

# NRC Sponsored Research on Primary Water Stress Corrosion Cracking

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NRC/RES

June 4, 2014

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U.S. Nuclear Regulatory Commission

# Objectives

- Obtain crack growth rate data to inform inspection requirements
  - Components manufactured using Alloy 690/152/52
  - Weld overlays and inlays
  - Dissimilar metal weld dilution zones
- Recent areas of testing focus
  - Effects of cold work on crack growth rates in Alloy 690
  - Weld dilution zones

# Effects of Cold Work

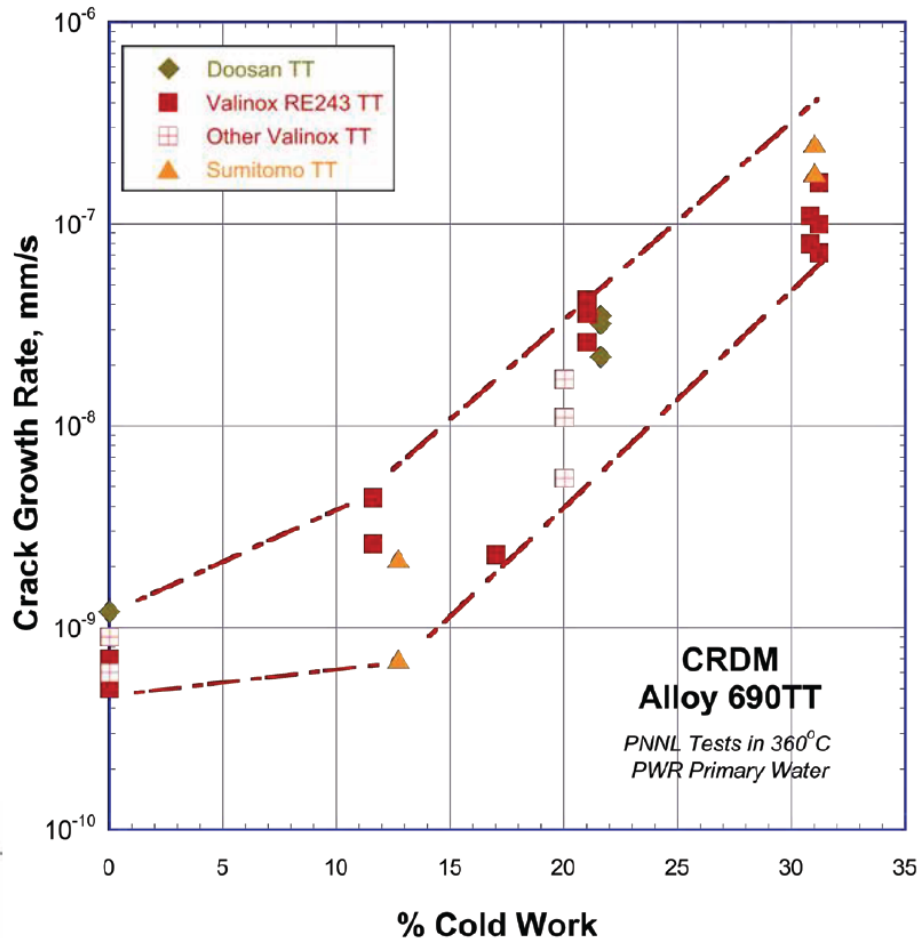
# Cold Work Effects on Alloy 690 Crack Growth Rates

- Crack growth rates on non-cold worked Alloys 690 are low ( $\sim 10^{-9}$  mm/s) but number of materials tested is limited
- Data show strong effect of cold work, with crack growth rates above  $10^{-8}$  mm/s at 20%+ cold work
- Systematic study of cold-work effects ongoing at PNNL

# Materials Tested

- Alloy 690TT CRDM tube
  - Valinox, Sumitomo, Doosan materials
  - Various cold work levels, up to 20% tensile strain, 31% cold roll, 31% cold forge
- Alloy 690 Plate/Bar/Billet
  - ANL, GE, TK-VDM, Allvac, ENSA materials
  - Various cold work levels, up to 26% cold roll, 32% cold forge

