ELECTRIC POWER RESEARCH INSTITUTE

# SCC of Alloy 52 & 152 Weld Metals in PWR Primary Water


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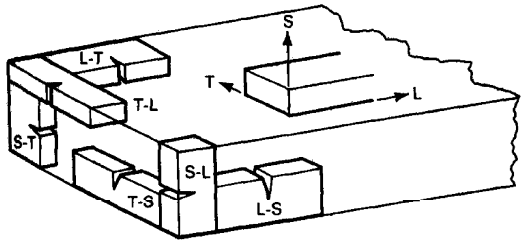
*NRC – EPRI Meeting* *June 2011*

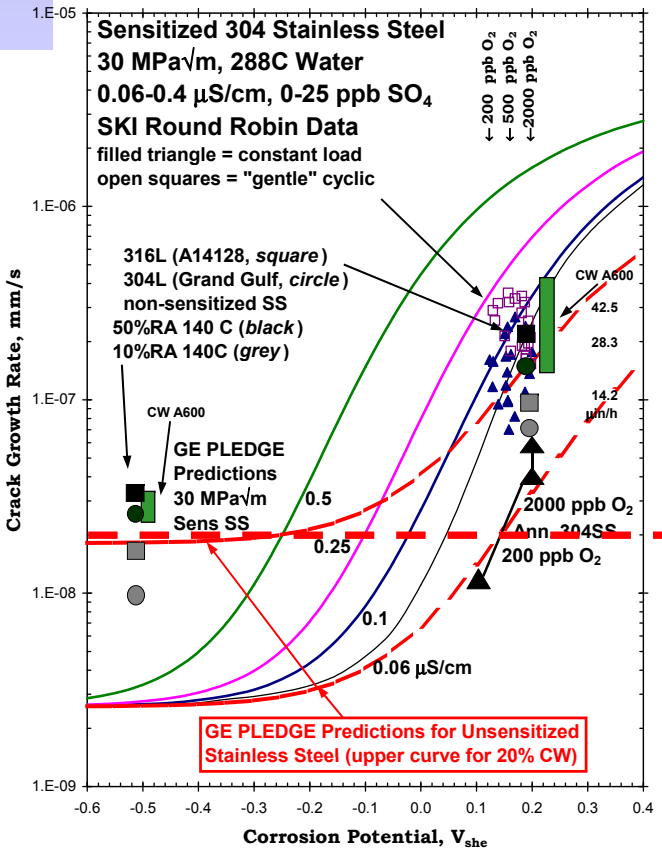
# Key Issues in SCC of Alloy 152/52 Welds

*Key questions potentially affecting crack growth in 152/52:*

1. *Inhomogeneous solidification micro-chemistry.*
2. *Residual shrinkage strain in the weld metal.*
3. *Ductility dip cracking, solidification cracking, etc.*
4. *Variations in composition and welding practice/cleanliness*
5. *Effect of weld repairs*
6. *Effect of aging*

