# Crack Growth Response of Alloy 152 and 52 Weld Metals in Simulated PWR Primary Water

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# Alloy 152/52 Crack Growth Tests in Simulated PWR Water at PNNL

- *Testing to date has been performed on specimens fabricated from industry mockup welds.*
- **Alloy 152/52 - Five specimens complete, six on-going**
  - MHI alloy 152 mockup: specimen CT013 in as-welded (AW) condition
  - MHI alloy 152 mockup: specimen CT017 in AW + LAS heat treatment (610°C/12 h/AC) condition, specimen CT018 in AW condition
  - Alloy 52: specimen CT024 is AREVA mockup in AW condition, specimen CT025 is MHI mockup in AW condition
  - Ringhals alloy 82/52M inlay mockup: CT030 & CT031 both in AW condition (now testing in alloy 52M inlay material)
  - Alloy 52: specimen CT032 is AREVA mockup in AW condition, specimen CT025 is MHI mockup in AW condition (on-going)
  - Ringhals alloy 182/52M overlay mockup: CT034 & CT035 both in AW condition (now establishing crack growth in alloy 182 region)

# Alloy 152/52 Materials

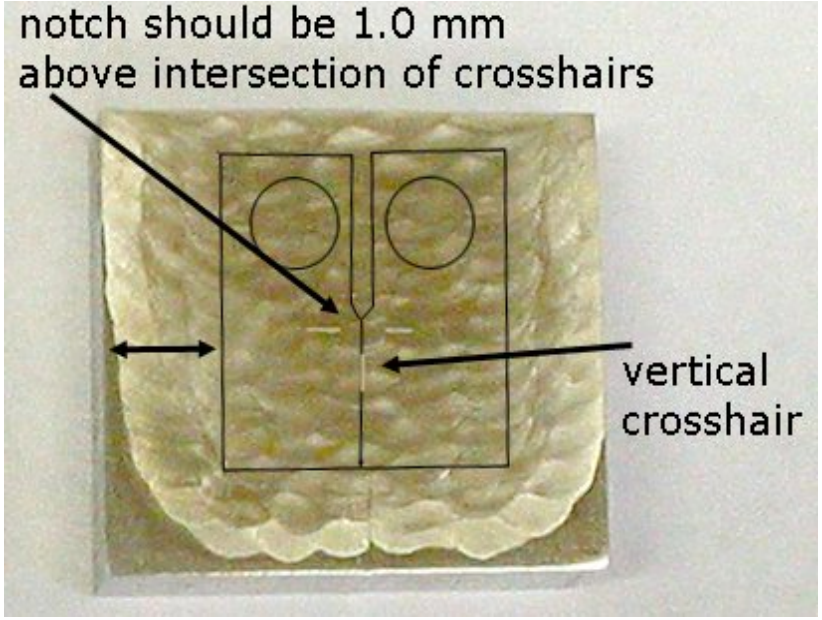
- Weld metal sources
  - Alloy 152 and alloy 52 U-groove mockups made by MHI for Kewaunee
  - Alloy 52 butt weld made by AREVA
- Compositions
  - MHI Alloy 152, heat 307380: 9.1Fe, 28.7Cr, 0.03C, 3.6Mn, 0.33Si, 0.15Al, 0.12Ti, Bal Ni
  - MHI Alloy 52, heat NX2686JK: 10.0Fe, 29.1Cr, 0.024C, 0.25Mn, 0.13Si, 0.71Al, 0.52Ti, 0.01$N_2$, Bal Ni
  - AREVA Alloy 52, heat NX3926JK: 10.0Fe, 29.1Cr, 0.024C, 0.25Mn, 0.13Si, 0.71Al, 0.52Ti, 0.01$N_2$, Bal Ni
- Thermomechanical conditions
  - All specimens but one tested in as-welded (AW) condition
  - One alloy 152 specimen heat treated at 610°C/12 h/AC (LAS heat treat)

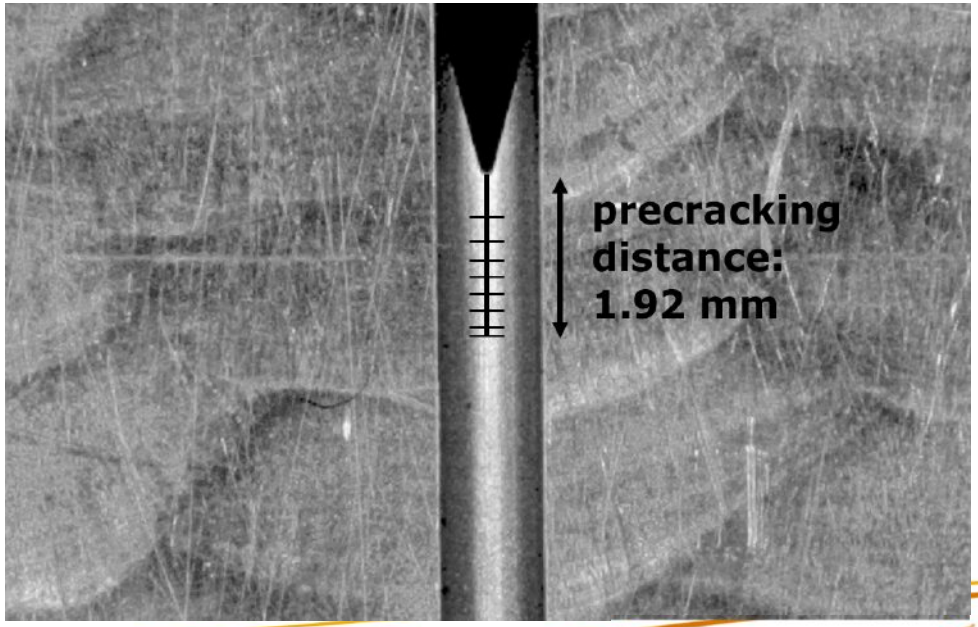
# Crack Growth Testing Methodology

- Alloy 690/152/52 are very resistant to stress corrosion cracking in nearly all material conditions, has been very difficult to obtain stable crack growth.
- As a means to assess constant K growth rates and obtain maximum SCC crack front engagement, different transitioning methods have been investigated and are routinely used.
  - Varied R from 0.5 to 0.7
  - Varied hold time
  - Varied length of time at each step during transitioning
  - Varied cyclic loading waveform rise time and fall time
- Transition to constant K several times in each test.
- If possible, examine crack growth response at two K levels.

# Fabrication of Specimens from Weldments

- Notch and precrack positioned to allow SCC growth to begin in the middle of a weld pass.
- Crack oriented along dendrite direction as best as possible.
- In some instances, specimens were machined to evaluate different weld passes.



