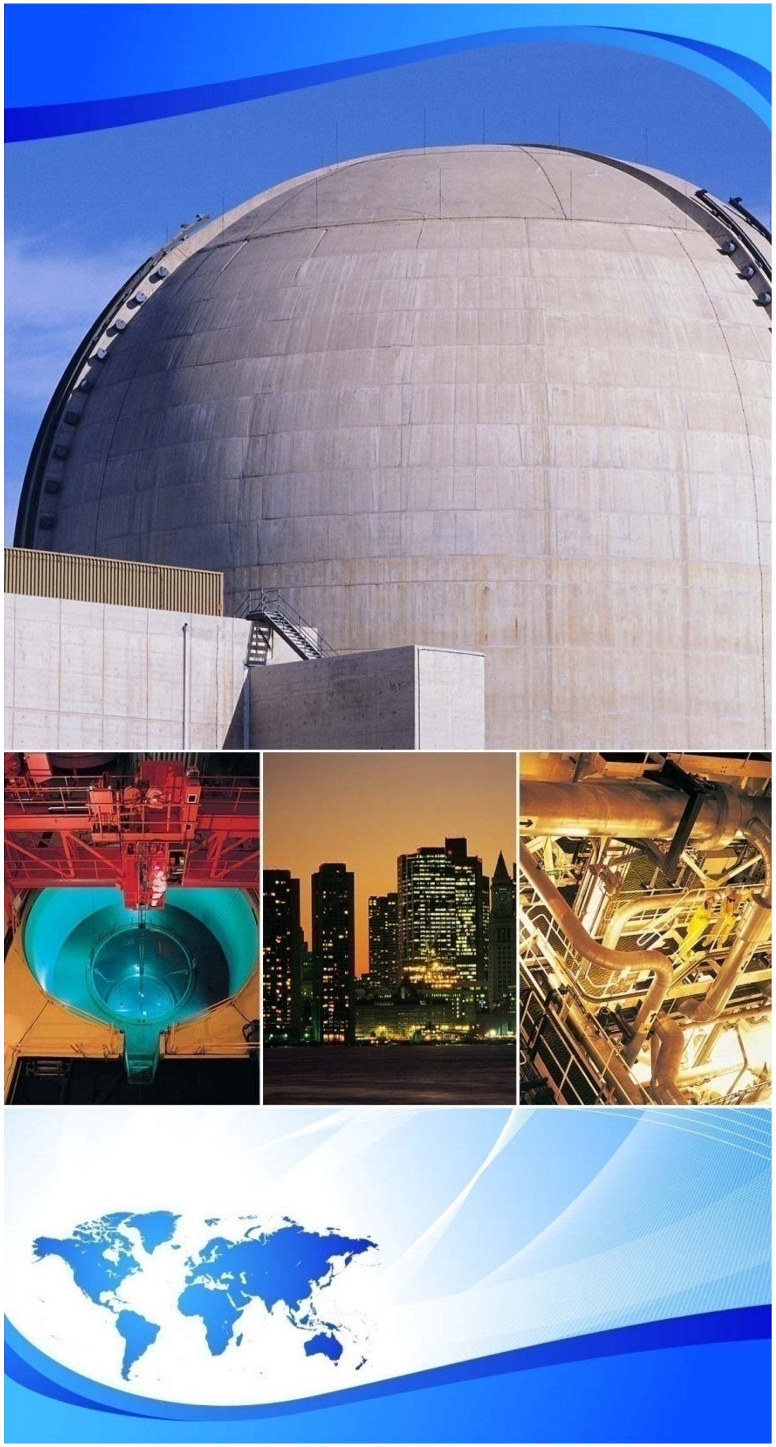


EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Overview of SCC Programs at SERCO, Ciemat and MHI

Peter Andresen
GE Global Research Center

NRC-EPRI Meeting *June 2011*

Serco Research Summary

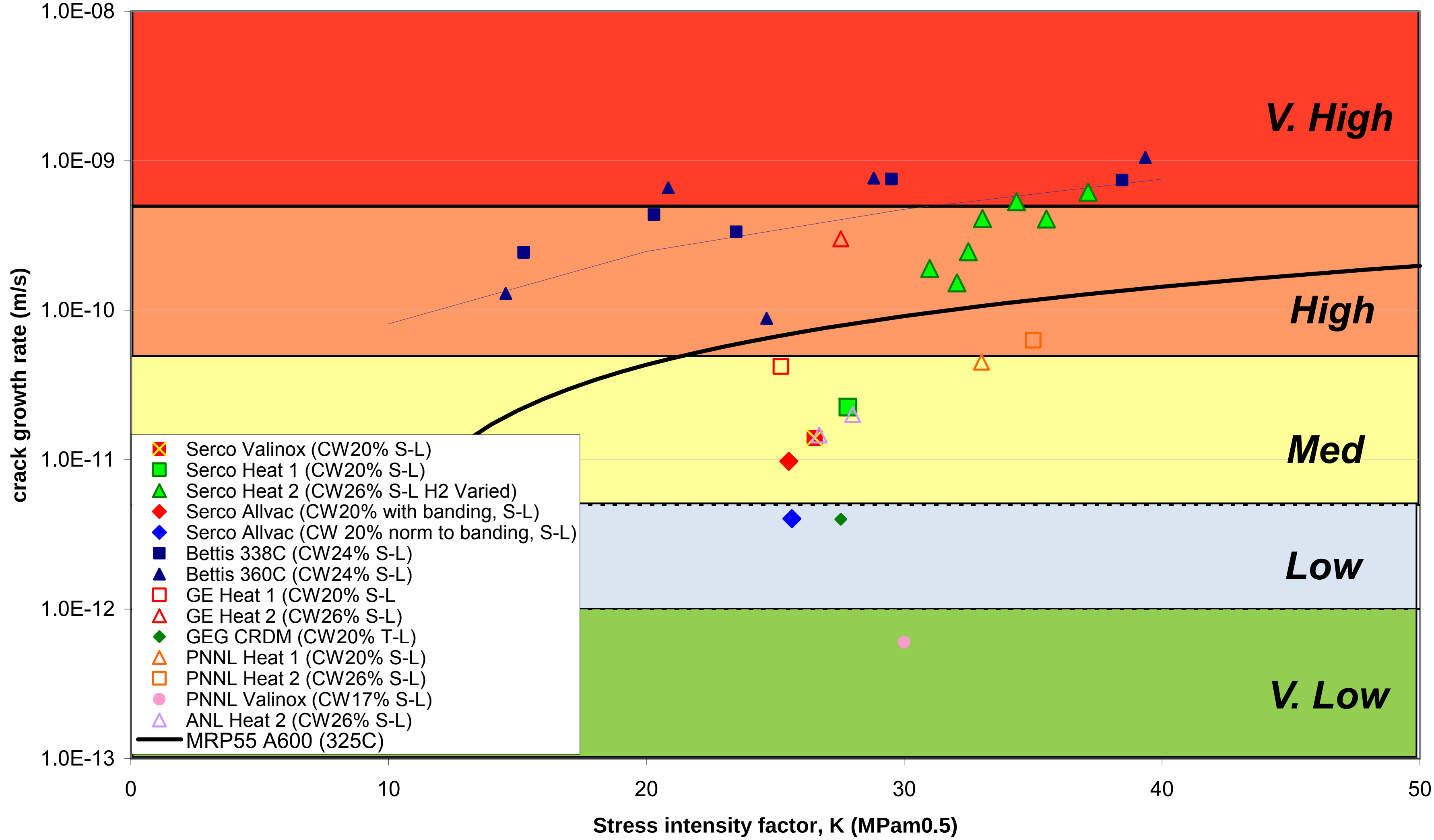
Serco – Summary of Materials Tested

- **GE MATERIAL:** S-L, 20%CW (2 PASSES), CGR **$1.3\text{-}2.3X10^{-8}$** mm/s
  - SUPPLIED IN CW FORM BY GE-GRC
- **ANL MATERIAL:** S-L, 26%CW (3 PASSES), CGR **$1.9\text{-}4X10^{-7}$** mm/s
  - SUPPLIED IN CW FORM BY GE-GRC
- **ALLVAC BAR** (// TO BANDING): S-L, 20%CW (10 PASS), **$9.8X10^{-9}$** mm/s
  - HEAVILY BANDED MATERIAL
- **ALLVAC BAR** (⊥ TO BANDING): S-L, 20%CW (8 PASS), **$4X10^{-9}$** mm/s
- **VALINOX CRDM:** S-L, 20%CW (4 PASS), CGR **$1.4X10^{-8}$** mm/s