# Alloy 152/52 SCC



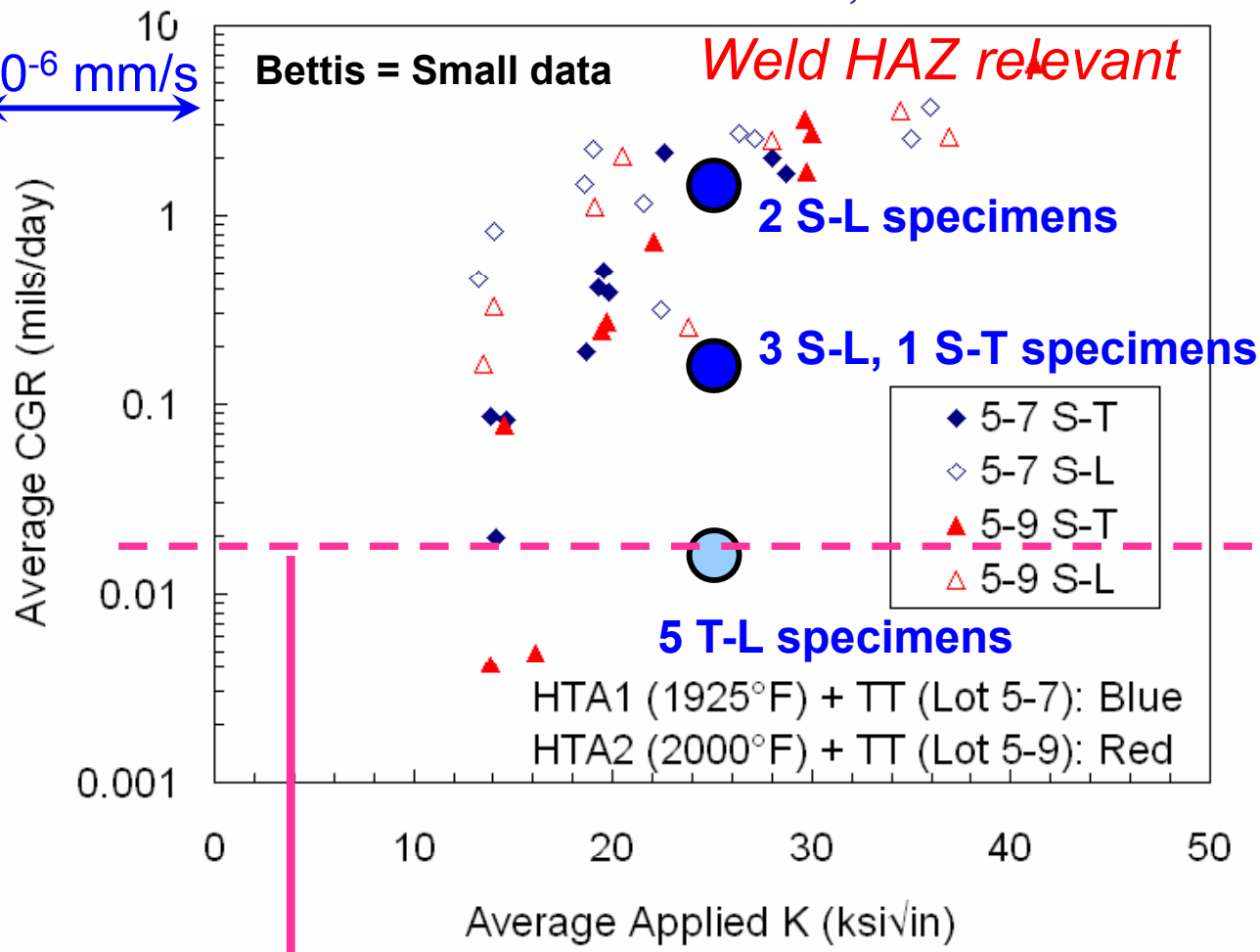




Sens & CW 304SS, BWR

No SCC ⟷ SCC in plants in ~30 yrs

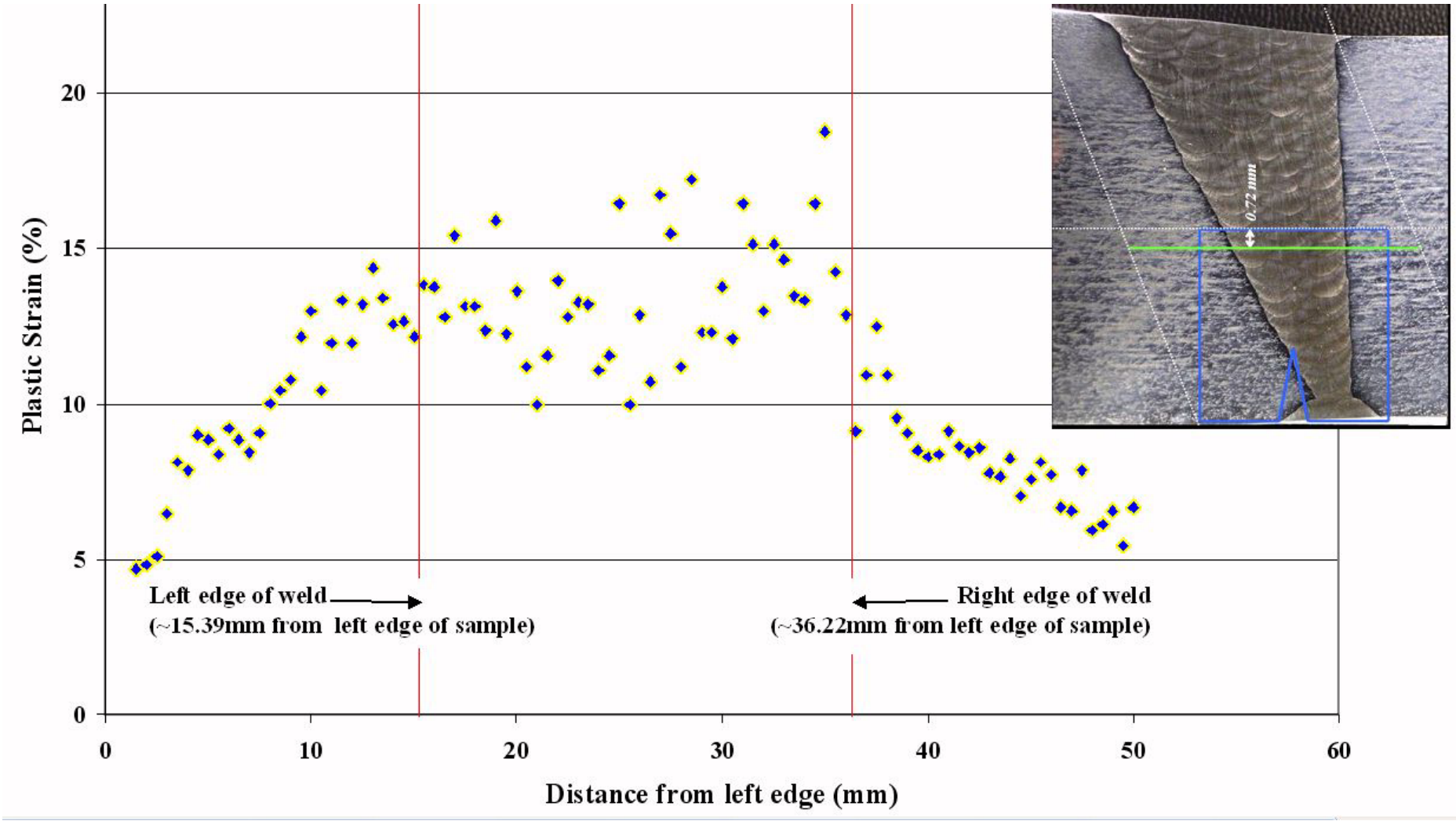
$10^{-6}$ mm/s

24% Cold Rolled 690, PWR Water




All weld metals but one show pretty low growth rates

# Residual Shrinkage Strain in the Weld Metal



# Testing Approach

*Crack growth rates conditions for alloy 690 and 152/52 welds:*

- *690 cold worked by forging or 1-D rolling at 25 ºC*
  - *by 20, 26 and 40% reduction in thickness*
  - *S-L, S-T and T-L orientations, ~10 heats, ~32 specimens*
  - *cold work broadly simulates weld residual strain in HAZ*
  - *152/52 weld: T-S orientations, ~6 heats, 6 specimens*
  - *used resistivity coupon for dcpd correction*
- *0.5T CT specimens in 360 ºC (290–340ºC) PWR primary water*
- *testing at 25 – 35+ ksi√in, including "Varying-K"*
- *$H_2$ level designed to be near Ni/NiO at the test temperature*
- *good water chemistry: ~2 volume exchanges per hour, full-flow demineralization, and active $H_2$ sparging*
- *measured potentials of 690 & Pt vs. $Cu/Cu_2O/ZrO_2$*

# Alloy 52/152 Weld Metals Options

*Options for 52/152 materials:*

- *B&W Alloy 52 / 152 weld: tested*
- *GENE Alloy 52 weld: in test*
- *MHI/NMC/Charlotte Alloy 52 / 152 welds: 152 in test*
- *Areva Alloy 152 weld (small pieces): not tested*
- *KAPL MLTS-27 NG & DM welds: not tested*
- *KAPL 52i weld metal: EPRI weld about to start*
- *Bogdan's 152 mock-up*
- *PG&E mock-up*
- *MHI – 52 long. weld along CRDM, & 2" plate with 152*
- *CIEMAT / ENSA - two commercial welds*
- *Others: EPRI Charlotte, Efsing, MHI…*

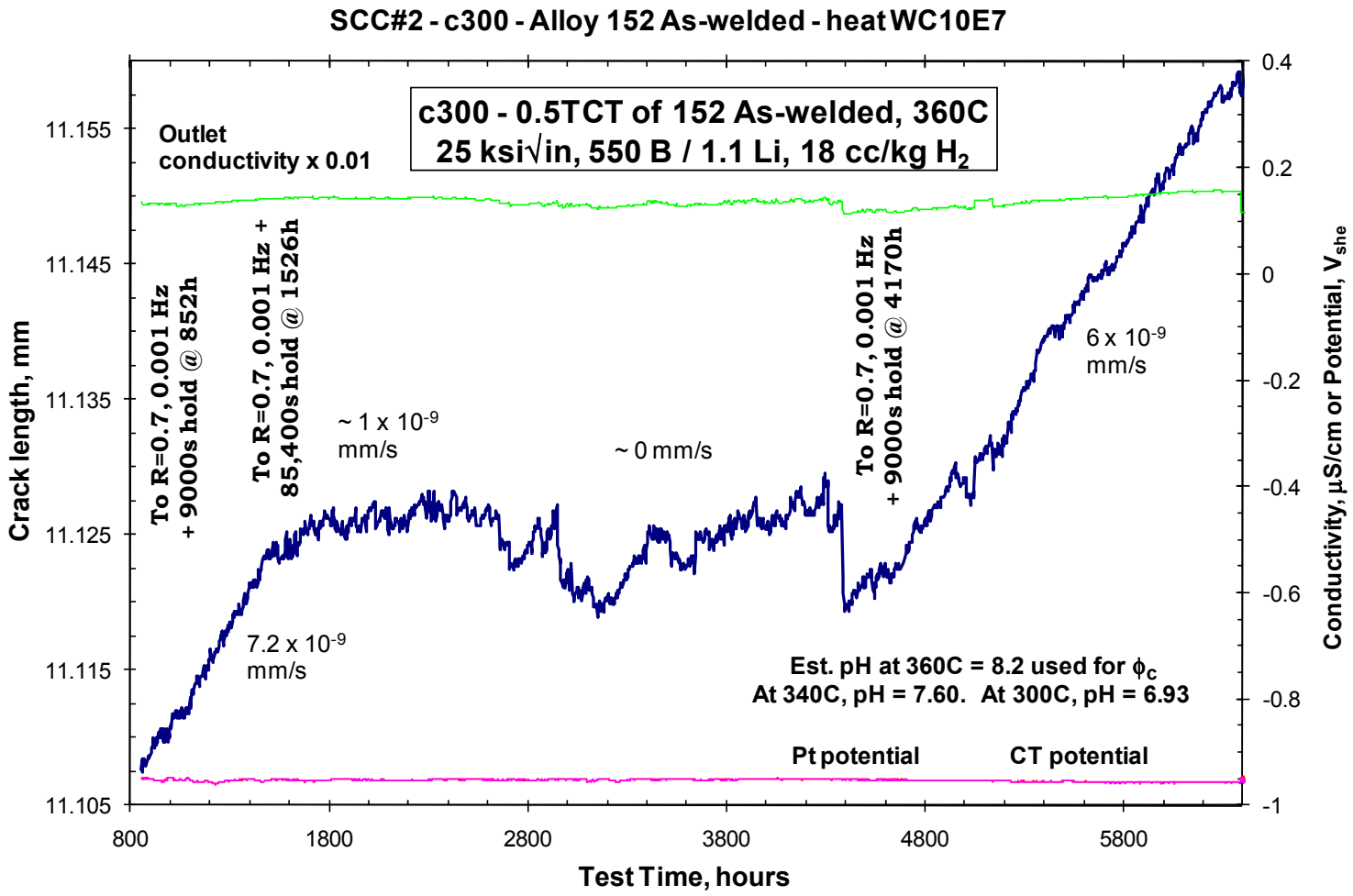
# Preliminary Alloy 152/52 CGR Data

| CT | Material | Source | Orient. | Condition | Hours | No Cycling CGR, mm/s | MPa/m | Mat'l - Heat | Location |
|---|---|---|---|---|---|---|---|---|---|
| Welds | | | | | <5e-9 | code | >5e-8 | >3e-7 mm/s | |
| c528 | 25Cr, MLTS-25 | KAPL | T-S | As-Welded | 2400 | 2.50E-09 | **33** | 52i | 82SK8 |
| c527 | 152, 307380 | MHI Archive | T-S | AW+20%CW | 2400 | 7.00E-09 | **33** | 152 | 82SK8 |
| c526 | 52i, 187775 | EPRI | T-S | As-Welded | 2500 | 2.60E-09 | **33** | 52i | 82SK7 |
| c525 | 152, 146444 | ANL | T-S | As-Welded | 2500 | 4.00E-09 | **33** | 152 | 82SK7 |
| c511 | 52 NX2686JK | MHI Archive | T-S | As-Welded | 6200 | 6.00E-10 | **33** | 152 | 84SK2 |
| c510 | 152 WC51G0 | Arvea | T-S | As-Welded | 6200 | 1.00E-09 | **33** | 152 | 84SK2 |
| c502 | 52 NX6133JK | Ciemat | T-S | As-Welded | 5154 | 3.00E-09 | **33** | 52 | 82SK8 |
| c501 | 152 747136 | Ciemat | T-S | As-Welded | 5154 | 2.50E-09 | **33** | 152 | 82SK8 |
| c500 | 152i 187775 | KAPL | T-S | As-Welded | 6111 | 4.00E-09 | **33** | 152i | 82SK7 |
| c499 | 52i 187775 | KAPL | T-S | As-Welded | 6111 | 2.50E-09 | **33** | 52i | 82SK7 |
| c337 | 52 NX0B05TS | GE Nuclear | T-S | As-Welded | 5553 | 2.00E-09 | **27.5** | 52AW | 82SK5 |
| c336 | 152 307380 | MHI Archive | T-S | As-Welded | 5553 | 5.00E-10 | **27.5** | 152AW | 82SK5 |
| c301 | 52 NX2578JK | B&W Canada | T-S | As-Welded | 10278 | 4.00E-10 | **27.5** | 52AW | 45A2 |
| c300 | 152 WC10E7 | B&W Canada | T-S | As-Welded | 10278 | 1.00E-09 | **27.5** | 152AW | 45A2 |
| | | | | **TOTAL Hrs =** | **76392** | | | | |