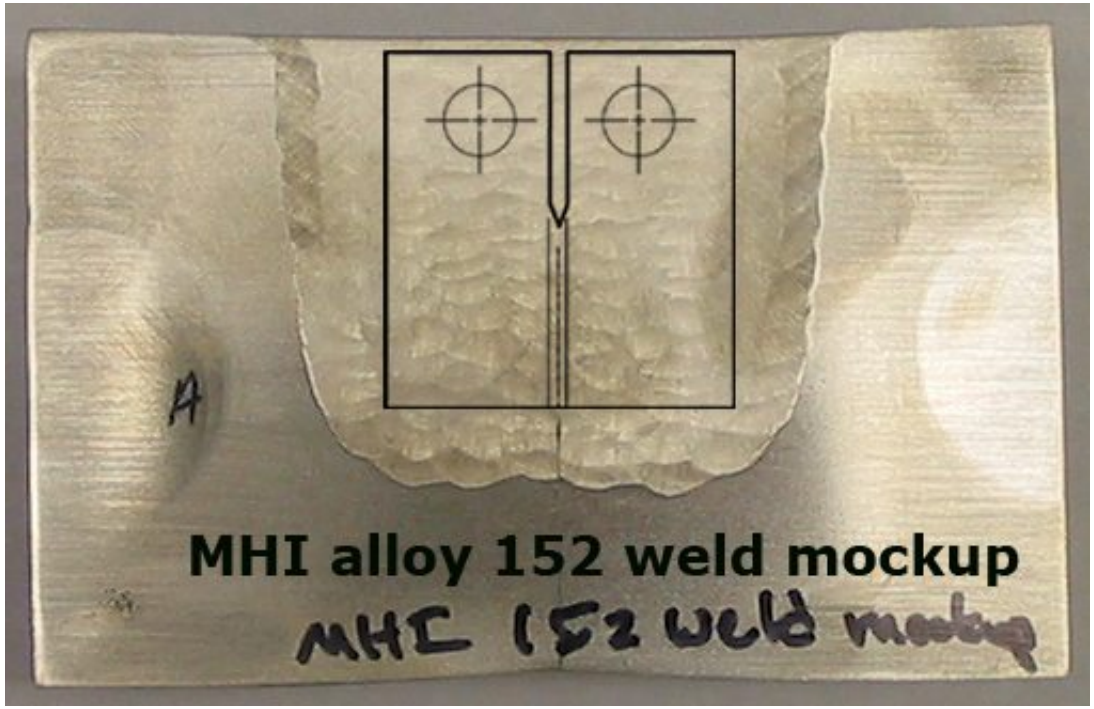



# Alloy 152/52 Crack Growth Tests in Simulated PWR Water at PNNL

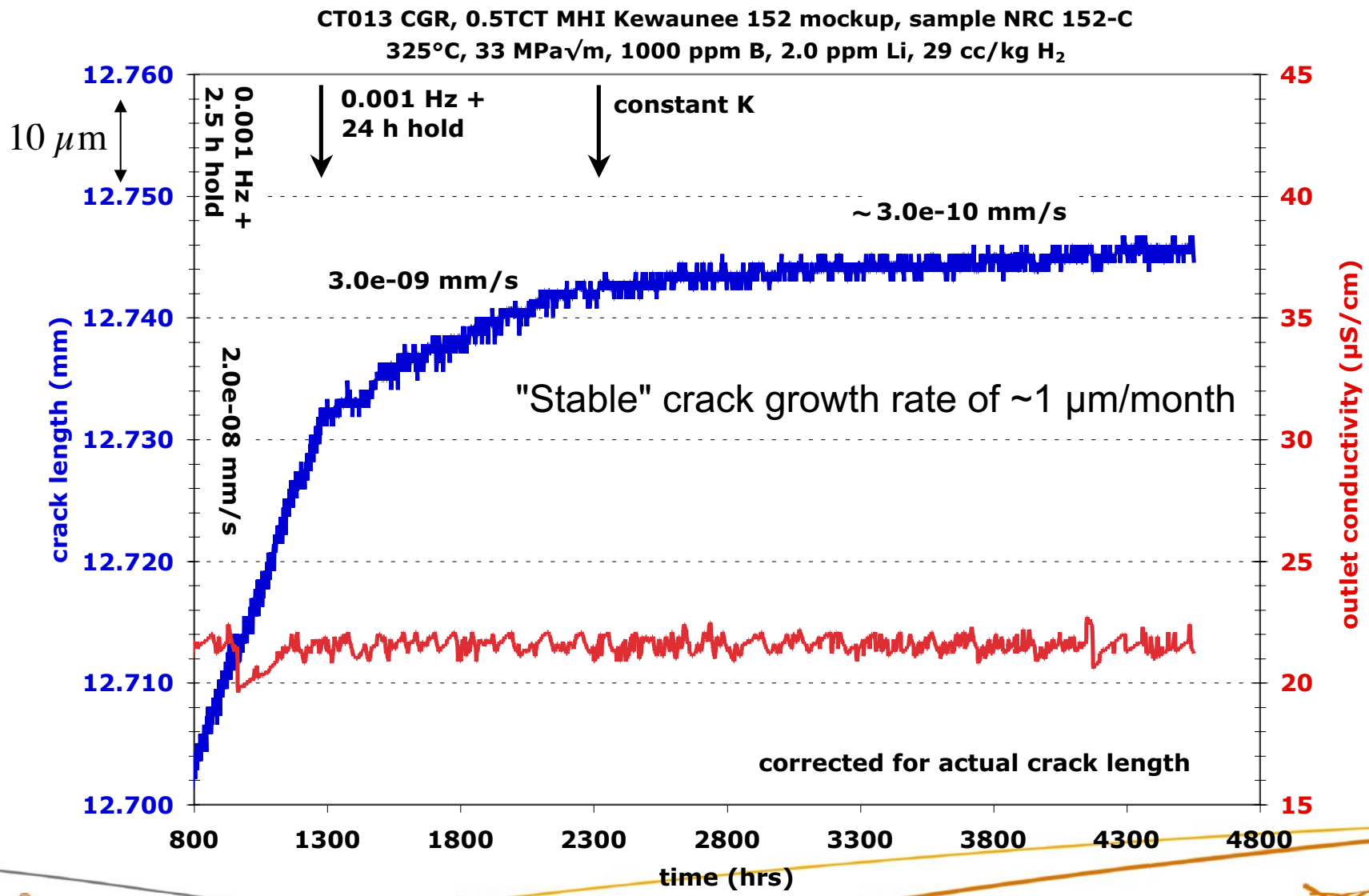
- **Alloy 152/52 - Five specimens complete**
  - ***MHI alloy 152 mockup: specimen CT013 in as-welded (AW) condition***
  - ***MHI alloy 152 mockup: specimen CT017 in AW + LAS heat treatment (610°C/12 h/AC) condition, specimen CT018 in AW condition***
  - Alloy 52: specimen CT024 is AREVA mockup in AW condition, specimen CT025 is MHI mockup in AW condition

