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Stress Corrosion Cracking of Alloy 152 Weld Butter near the Low Alloy Steel Interface

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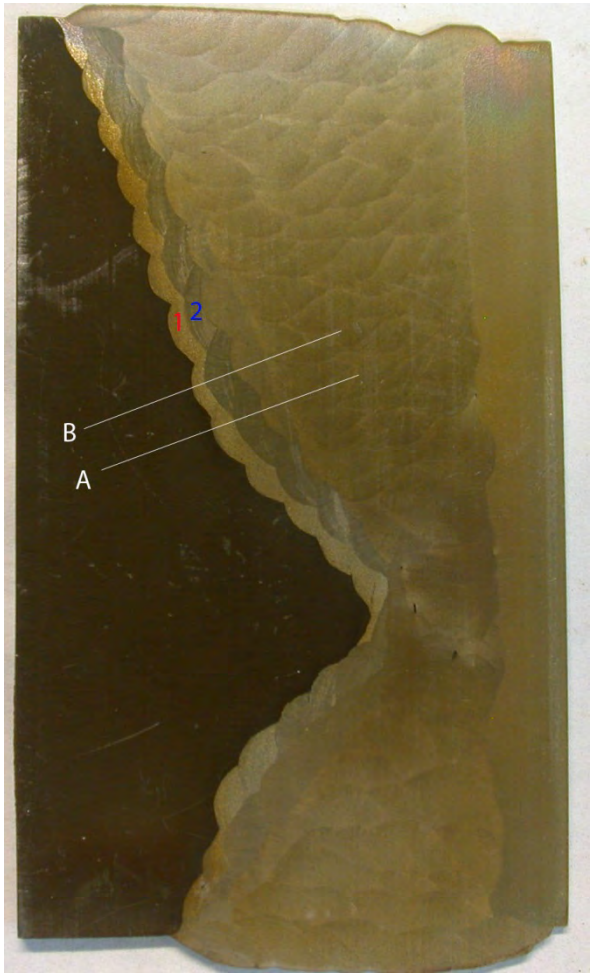
Presentation Outline

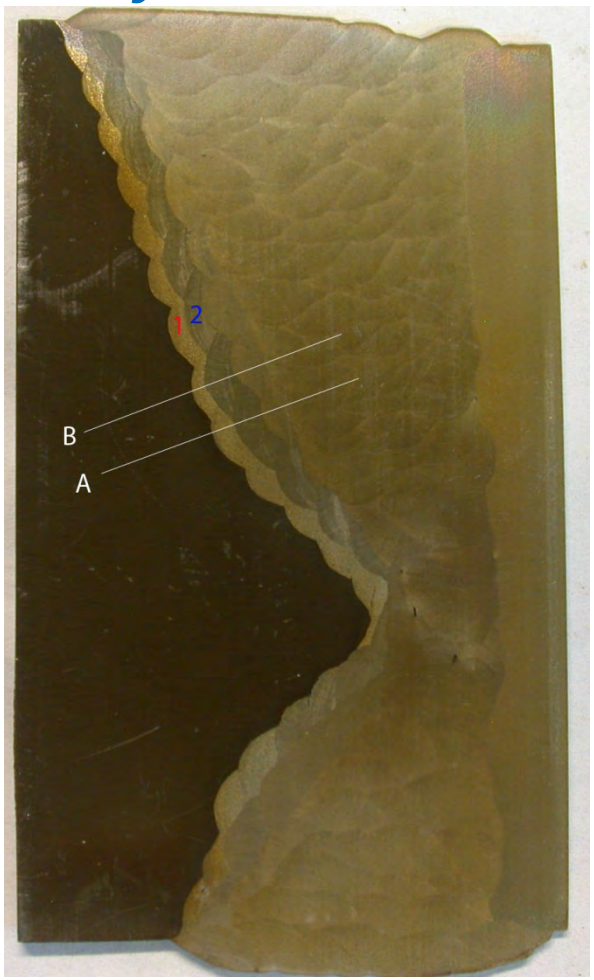
- Alloy 152-LAS weld butter produced at ANL Central Shops
- SCC CGR testing approach
- SCC CGR data resulting from two tests
- Comparison with Alloy 52M WOL “first” weld layer response
- Conclusions

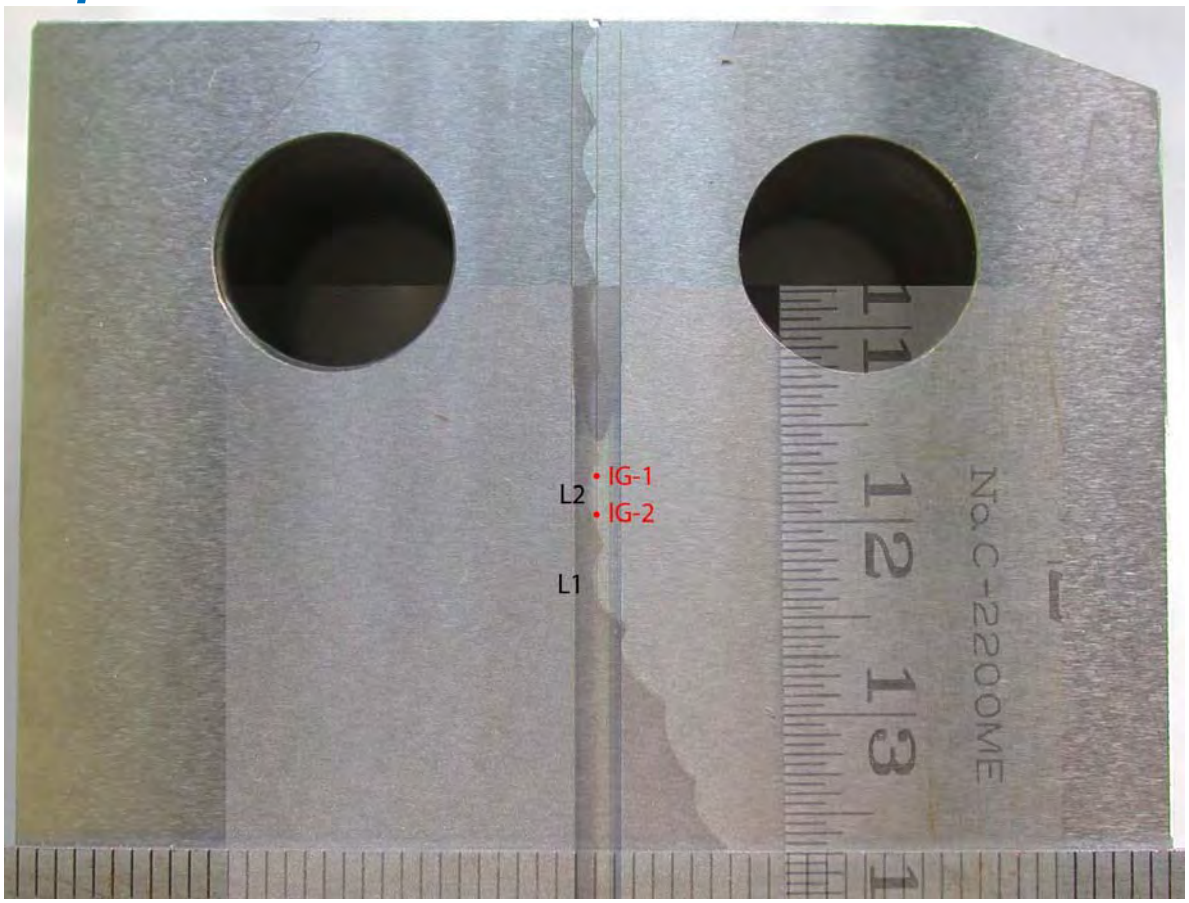
Alloy 152-LAS weld butter



- LAS – Alloy 690 joint produced at ANL using Alloy 152 for welding and buttering – “N152”
- Welding procedure qualified to ASME IX
- Specimens machined in the first layer of the Alloy 152 butter
- LAS: Alloy 533-Gr B Heat A5401 (Midland reactor lower head)
- Alloy 152 butter first layer: heat 720129 (28.9 Cr)
- PWHT: 1150 ± 25ºF / 3h

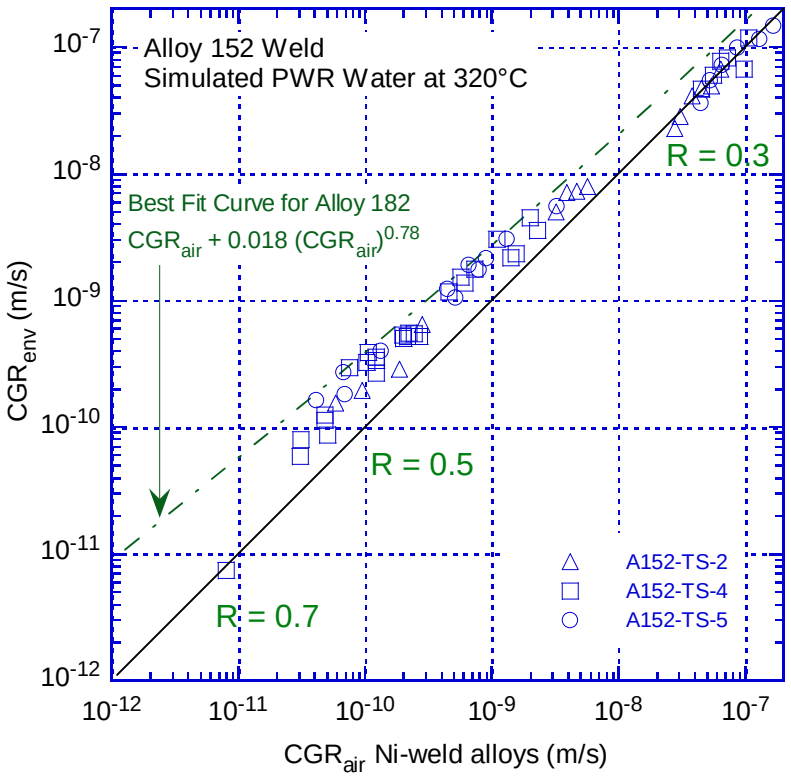
Alloy 152-LAS dilution specimen N152-LAS-1

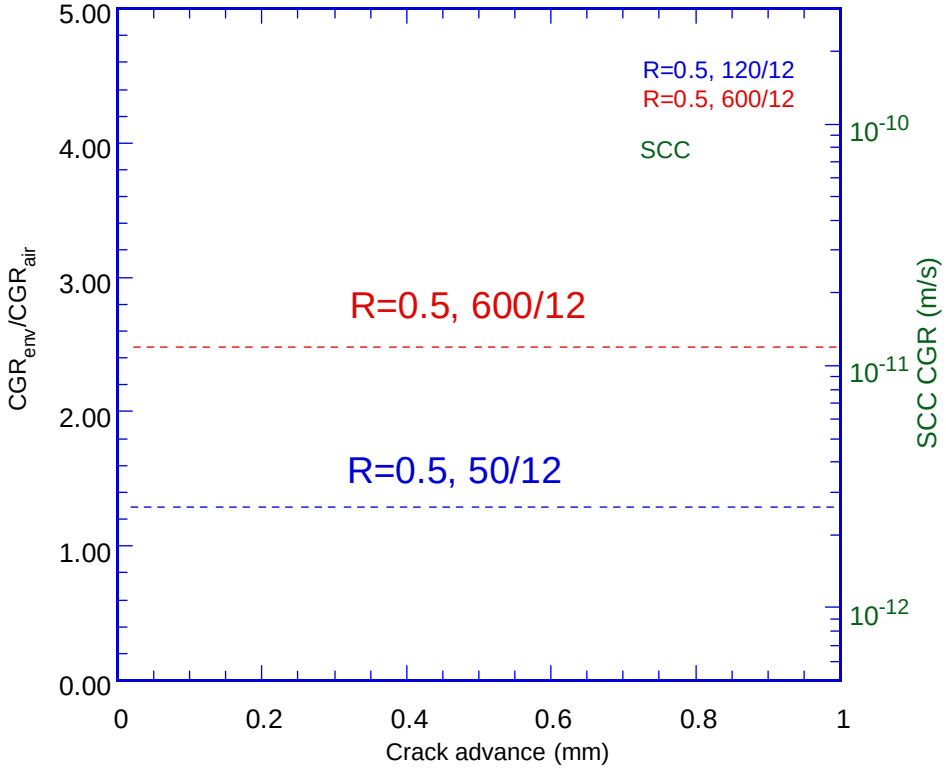




- Objective: determine SCC CGRs at two locations: IG-1 and IG-2
- Challenge: crack direction vs. orientation of the dendritic grains
- Approach: monitor environmental enhancement of two “known” conditions, and set at constant load at “favorable” location

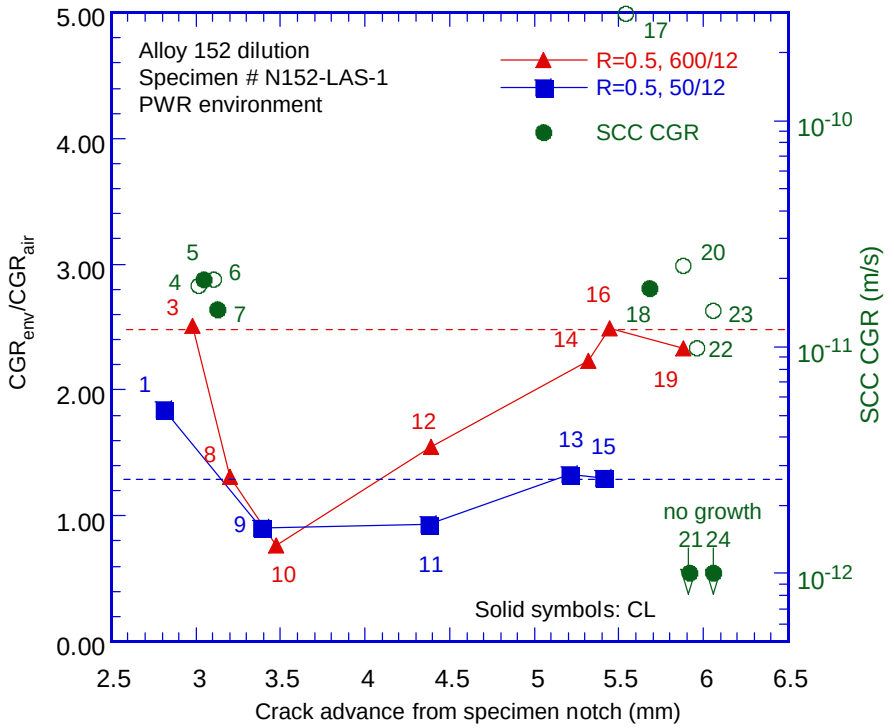
"Known" behavior: Alloy 152 cyclic response of a symmetrical double-J weld





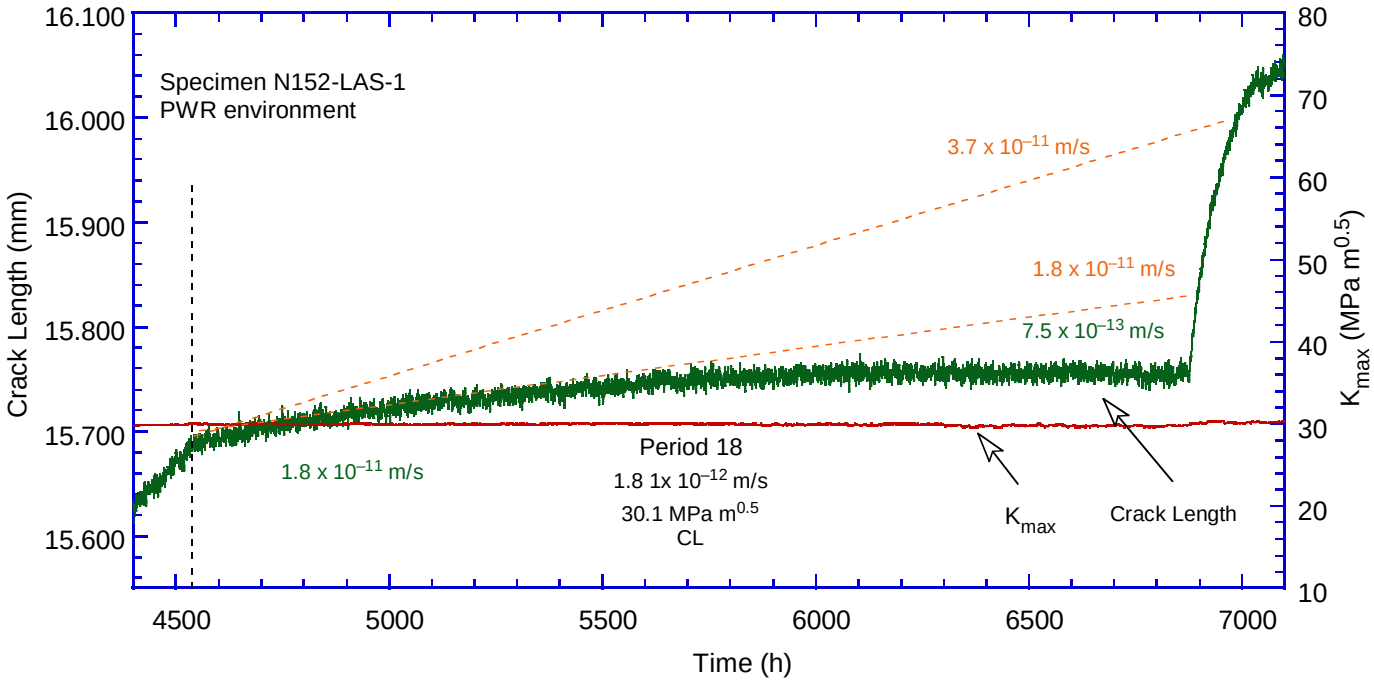
- Good understanding of Alloy 152 response vs. R and rise time in TS specimens
- "Favorable" location = response consistent with IG SCC propagation in Alloy 152 (crack front aligned with the dendritic grains)