*All weld metals have cracked at low rates in our tests (except c527 with 20% additional cold work)*

# Specimen c300

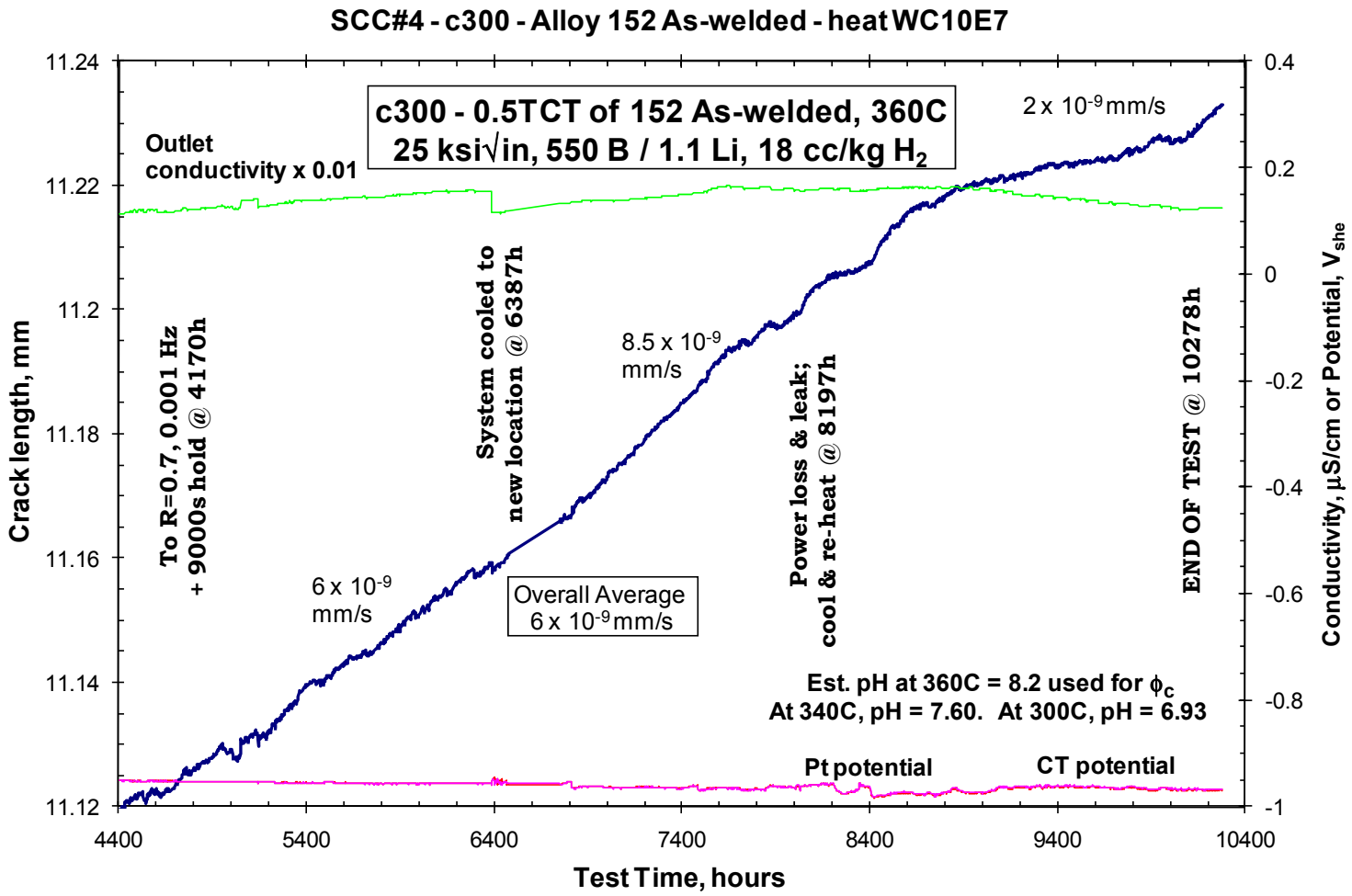
## 152 Weld – B&W




*No growth even when cycling with long hold time*

# Specimen c300

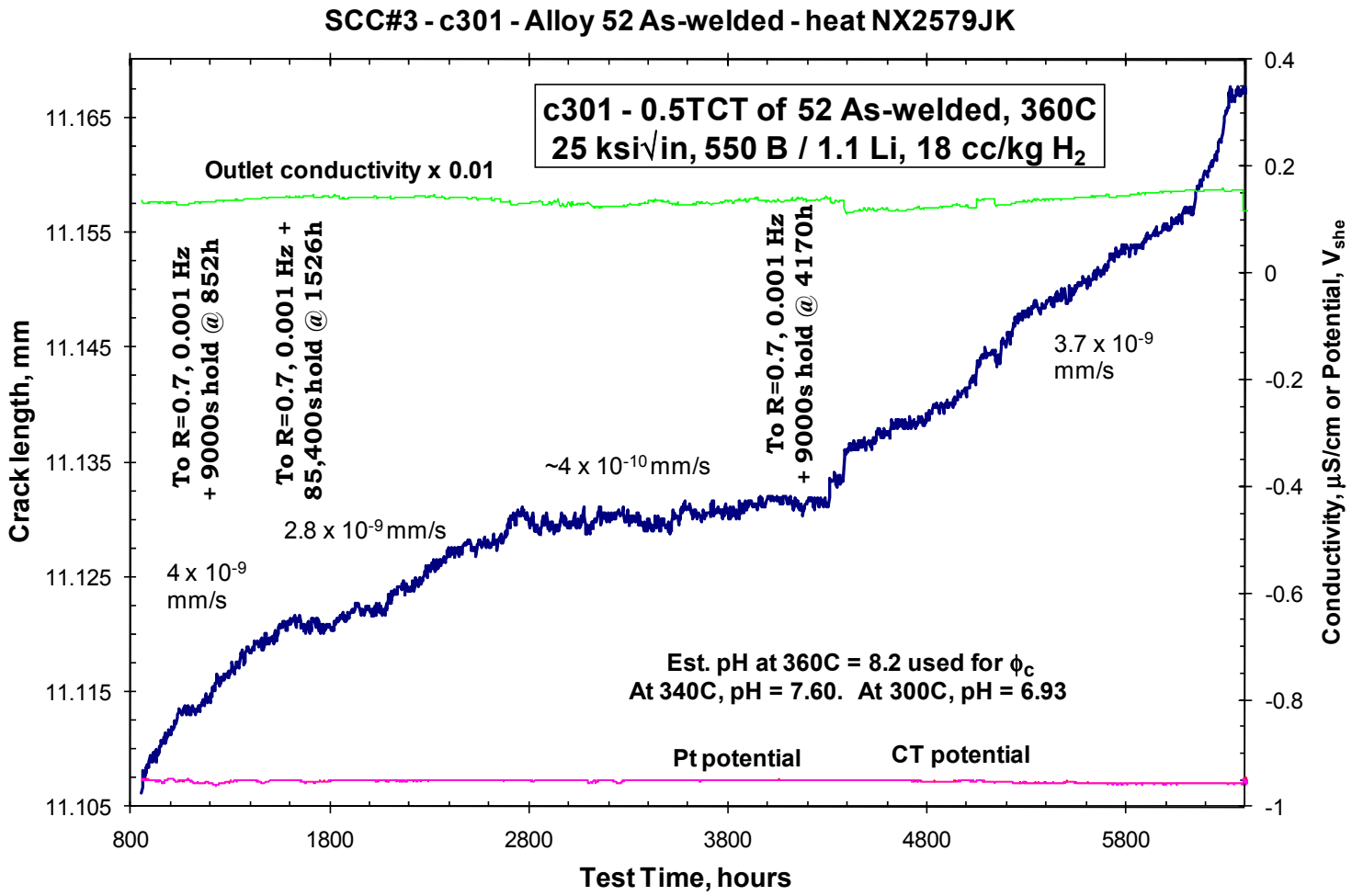