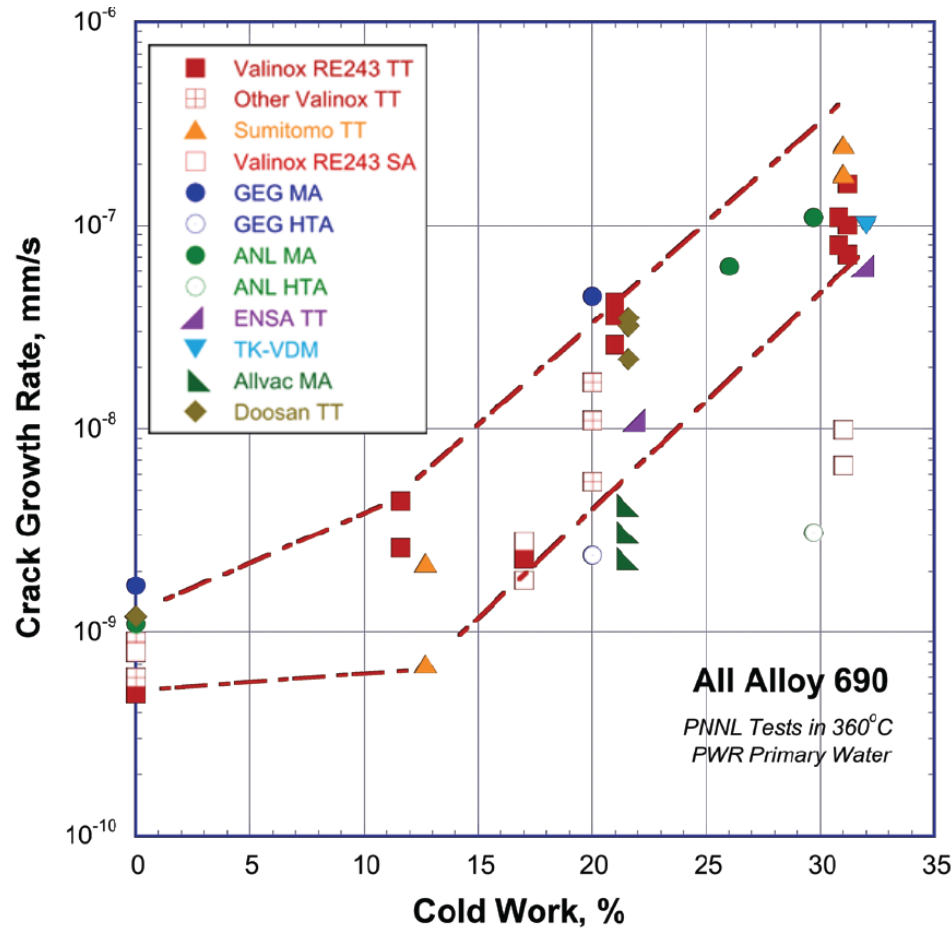
# Crack Growth Rates – CRDM Materials



Notable increase in growth rate above 10-15% cold work

Bruemmer, *et al*, ICG-EAC, 2014

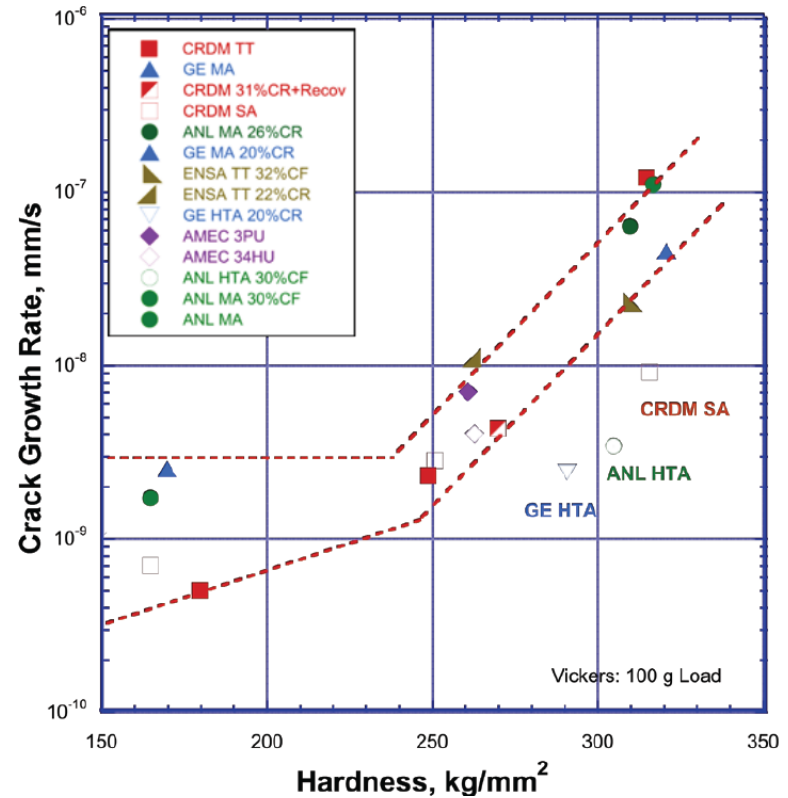
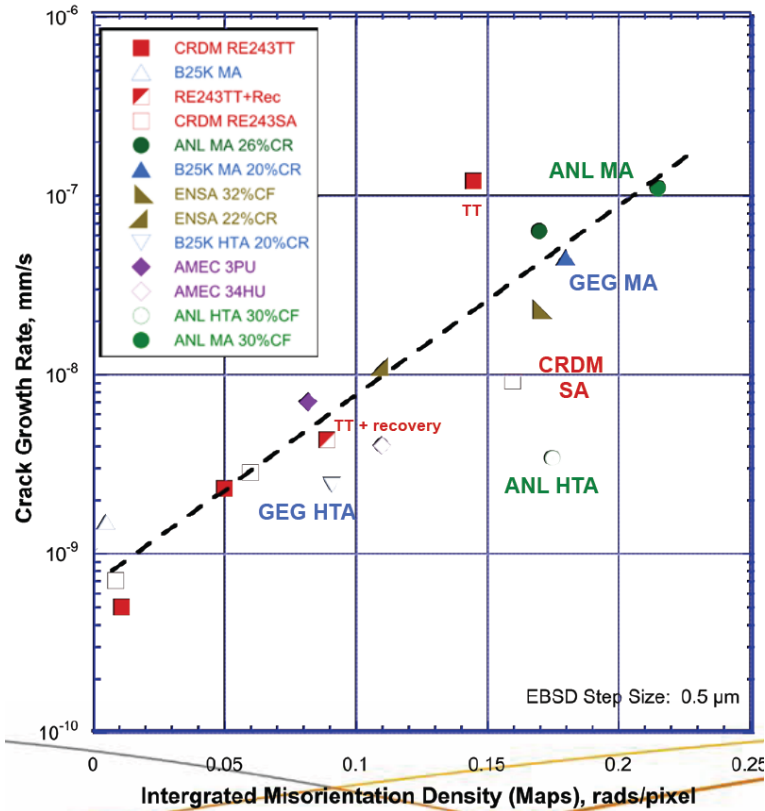
# Crack Growth Rates – All Materials



Data trend is consistent with addition of bar/plate materials