Not listed, but most of Serco's 690 data is at 350C

Serco, Ciemat, MHI

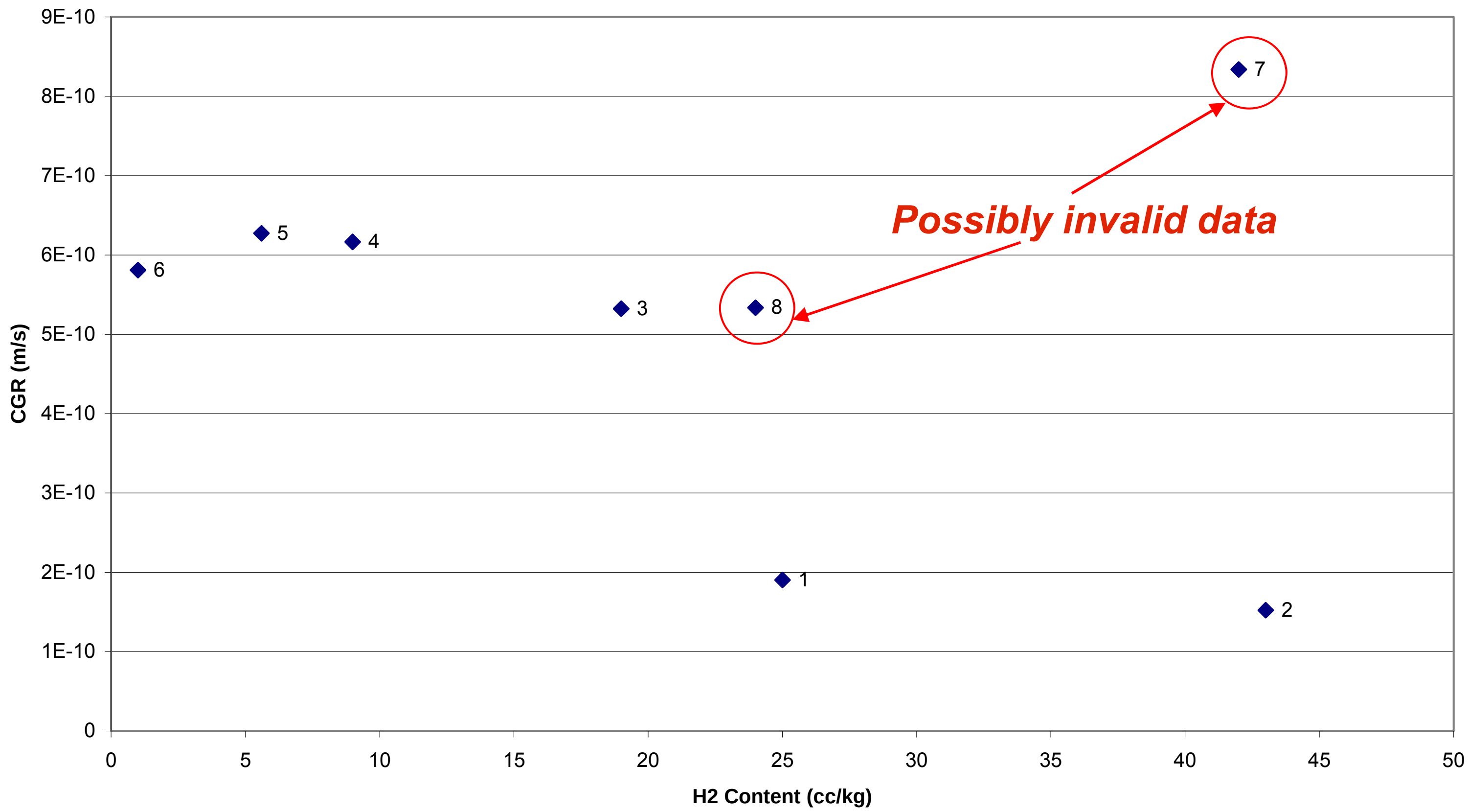
Comparative rates + classification



Serco, Ciemat, MHI

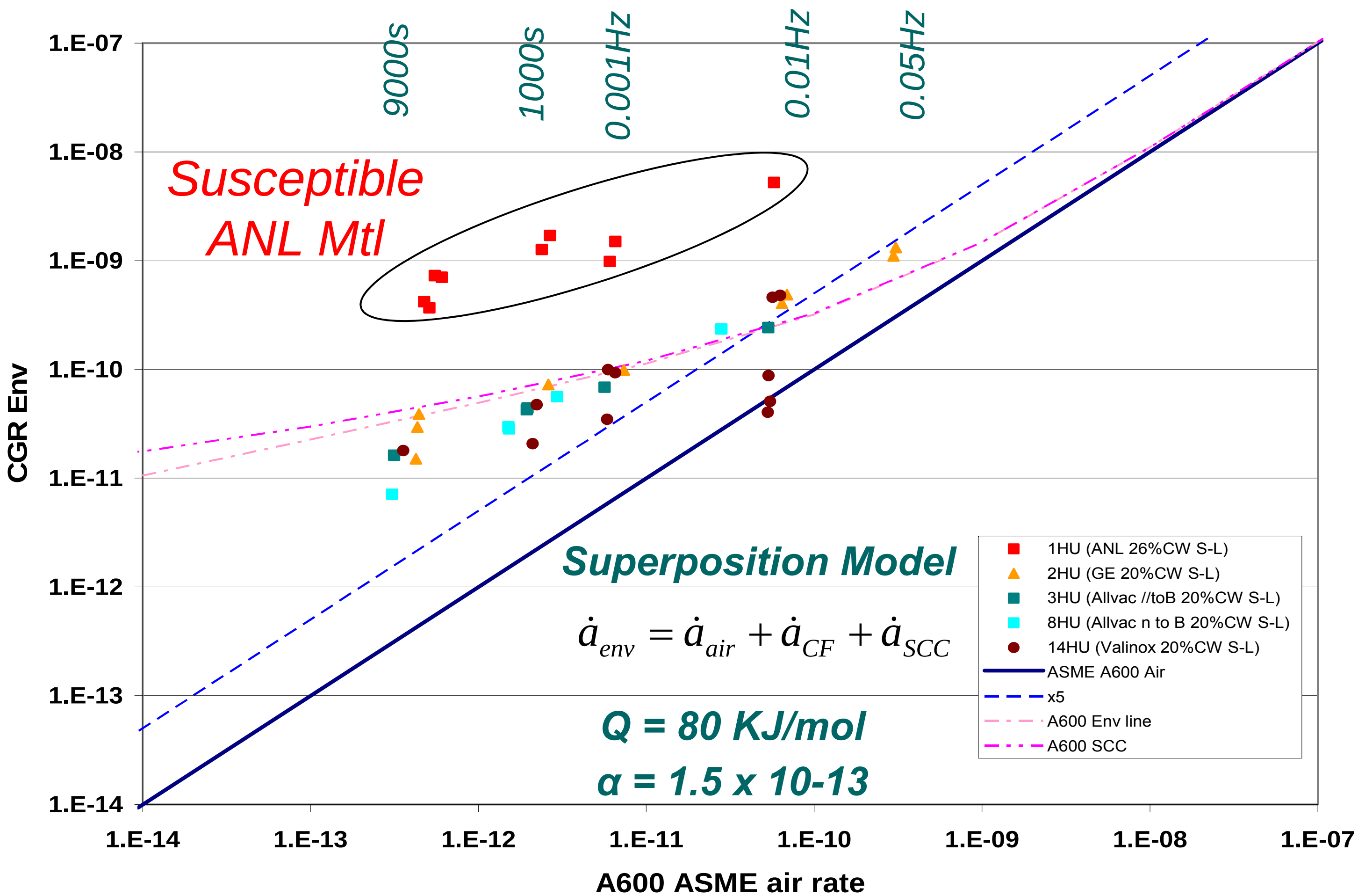
Effect of Hydrogen Content on Crack Growth Rate ANL heat NX3297HK12

Apparent reduction in crack growth rate at high dissolved H_2 concentration



Serco, Ciemat, MHI

Data Presentation on Corrosion Fatigue

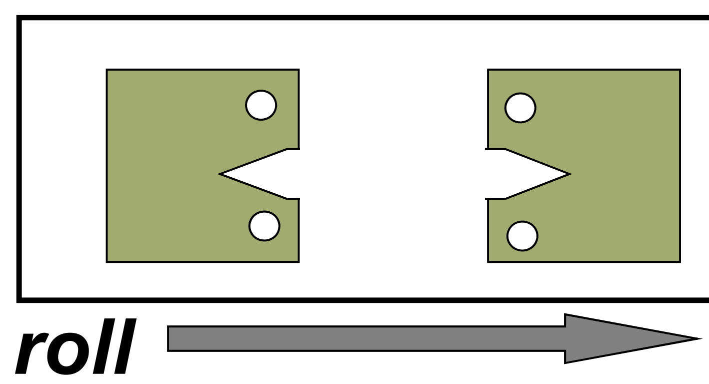


Most data bounded by non-CW Alloy 600 superposition model.

26% CW ANL heat showed significantly higher rates.

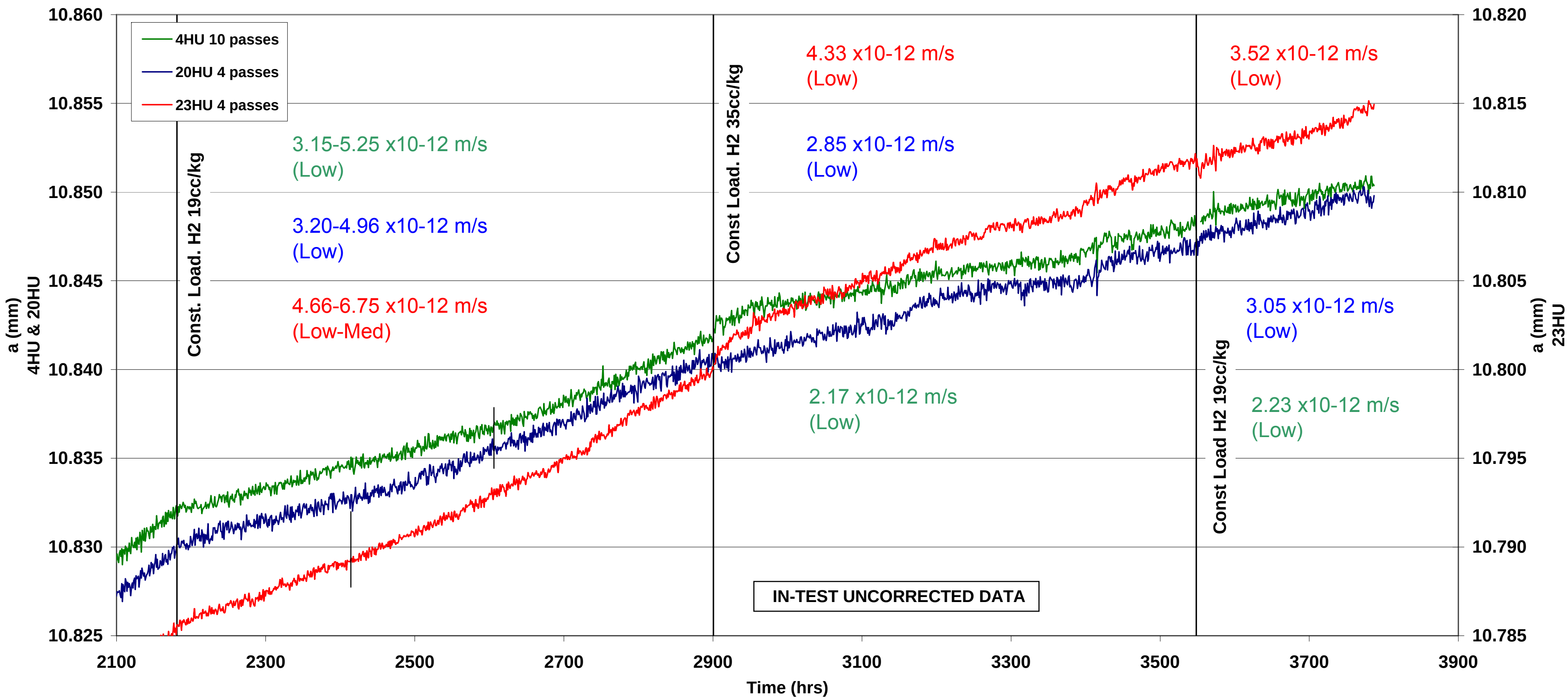
Current test - 'Aggressive' rolling effects

- Investigate variability in rolling method to achieve equivalent reduction in thickness.
  - Usually dependent on machine limits.
- It has been suggested that the number of passes used when cold rolling may affect the susceptibility and CGR.
- Testing Allvac billet material (heavily banded).
  - Deliberate ploy to concentrate on one (Allvac) Material.
- 20%CW 1D rolled, with 4 or 10 passes (SL, banding along rolling direction)
- Also looking at CGR with respect to direction of rolling.
- 3 specimen test
  - 10 pass specimen as in previous test
  - two 4 pass specimens cut as shown