## 152 Weld – B&W




*Low growth rate even when cycling with 9000s hold time*

# Specimen c301

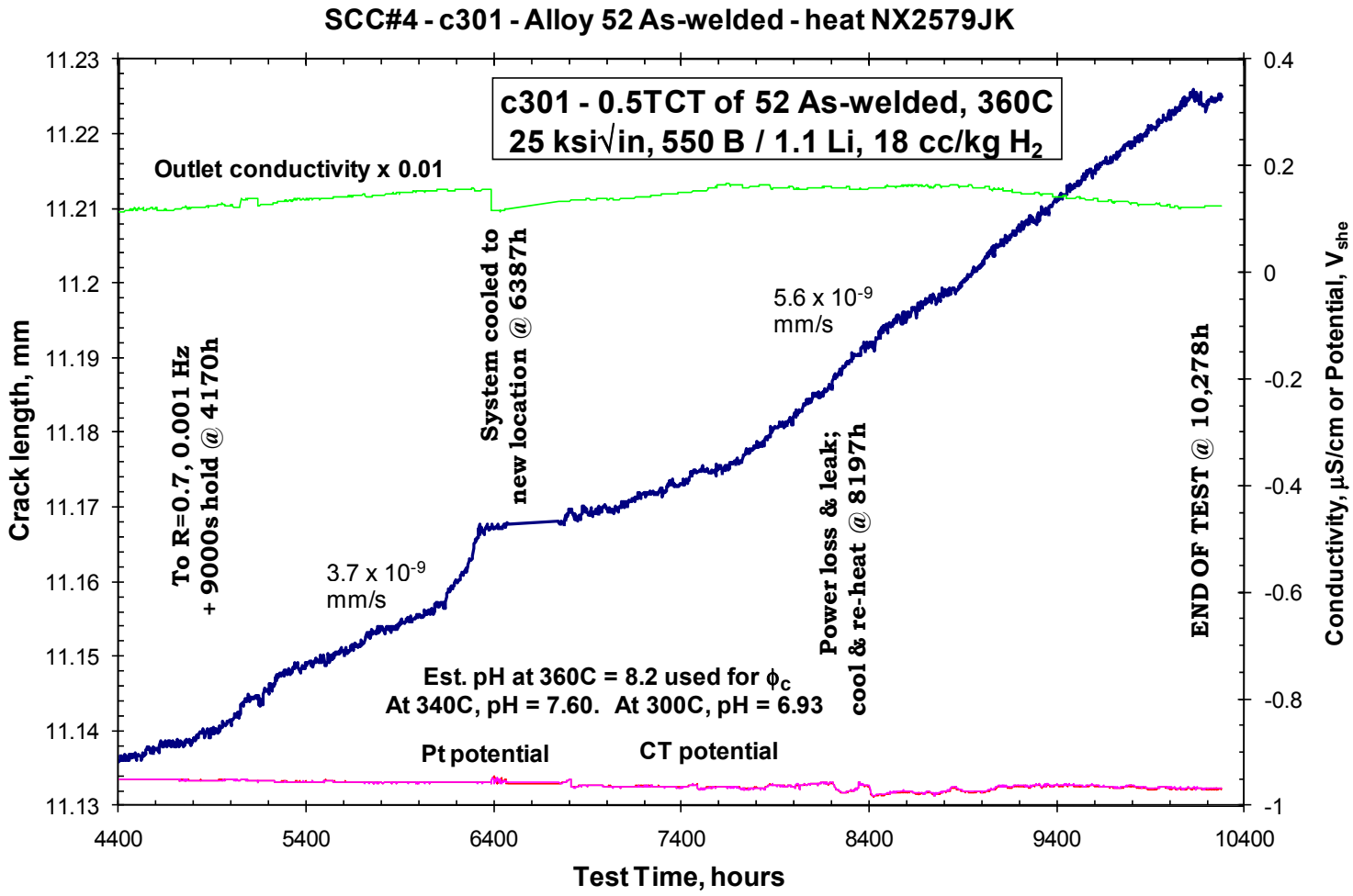
## 52 Weld – B&W




*Low growth rate even when cycling with long hold time*

# Specimen c301

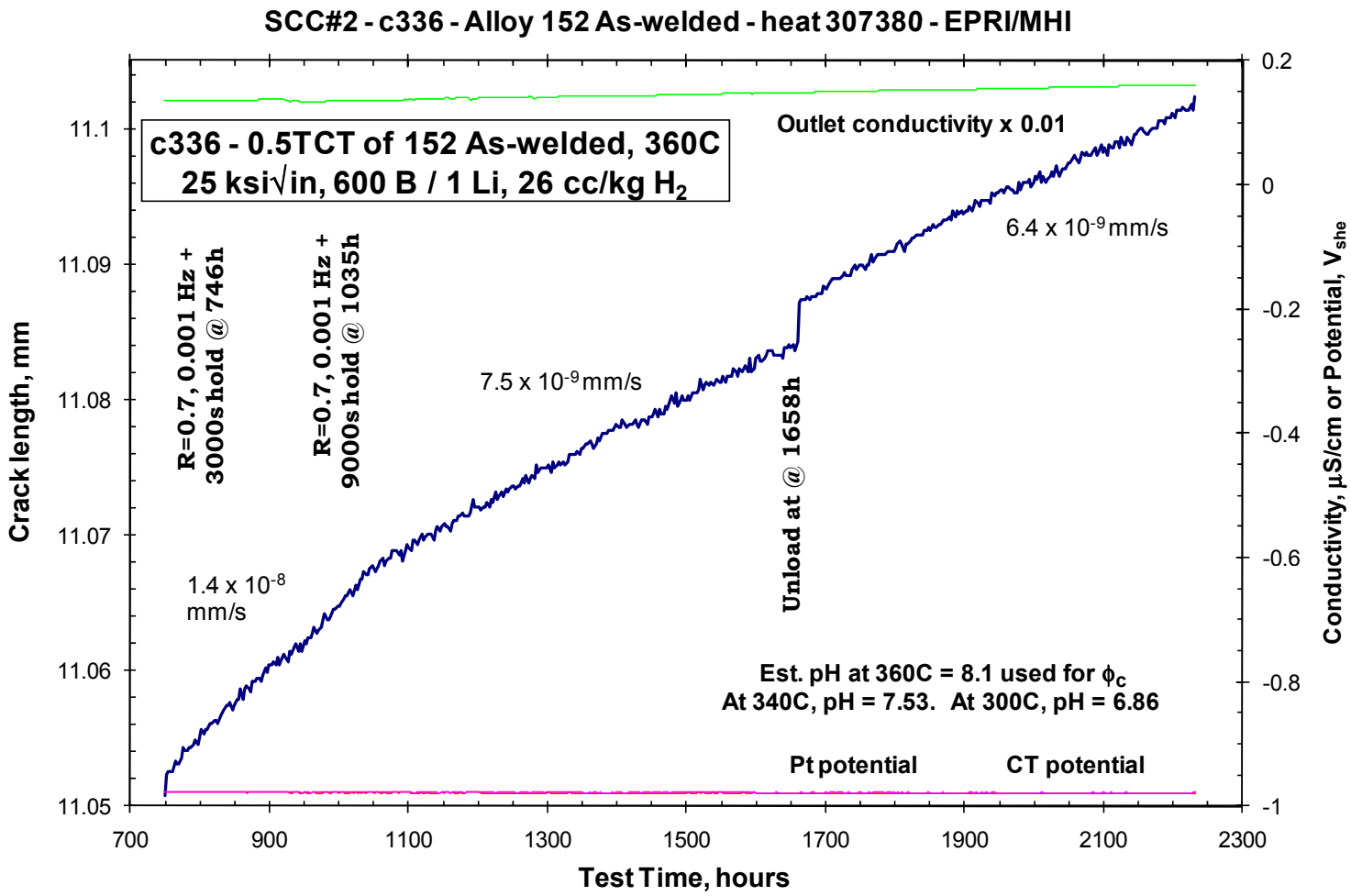
## 52 Weld – B&W




*Low growth rate even when cycling with 9000s hold time*