# MHI Alloy 152 U-Groove Mockup

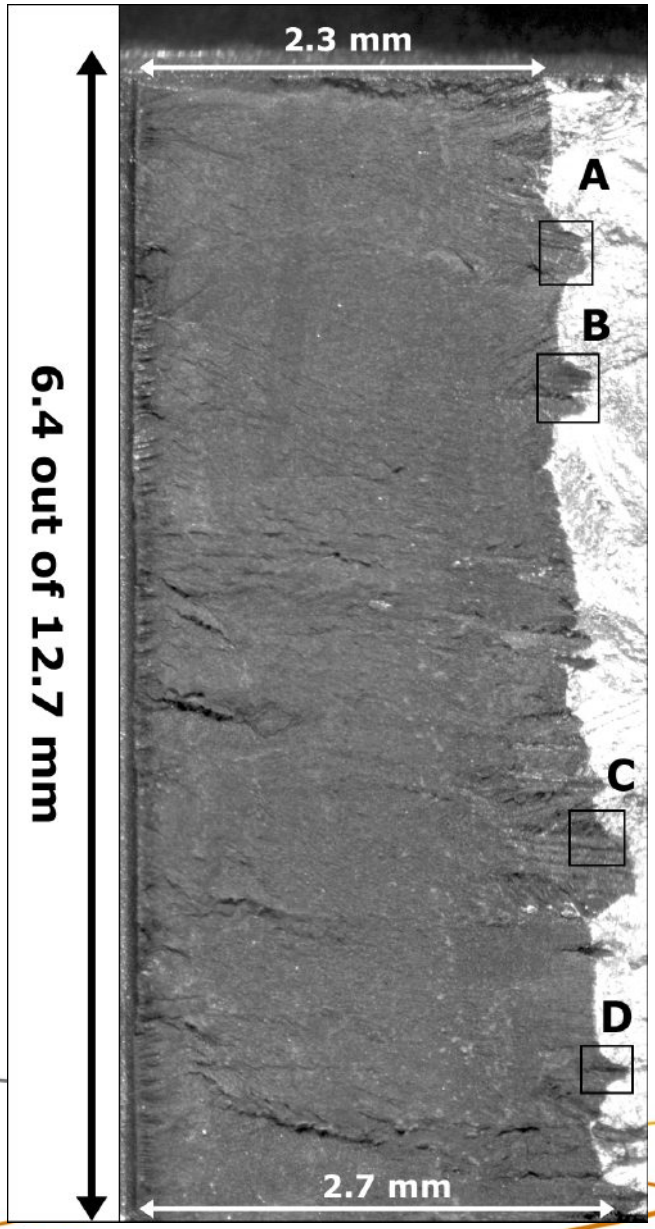
- U-groove weld joining 304 SS plate.
- Specimens oriented to test weld passes near middle of weld.