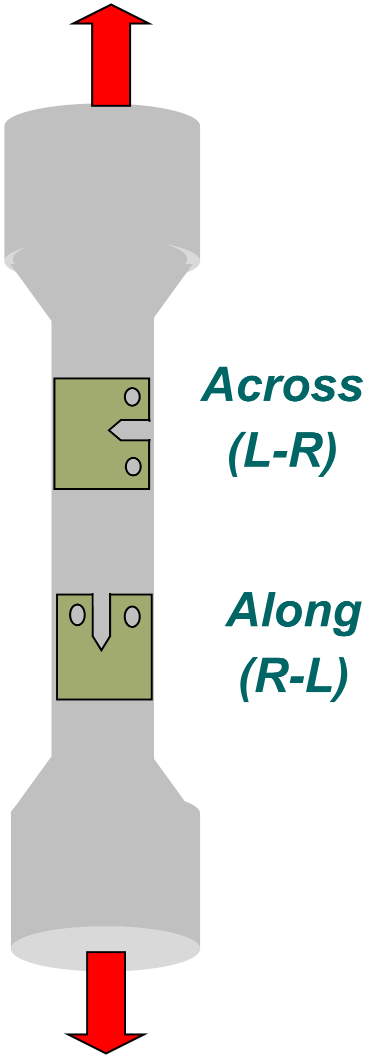
Serco, Ciemat, MHI

In-test Data



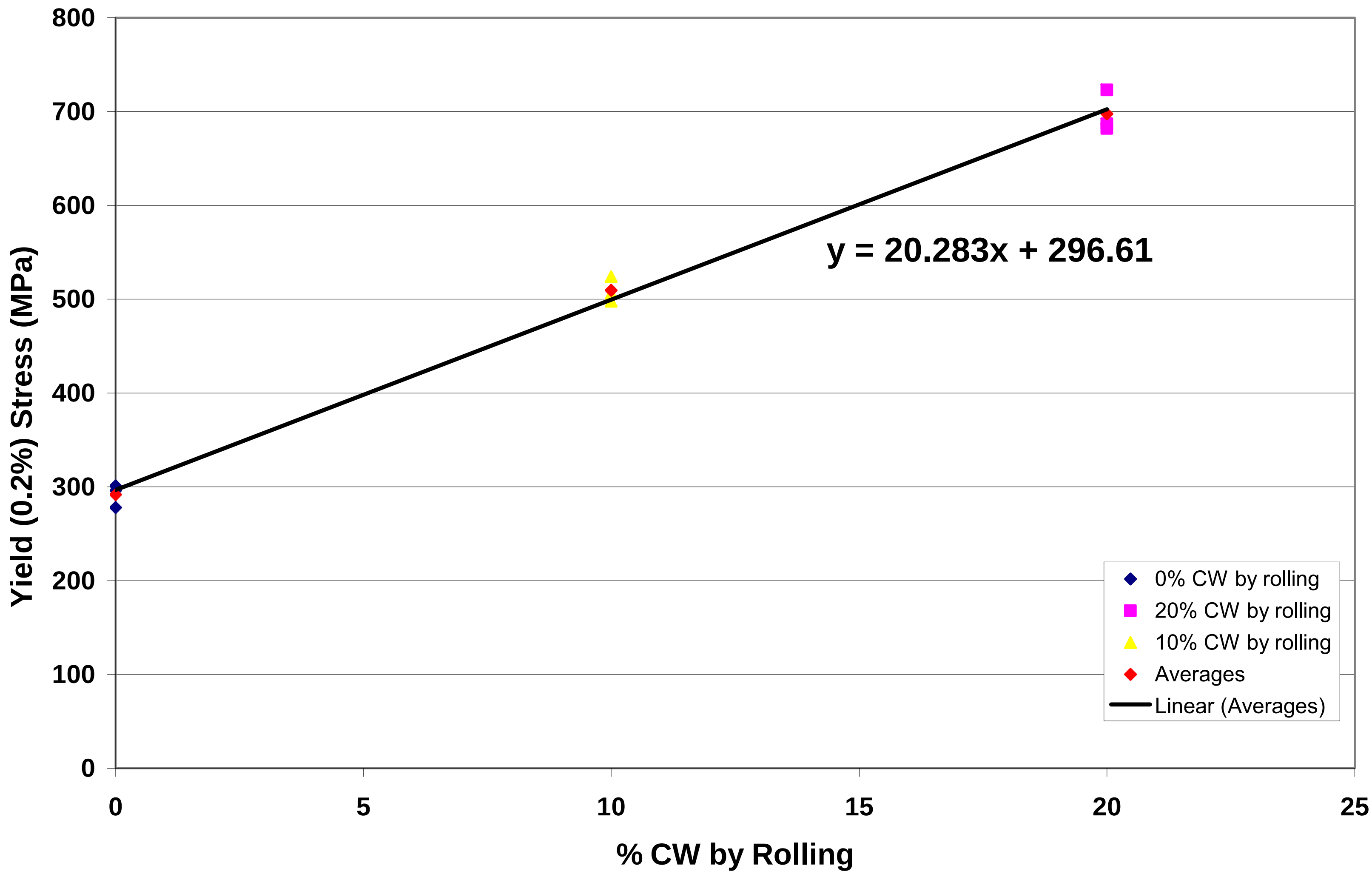
Very similar rates for 4 and 10 passes.

Upcoming Test - Single Pull Allvac Material



- Compare CGRs with those of previous tests that performed CW by uni-directional cold rolling and forging.
- For direct relation to Cold Working by rolling, performed tensile tests on material CW by 0, 10 and 20% to measure the proof stress.
- Related proof stress to % thickness reduction to calculate true stress to be applied by single pull.
- SCC Tests in ‘Along’ (R-L) and ‘Across’ (L-R) orientations
- Compare hardness profiles and microstructures.
- More representative of weld shrinkage?

Tensile Data of CW Material



Single Pull Method

- Applied True Stress of 700MPa.
- Limited material available, making 8mm CTs.
  - Validity of specimens and available ligament compared with arguments in ASTM 647 and paper by P. Andresen at 11^{th} Env Deg, K/size effects.
- Test alongside a CT from a 20% 1D cold rolled specimen (Allvac $\perp$ to banding) as control for size effects with an already tested material.

SERCO Summary

- SCC testing of four materials
  - GE Plate, ANL Plate, Allvac Bar and Valinox CRDM.
  - All Low-Med rates with exception of ANL heat (High).
  - Possible H_2 effect measured on susceptible ANL heat.
- Ongoing comparison of data between laboratories
- Concentrating on systematic evaluation of single material - Allvac bar
  - Alignment to banding
  - Hydrogen effects
  - Number of passes used for Cold Rolling
  - Single Pull, comparing application of cold work.

Influence of rolling and tensile deformation on the Alloy 690 CGR UNESA-EPRI Project

D. Gómez-Briceño, J. Lapeña, M. S. García, L. Castro, F. Perosanz (CIEMAT)
L. Francia (UNESA)
K. Ahluwalia - EPRI manager

Dresden, Germany. May 9, 2011

Objective and scope

✓ To compare the response of Alloy 690 TT deformed by rolling and tensile to SCC in primary water conditions.

✓ Material have been deformed up to 20%

✓ CGR tests have been performed in primary water conditions at 325ºC

✓ CT specimens (12 mm thickness) with T-L orientation

CRDM Alloy 690TT tube supplied by Valinox (heat WP 787)

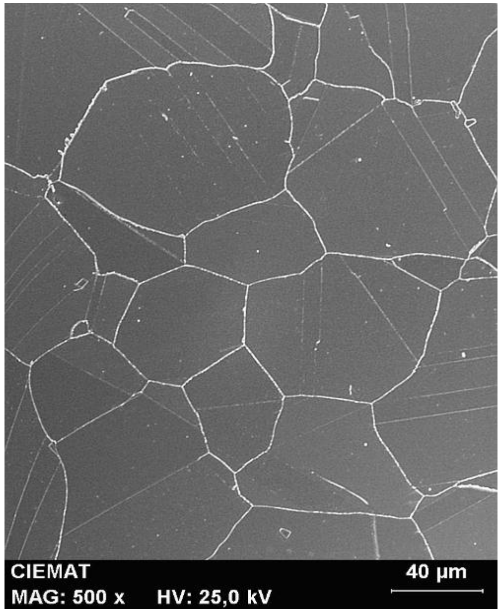
Materials

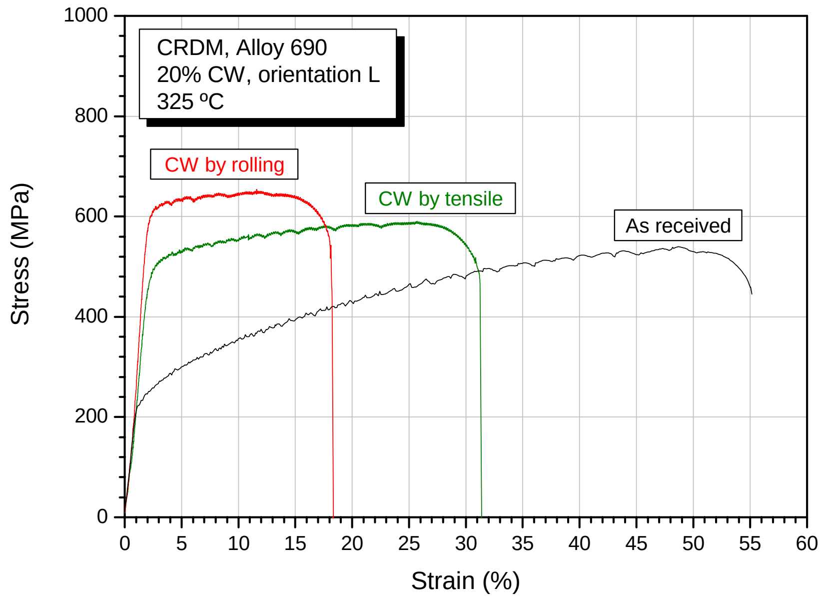
✓ CRDM Alloy 690TT tube supplied by Valinox (heat WP 787)
Electric Arc Furnace + ESR (Electroslag Remelt)
Thermal treatment : 1050ºC, 6 hours at 715ºC

✓ Homogeneous microstructure, high grain boundary coverage with small carbides, no banding. Grain size ASTM No 3.5-4 (~ 90 μm)

✓ Material has been deformed up to 20% by rolling in three passes and by straining tensile

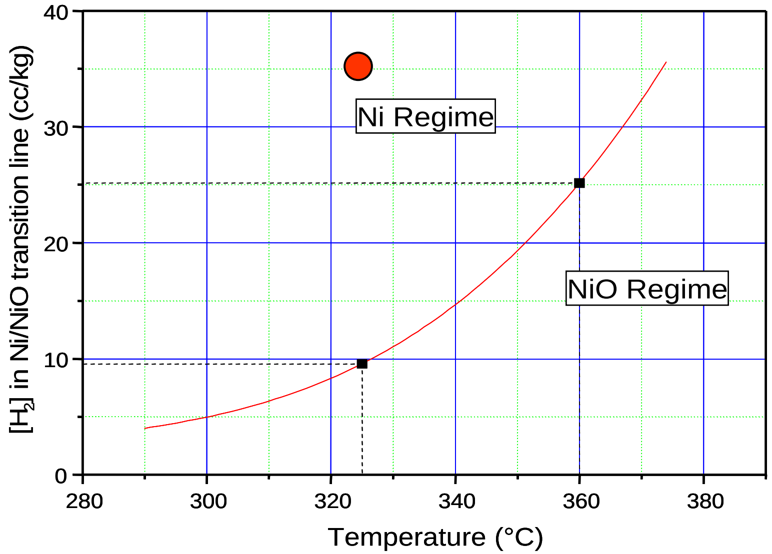
✓ *Average Hardness*
As received: 165HV1
Tensile deformed : 279HV1
Rolling deformed : 298HV1

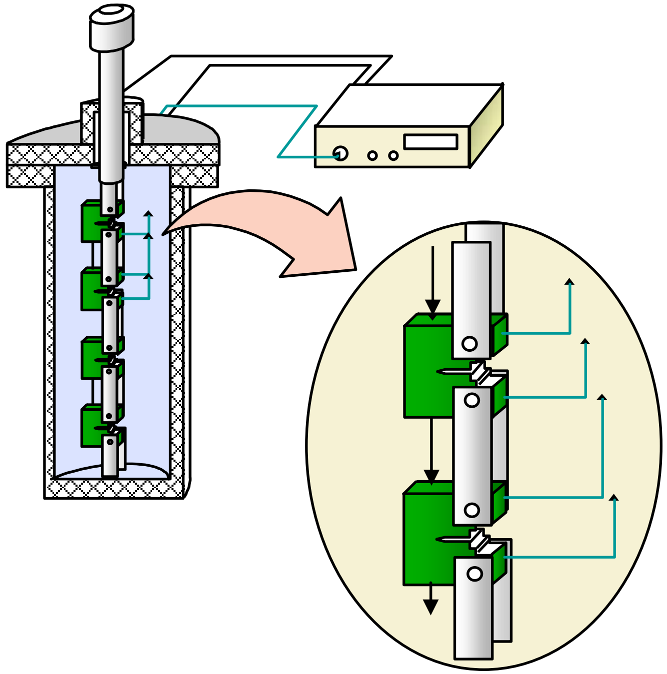




Experimental conditions

900 ppm B, 2.5 ppm Li,pH=7.2 at 310ºC
H_2 = 35 cc/Kg H_2O at 325ºC (●)