## Specimen c336

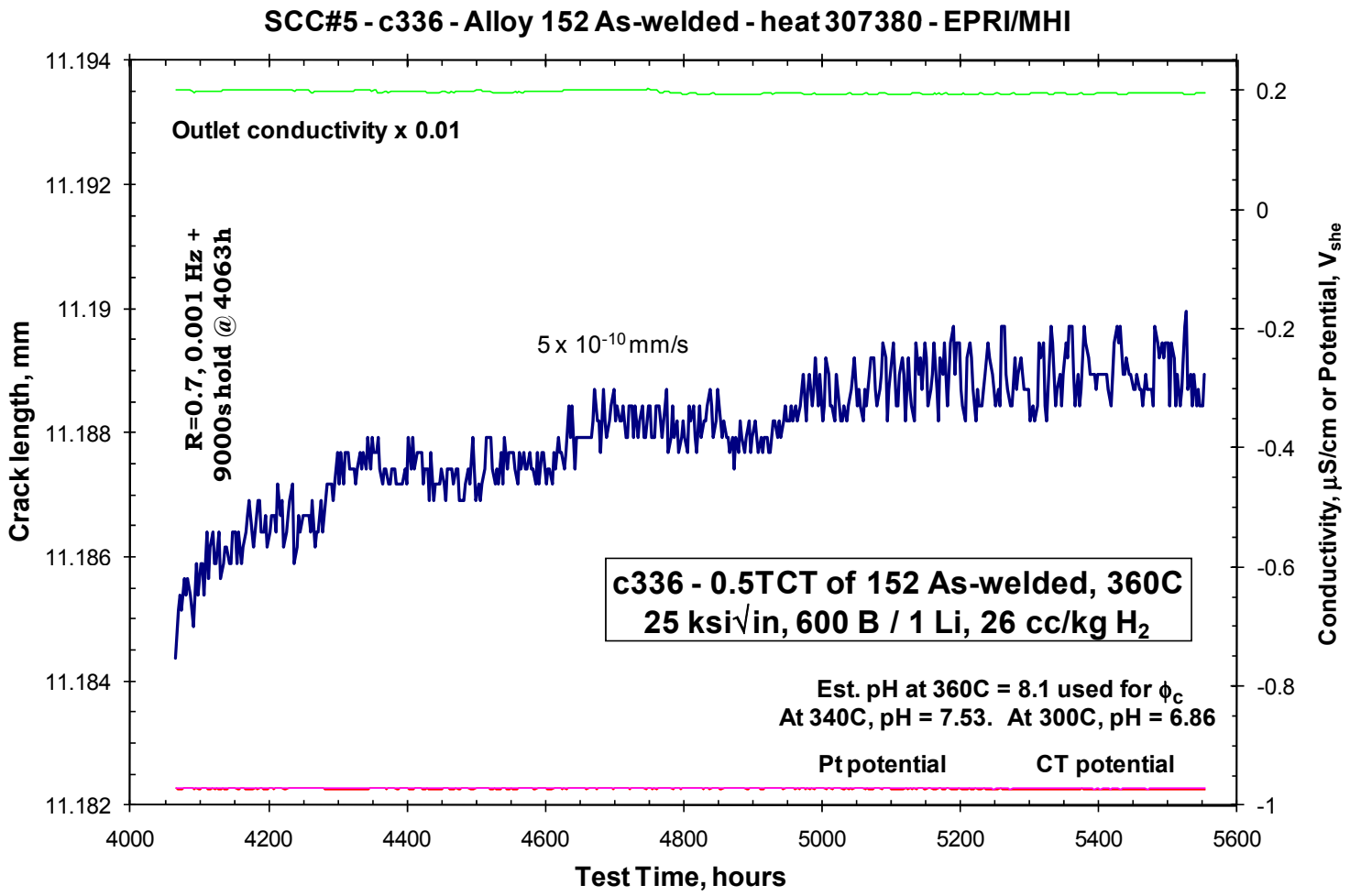
# 152 Weld – MHI




*~Low growth rate even when cycling with 9000s hold time*

## Specimen c336

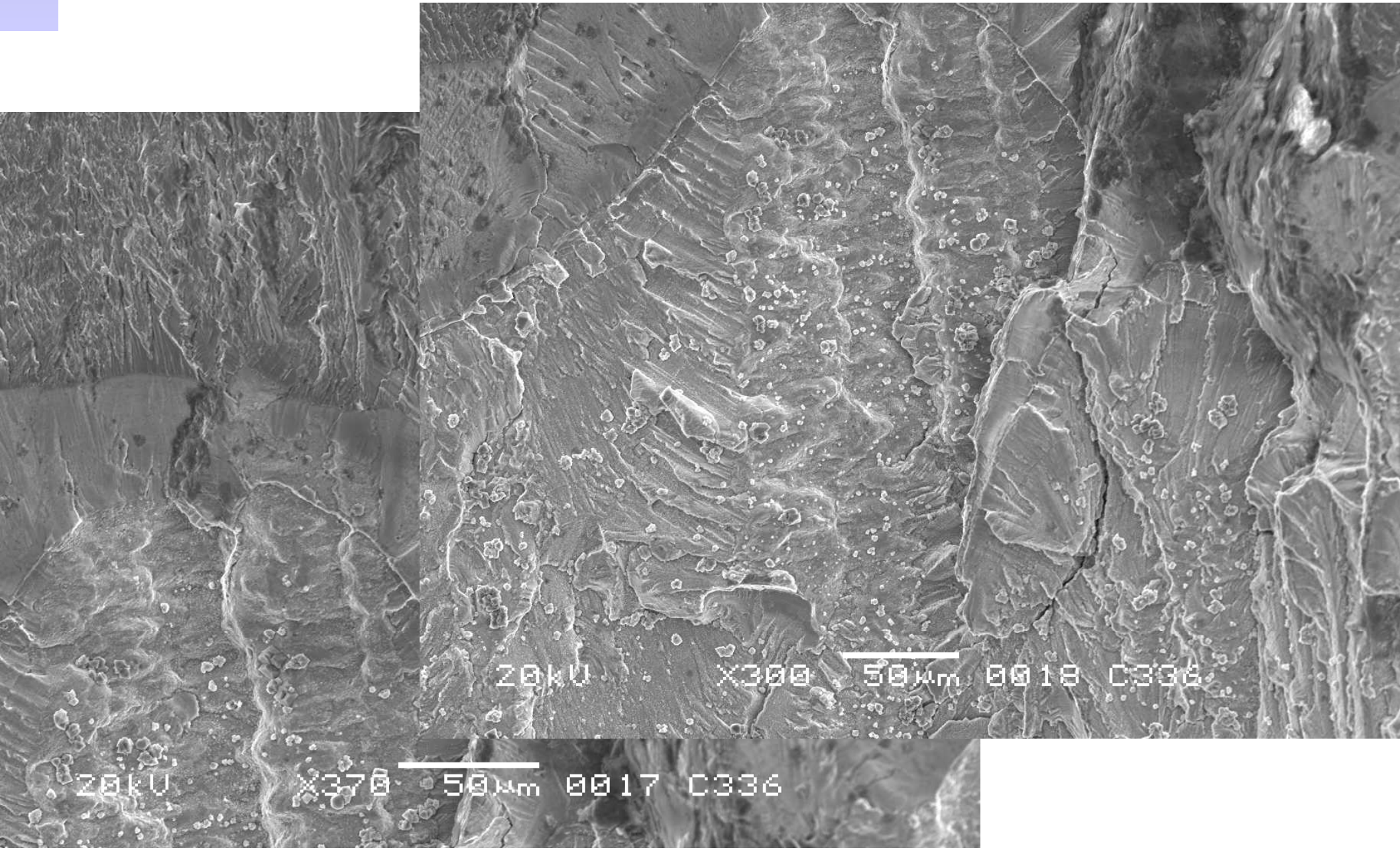
# 152 Weld – MHI




*Low growth rate even when cycling with 9000s hold time*

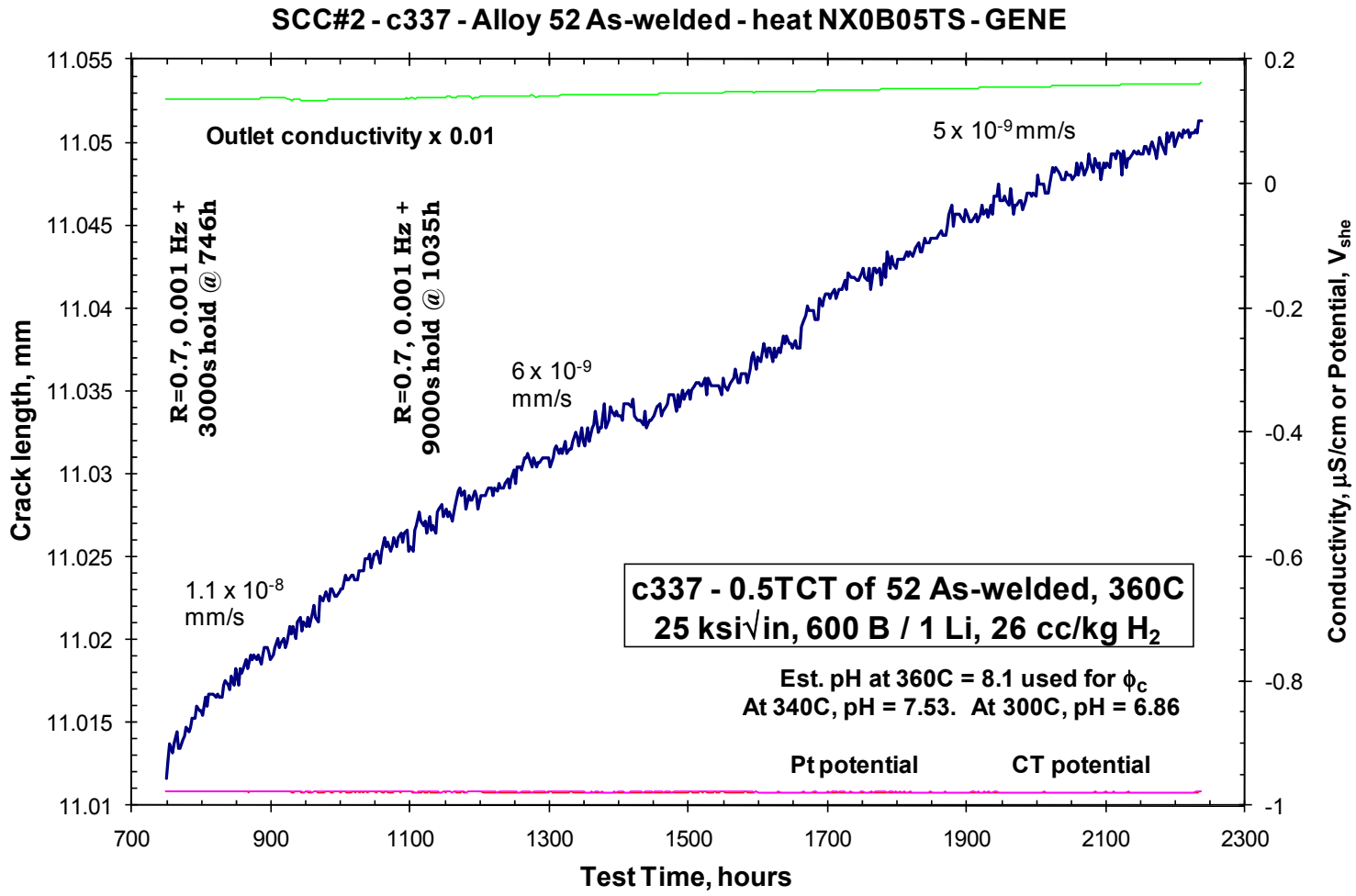