Alloy 152-LAS dilution specimen N152-LAS-1



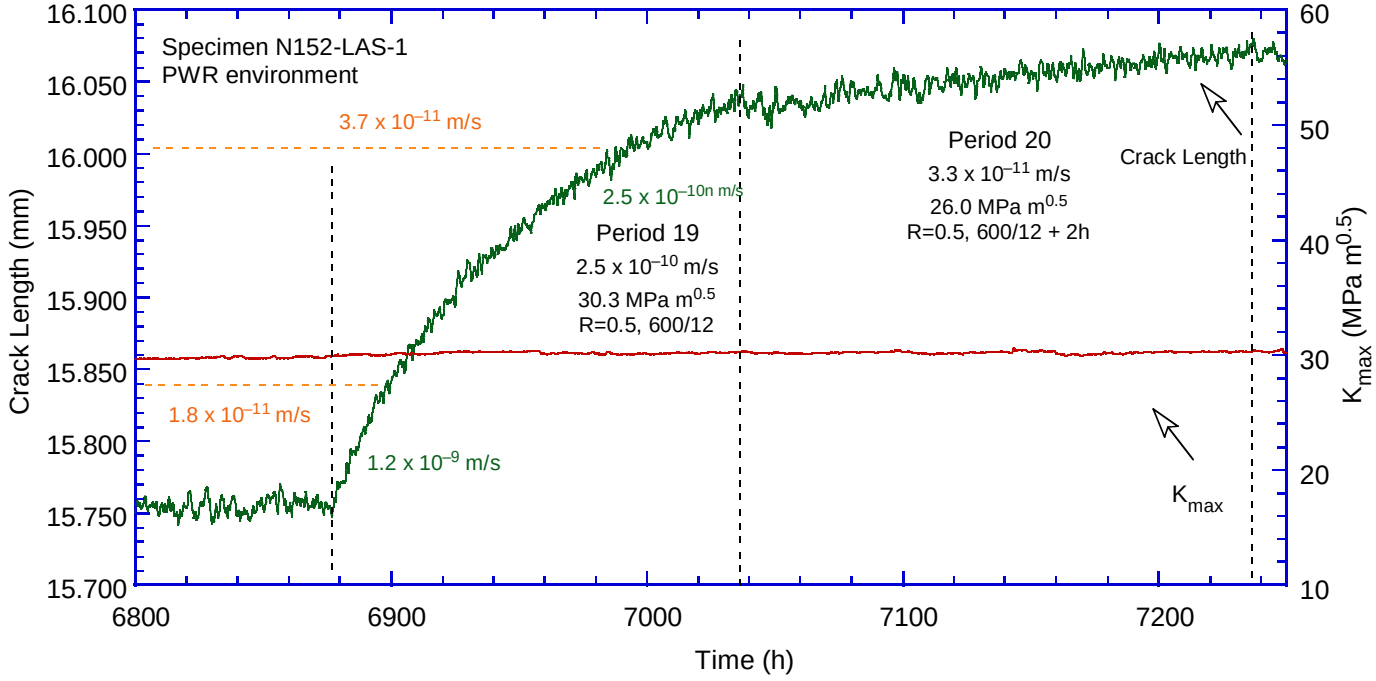
- Environmental enhancement is a good predictor for PWSCC behavior
- Two regions with largely similar cyclic and SCC CGR responses (with one exception)
- Post test examination: off-plane growth responsible for the med/low SCC CGRs

Alloy 152-LAS dilution specimen N152-LAS-1 (IG-2)



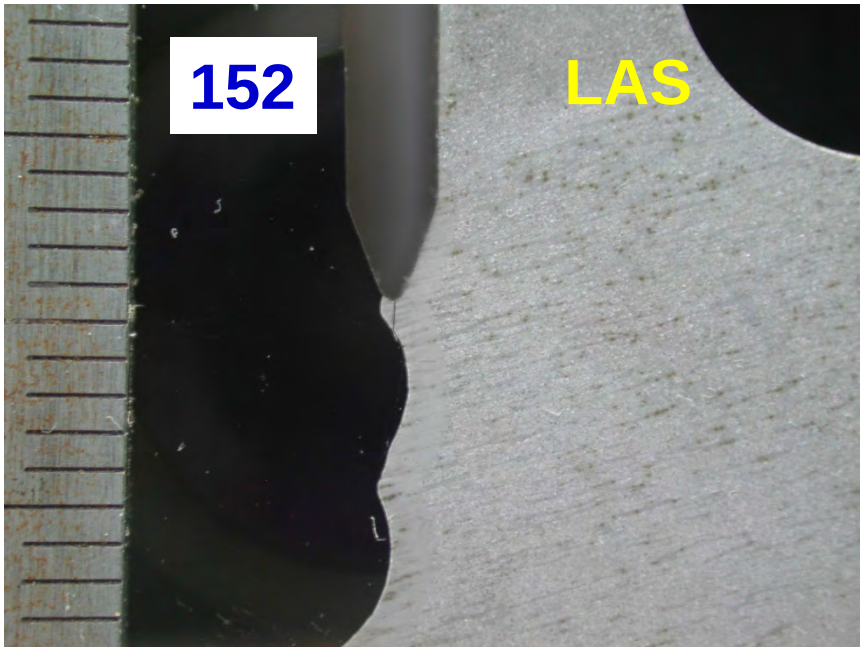
- Constant load: CGR 1.8 $\times 10^{-11}$ m/s rate for over 1,000 h, then diminishes
- Is there crack arrest, the effect of unbroken ligaments, or off-plane cracking?

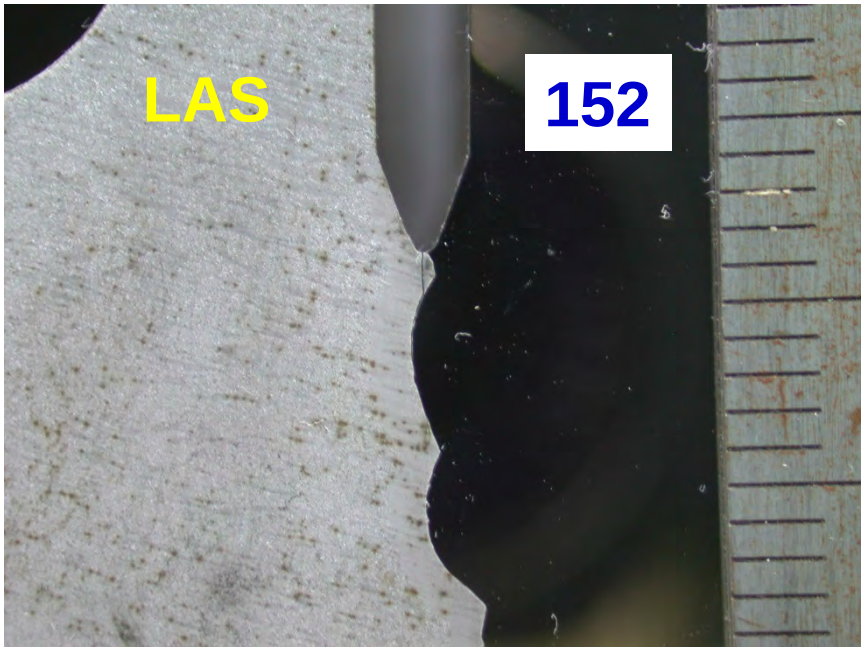
Alloy 152-LAS dilution specimen N152-LAS-1 (IG-2)



- Shape of the subsequent test period: factor 5 decrease in CGR
- SCC CGR of 1.8E $\times 10^{-11}$ m/s underestimates the full extent of growth in prior test period

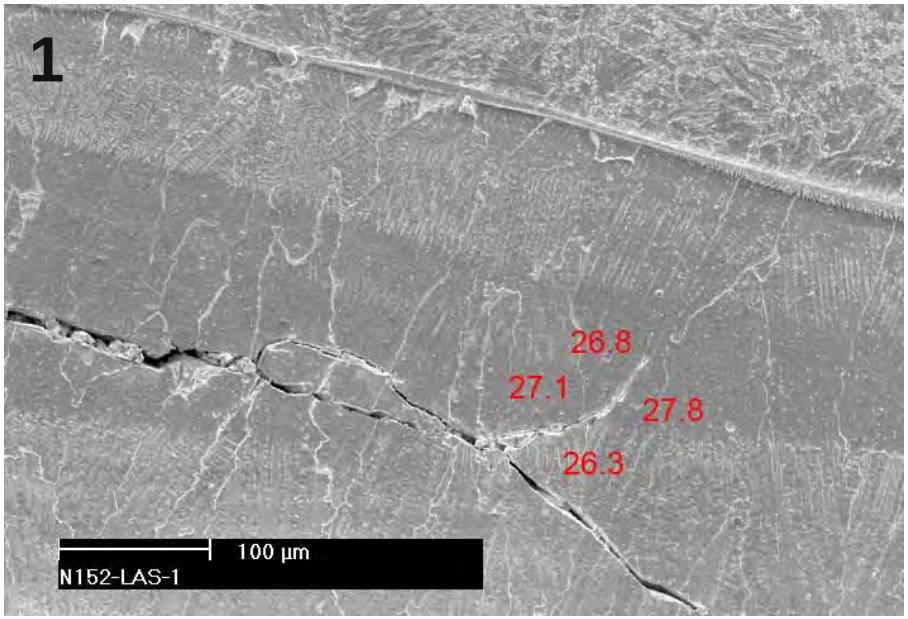
Specimen N152-LAS-1 – post-test examination

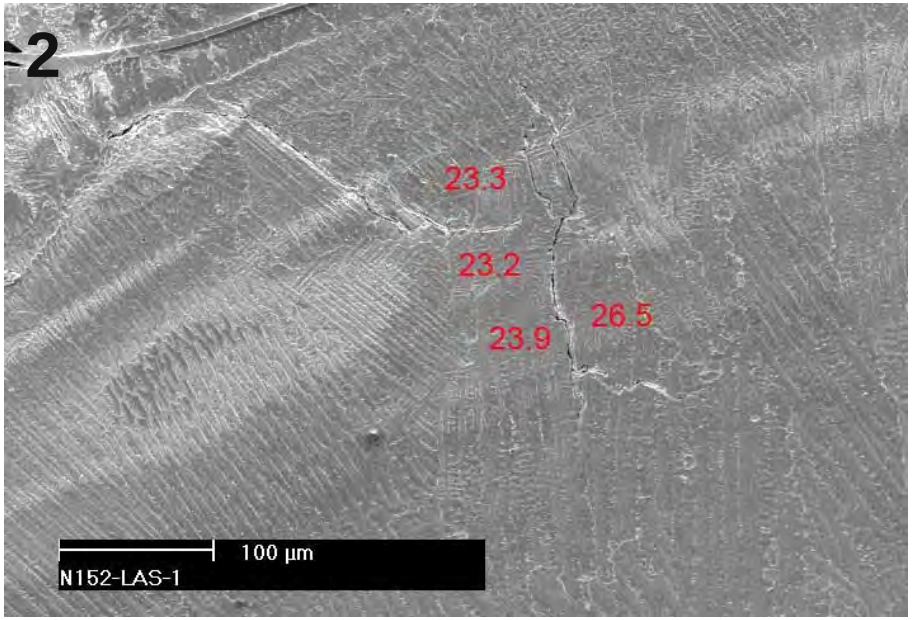




- Outcome matches expectations, crack close to the interface

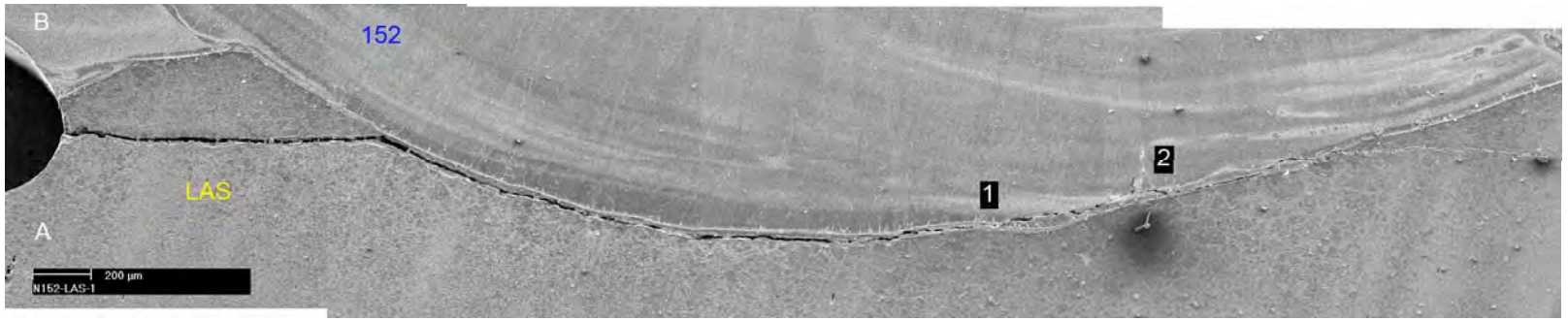
Specimen N152-LAS-1 – Side Surface 1

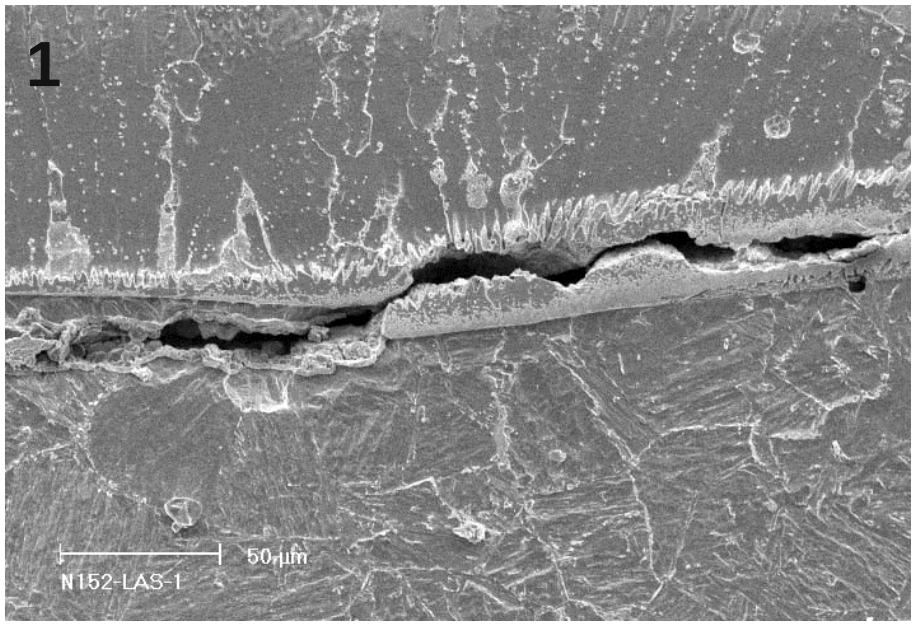


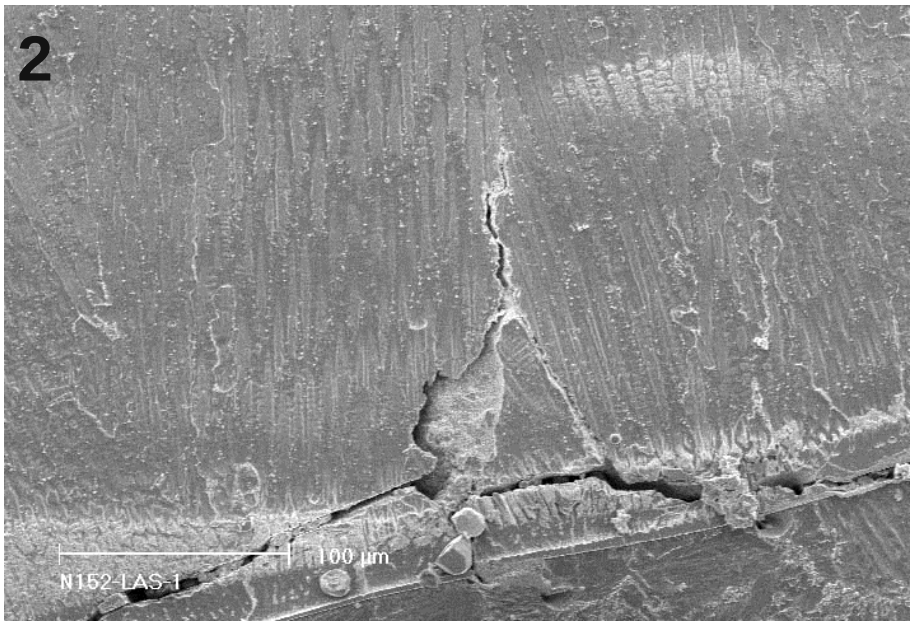


- Off-plane cracking (along dendritic grains) appears to be the preferred direction
- Elemental concentration (wt.% Cr 27.0 vs 24.1) does not seem to make a difference