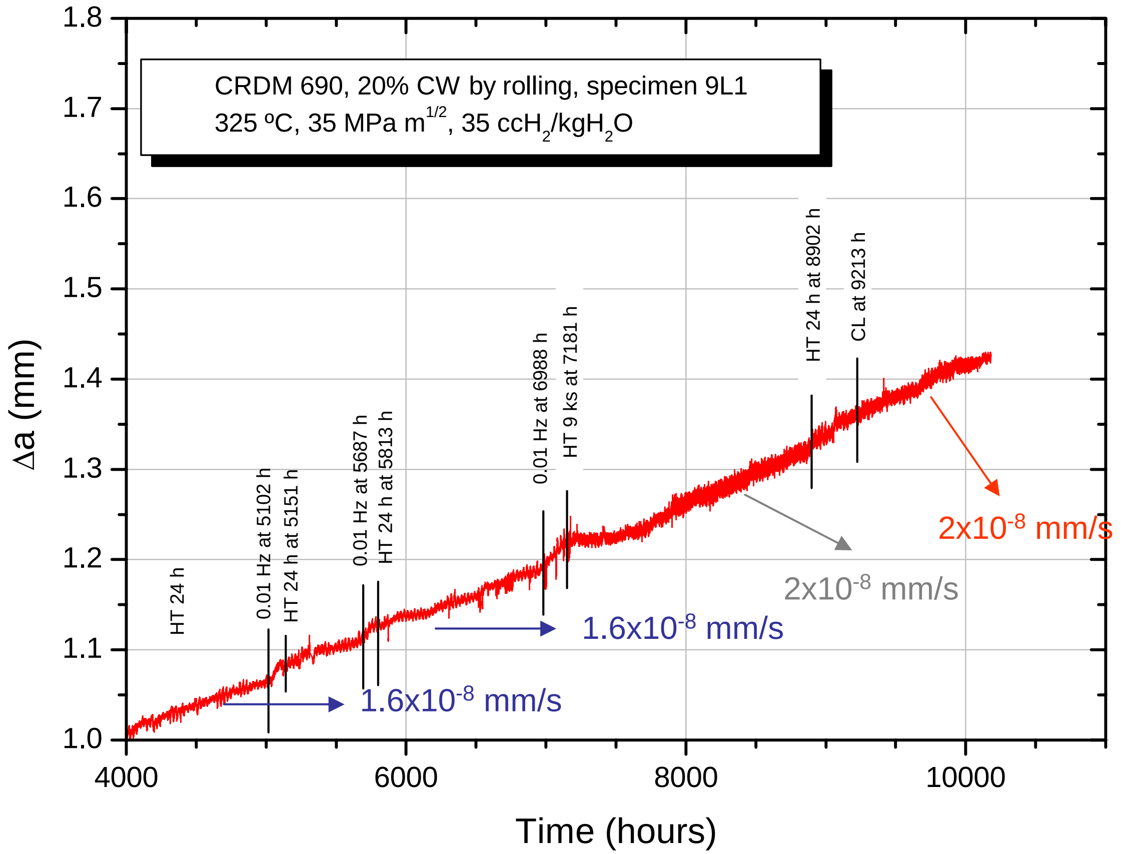
Four CT specimens in daisy chain. All of them instrumented by DCPD

- ✓Pre-cracking in air: R =0.3 to 0.7and 1-2 Hz
- ✓Fatigue pre-cracking in high T water: R=0.7 and 0.05 -0,01-0,001Hz
- ✓Constant Load (CL) with gentle unloading: 0.001Hz + 9000 s and 24h hold time
- ✓Pure constant load.

Specimen 9L1. 20% CW by rolling. CRDM tube WP787

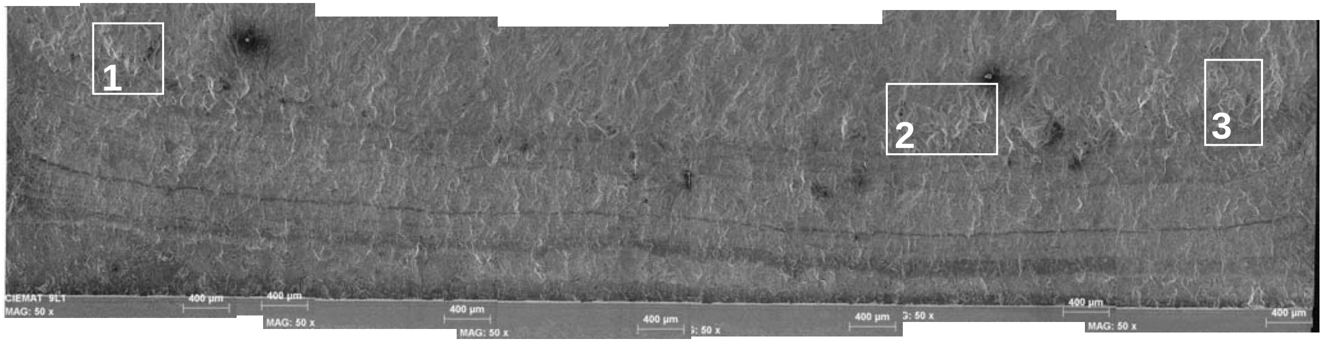
325ºC, 35 ccH_2/kgH_2O, K_I= 37 MPa√m

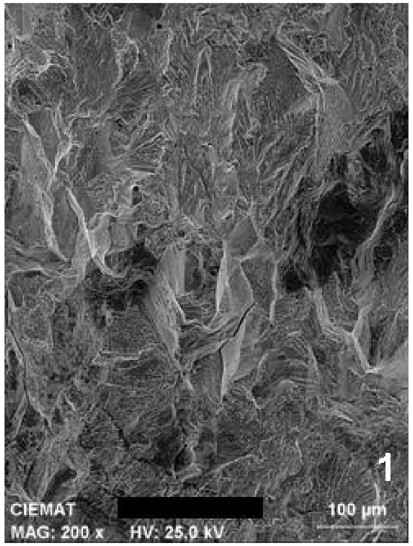
DCPD data during hold time and constant load periods (corrected by fractography)