# 152 Weld – MHI

## Specimen c336



# Specimen c337

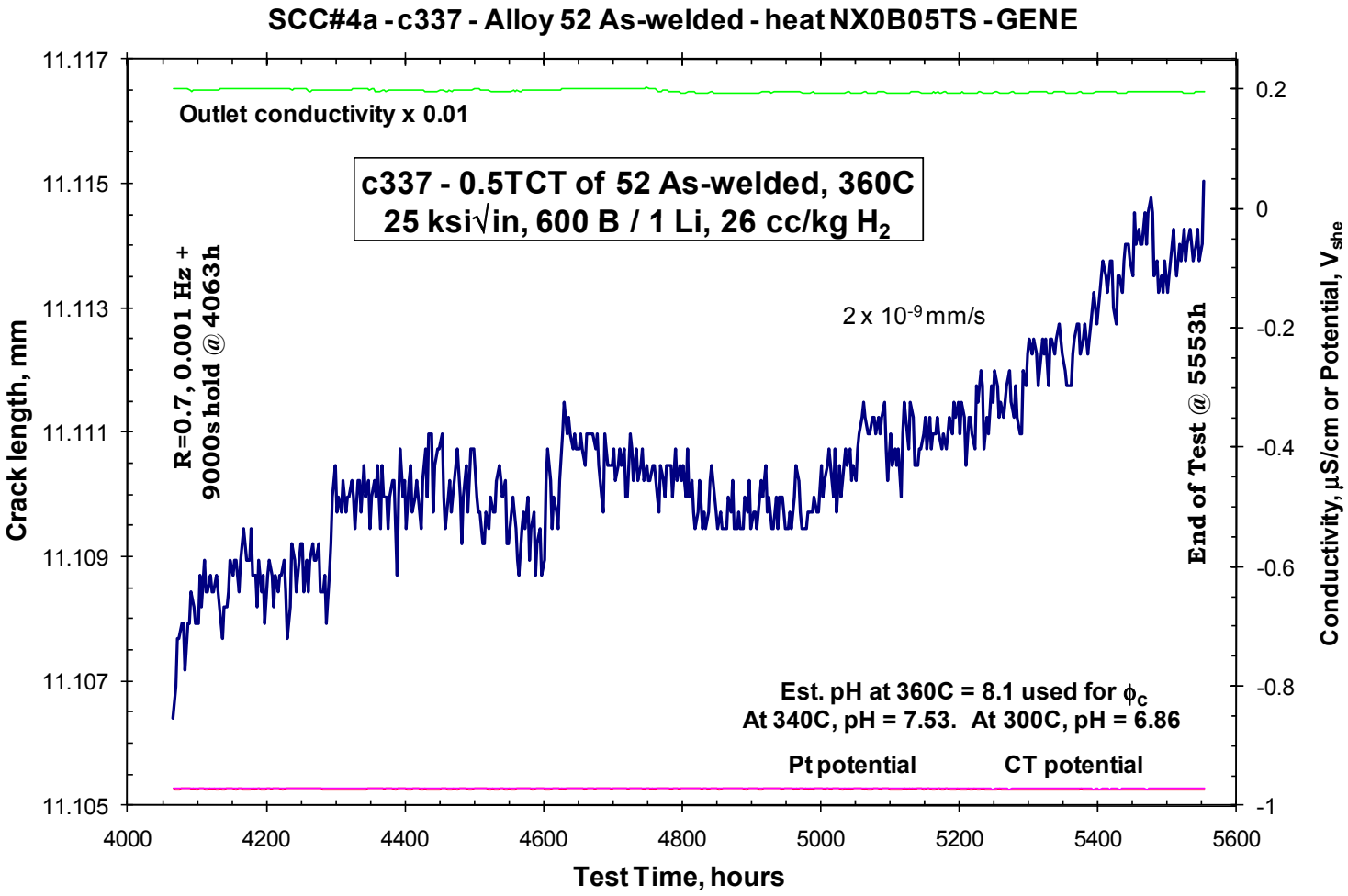
## 52 Weld – GE Nuclear




*~Low growth rate even when cycling with 9000s hold time*

# Specimen c337

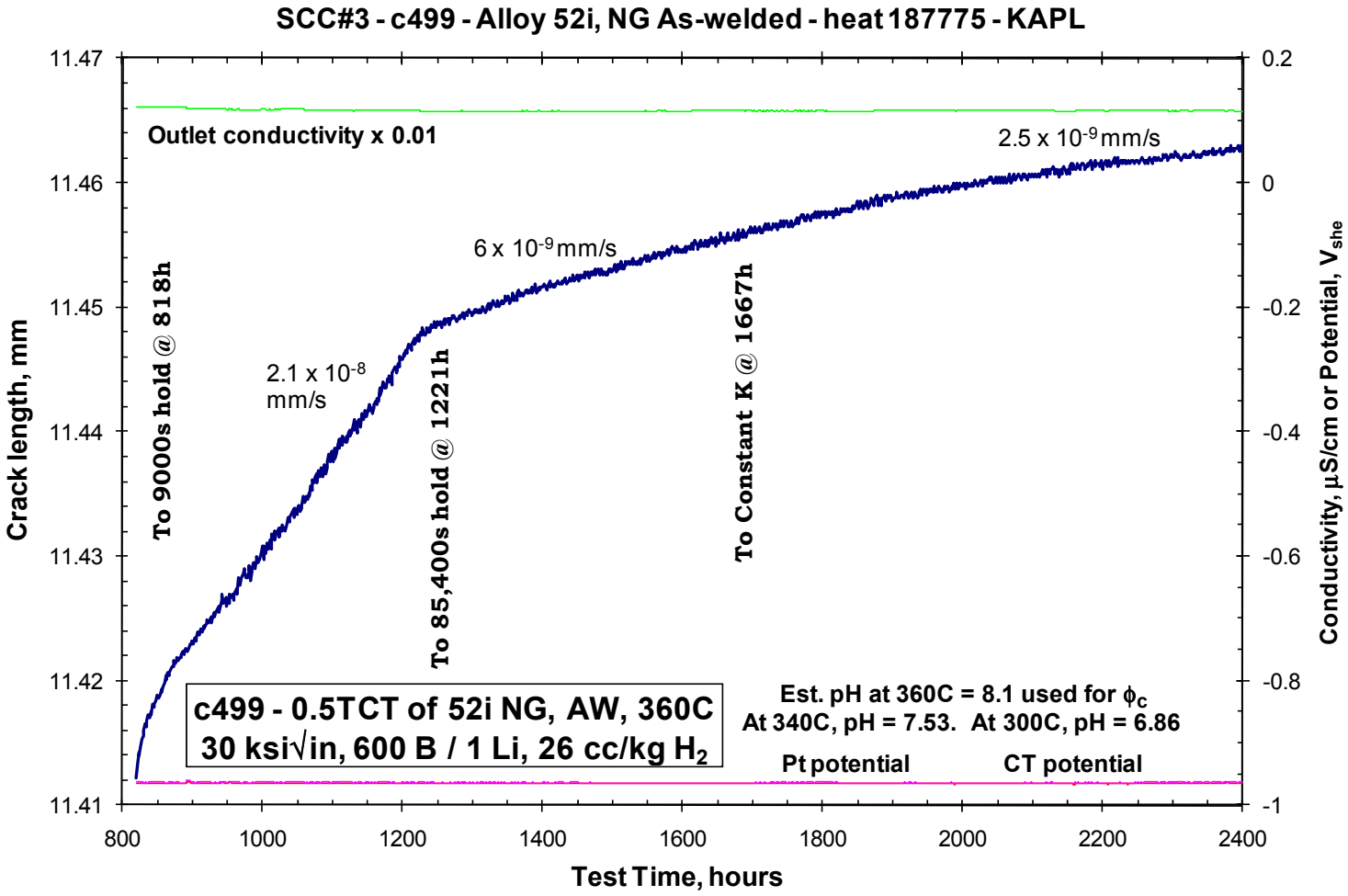
## 52 Weld – GE Nuclear




*Low growth rate even when cycling with 9000s hold time*