Specimen N152-LAS-1 – Side Surface 2

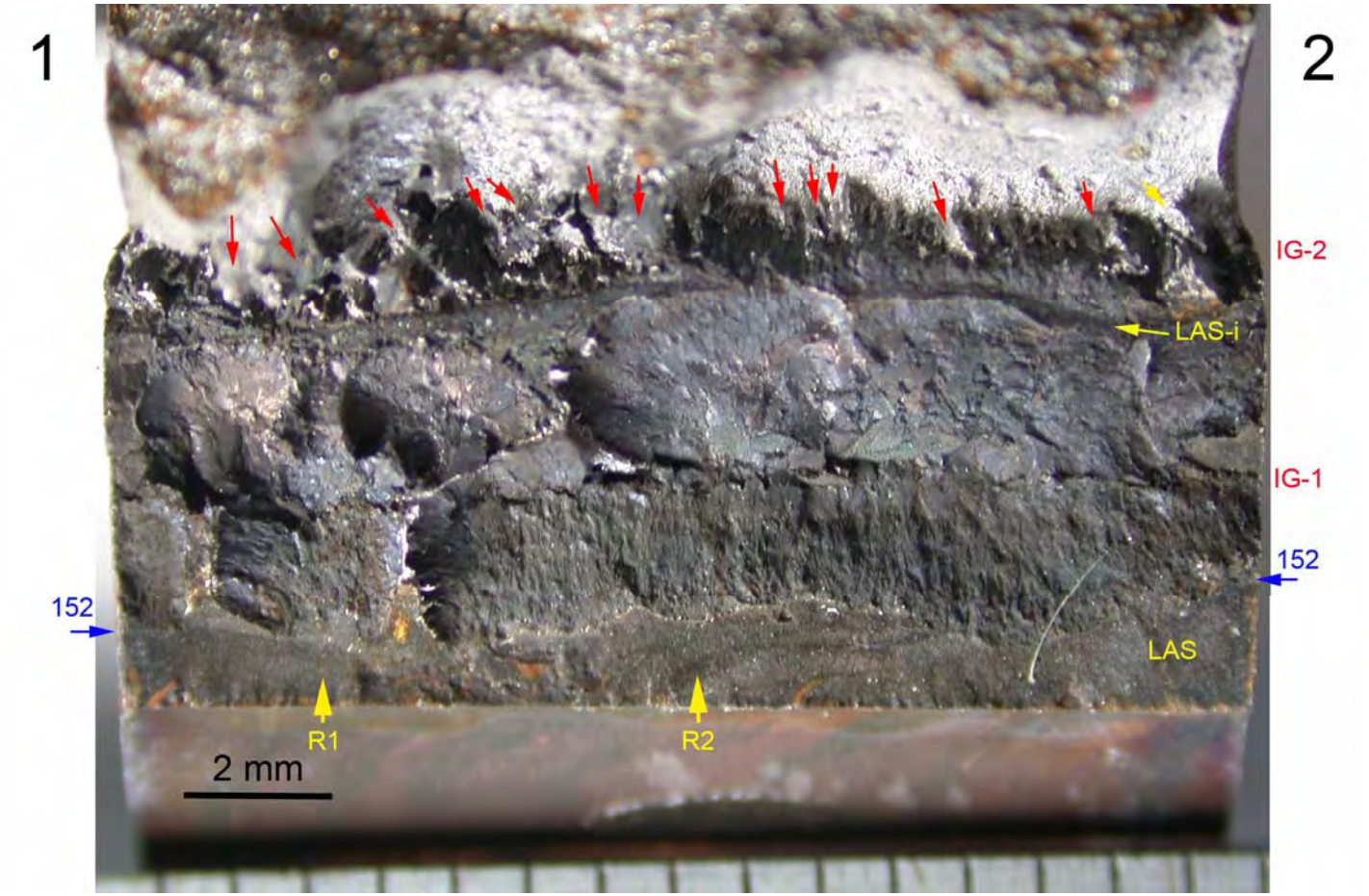






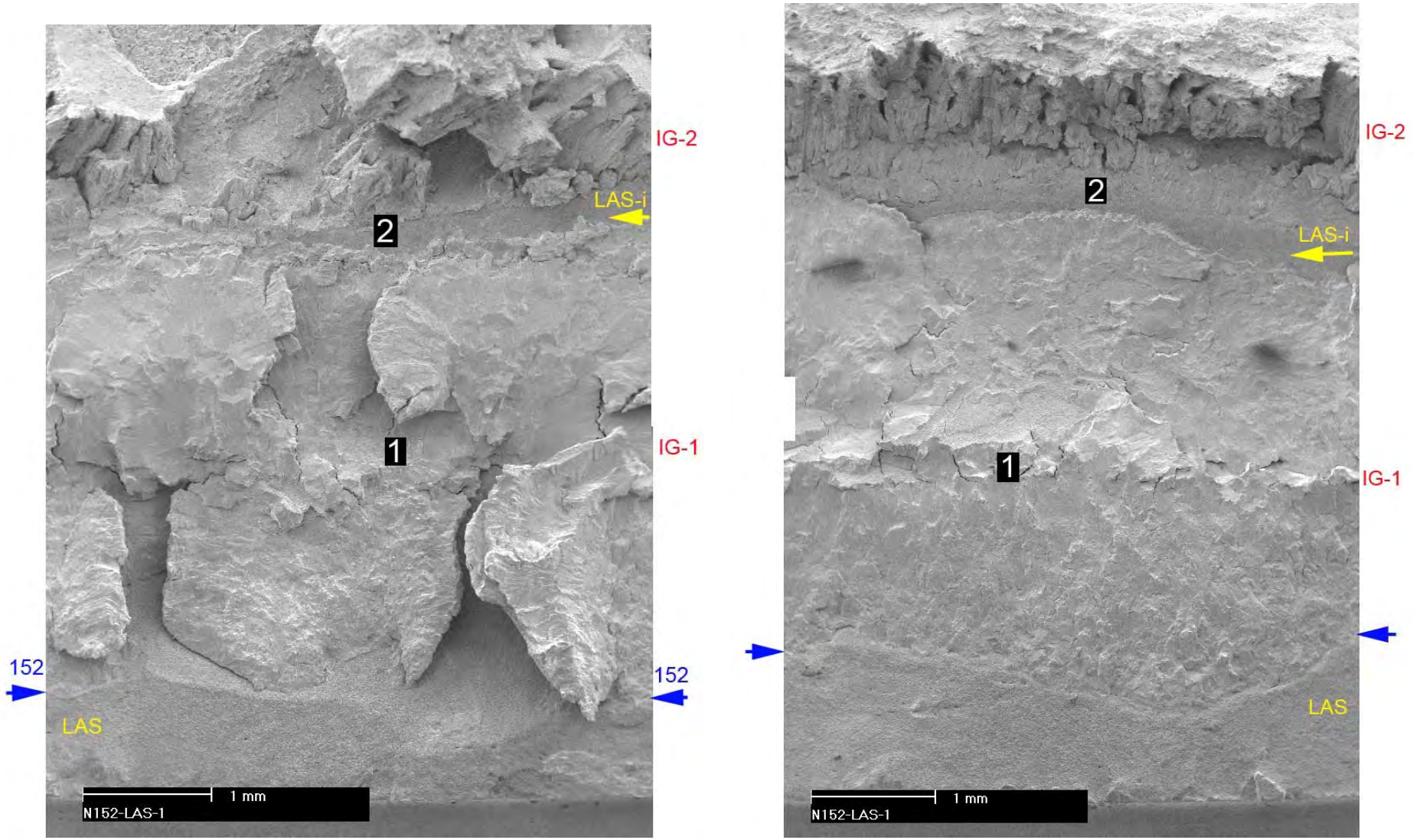
- Ample opportunity for interface/LAS cracking, the crack eventually enters the weld
- Preferred path for SCC: along interdendritic grain boundaries of the Alloy 152 weld

Specimen N152-LAS-1 fracture surface – Side B tilted



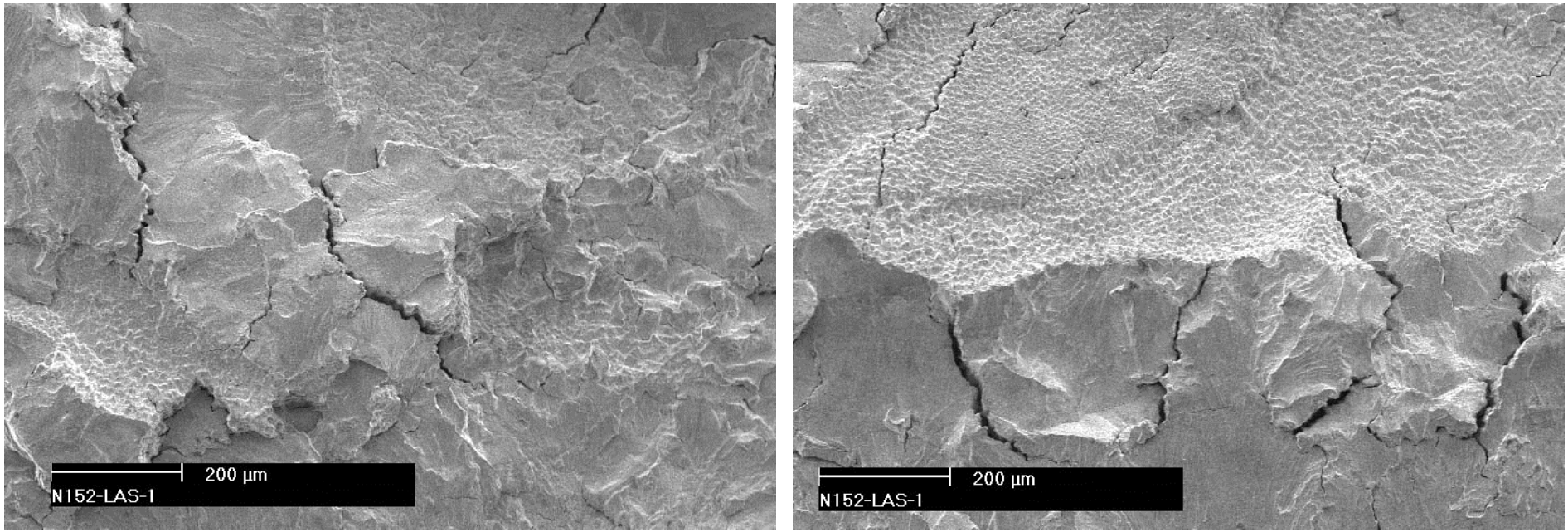
- Tilted to show the full extent of IG-2 and identify unbroken ligaments (5 x DCPD)
- Appears that SCC occurred during both transitioning attempts (off-plane)
- Off-plane cracking and ligaments result in “no growth” towards the end of the test

Specimen N152-LAS-1 fracture surface – locations R1 and R2



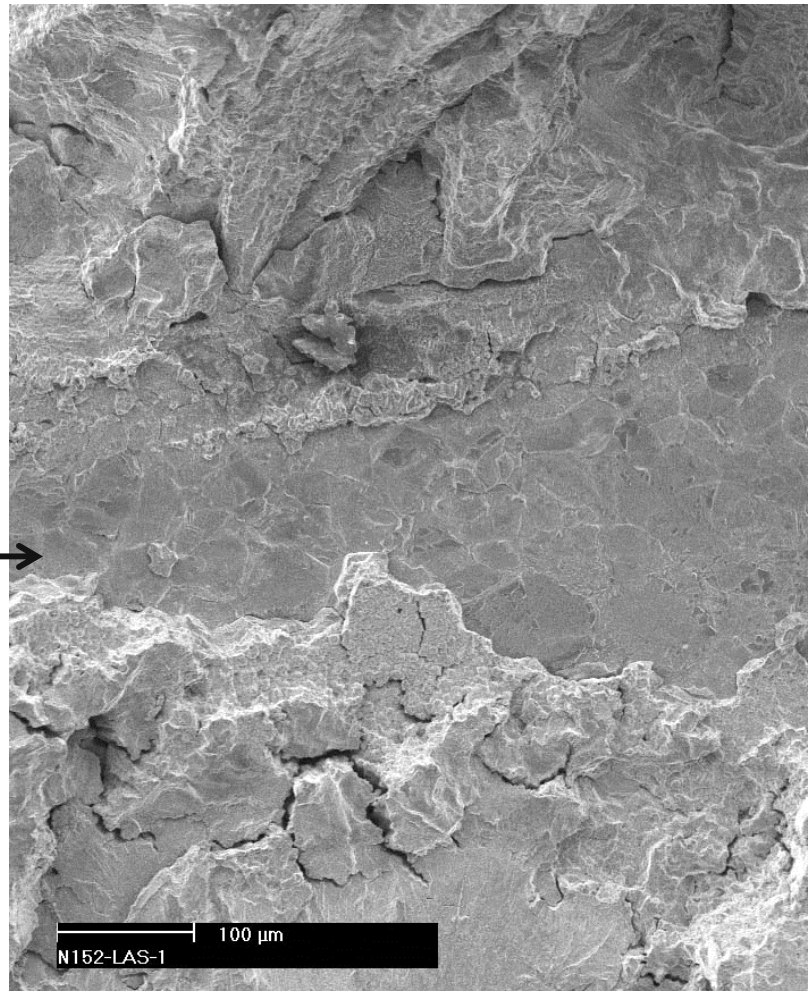
- R1: ligaments during fatigue and corrosion fatigue

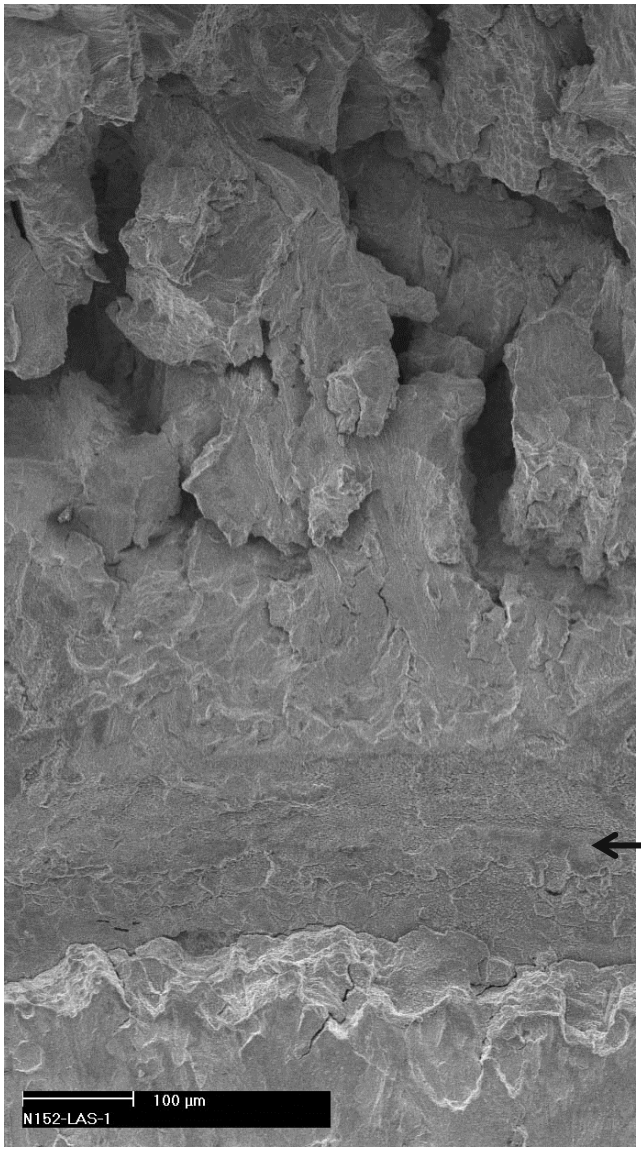
Specimen N152-LAS-1 fracture surface – IG-1 locations "1" in regions R1 and R2



- Mixed TG + IG mode (normal to the dendritic grains), secondary cracking
- Preferred SCC crack path appears to be off-plane