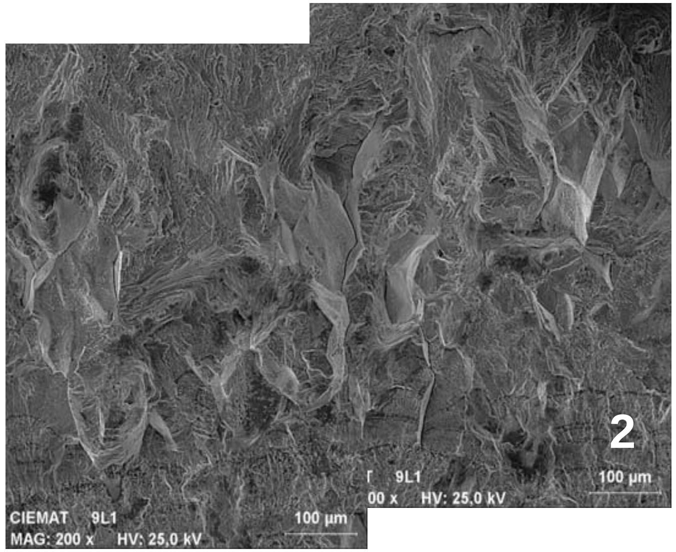


Specimen 9L1. 20% CW by rolling. CRDM tube WP787

325ºC, 35 ccH_2/kgH_2O, K_I= 37 MPa√m





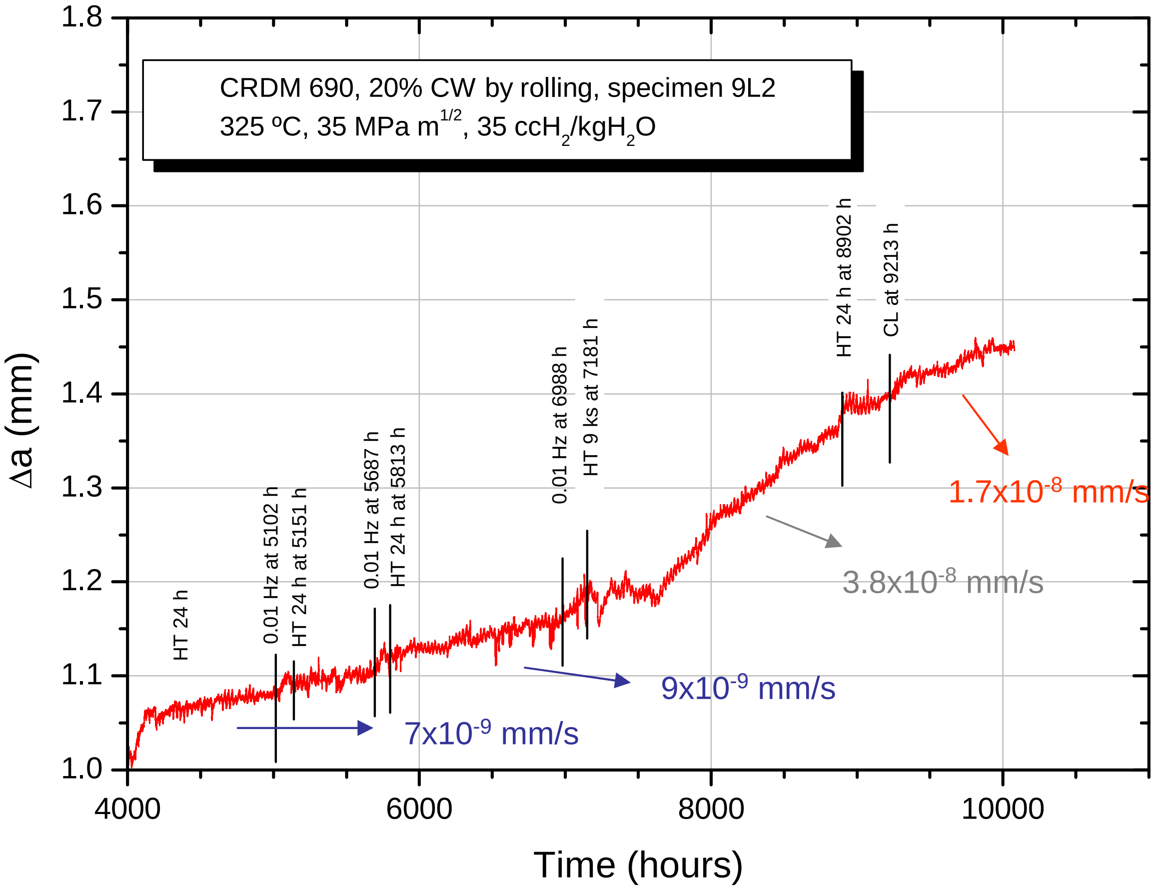


Intergranular areas at the crack tip

Specimen 9L2. 20% CW by rolling. CRDM tube WP787

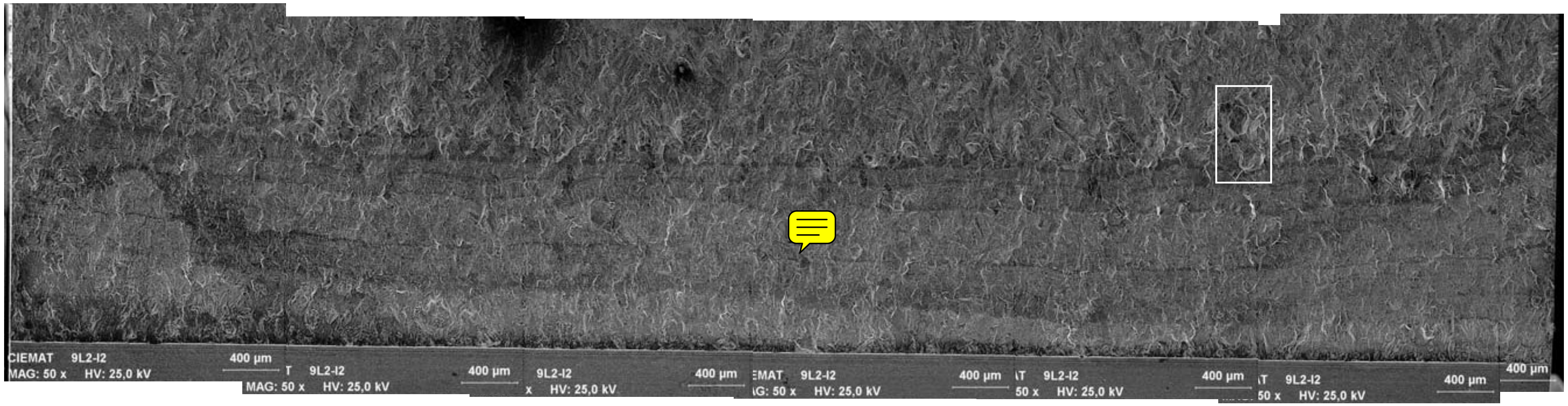
325ºC, 35 ccH_2/kgH_2O, K_I= 37 MPa√m

DCPD data during hold time and constant load periods (corrected by fractography)



Specimen 9L2. 20% CW by rolling. CRDM tube WP787

325ºC, 35 ccH_2/kgH_2O, K_I= 37 MPa√m

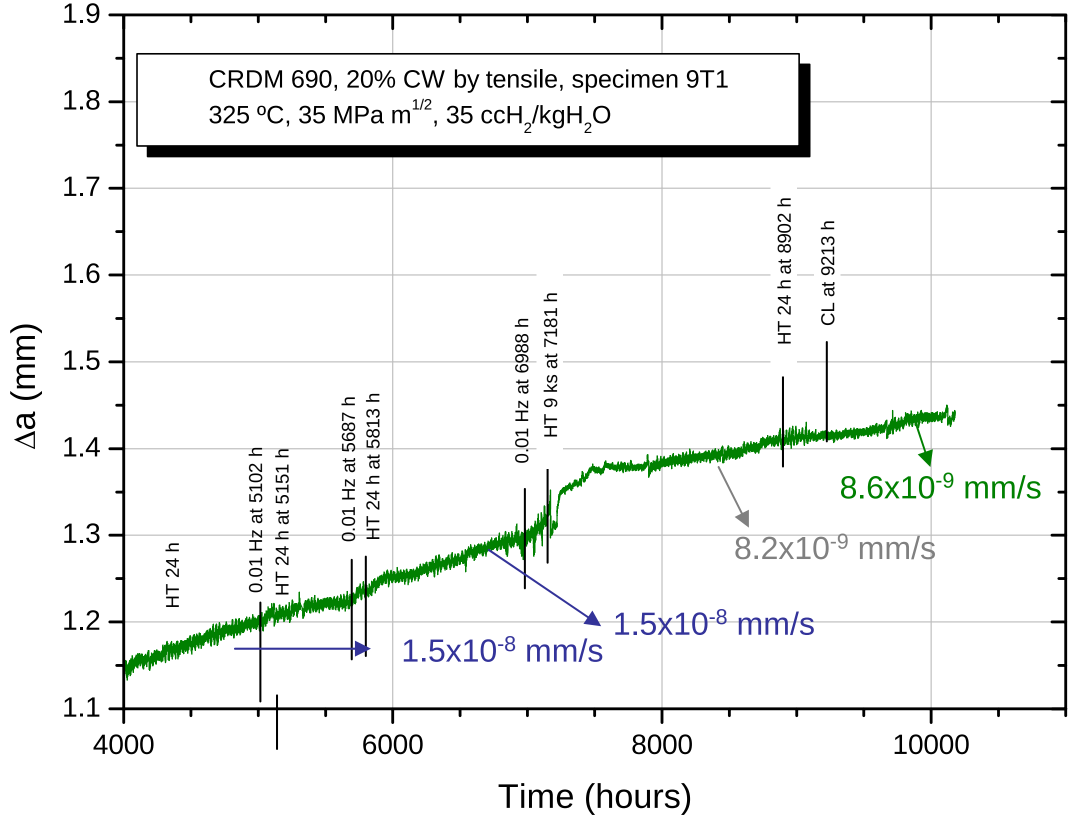


- ✓ The fracture appearance is very similar to the specimen 9L1
- ✓ Estimated final K_I = 36.8 MPa√m

Specimen 9T1. 20% CW by tensile. CRDM tube WP787

325ºC, 35 ccH_2/kgH_2O, K_I= 37 MPa√m

DCPD data during hold time and constant load periods (corrected by fractography)

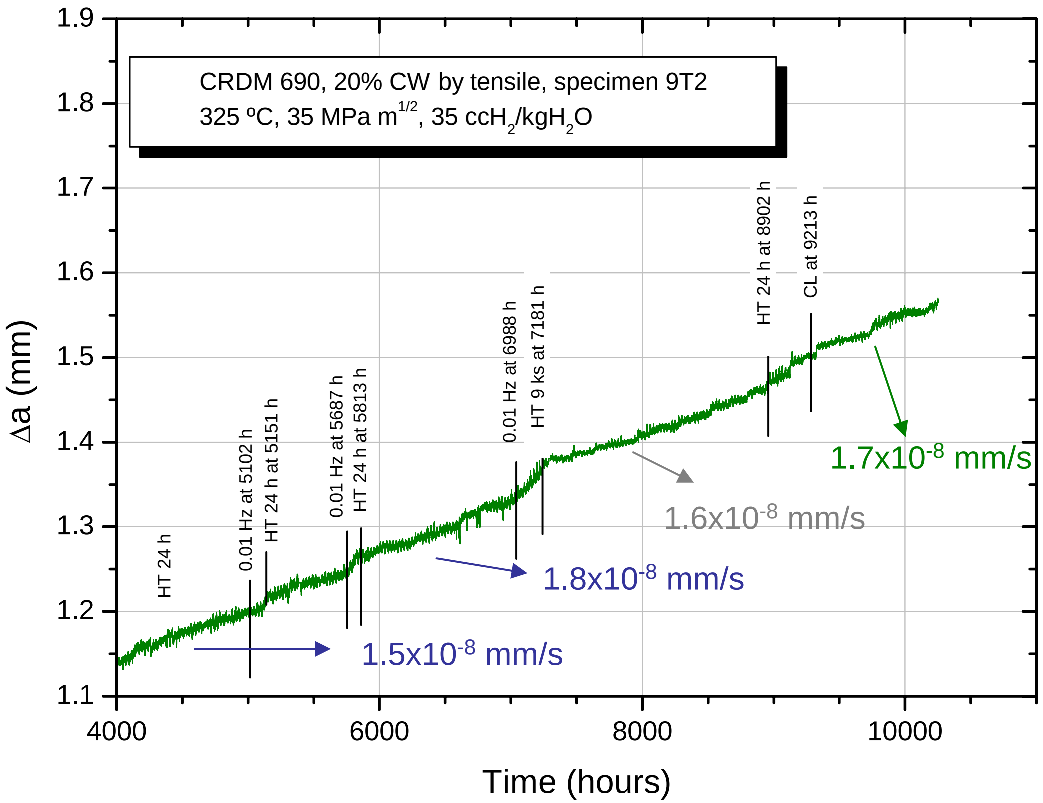


MATERIALS DIVISION

Specimen 9T2. 20% CW by tensile. CRDM tube WP787

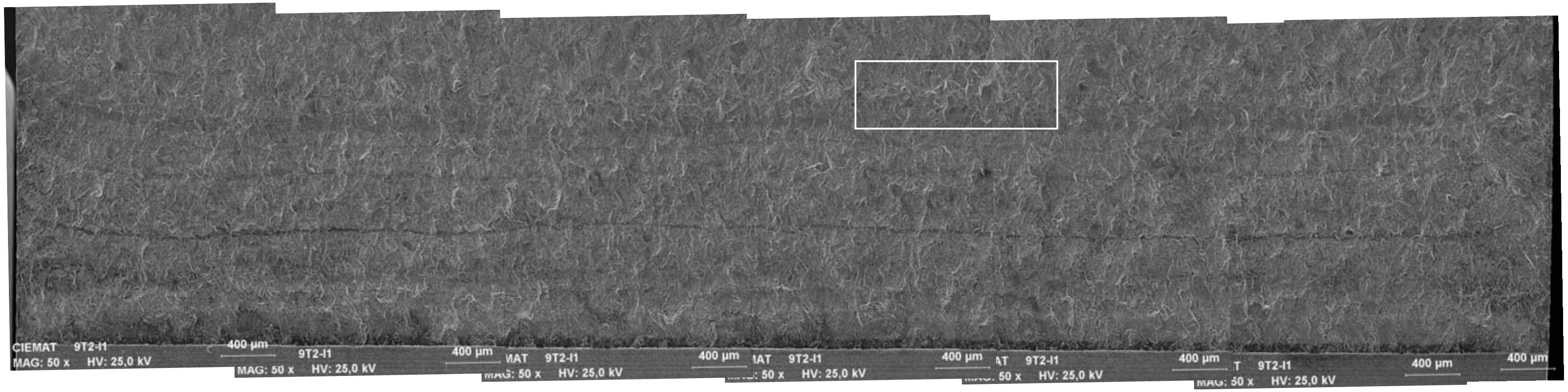
325ºC, 35 ccH_2/kgH_2O, K_I= 37 MPa√m

DCPD data during hold time and constant load periods (corrected by fractography)



Specimen 9T2. 20% CW by tensile. CRDM tube WP787

325ºC, 35 ccH_2/kgH_2O, K_I= 37 MPa√m



✓ Fracture surface is mainly TG. Only minor IG isolated areas have been found at the crack tip, but more than in the specimen 9T1