Bruemmer, *et al*, ICG-EAC, 2014

# Internal Strain and Hardness Correlations



Internal strain and hardness generally increase with CW and correlate well with measured crack growth rate

Bruemmer, *et al*, ICG-EAC, 2014

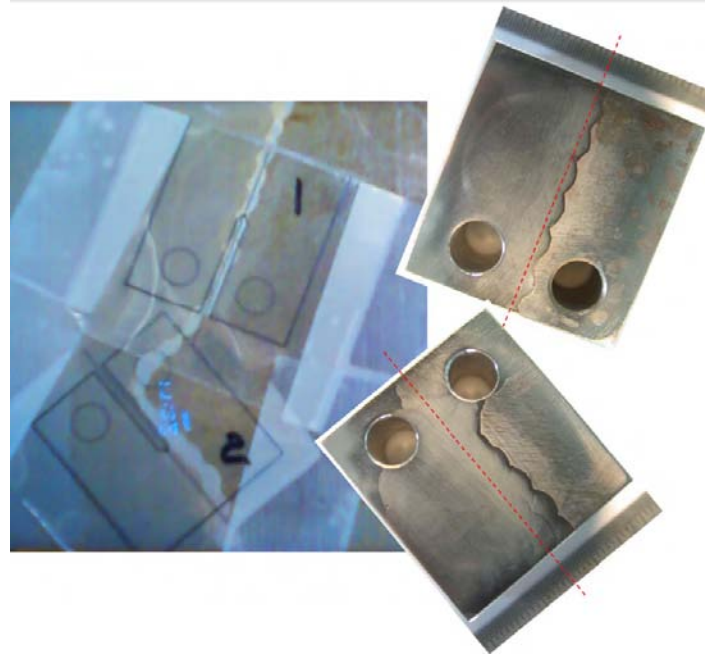
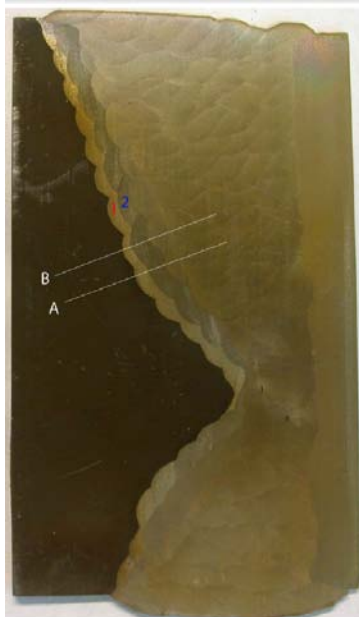