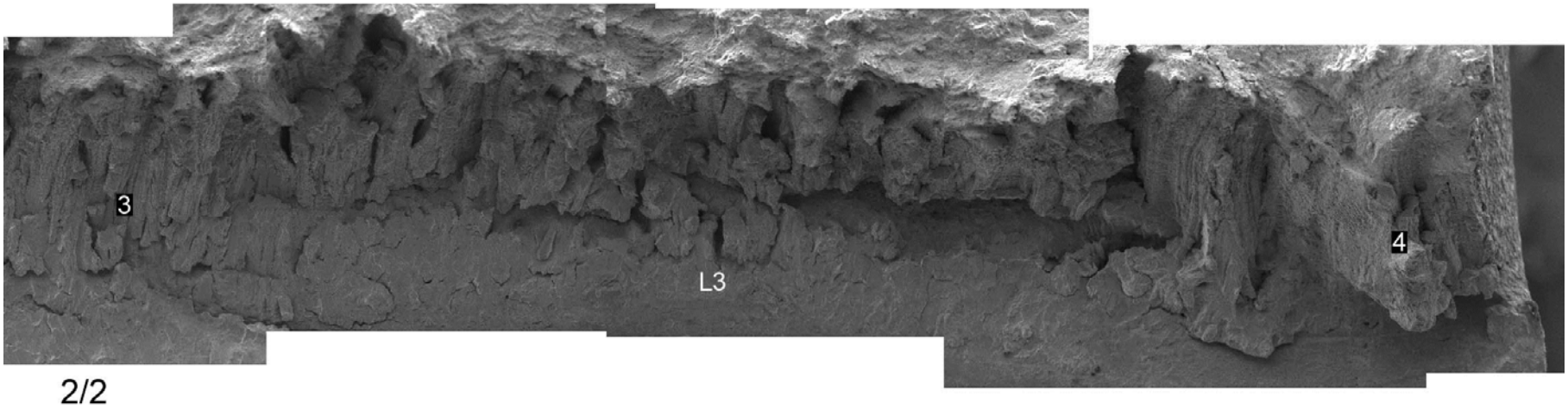
Intersection with the LAS interface – locations "2" in regions R1 and R2



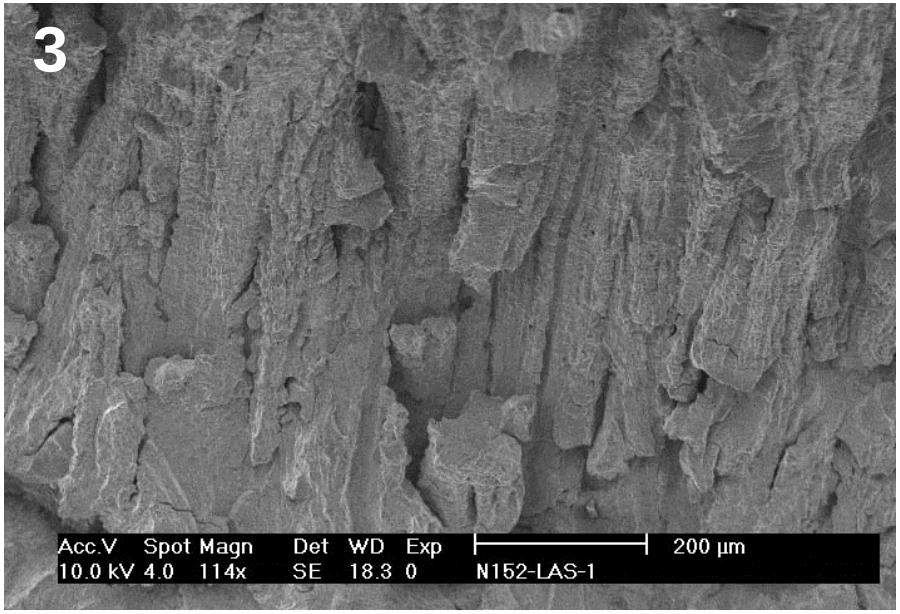


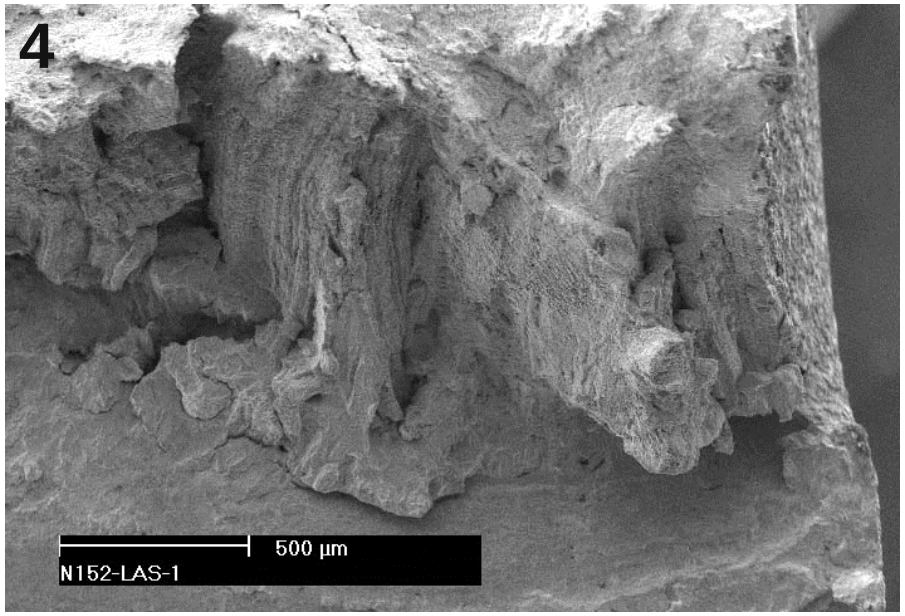
- The LAS does not seem susceptible to PWSCC
- Crack advanced by gentle cycling
- Alternative absent gentle cycling: remain as unbroken ligaments (see N152-LAS-11 next)

N152-LAS-1 fracture surface – IG-2 2/2



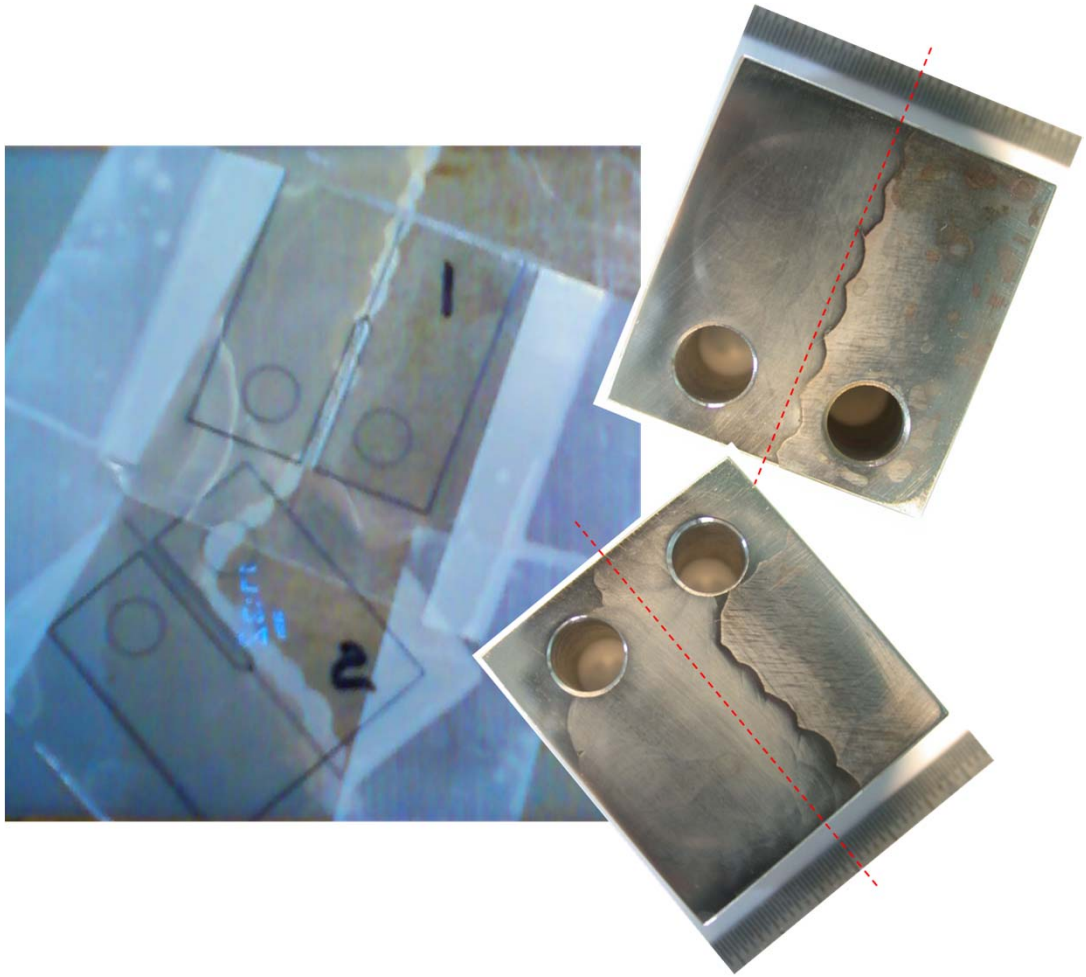
2/2





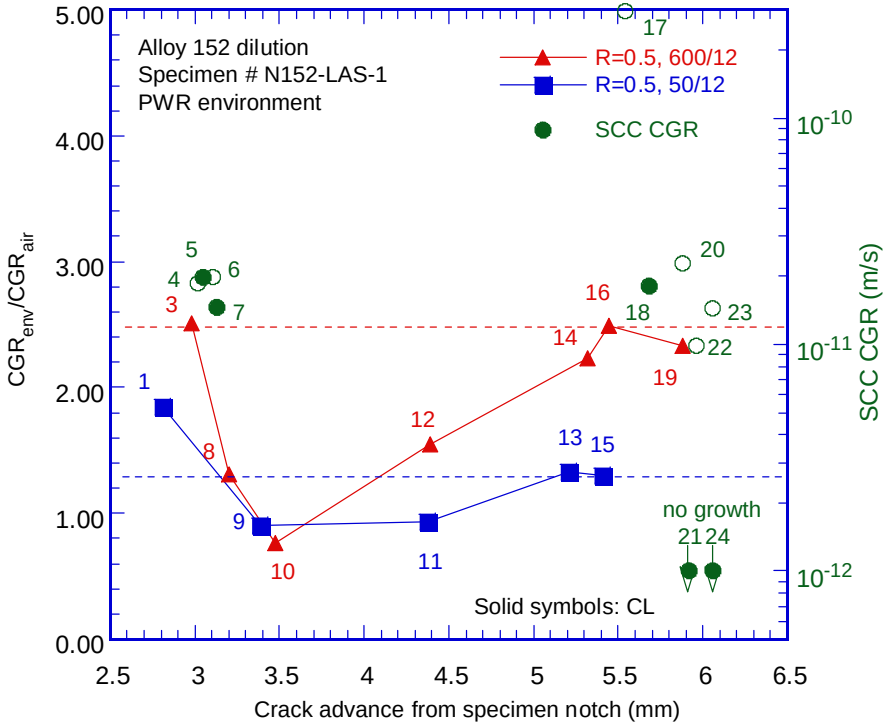
- Extensive IG and ligament

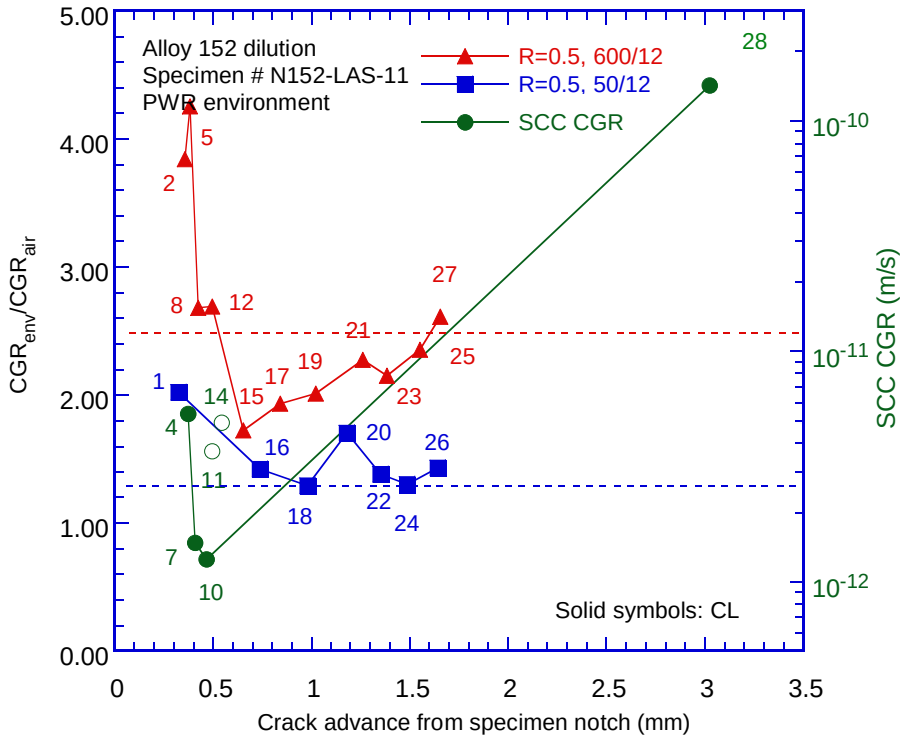
Specimen N152-LAS-11



- Similar to N152-LAS-1: first layer of the Alloy 152 butter

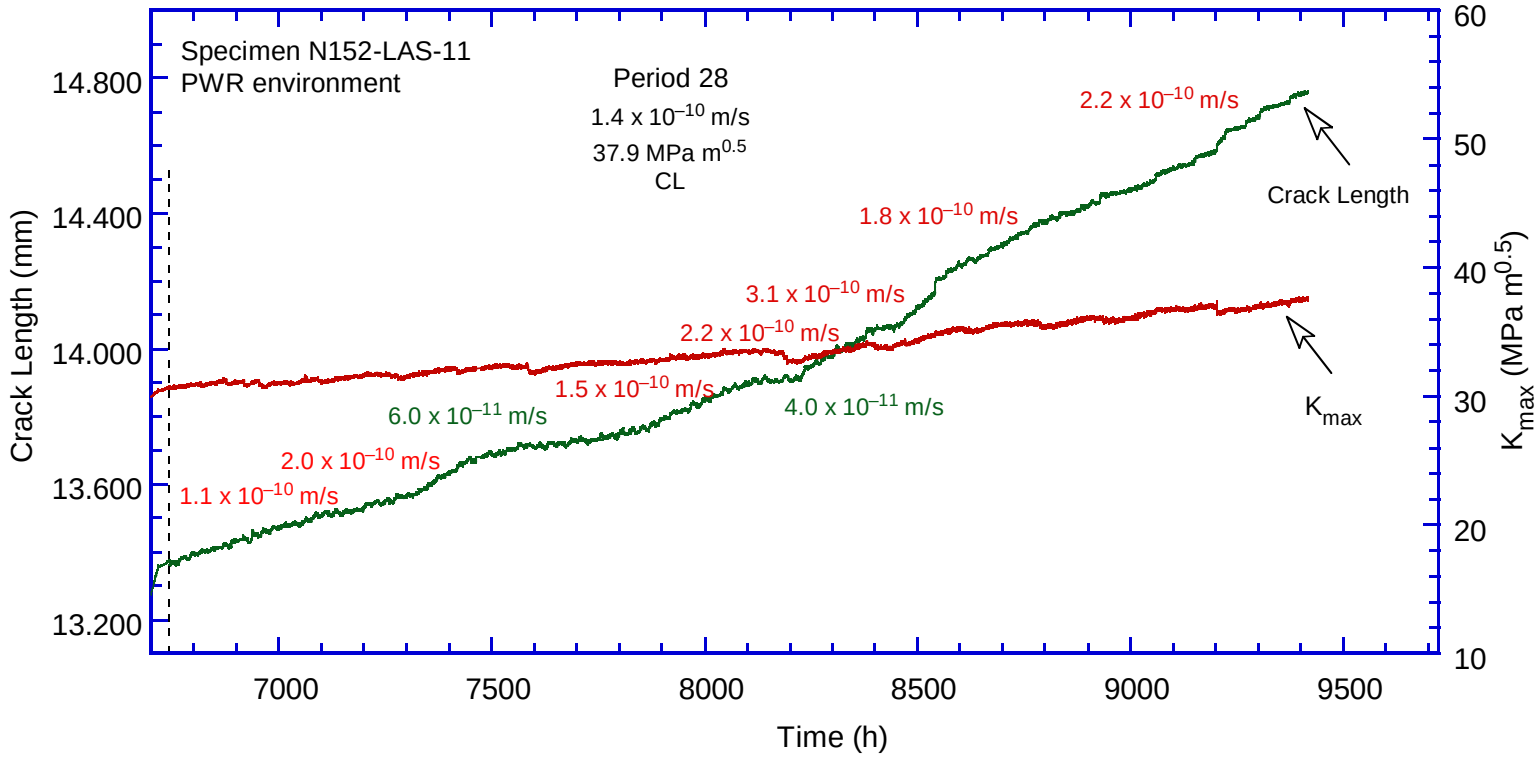
Alloy 152-LAS dilution specimens





- Cyclic response from the two specimens in excellent agreement
- N152-LAS-11: areas of “low” and “high” SCC susceptibility
- Post test examination will show that these are off-plane/in-plane cases