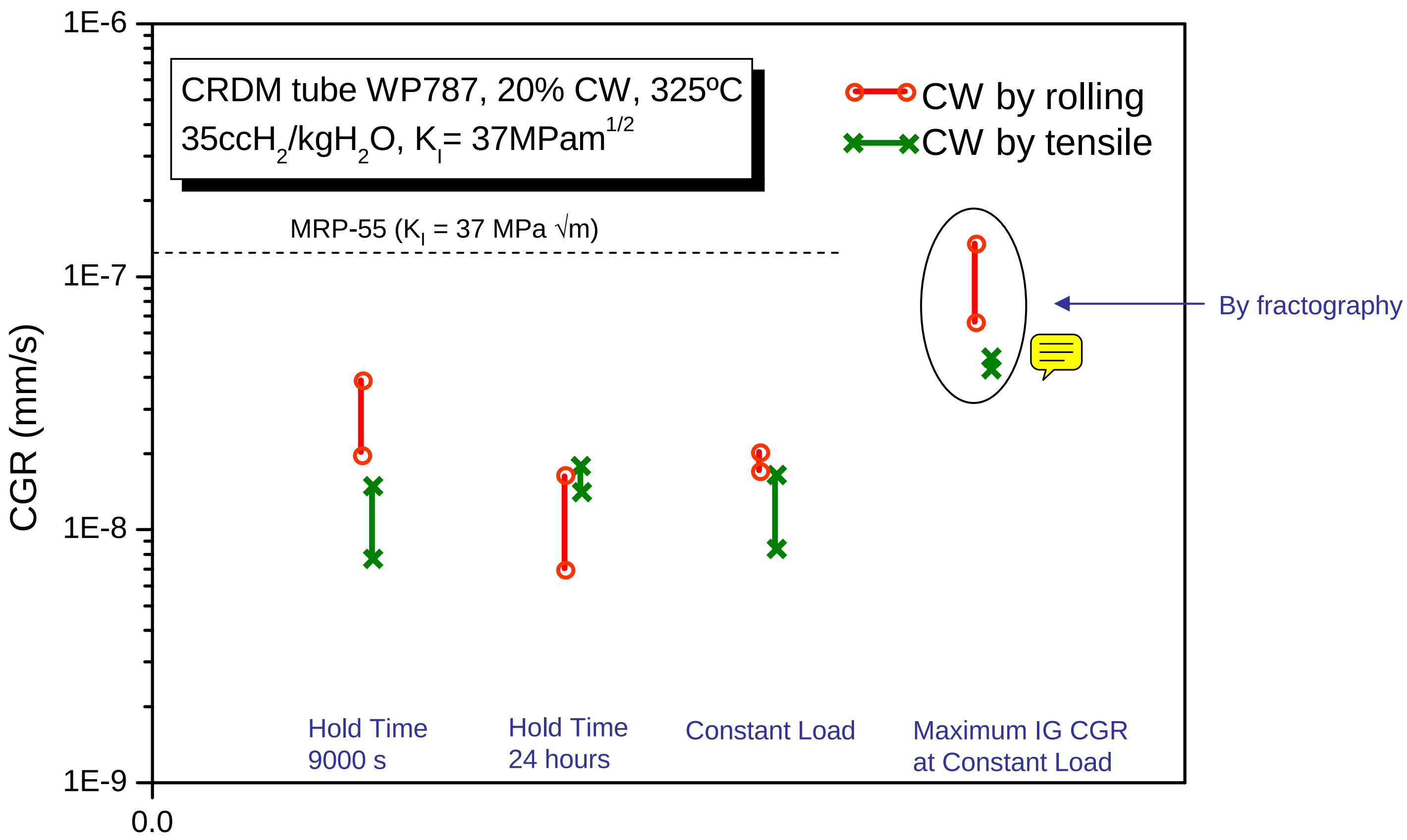
✓ Isolated grains are found in the commencement of Hold Time periods.

✓ Estimated final K_I = 37.7 MPa√m

Summary of results. CRDM tube WP787. 20% CW

325ºC, 35 ccH_2/kgH_2O, K_I= 37 MPa√m

CGR by DCPD signal, corrected by fractography



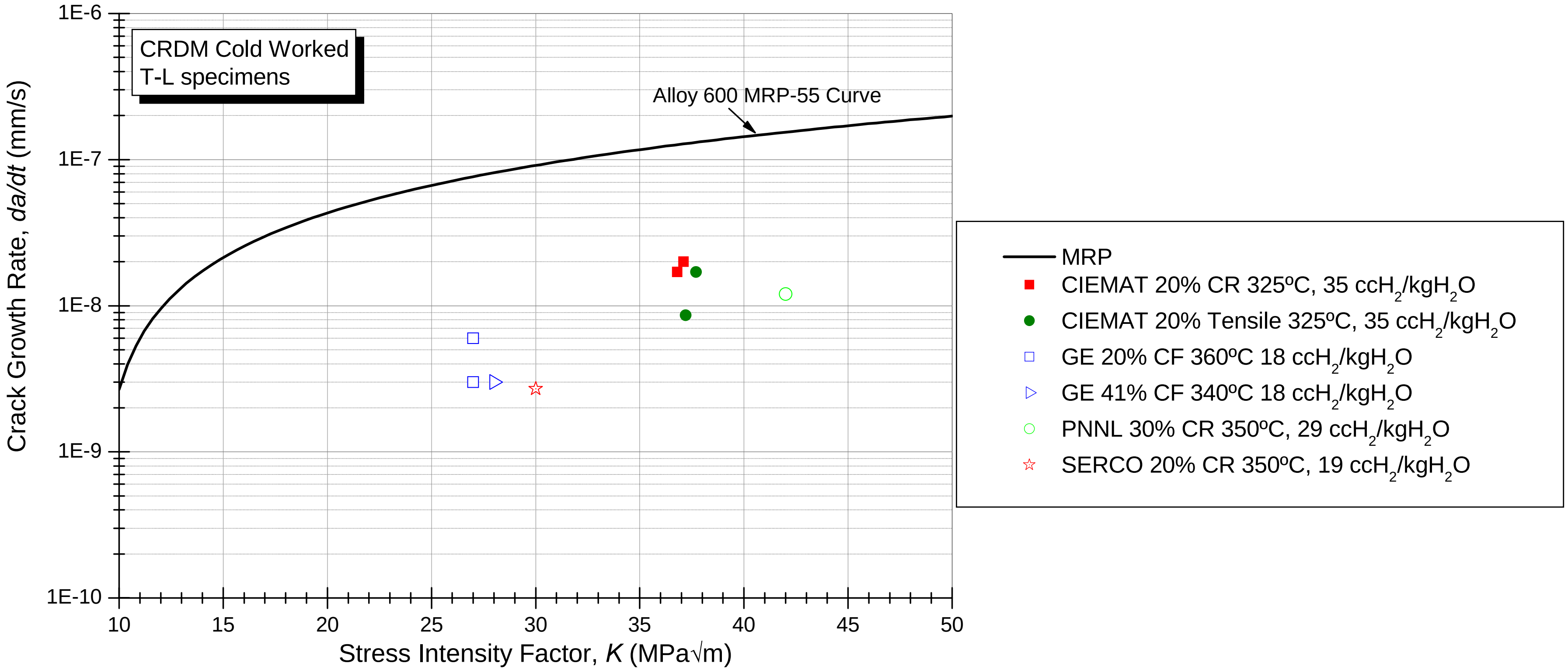
CGR is higher in the CRDM Alloy 690TT cold worked by rolling than by tensile straining

MATERIALS DIVISION

Summary of results. CRDM tube WP787. 20% CW

Comparison with other laboratories

CRDM 20-41 % Cold Worked
T-L orientation, Temp. 325-360ºC
H_2: 18-35 ccH_2/kgH_2O



Summary of results. CRDM tube WP787. 20% CW

325ºC, 35 ccH_2/kgH_2O, K_I= 37 MPa√m

✓ Under Constant Load, CGRs for rolling material is higher than CGRs for tensile strained material

✓ The specimens CW by rolling show larger IG areas than the ones CW by tensile straining

✓ Small secondary cracks have been only observed in the specimens CW by rolling

✓ Mainly Transgranular morphology has been associated to the Hold Time periods.

Discussion

CGRs for 20% CW Alloy 690 TT is higher
for rolled material than for tensile strained material

	20% CW rolling	20% CW tensile
YS (MPa) at 325 ºC	557	444
Hardness, HV1	298	279
Equivalent deformation, %	24.9	18.6
Average misorientation	0.95	0.72

What is the point in comparing “different” materials?
What should be the more adequate parameter for comparison?

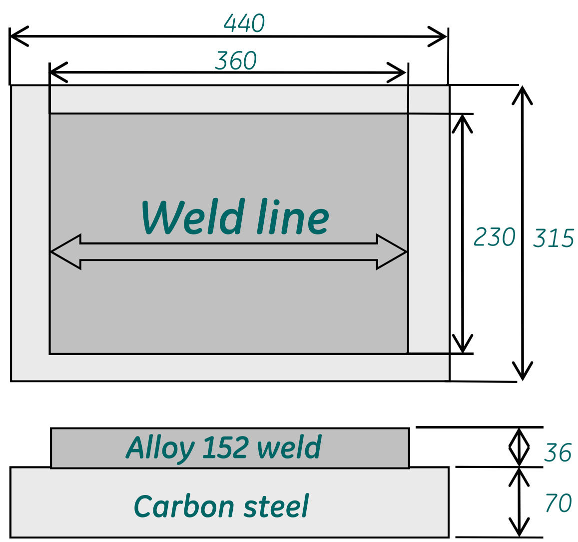
MHI Research Summary

PWSCC CGR of Cold Rolled Alloy 152 Weld

Chemical Composition of Alloy 152 specimen

C	Si	Mn	P	S	Cu	Cr	Ni	Fe	Al	Ti	N	O	Nb+Ta
0.036	0.28	4.24	0.003	0.002	0.01	28.79	Bal.	8.91	0.09	0.08	0.018	0.06	1.46

Geometry of Alloy 152 specimen

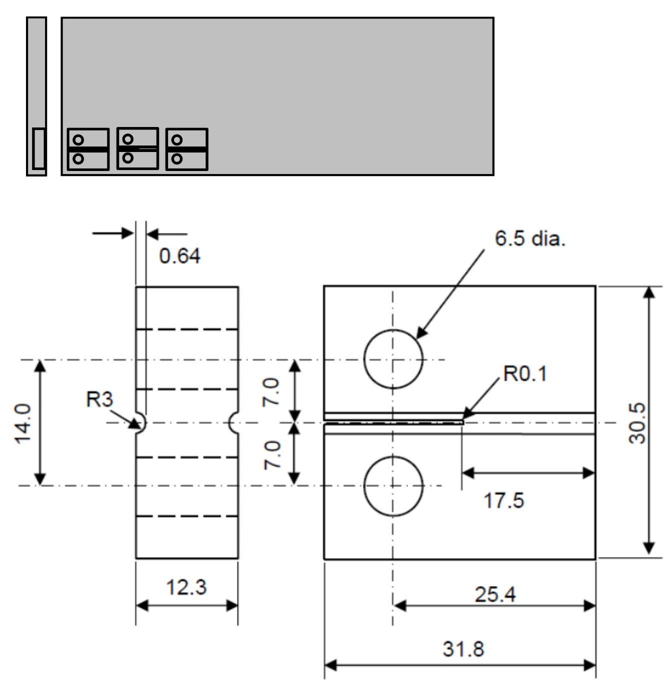


SMAW weld

1D Cold

Rolling

(CR:15, 30 and 50%)