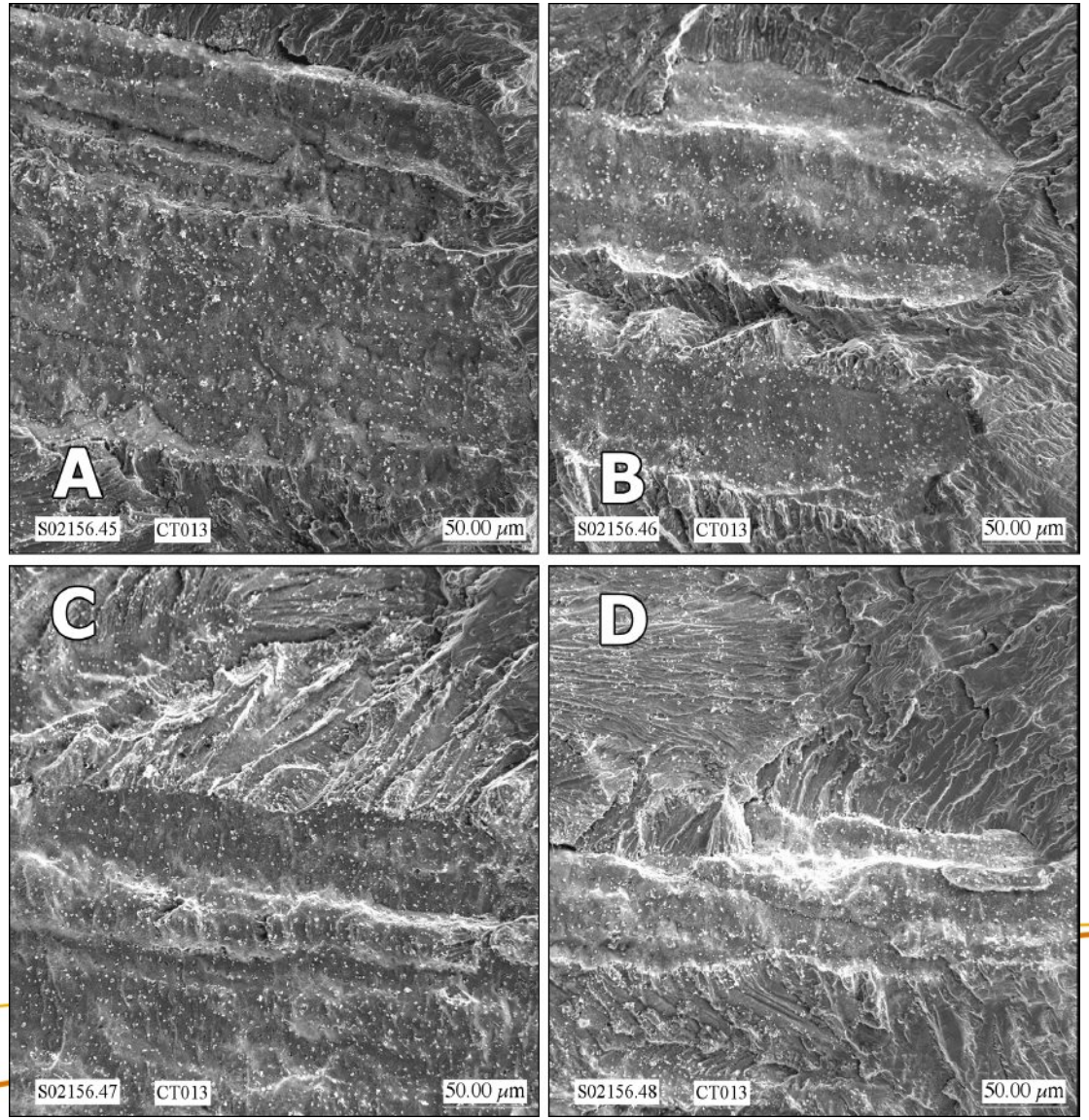
# MHI Alloy 152 Test #1



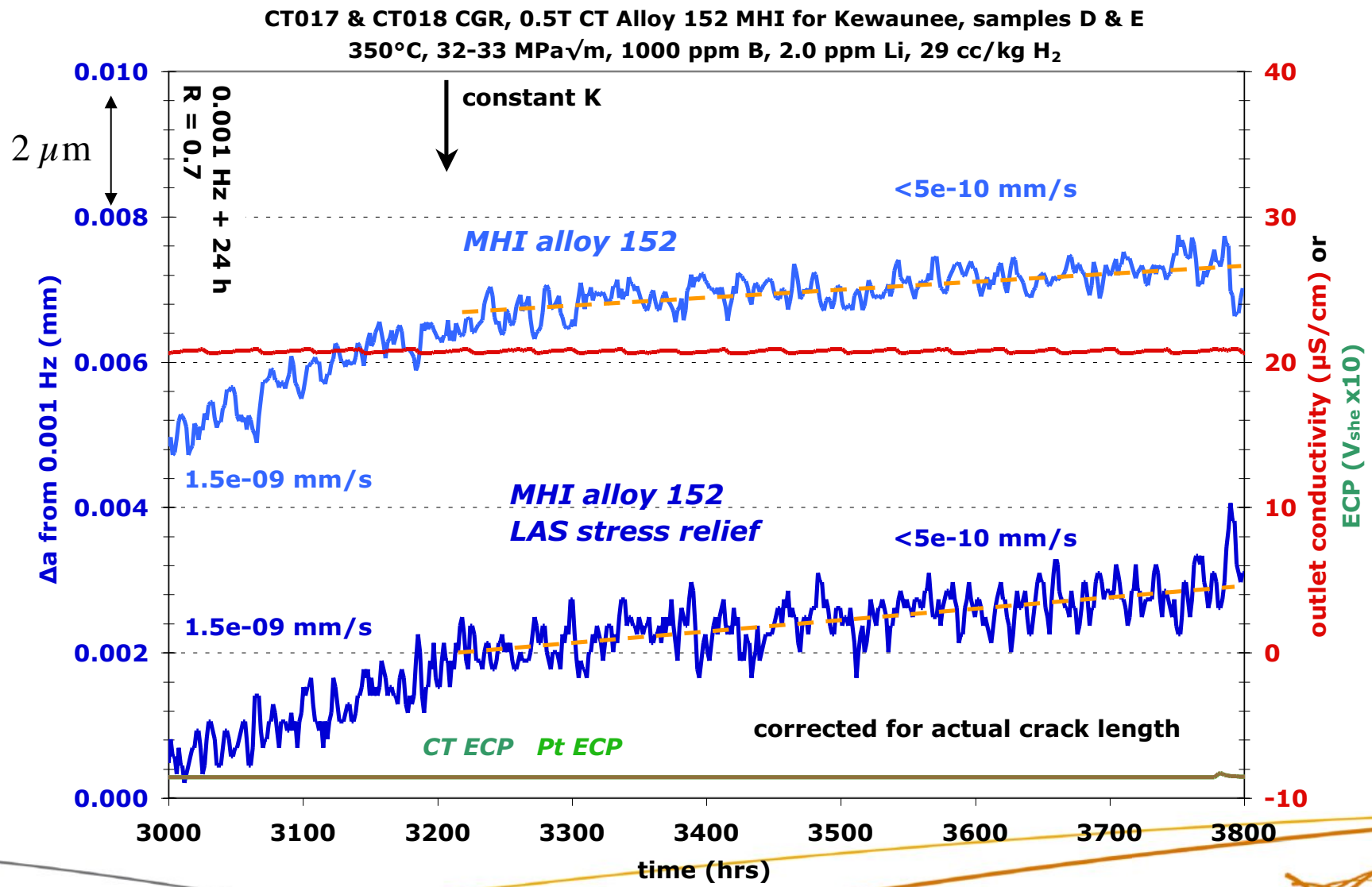
# MHI Alloy 152 Test #1
# Crack Growth Surface




~35% IG, CGR of IG fingers is ~$1.5 \times 10^{-9}$ mm/s



# MHI Alloy 152 Test #2
# Constant K at 350°C, 32-33 MPa√m




Extremely slow crack growth rate consistent with previous test.

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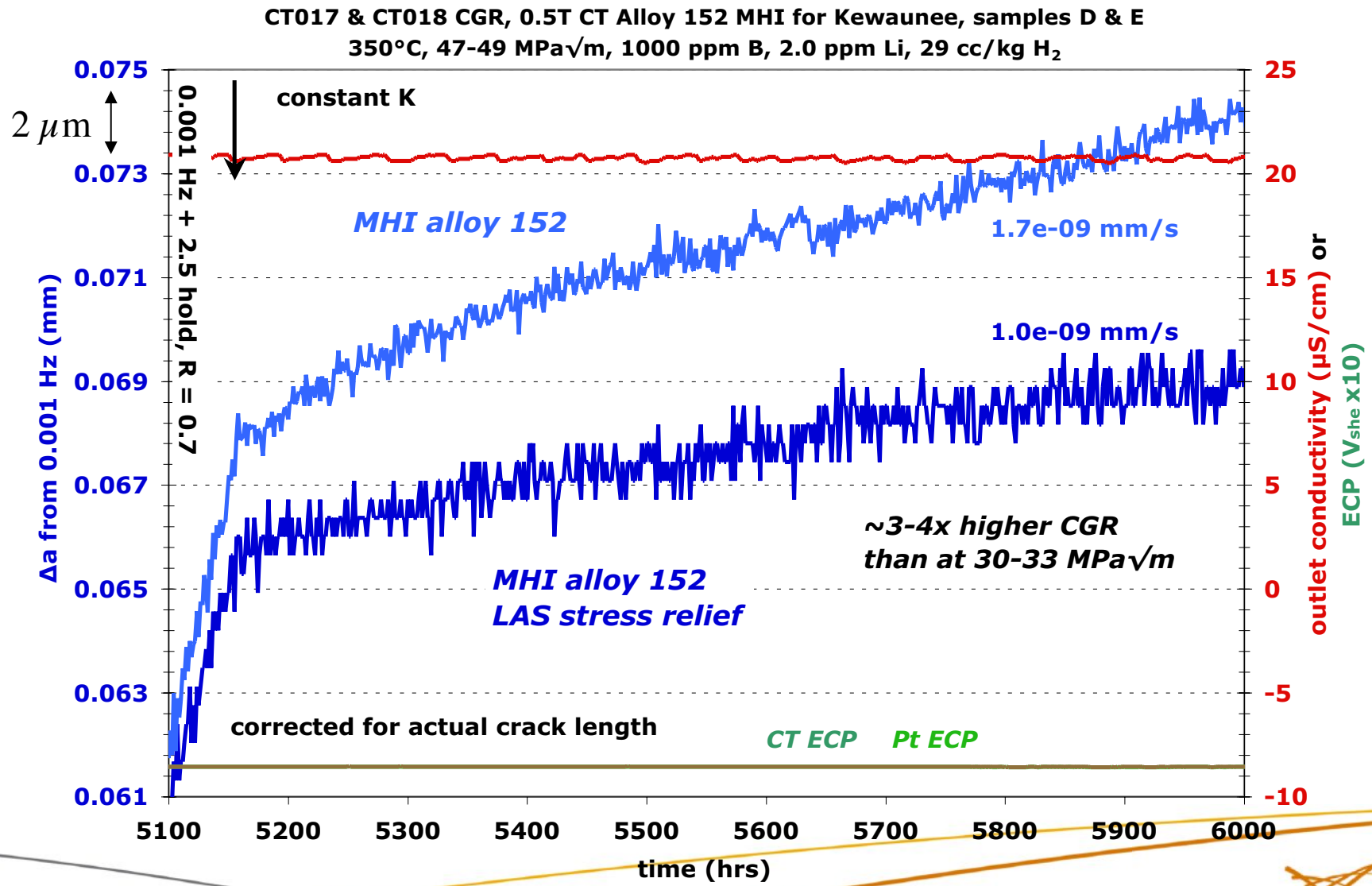
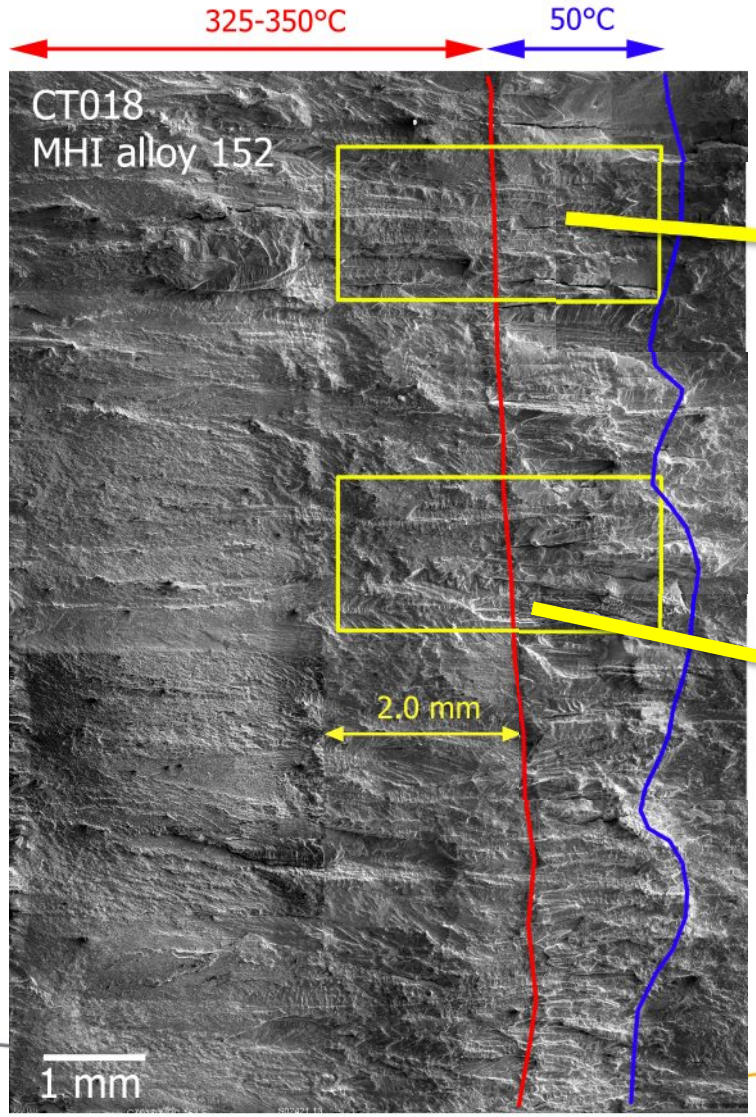
# MHI Alloy 152 Test #2
# Constant K at 350°C, 47-49 MPa√m