Alloy 152-LAS dilution specimen N152-LAS-11

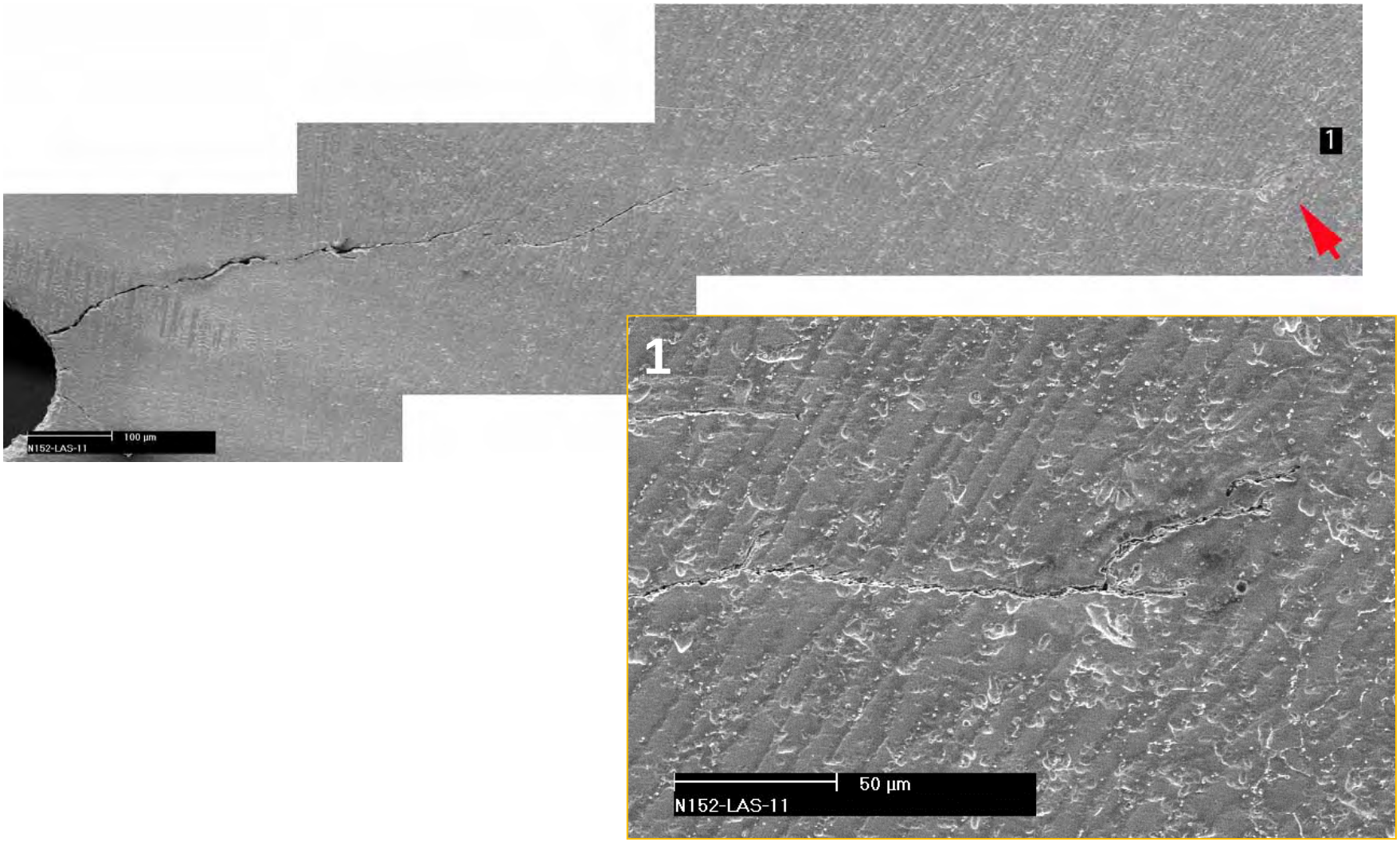


- Average SCC CGR = 1.4 $\times 10^{-10}$ m/s

Alloy 152-LAS dilution specimen N152-LAS-11

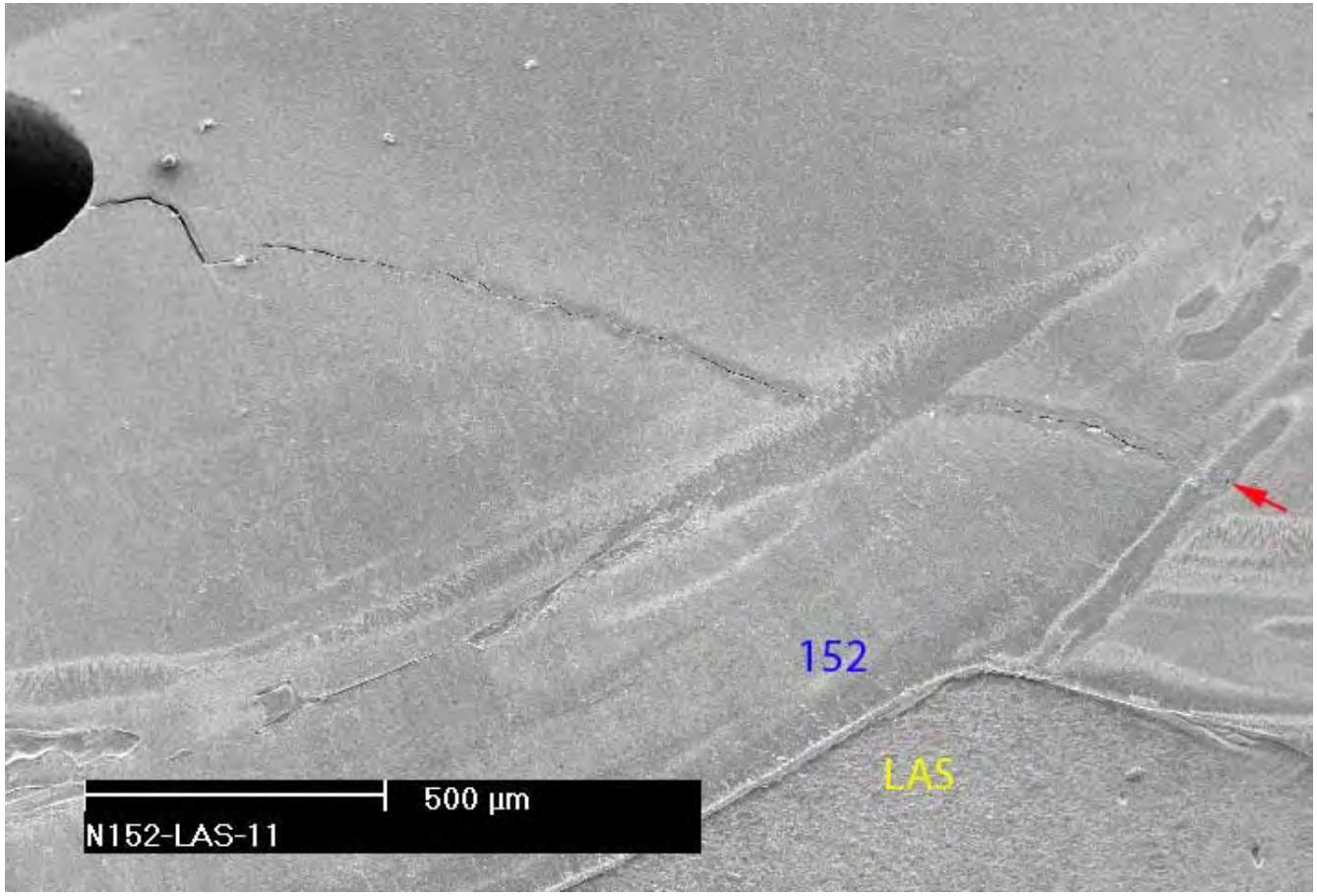
- Post-test examination confirmed alignment
- Subsequent examination confirmed that the crack was in Alloy 152

N152-LAS-11 - Side surface 1



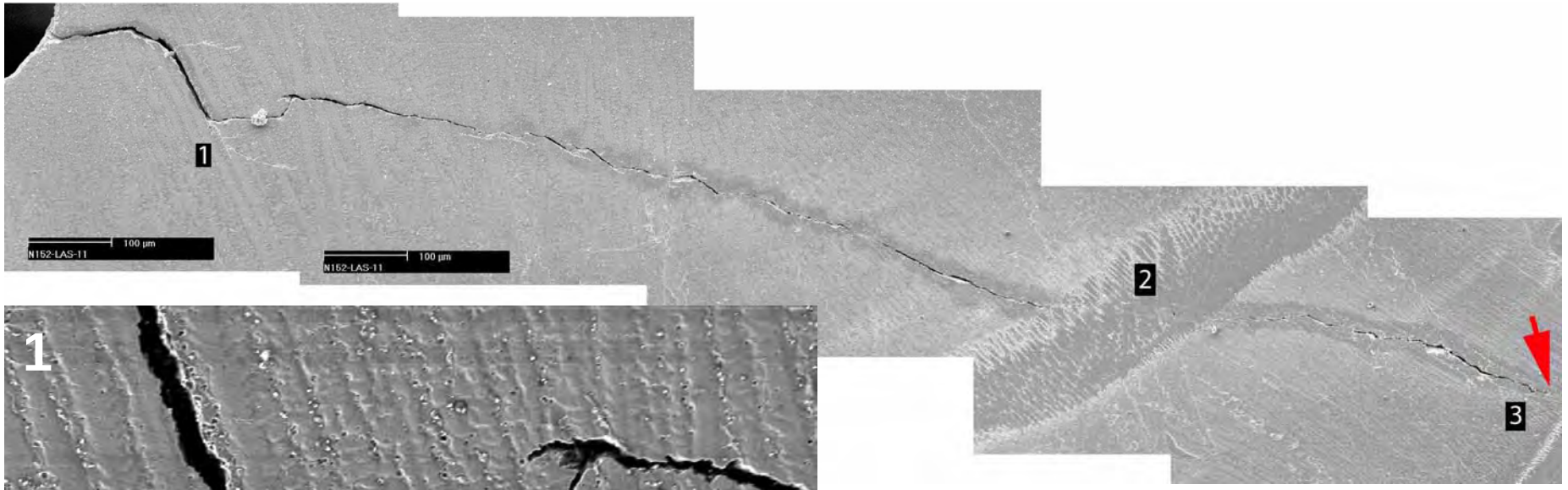
- Test appears to have started and ended in the Alloy 152 weld

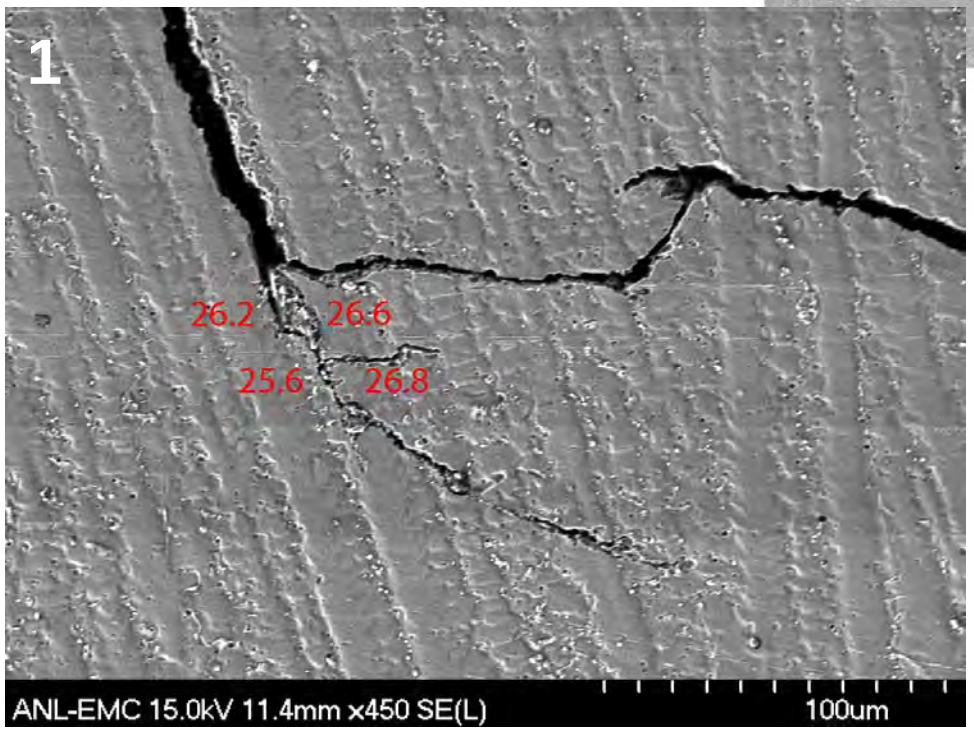
N152-LAS-11 - Side surface 2



- Test appears to have started and ended in the Alloy 152 weld

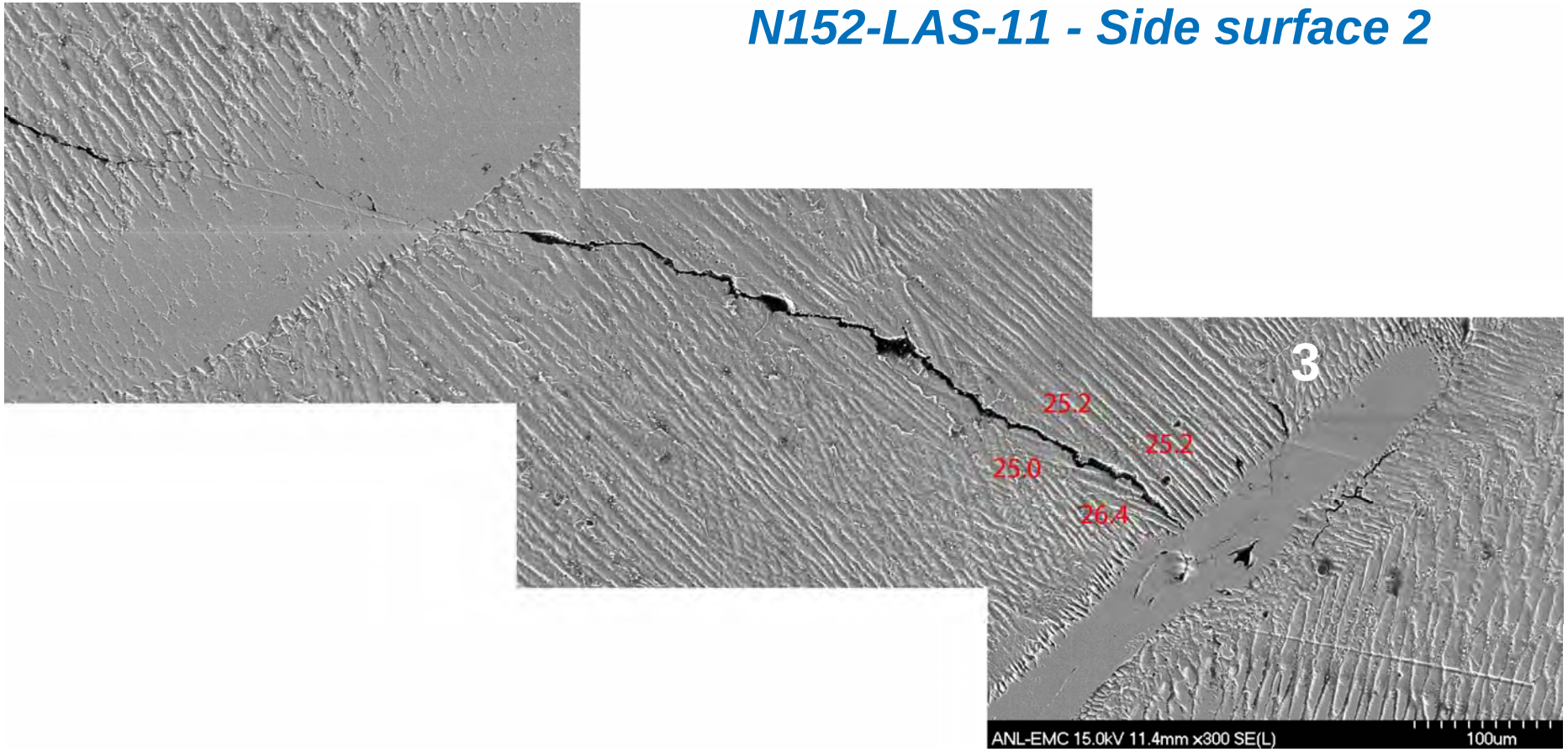
N152-LAS-11 - Side surface 2





- Location 1 (IG-1) – low SCC CGRs
- Average composition (wt. %) at location 1: 26.1 Cr - 24.4 Fe - 49.5 Ni