# Weld Dilution

# Effects of Chromium Dilution on PWSCC Crack Growth Rate

- Cr can be compositionally diluted near the fusion line between high-Cr weld metals and base material or low-Cr weld metal
- Ongoing studies measure crack growth in weld dilution zones
- Materials tested
  - 152M-LAS, 52M-LAS, 152-SS at PNNL
  - 52M-182 overlay, **152-LAS at ANL**

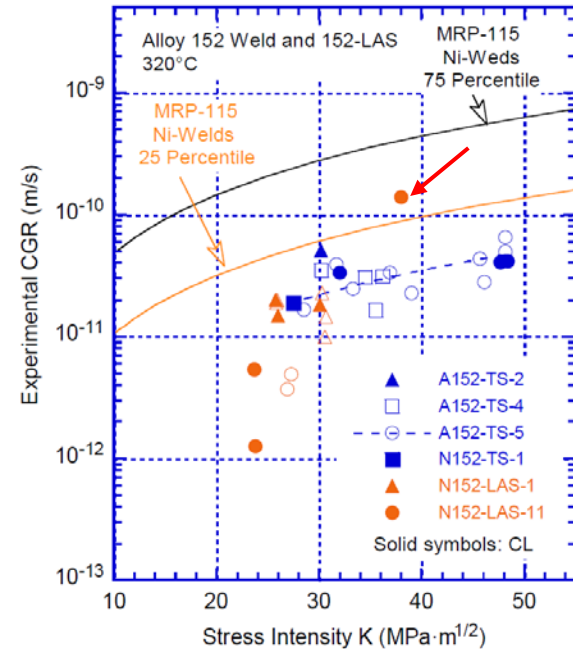
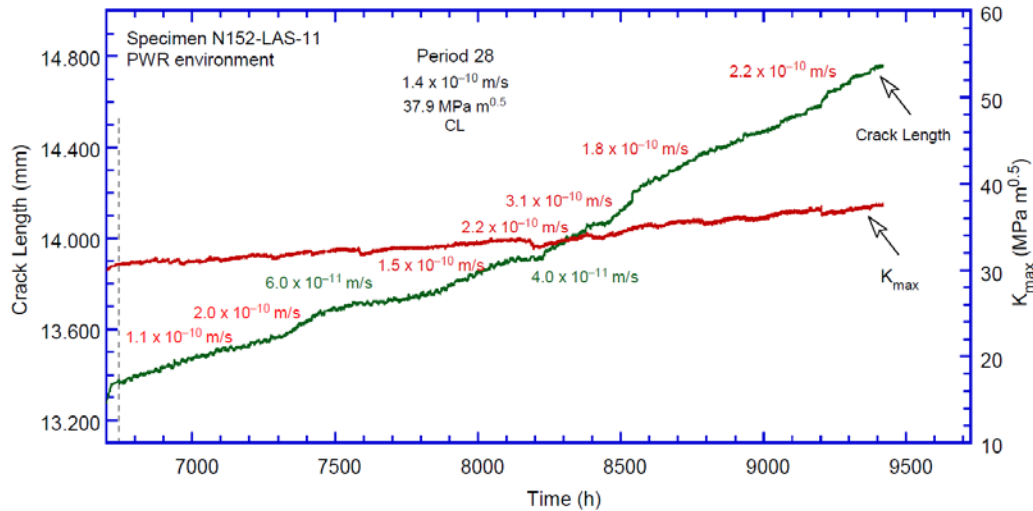
# ANL Test on 152-LAS