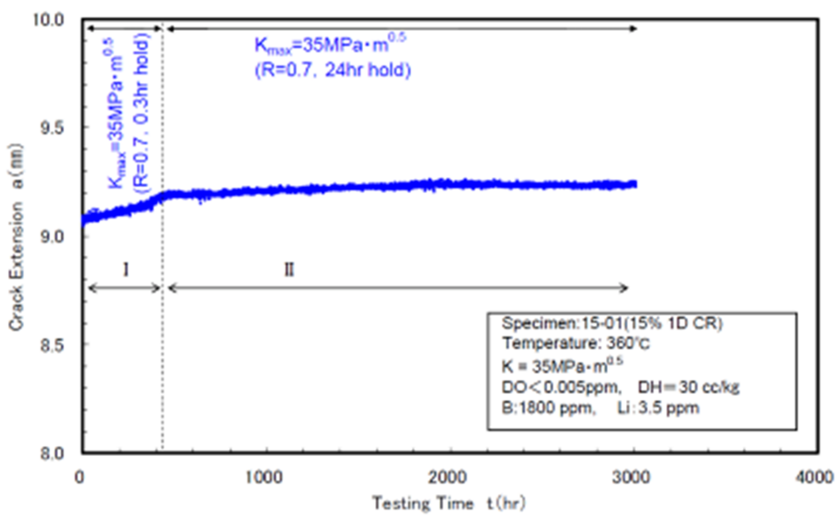
Experimental Procedure for Crack Propagation Test

PWSCC Crack Propagation Test Condition

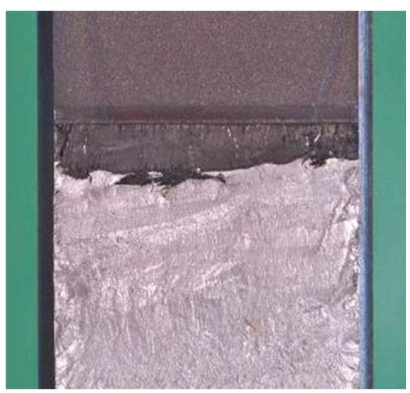
Test piece	0.5T CT
Loading	K_{max}= 35MPa·m$^{0.5}$ Initially R=0.7, 0.3hr holding at K_{max} Then R=0.7, 24hr holding at K_{max}
Environment	360℃ Simulated primary water DO<0.005ppm, DH:30 cc/kg B:1800 ppm Li：3.5 ppm

Crack Extension and Fracture Surface after the Test

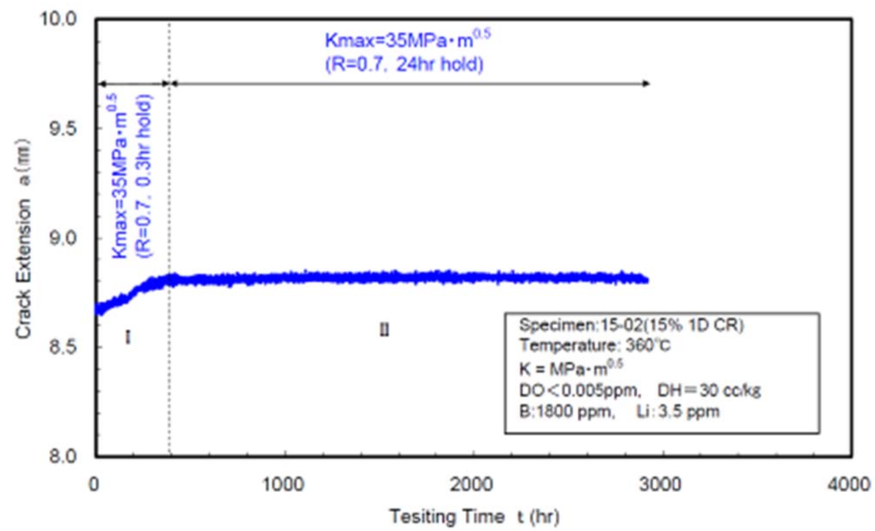
Specimen 15-01 (15% 1D CR)



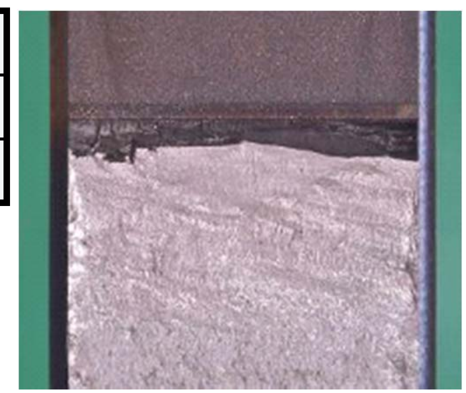
Period	CGR(mm/s)
I	5.1×10^{-8}
II	5.6×10^{-9}



Specimen 15-02 (15% 1D CR)

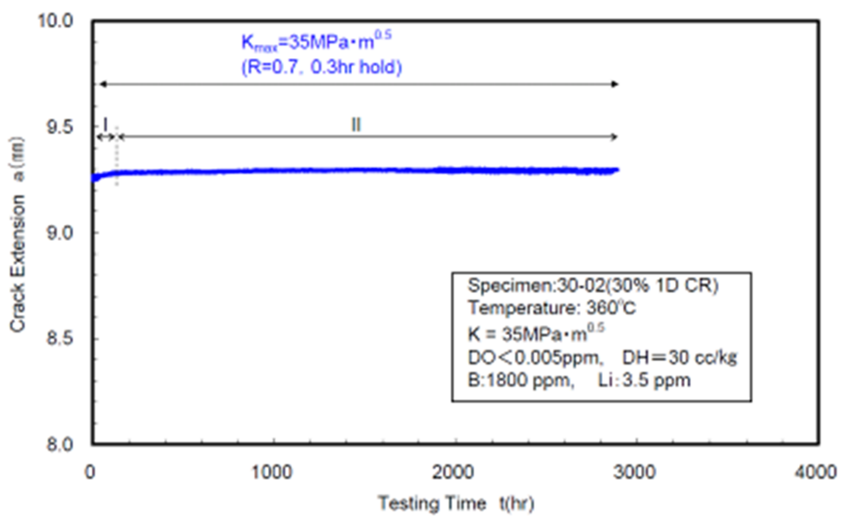


Period	CGR(mm/s)
I	1.1×10^{-7}
II	1.0×10^{-9}

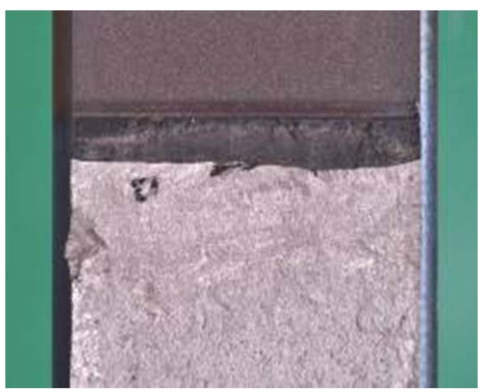


Crack Extension and Fracture Surface after the Test

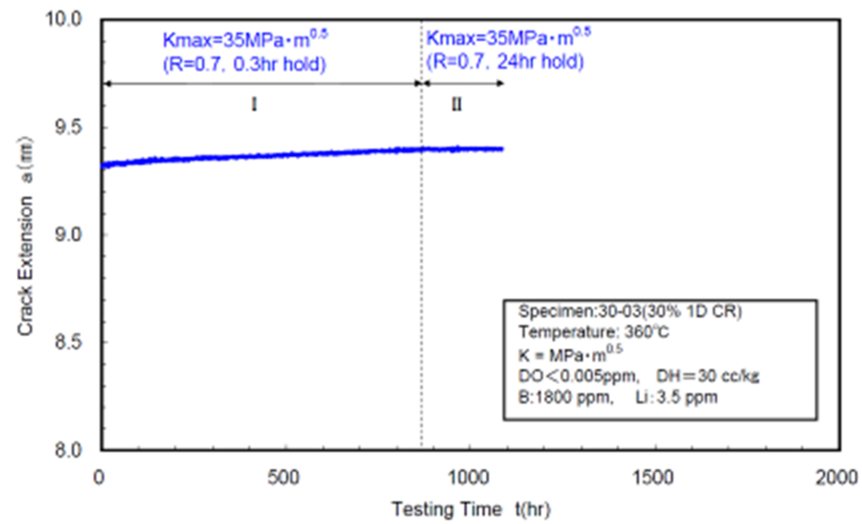
Specimen 30-02 (30% 1D CR)



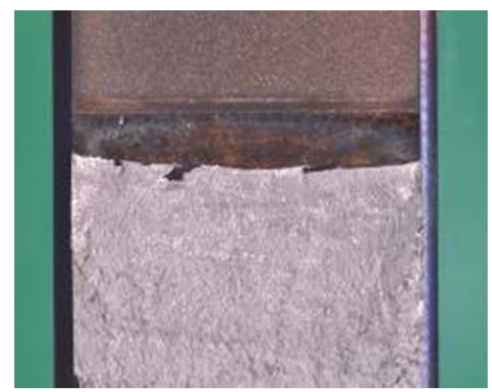
Period	CGR(mm/s)
I	$6.1x10^{-8}$
II	$8.0x10^{-10}$



Specimen 30-03 (30% 1D CR)



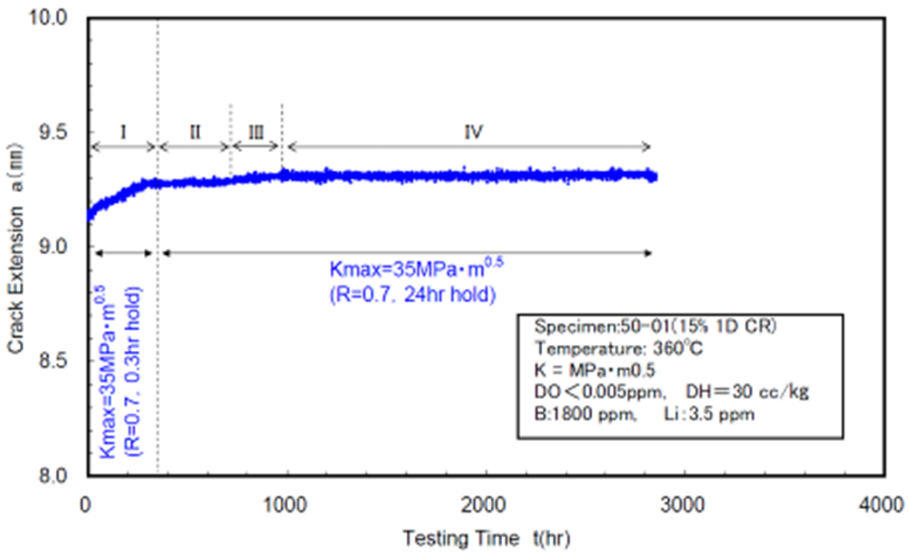
Period	CGR(mm/s)
I	$2.1x10^{-8}$
II	$3.0x10^{-9}$