N152-LAS-11 - Side surface 2

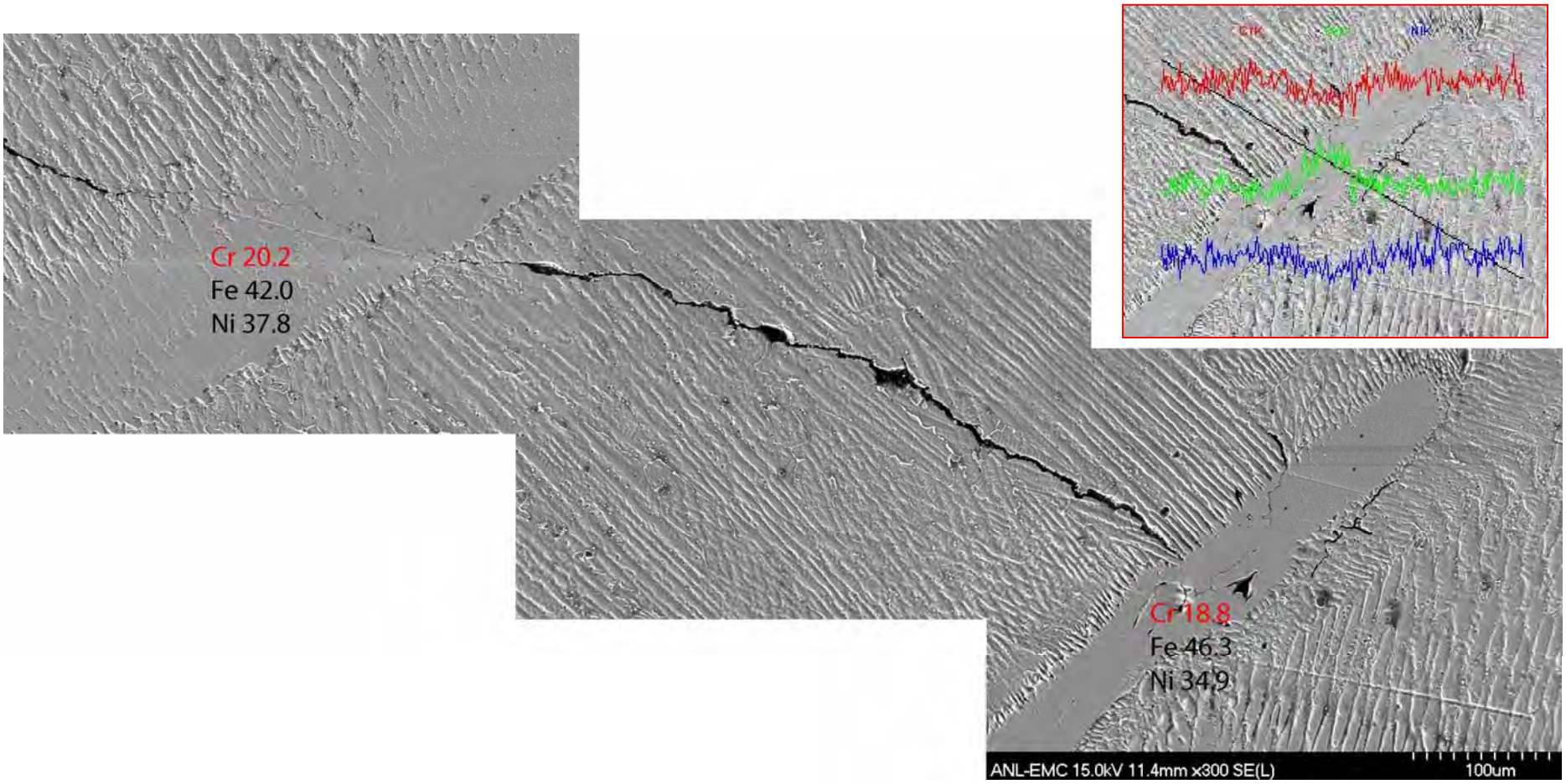


- "Streaks" appear to slow down/arrest SCC – will be addressed separately
- Location 3 (IG-2) – susceptible to PWSCC
- Average composition (%) at location 3: 25.4 Cr – 26.6 Fe – 48.0 Ni

(nearly identical to that measured at location 1)

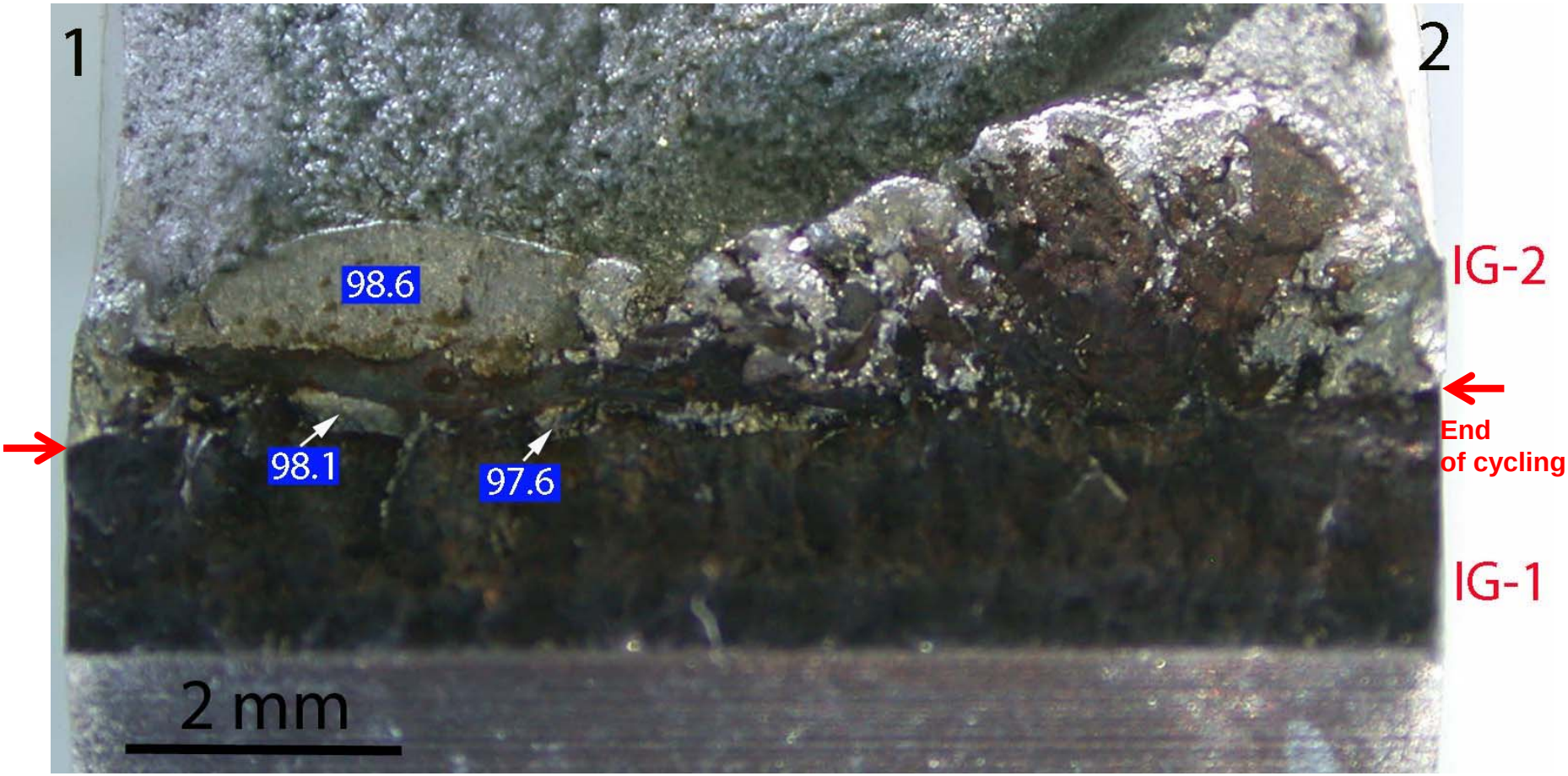
- Chemical composition does not seem to account for the apparent 10x increase in SCC CGRs

N152-LAS-11 - Side surface 2



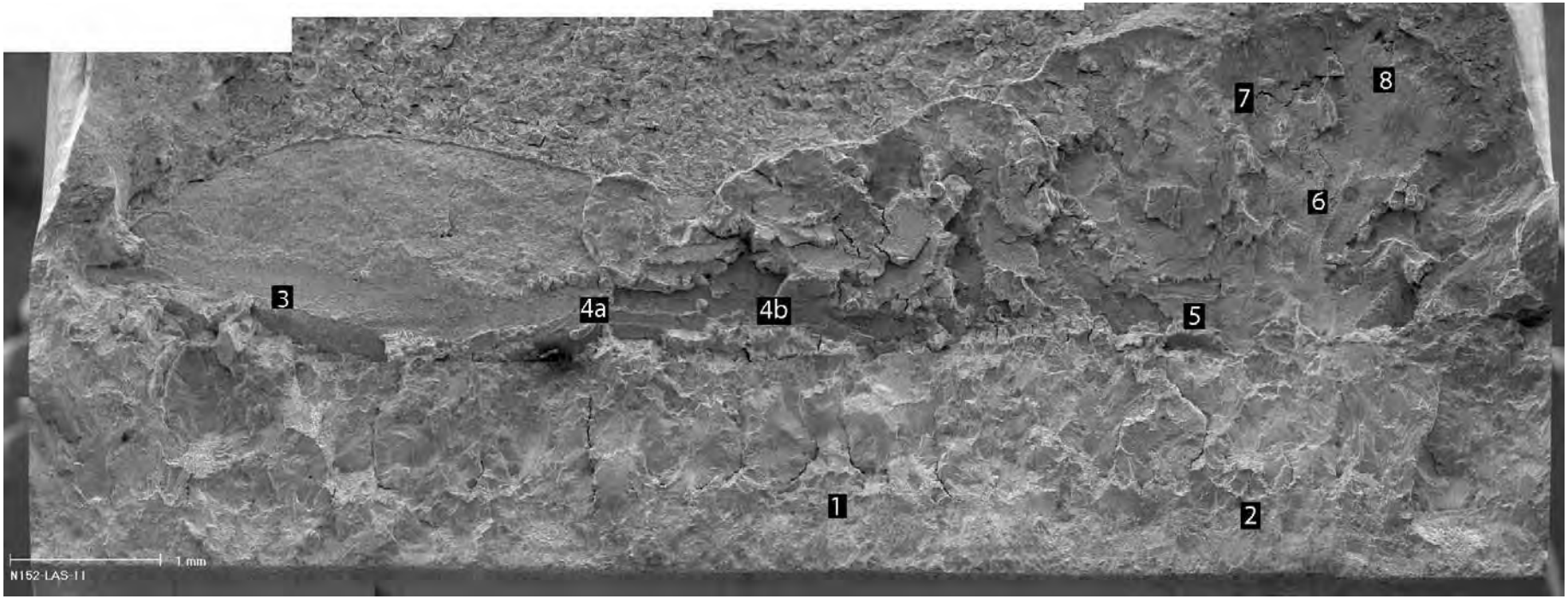
- "Streaks" appear to slow down/arrest SCC
- Average composition (wt. %): 19 Cr – 44 Fe – 36 Ni

Fracture surface of N152-LAS-11



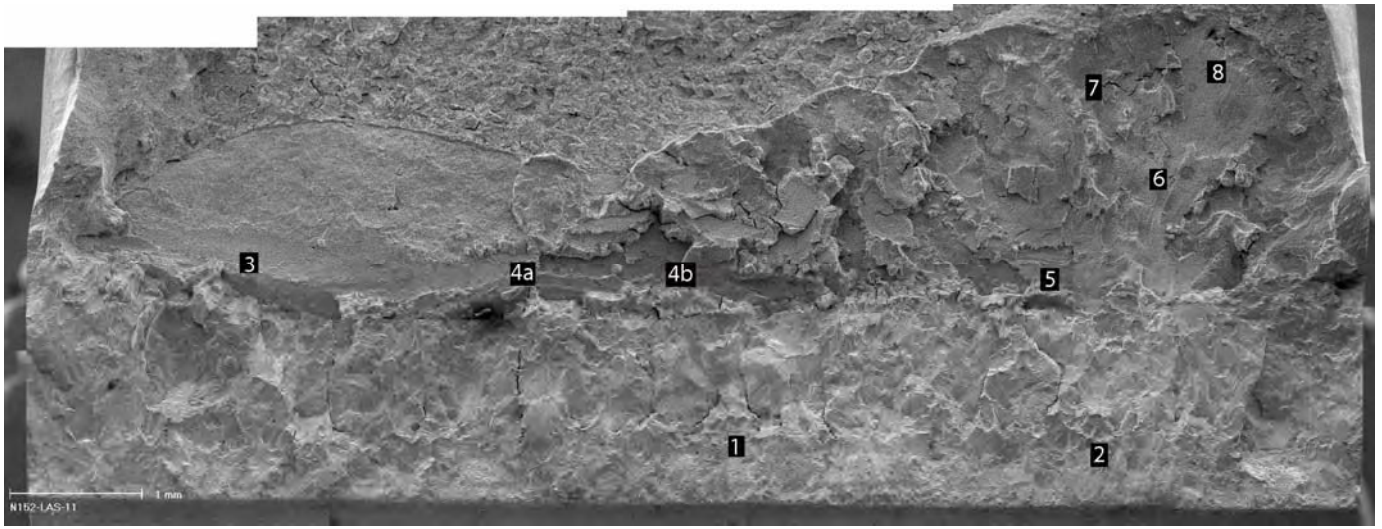
- LAS confirmed by EDX (Fe content in wt.% is shown)
- LAS arrested crack advance, large regions ended up as unbroken ligaments (at CL), but the SCC found a way around it
- Overall, factor 10 more growth under constant load than the 0.14 mm measured by the DC potential

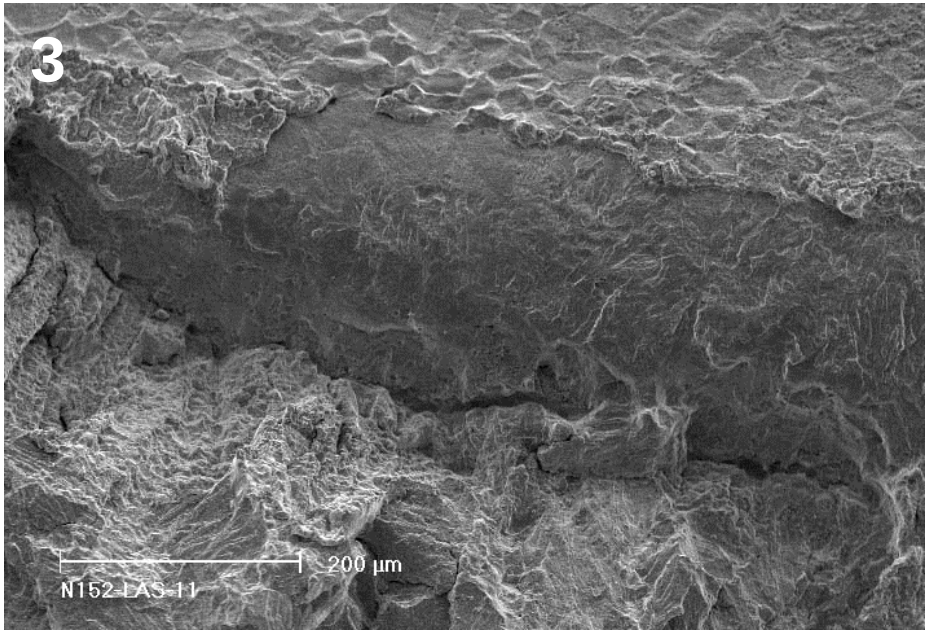
Fracture surface of N152-LAS-11

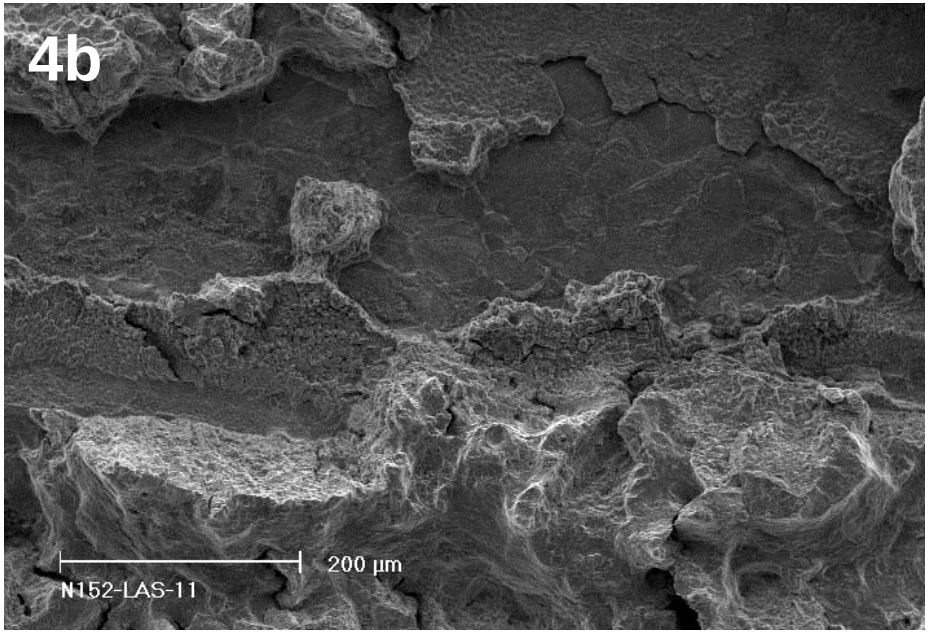


- Areas of interest:
- IG-1 (1, 2)
- Crack interaction with the LAS (3, 4a, 4b, 5)
- Crack propagation into the Alloy 152 weld (6, 7, 8)