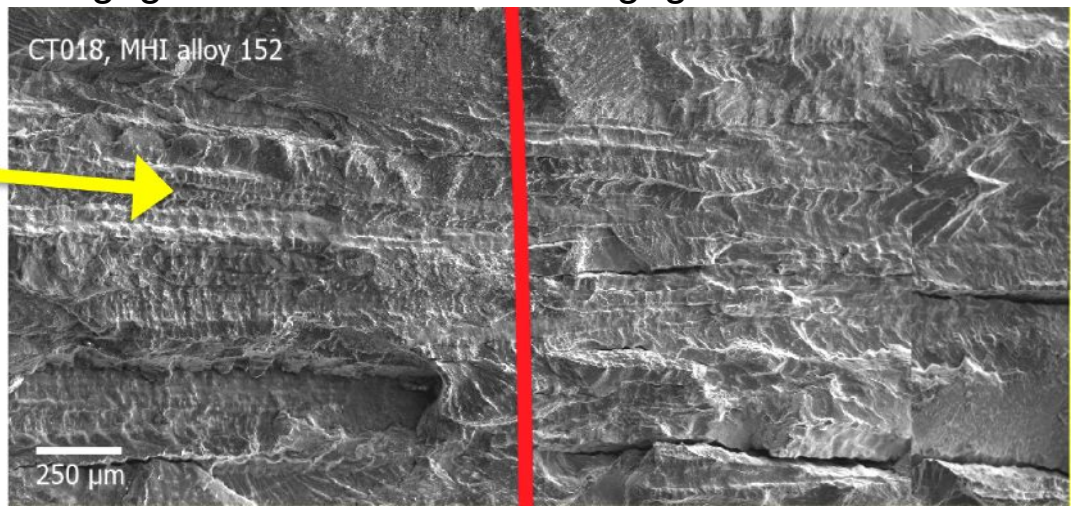



**Higher SCC growth rates at higher K**, remains low (<2x10$^{-9}$ mm/s)

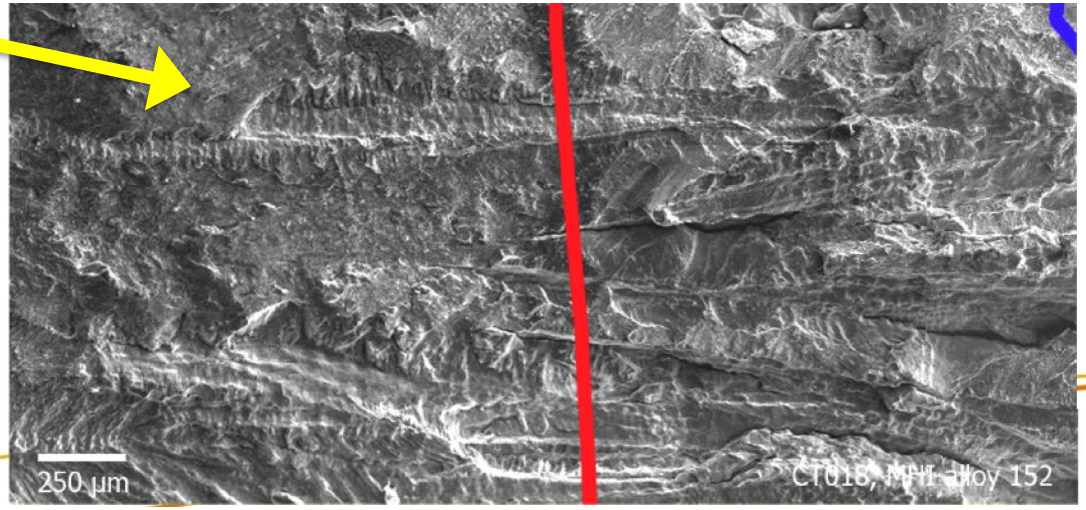
# MHI Alloy 152 Test #2
# Crack Growth Surface