- Alloy 690 to LAS mockup with Alloy 152 butter and weld
- CT specimens machined from first layer of Alloy 152 butter

Alexandrea, *et al*, Alloy 690 Expert Panel Meeting, 2013

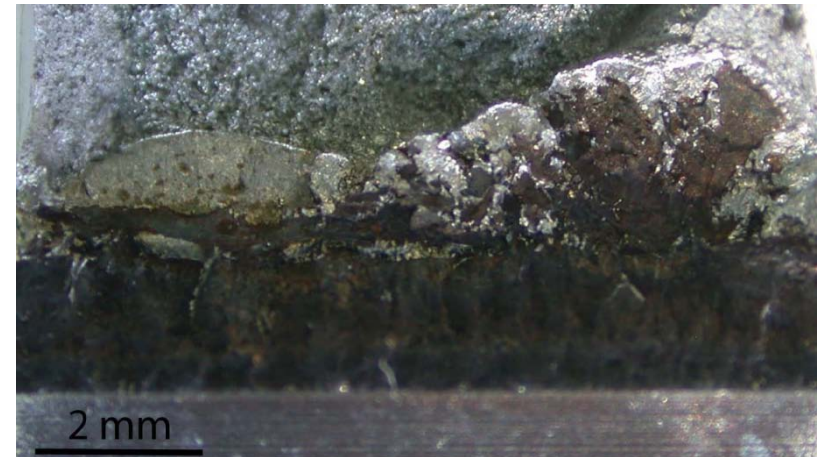
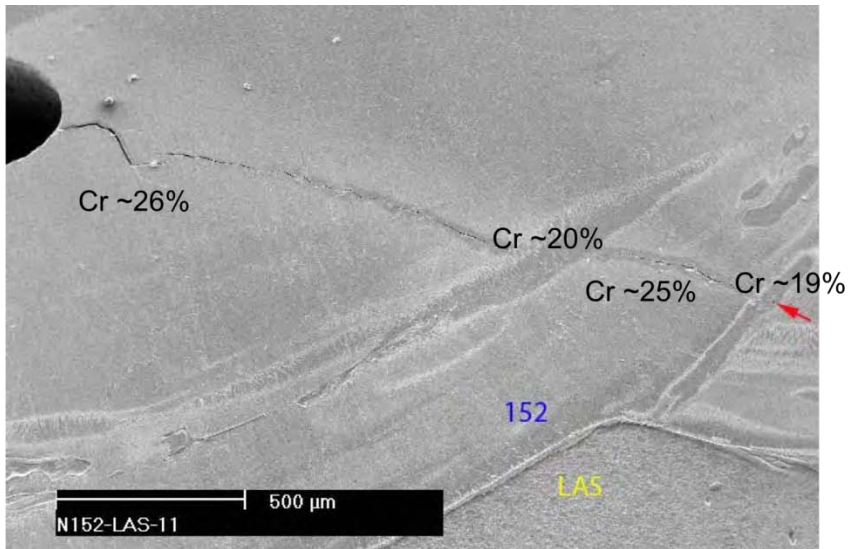
# Crack Growth Rate



- For about 2,700 hours at constant load, crack growth rate of about  $1.4 \times 10^{-7}$  mm/s
- Crack growth rate above the 25<sup>th</sup> percentile curve for Alloy 82/182 welds from MRP-115

Alexandreaanu, *et al*, Alloy 690 Expert Panel Meeting, 2013

# Crack Features



- Crack appears to advance in Alloy 152 butter layer
- LAS remains as unbroken ligaments
- Further analysis and additional testing ongoing at PNNL

Alexandrea, *et al*, Alloy 690 Expert Panel Meeting, 2013

# Future Work – Crack Growth Rate Testing

- NUREG/CR report on effects of cold work on Alloy 690 expected by late 2014
- Testing priorities
  - Weld dilution
  - Effects of welding parameters
  - Overlays and inlays with 52/152
- Mockups needed

# Future Work – Initiation Testing

- Anticipated start of NRC-sponsored testing program in 2015
- Data priorities
  - Alloy 600/82/182 to support xLPR code development
  - Effects of surface peening
- Exploring cooperative program with EPRI
  - Public meeting this Thursday afternoon