# Specimen c499

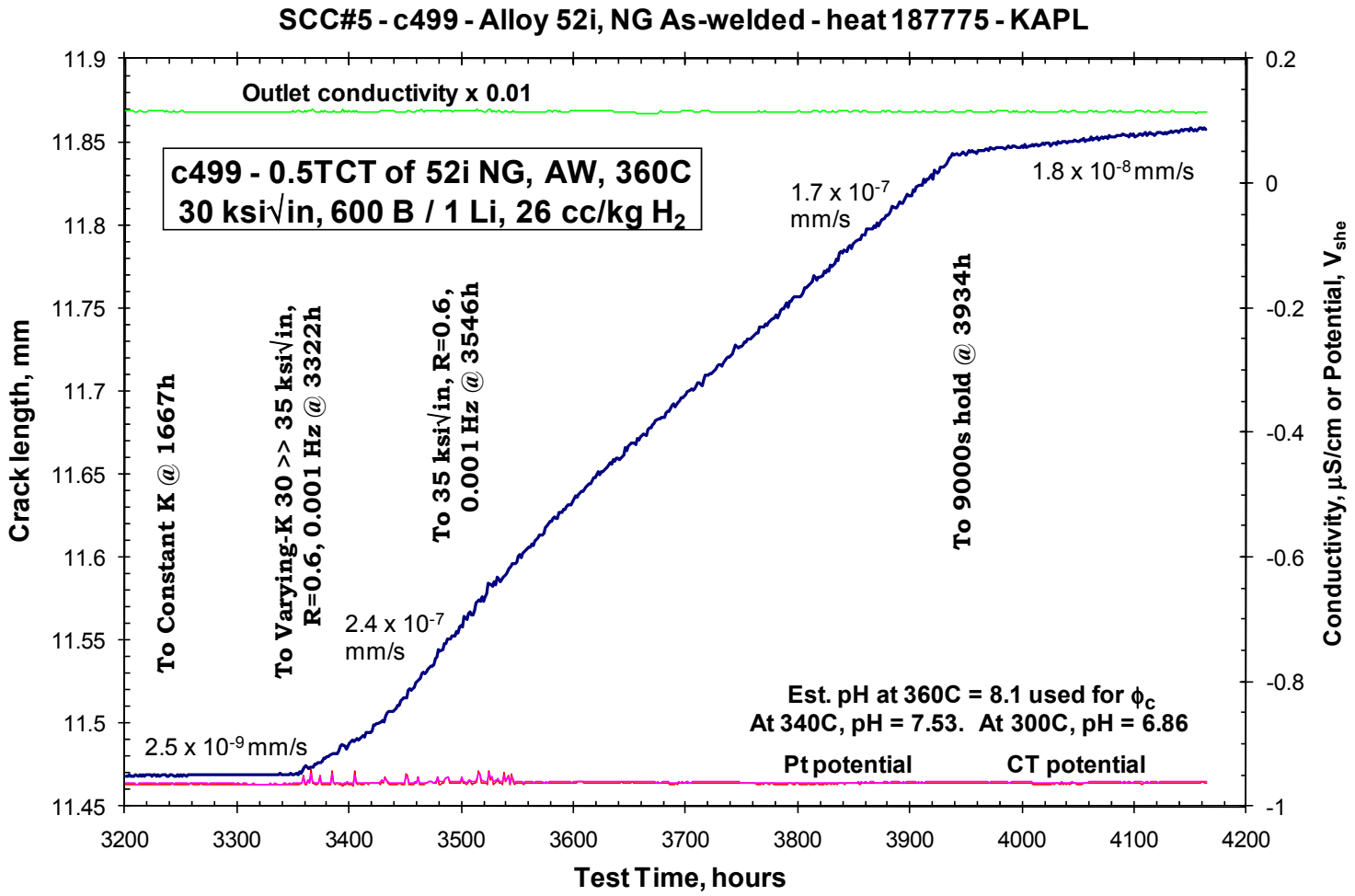
## 52i Weld – KAPL




*Low growth rate at constant K*

# Specimen c499

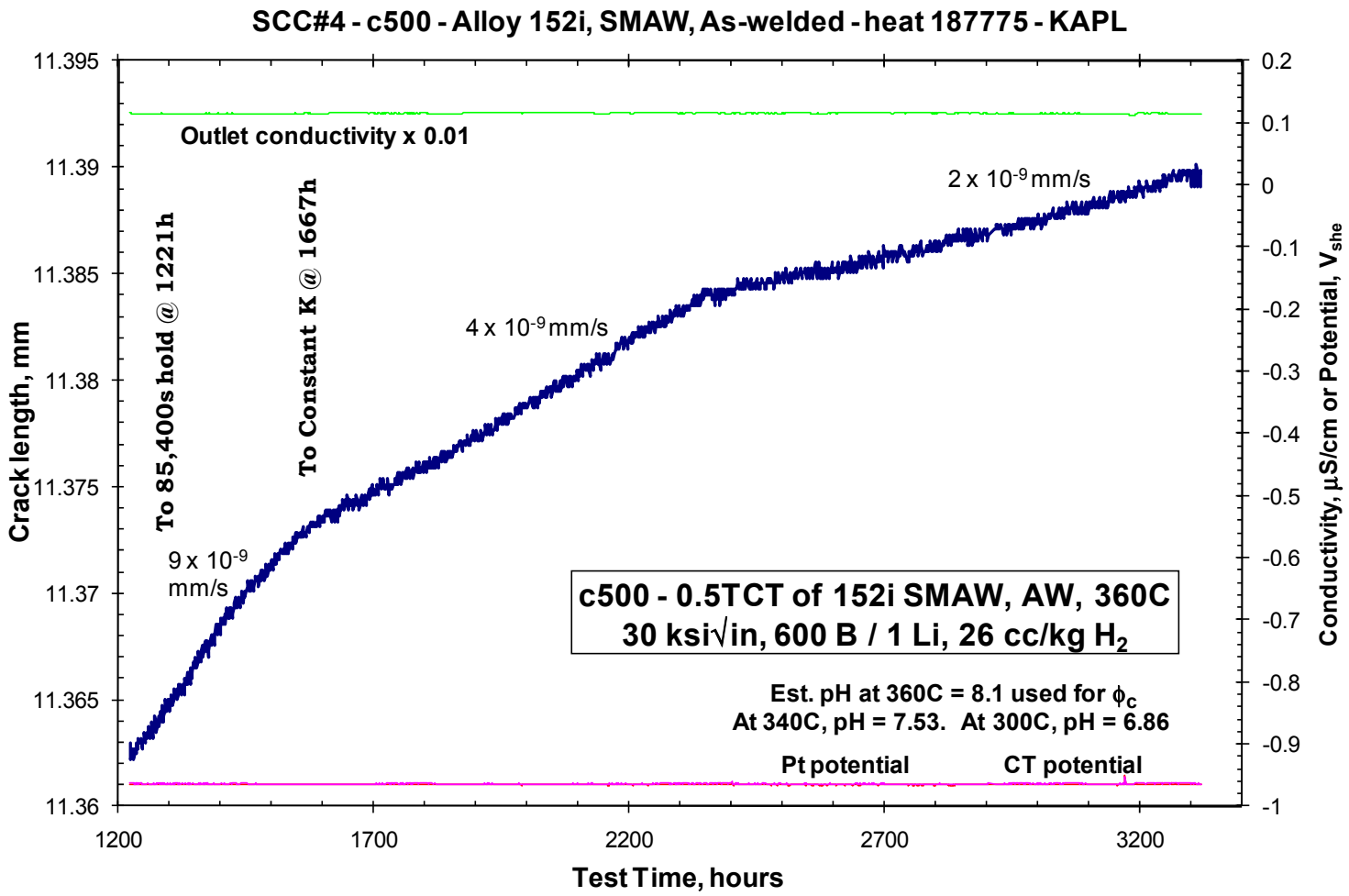
## 52i Weld – KAPL




*Approaching low growth rate at 9000s hold time*

# Specimen c500

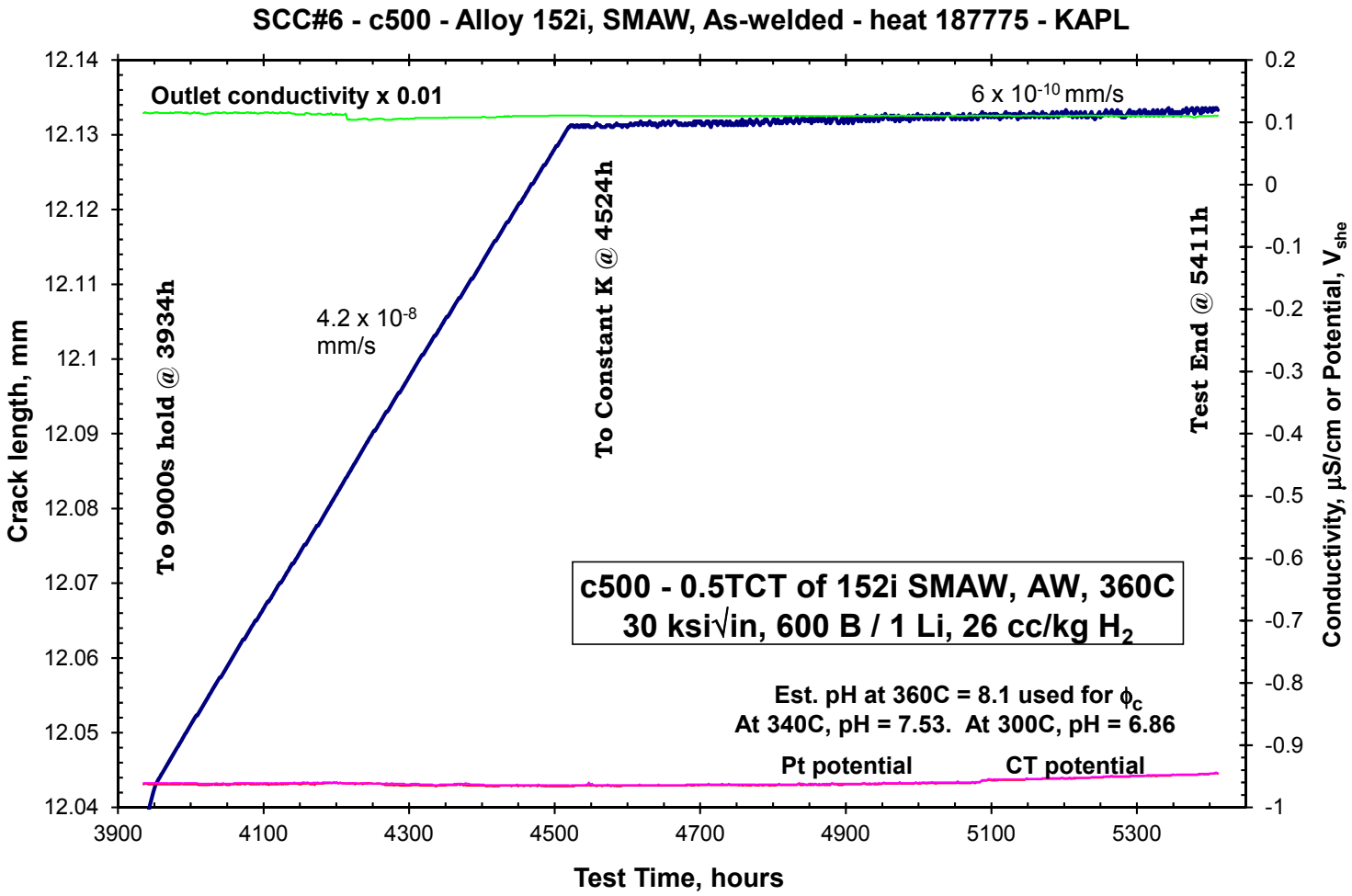