~40% IGSCC engagement at 350°C




>90% IG engagement at 50°C



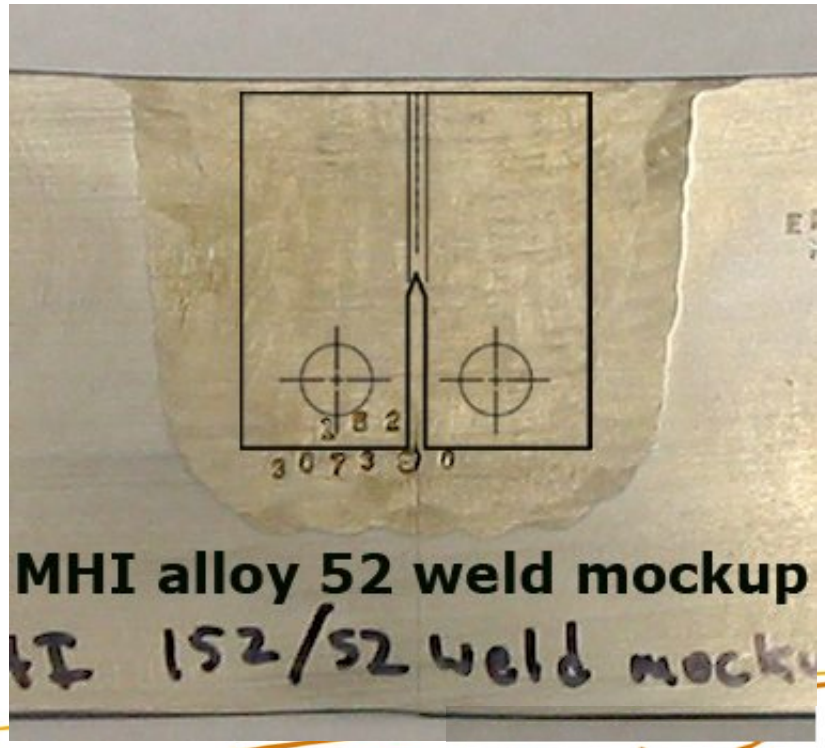

CGR of IG fingers is ~$1 \times 10^{-8}$ mm/s at 49 MPa√m

# Alloy 152/52 Crack Growth Tests in Simulated PWR Water at PNNL

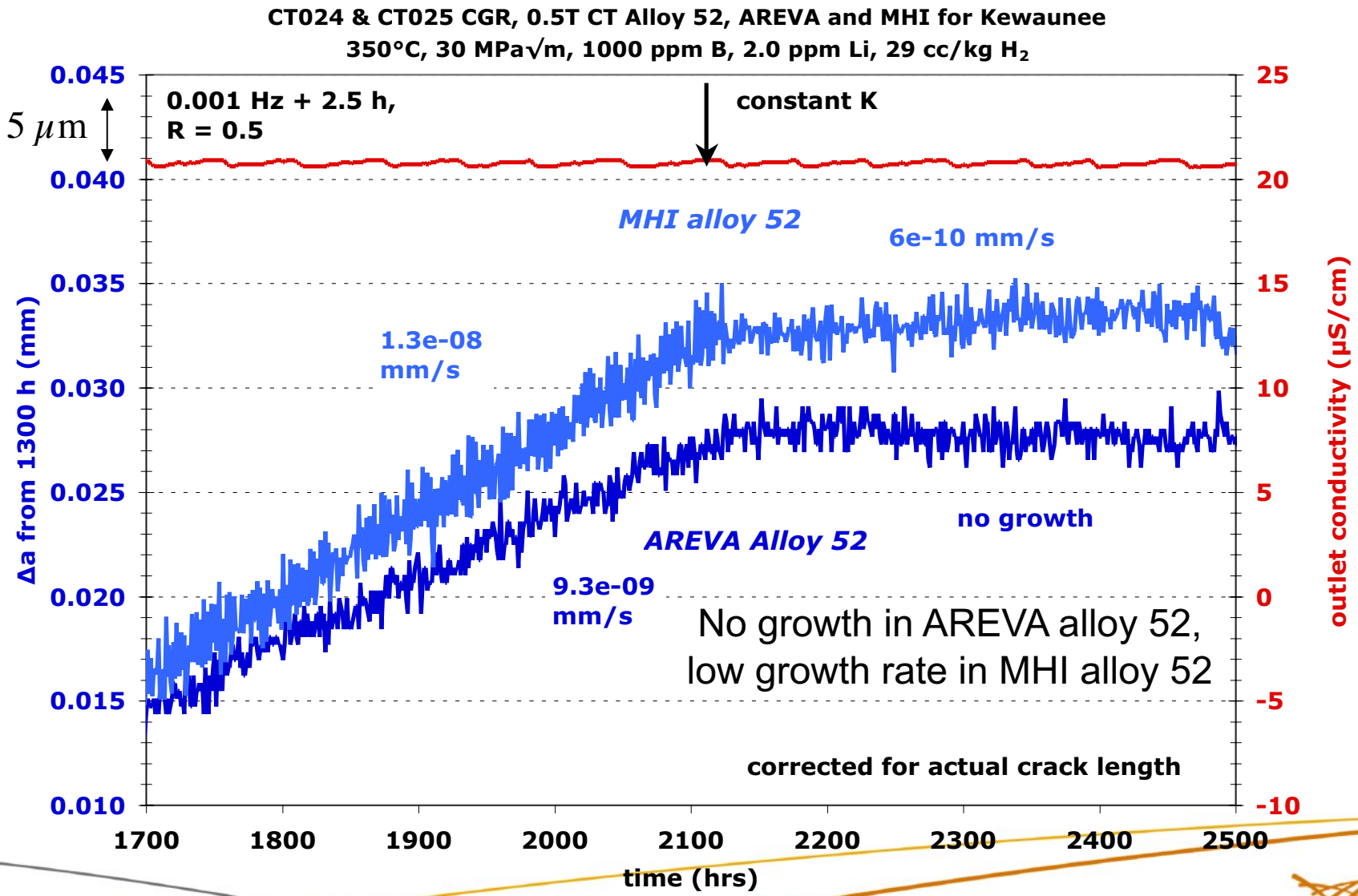
- **Alloy 152/52 - Five specimens complete, two on-going**
  - MHI alloy 152 mockup: specimen CT013 in as-welded (AW) condition
  - MHI alloy 152 mockup: specimen CT017 in AW + LAS heat treatment (610°C/12 h/AC) condition, specimen CT018 in AW condition
  - ***Alloy 52: specimen CT024 is AREVA mockup in AW condition, specimen CT025 is MHI mockup in AW condition***

# AREVA Alloy 52 and MHI Alloy 52 Mockups

- AREVA Alloy 52 butt weld joining alloy 600 plate
- MHI Alloy 52 U-groove weld joining 304 SS plate
- Both mockups made using alloy 52 weld filler from SMC