N152-LAS-11



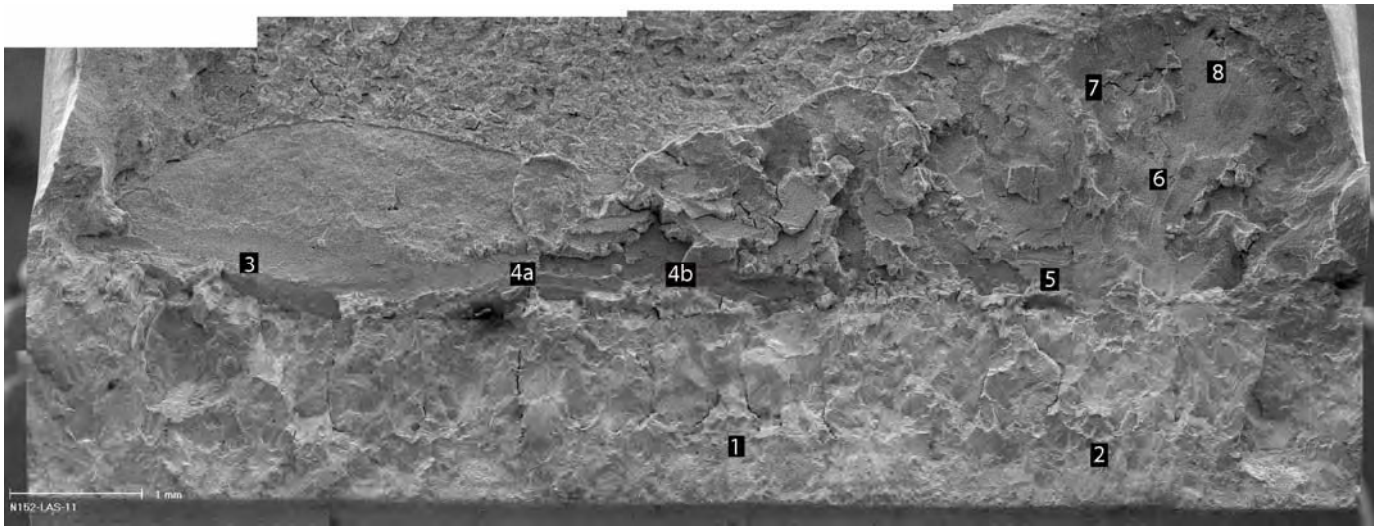


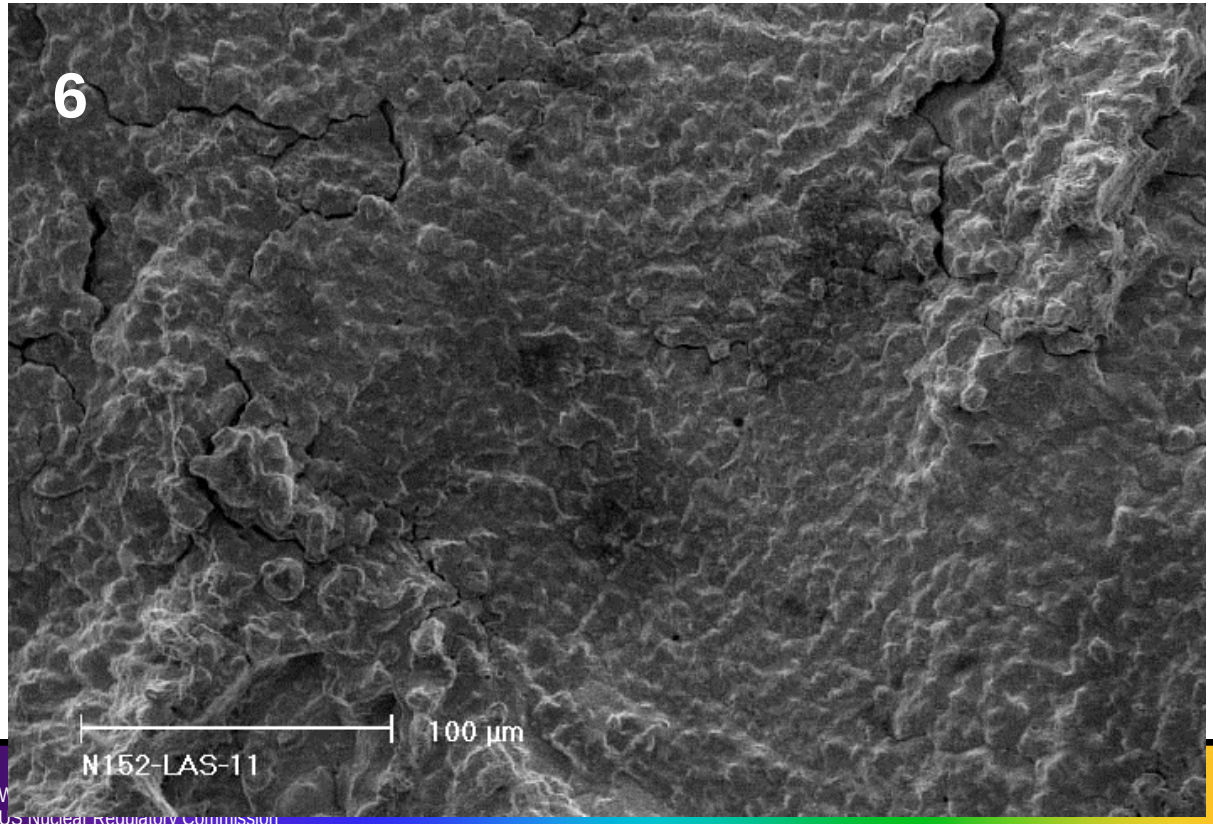


- Intersection with LAS results in unbroken ligaments (appear as unoxidized material)

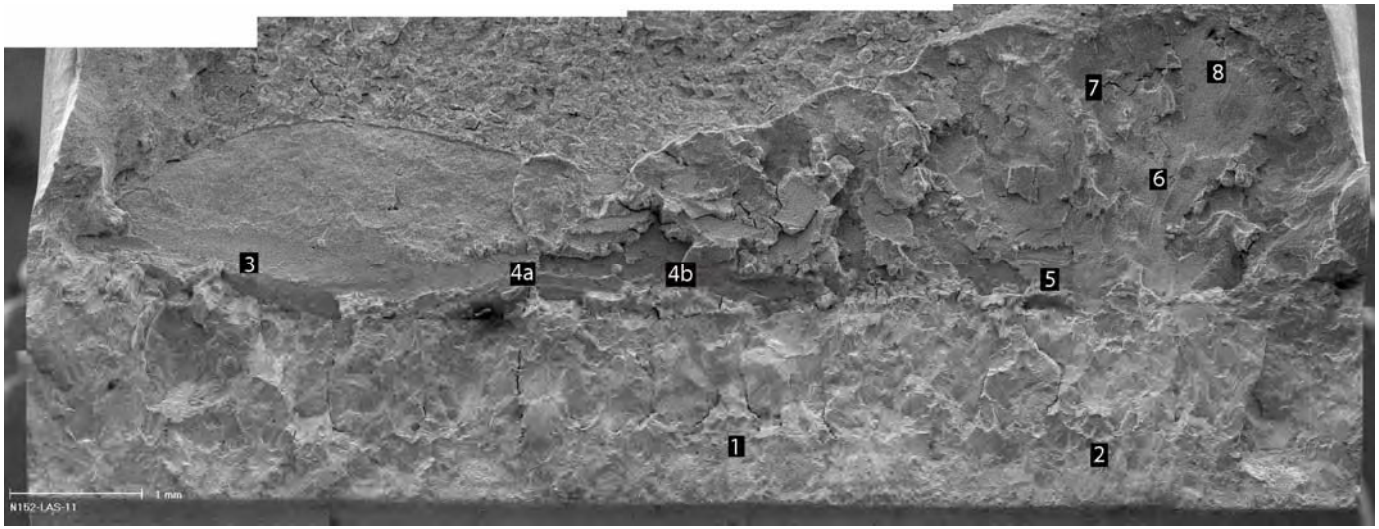
N152-LAS-11

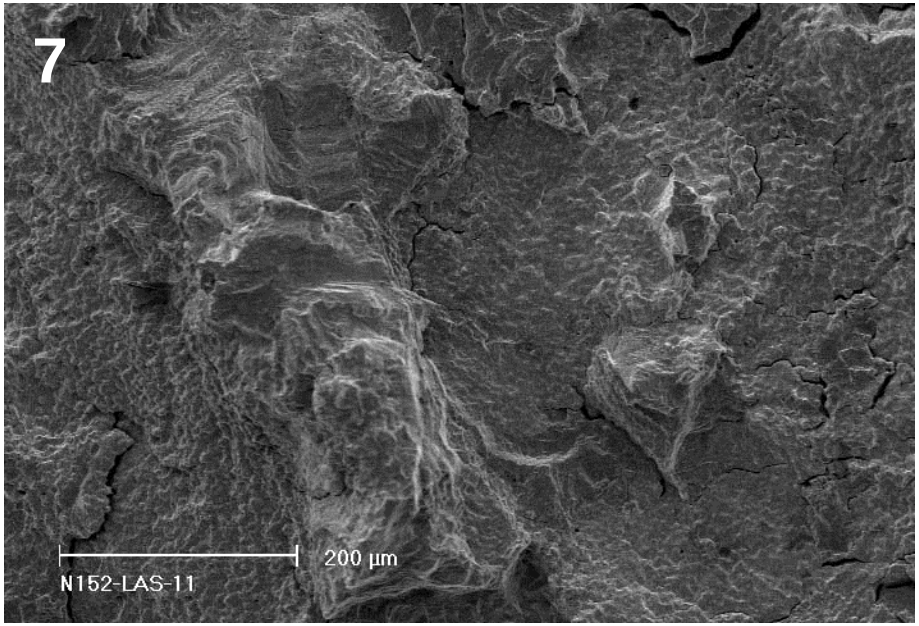
- IG interdentdritic growth in ST orientation (similar to the Alloy 52M WOL specimen)