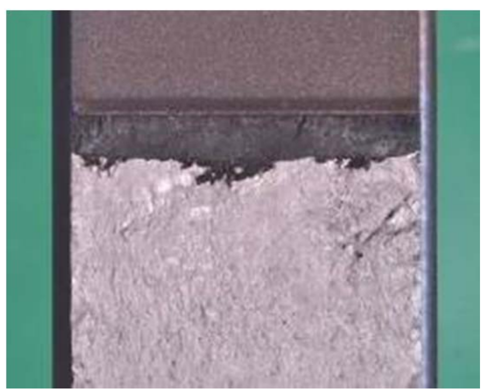
Serco, Ciemat, MHI

Crack Extension and Fracture Surface after the Test

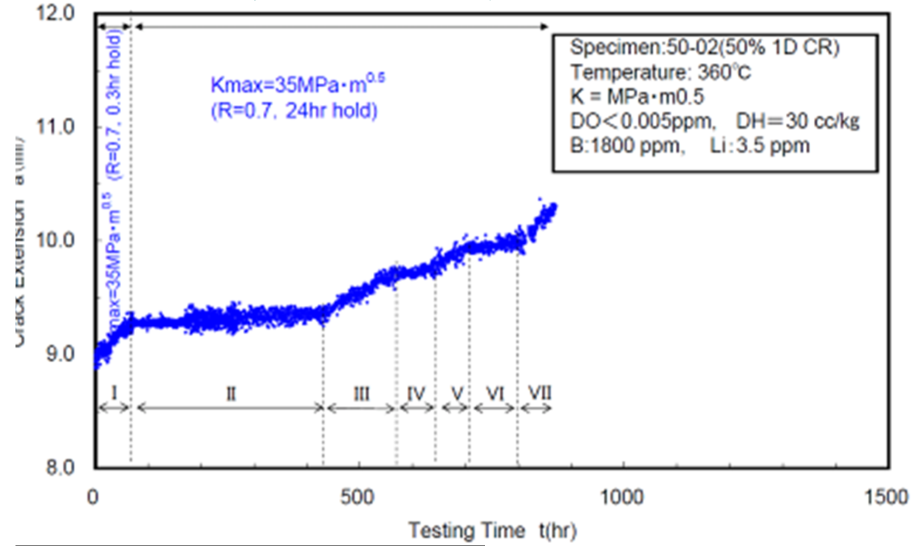
Specimen 50-01 (50% 1D CR)



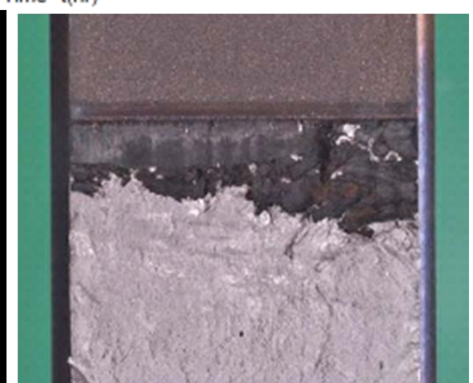
Period	CGR(mm/s)
I	$1.2x10^{-7}$
II	$6.3x10^{-9}$
III	$3.4x10^{-8}$
IV	$1.0x10^{-9}$



Specimen 50-02 (50% 1D CR)



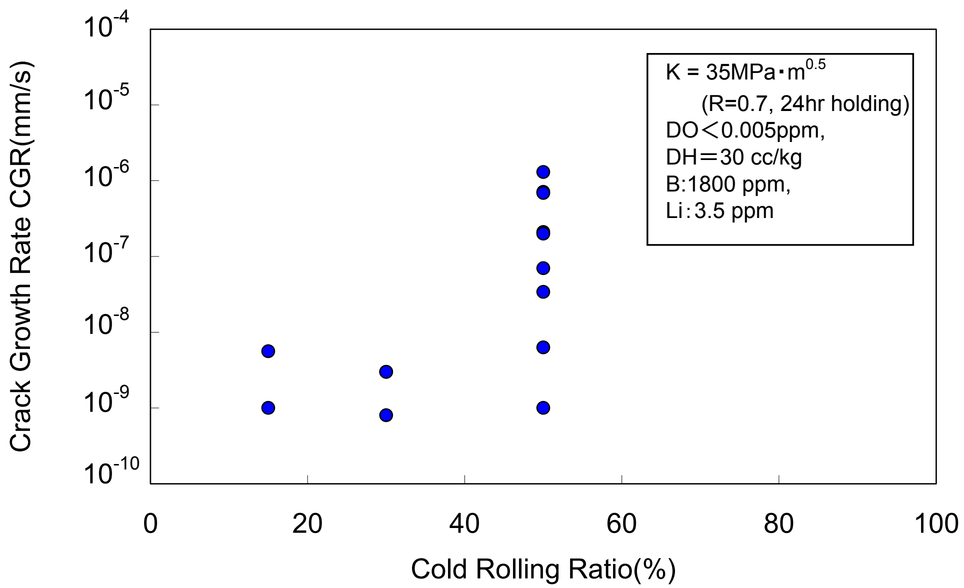
Period	CGR(mm/s)
I	$1.3x10^{-6}$
II	$7.0x10^{-8}$
III	$7.1x10^{-7}$
IV	$2.1x10^{-7}$
V	$6.9x10^{-7}$
VI	$2.0x10^{-7}$
VII	$1.3x10^{-6}$



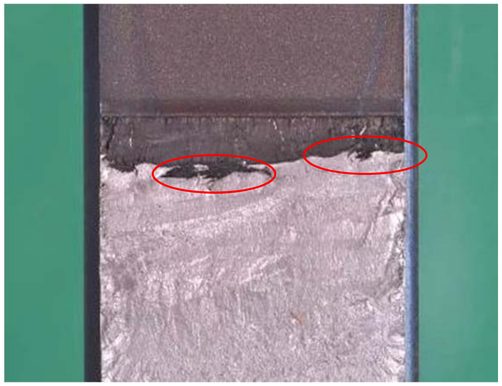
Discussion

CR ratio is one of the dominant factors in CGR.

However, CGR scatter is larger than change caused by CR ratio.

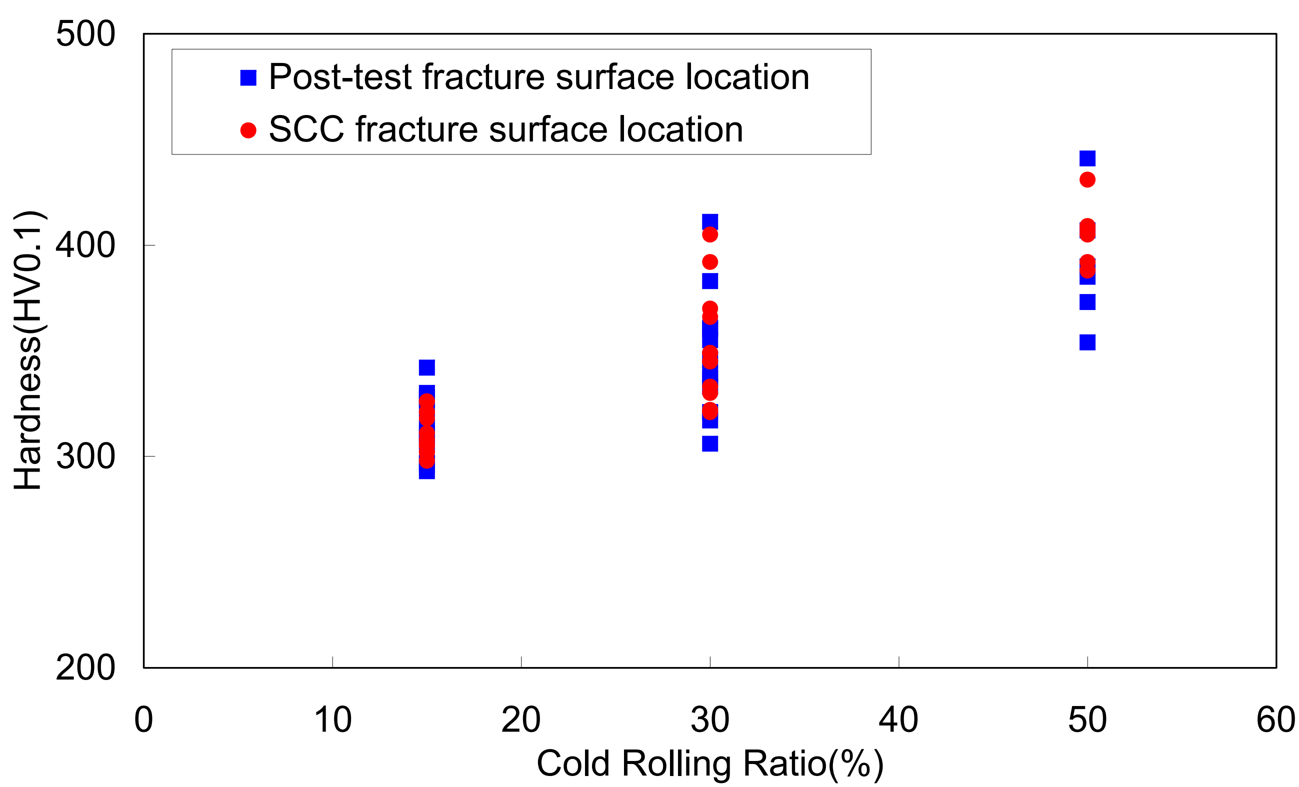


Example of local crack extension

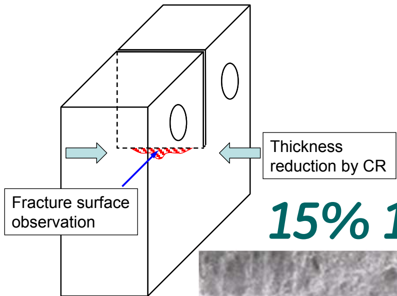


- *In all specimens, crack extension is local.*
- *Fracture surfaces were investigated to find cause of the local high CGR.*

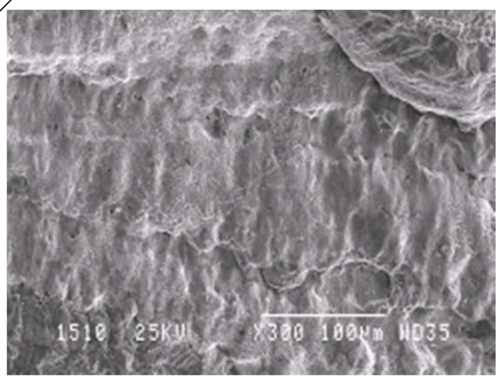
No significant difference between hardness of SCC fracture surface and that of post-fracture surface



Discussion: Fracture surface characteristics

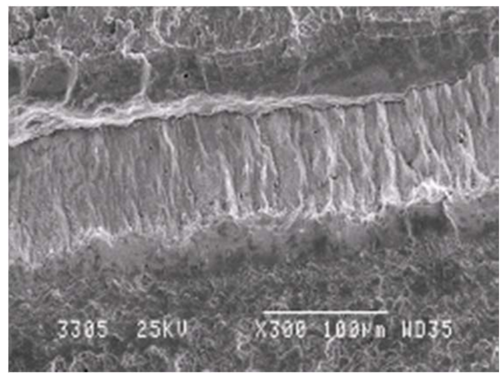


15% 1D CR



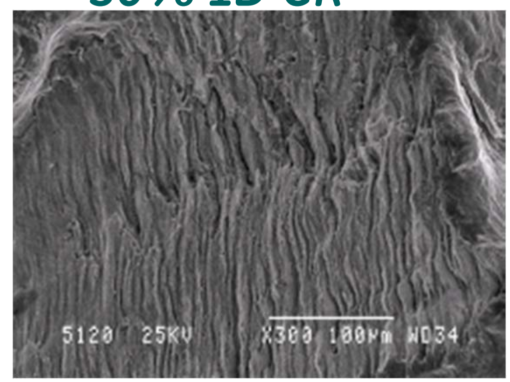
Interval of fringe 33um

30% 1D CR



Interval of fringe 17um

50% 1D CR



Interval of fringe 9um

Dendrite growth

- Interval of fracture surface fringe pattern is proportional to CR ratio.
- Therefore, the fringe reflects geometric change in microstructure caused by CR.
- The fringe is estimated to be surface of dendrite secondary arm.

MHI Summary

- PWSCC susceptibility of alloy 152 is strongly dependent of microstructure.
  - In the case of alloy 152 weld, CGR strongly depends on direction of dendrite growth.
- For alloy 690, CGR depends on grain boundary coherency.
- Cold working increases CGR of both alloy 152 & alloy 690.