# AREVA Alloy 52 and MHI Alloy 52




Comparable or greater resistance than alloy 152

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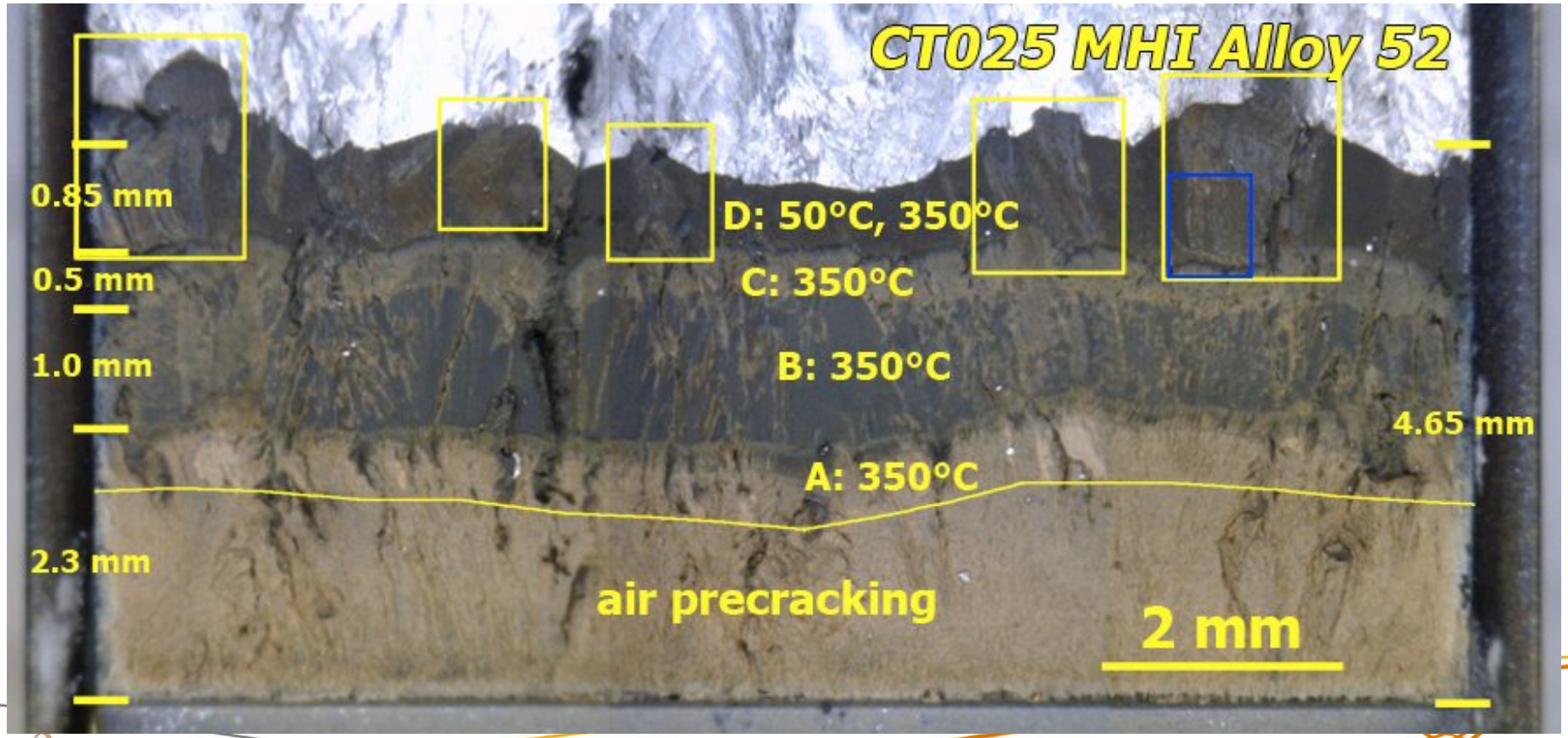
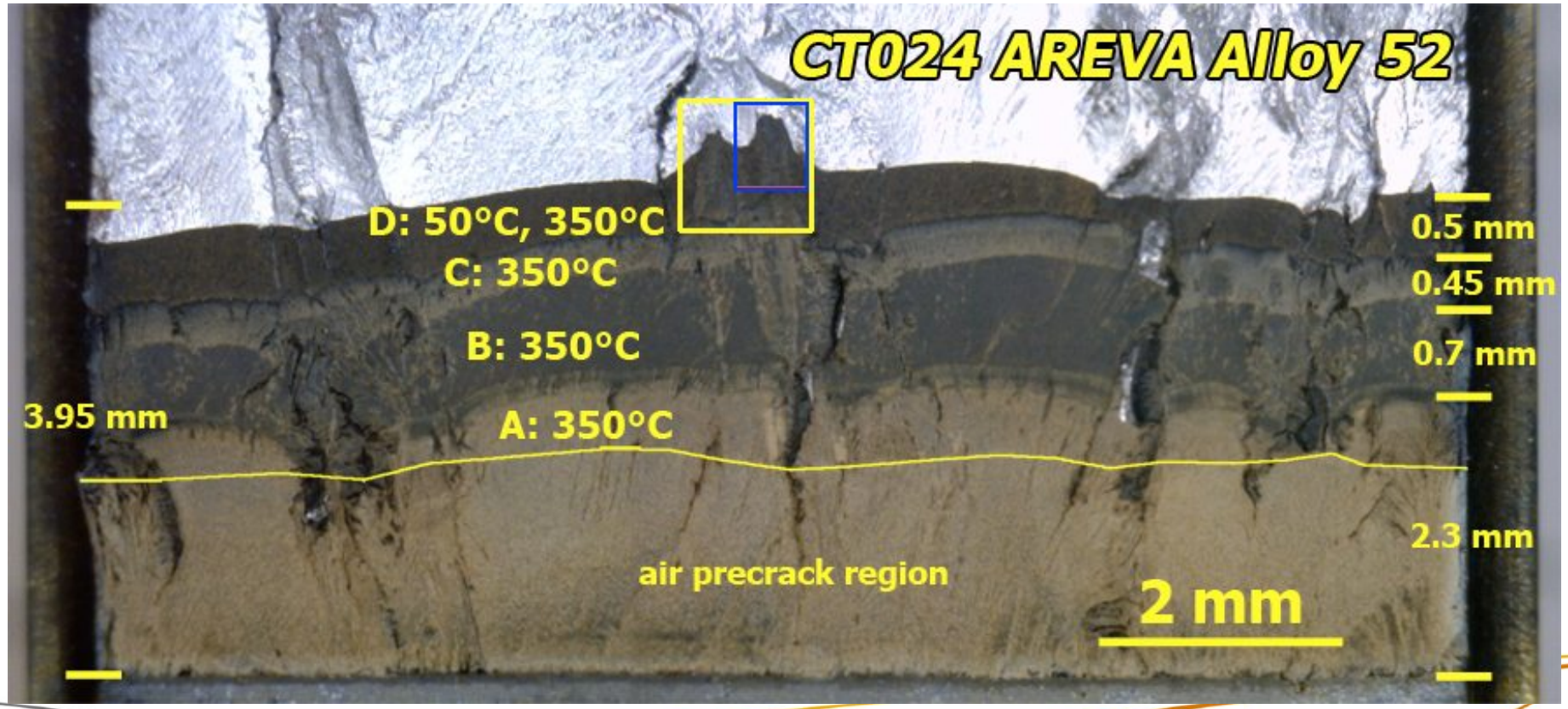
# MHI Alloy 52 Crack Growth Surface

- No IG cracking during 350°C testing.
- As much as 1 mm of IG extension during 50°C.
- Final crack front is 35-40% IG.