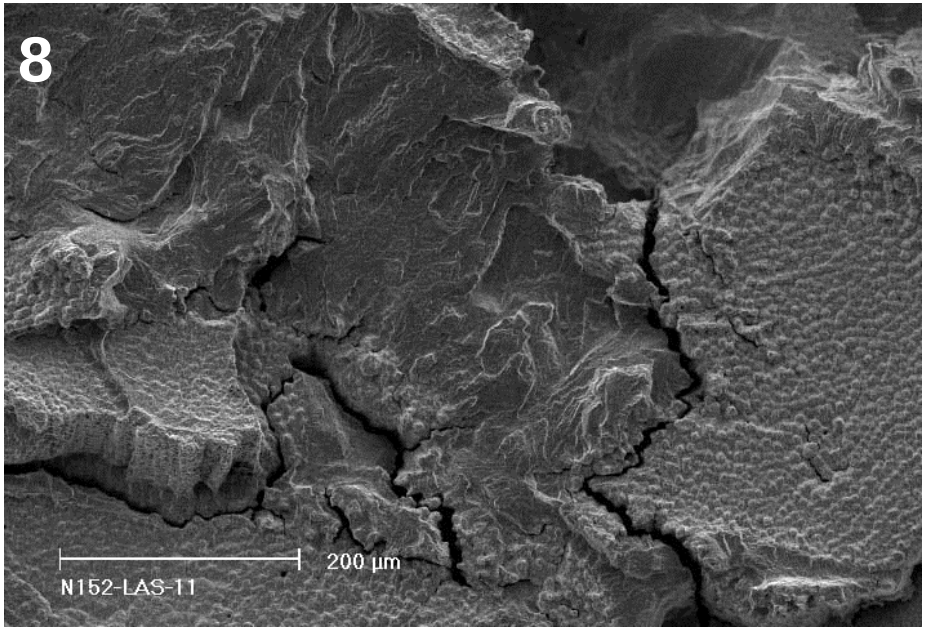




N152-LAS-11

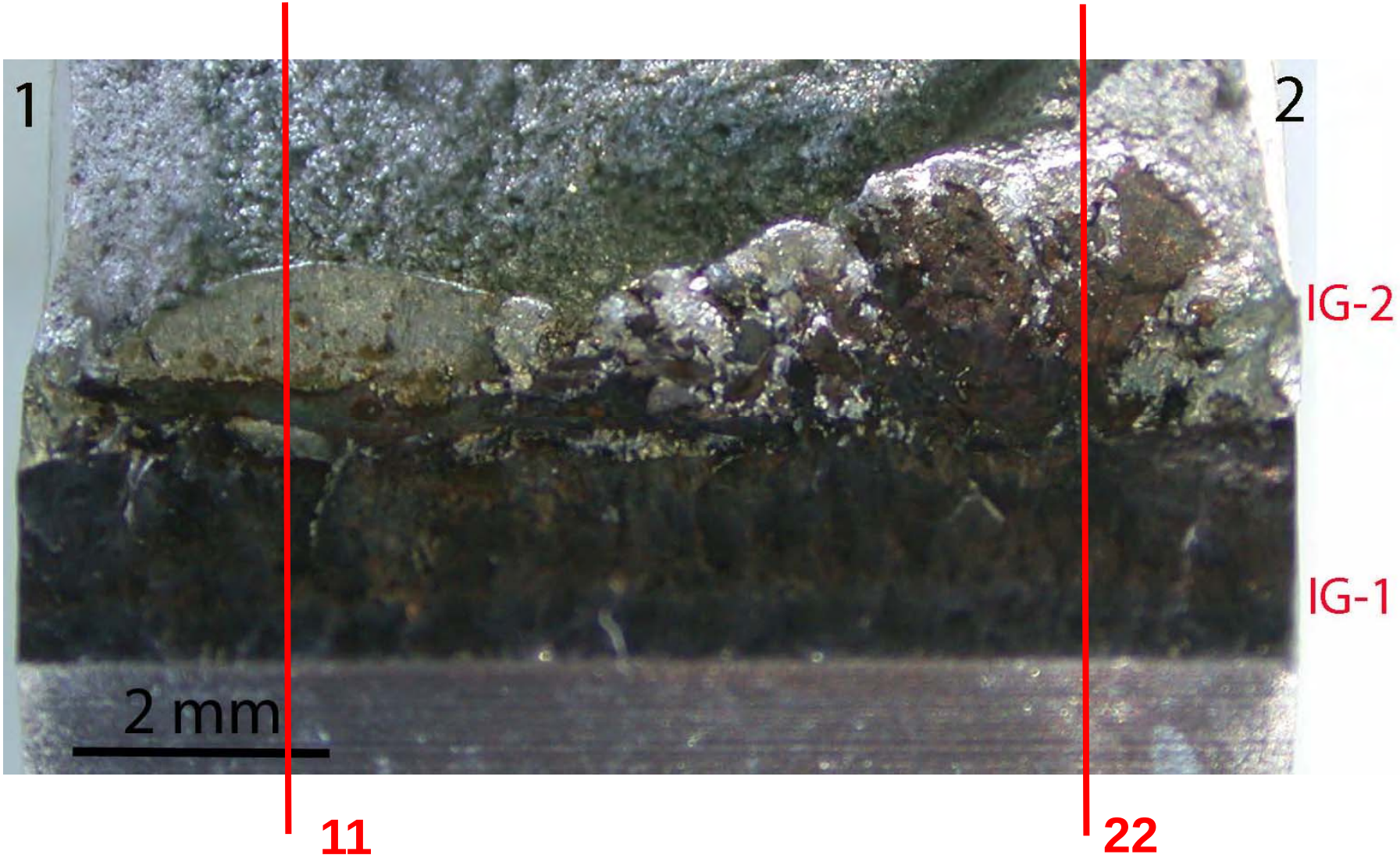




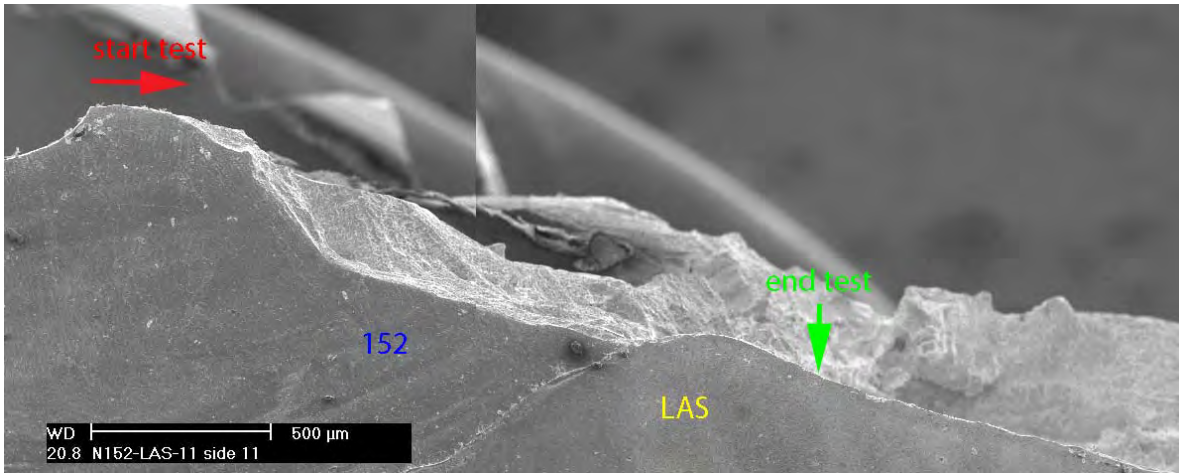


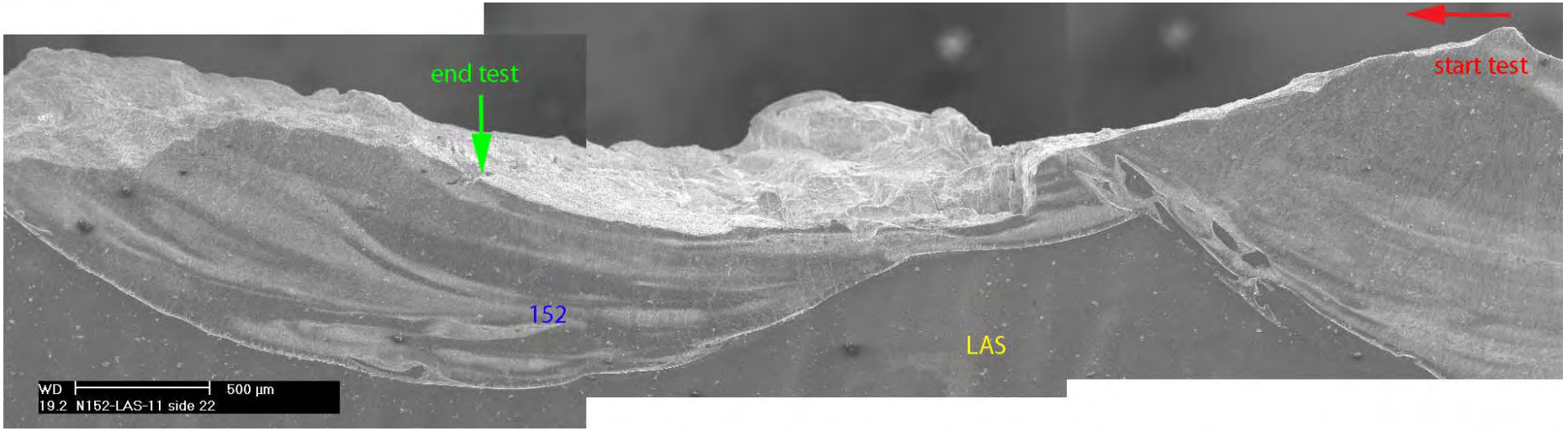
- IG interdentdritic growth in ST orientation (similar to the Alloy 52M WOL specimen)

Additional cross sections 11 and 22



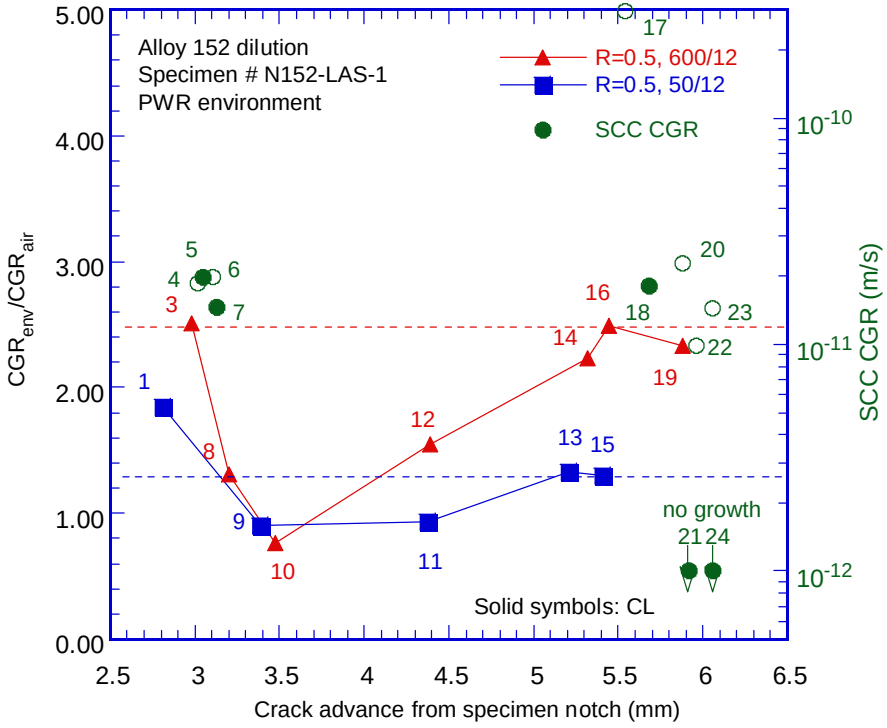
N152-LAS-11 – Cross sections 11 and 22

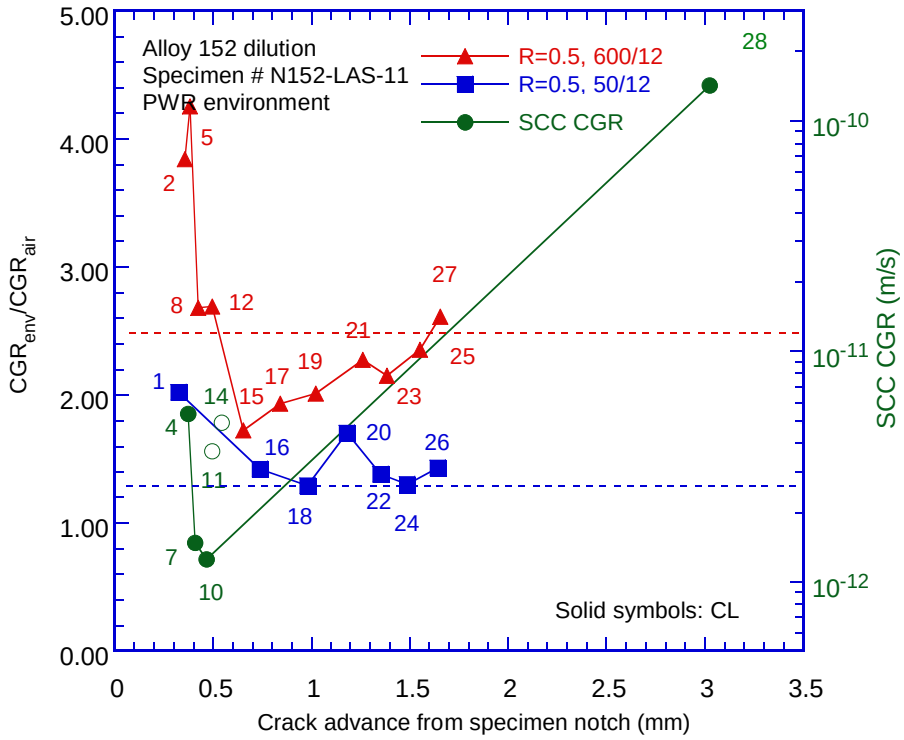




- Interaction with LAS stops arrest SCC (11)
- SCC continues in the Alloy 152 butter for millimeters

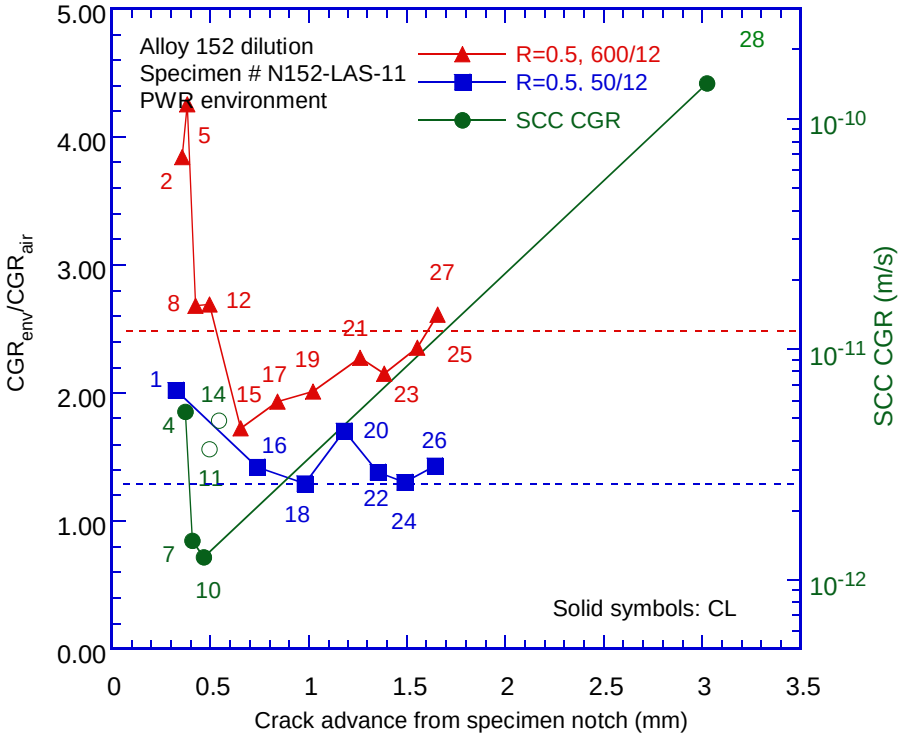
Alloy 152-LAS dilution specimens

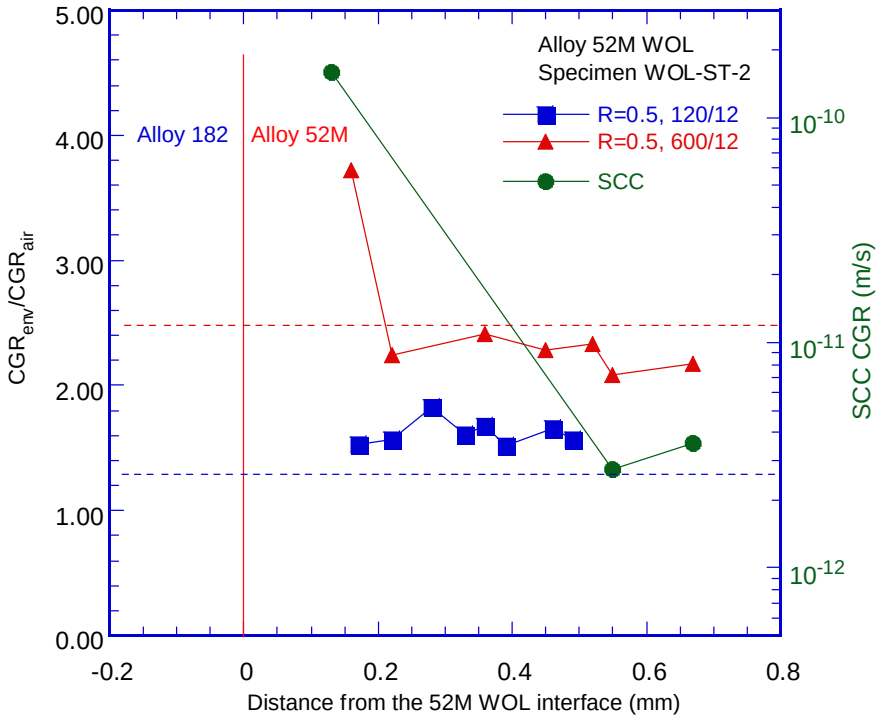




- Cyclic and SCC CGRs data from the two specimens in excellent agreement
- SCC-"susceptible" locations were identified in each specimen
- Off-plane SCC appears responsible for the scatter

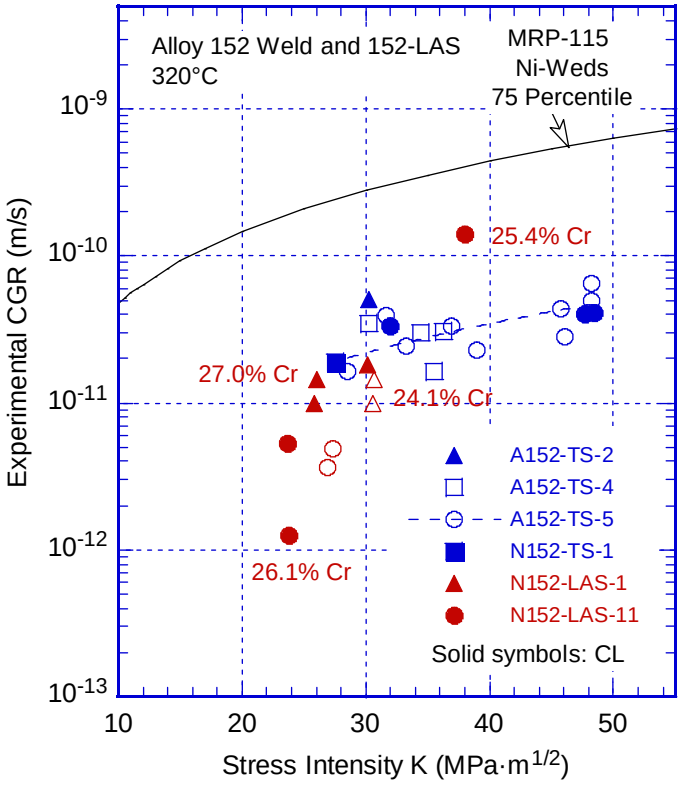
Alloy 152-LAS dilution layer – comparison with Alloy 52M WOL

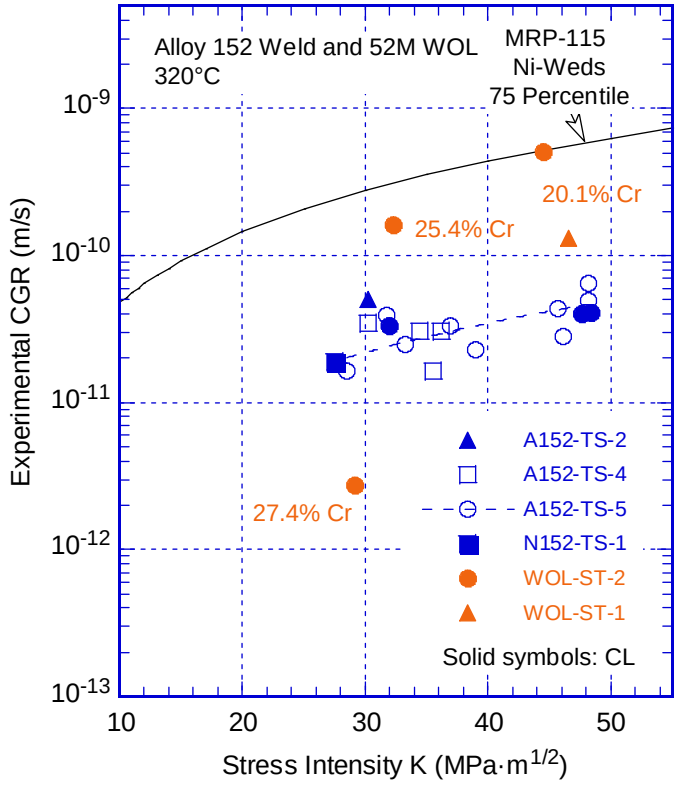




- Cyclic response from the two alloys in excellent agreement
- Environmental enhancement is a good predictor for PWSCC behavior

SCC CGR for Alloy 52M and 152 Welds in 1st Layer Configurations





- Alloy 152 first layer: role of Cr is not straightforward
- High SCC CGRs in Alloys 152 and 52M in 1st layer configurations
- Similar fracture modes (normal to the dendritic grains)
- Interfaces: 52M-182 is the most susceptible, while the 152-LAS is resistant

Conclusions

- SCC CGR testing was undertaken in the 1st layer of Alloy 152-LAS
- Test management was key: the ability to reproduce and interpret cyclic CGR response was critical for the success of those tests
- All locations were found to be susceptible to SCC, however, the preferred crack direction was off-plane in most cases
- The highest SCC CGR for Alloy 152 first layer butter showed approx. 2x improvement vs. MRP-115 75th pct. curve; fracture mode was normal to the dendritic grains
- Role of Cr is unclear: did not find a correlation between SCC response and Cr content, low Cr (20% wt. Cr) “streaks” were SCC-resistant
- Comparison with Alloy 52M WOL first layer: Similar cyclic and SCC CGR response, and fracture mode