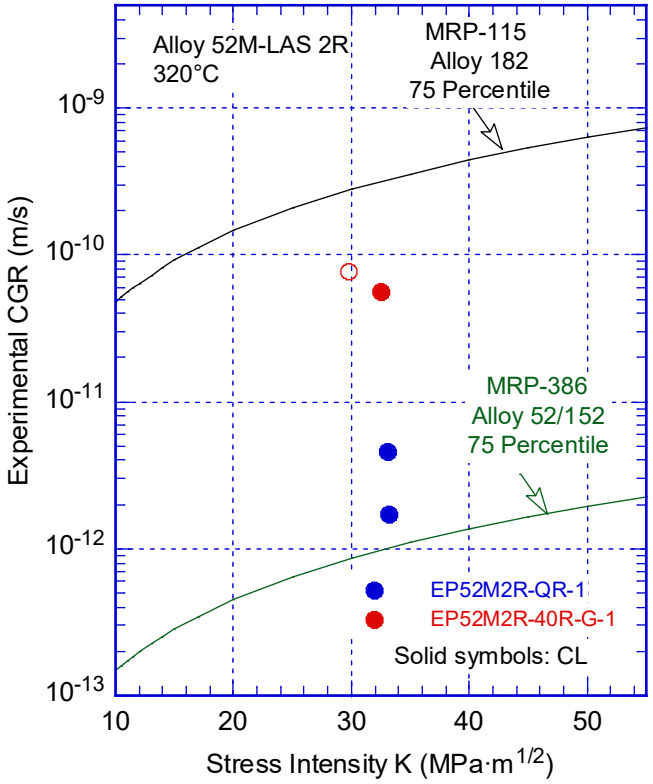
The double-repair weld – slice G (40% repair)



- Extensive IG SCC along the dendritic grains, similar to ANL specimen N152-LAS-1

EPRI DOUBLE REPAIR WELD

The double-repair weld – 1st layer



- SCC vs. K
- "G" specimen meets criteria for MRP-115, FOI = 20

SUMMARY

- In WOLs, cracks can propagate from Alloy 182 past the interface into Alloy 52M. The extent IG SCC transmission past the interface seems to correlate loosely with the dilution of Cr in the first layers of Alloy 52M.
- In the KAPL WOL crack extends into the second pass (Cr is 29 wt. %)
- Crack deflection at the interface with the WOL, and off-plane propagation along or near the interface in the diluted region of the Alloy 52M WOL was observed in all specimens. The extent of this behavior seems be correlate with the resistance to SCC of the WOL

- Alloy 52/125 weldments in 1st layer configurations can be susceptible to IG SCC:
- High CGRs based on extensive IG SCC demonstrated for Alloy 152–LAS, Alloy 152–182 (NUREG/CR-7226)
- Alloy 52M-508 (from the double-repair weld) appears susceptible, a high CGR based on extensive IG SCC and substantial growth (0.65 mm) was measured
- In one specimen the crack extended well into second pass (Cr is 29-30 wt. %) with no observed effect on the SCC CGR response