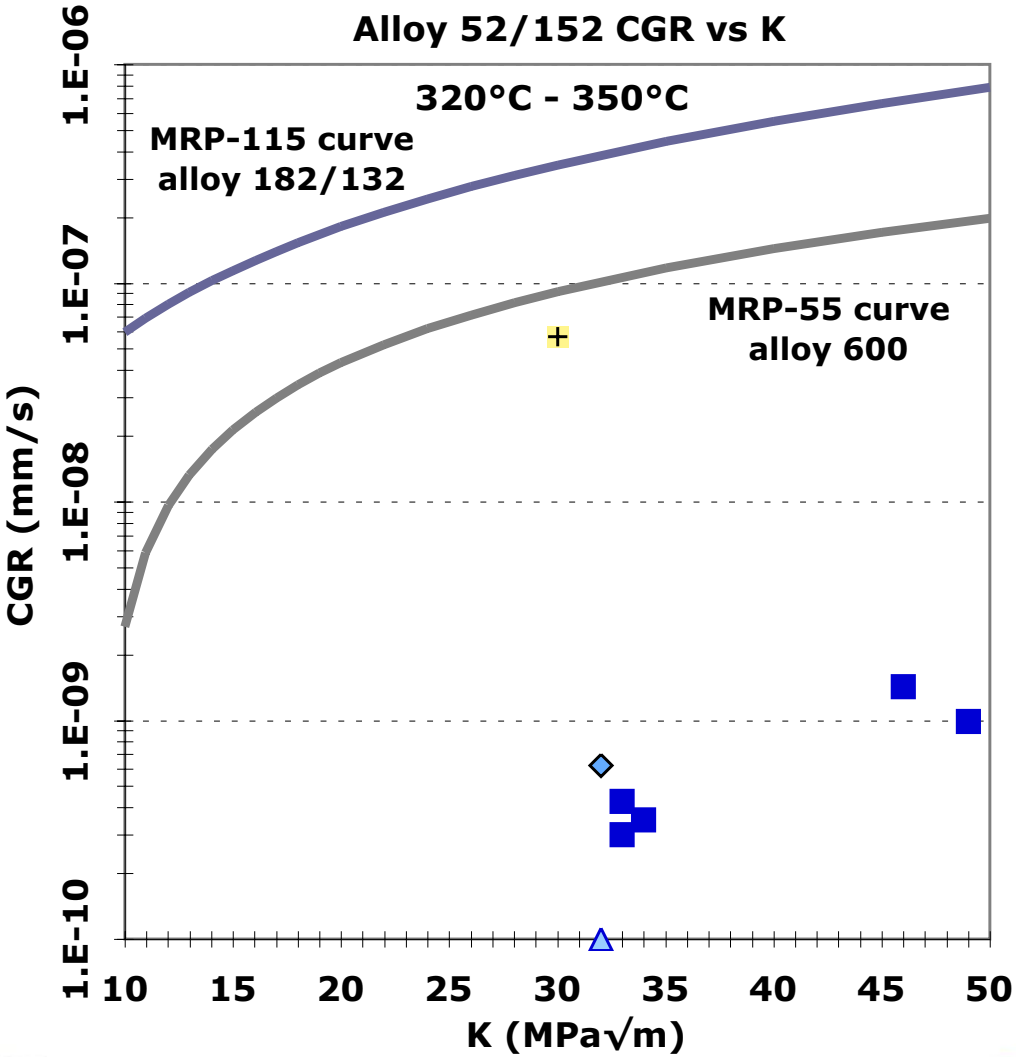


# AREVA Alloy 52 Crack Growth Surface

- No IG cracking during testing at 350°C.
- One small finger of intergranular extension begins at 50°C.
- Final crack front is ~10% IG.



# Alloy 152/52 Crack Growth Rate vs K Constant K or Constant Load Only




- alloy 152 MHI (PNNL)
- alloy 52 MHI (PNNL)
- alloy 52 AREVA (PNNL)
- alloy 152 (ANL)
- MRP-55 alloy 600
- MRP-115 alloy 182/132

- Possible K dependence, but crack-growth rates at higher K are still very low.
- Constant K data on alloy 152/52 remains very limited.

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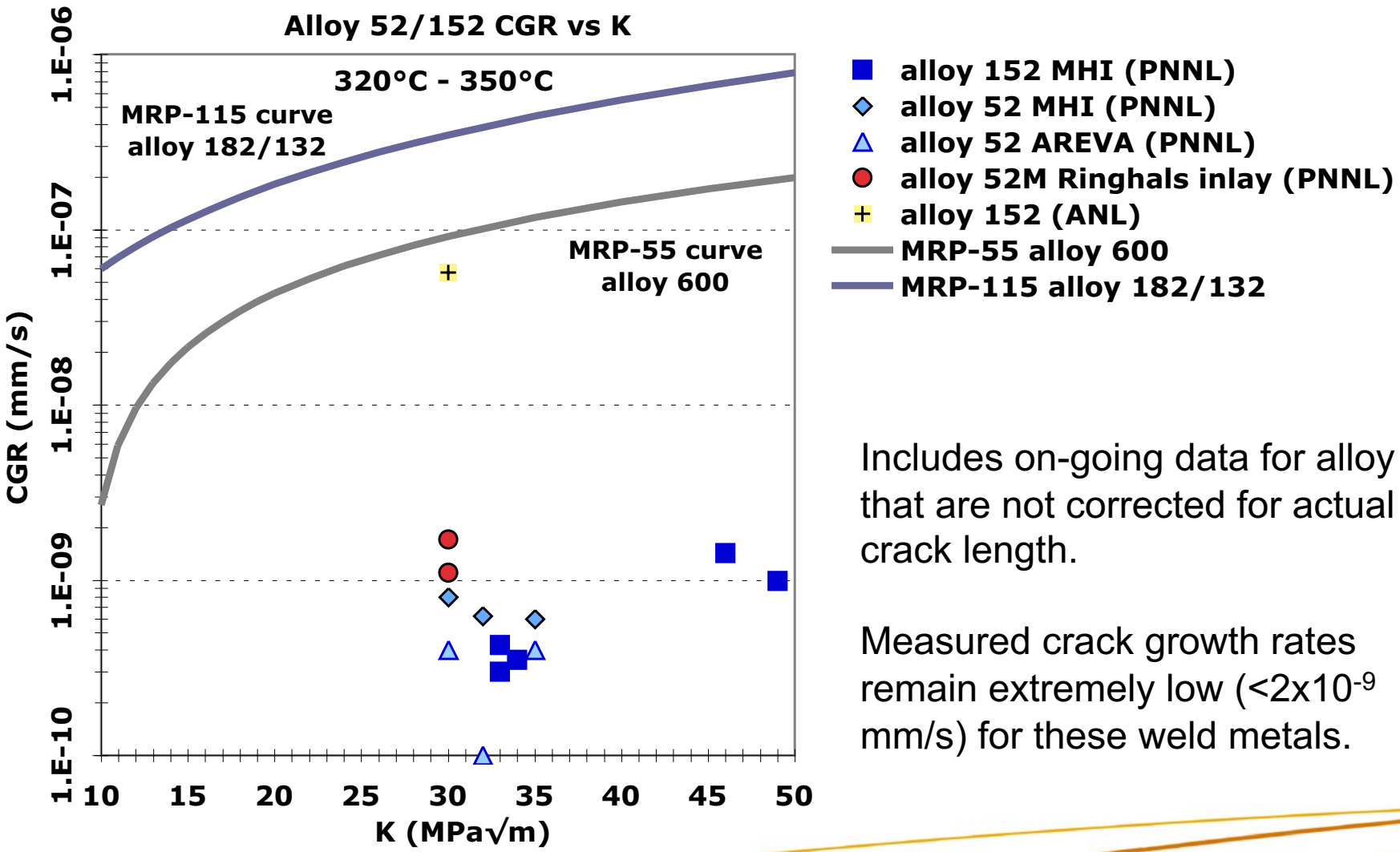
# Constant K or Constant Load Only




Includes on-going data for alloy 52 that are not corrected for actual crack length.

Measured crack growth rates remain extremely low (<$2 \times 10^{-9}$ mm/s) for these weld metals.

# Alloy 152/52 Summary

- Testing performed in simulated primary PWR water at 325-350°C with the crack oriented along dendrite boundaries in a single pass.
- Stable crack advance under gentle cycle + hold conditions and constant K conditions, but at very low growth rates (<$1 \times 10^{-9}$ mm/s).
  - Low alloy steel stress relief heat treatment had no effect on CGR.
  - Indication of a slight K dependence on CGR.
- Fractography
  - alloy 152: IGSCC observed during cycle + hold and constant K at 350°C.
  - alloy 52: No IGSCC observed during testing at 350°C.
- Alloy 52 mockups appear to have equal or greater SCC crack growth resistance than alloy 152.
- SCC crack-growth tests ongoing to expand database for alloy 52 and 52M weld metals.