## 152i Weld – KAPL




*Low growth rate at constant K*

## Specimen c500

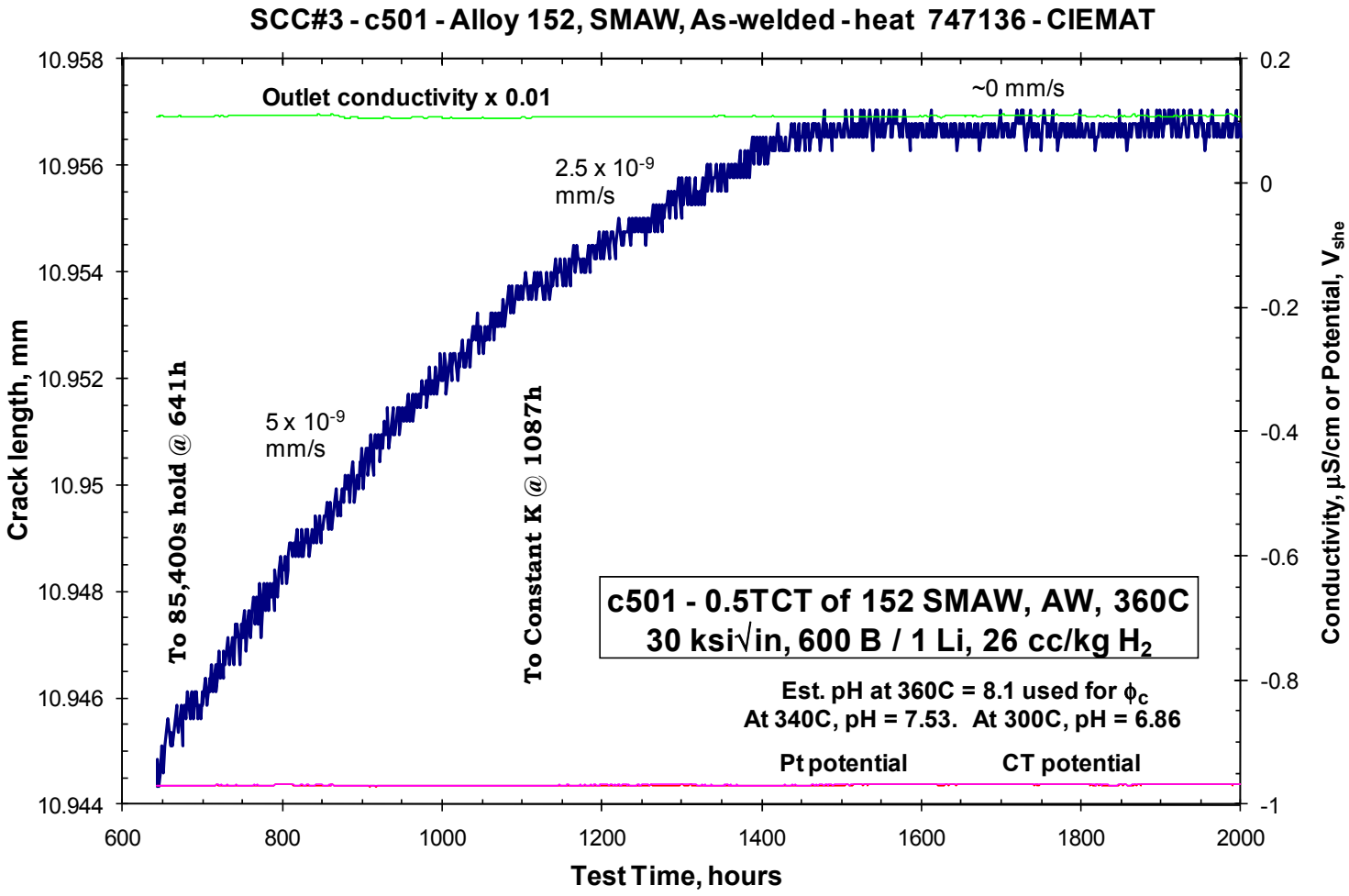
# 152i Weld – KAPL




*Medium growth rate when cycling with 9000s hold time*

# Specimen c501

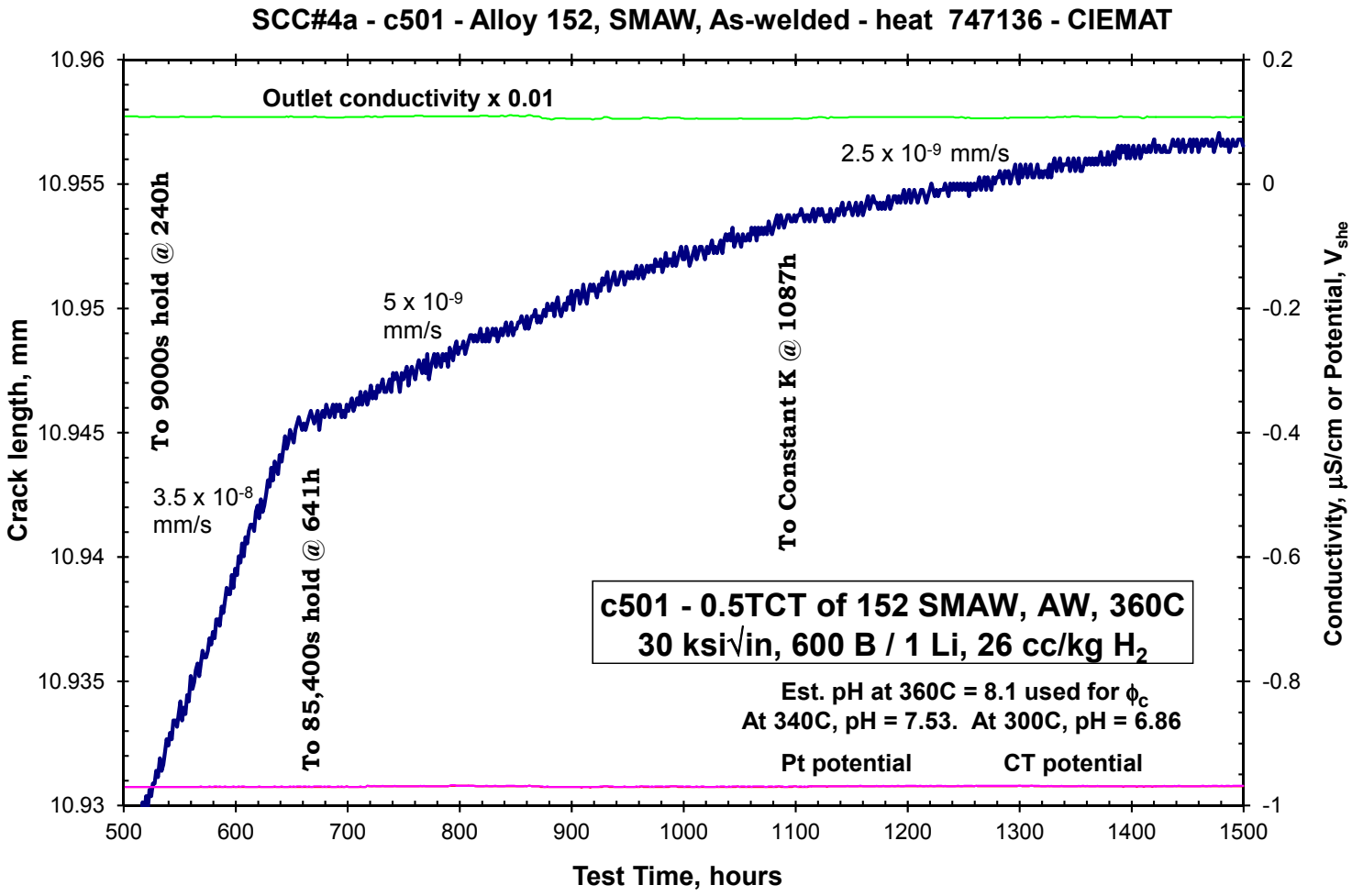
## 152 Weld – CIEMAT




*Very low growth rate at constant K*

# Specimen c501

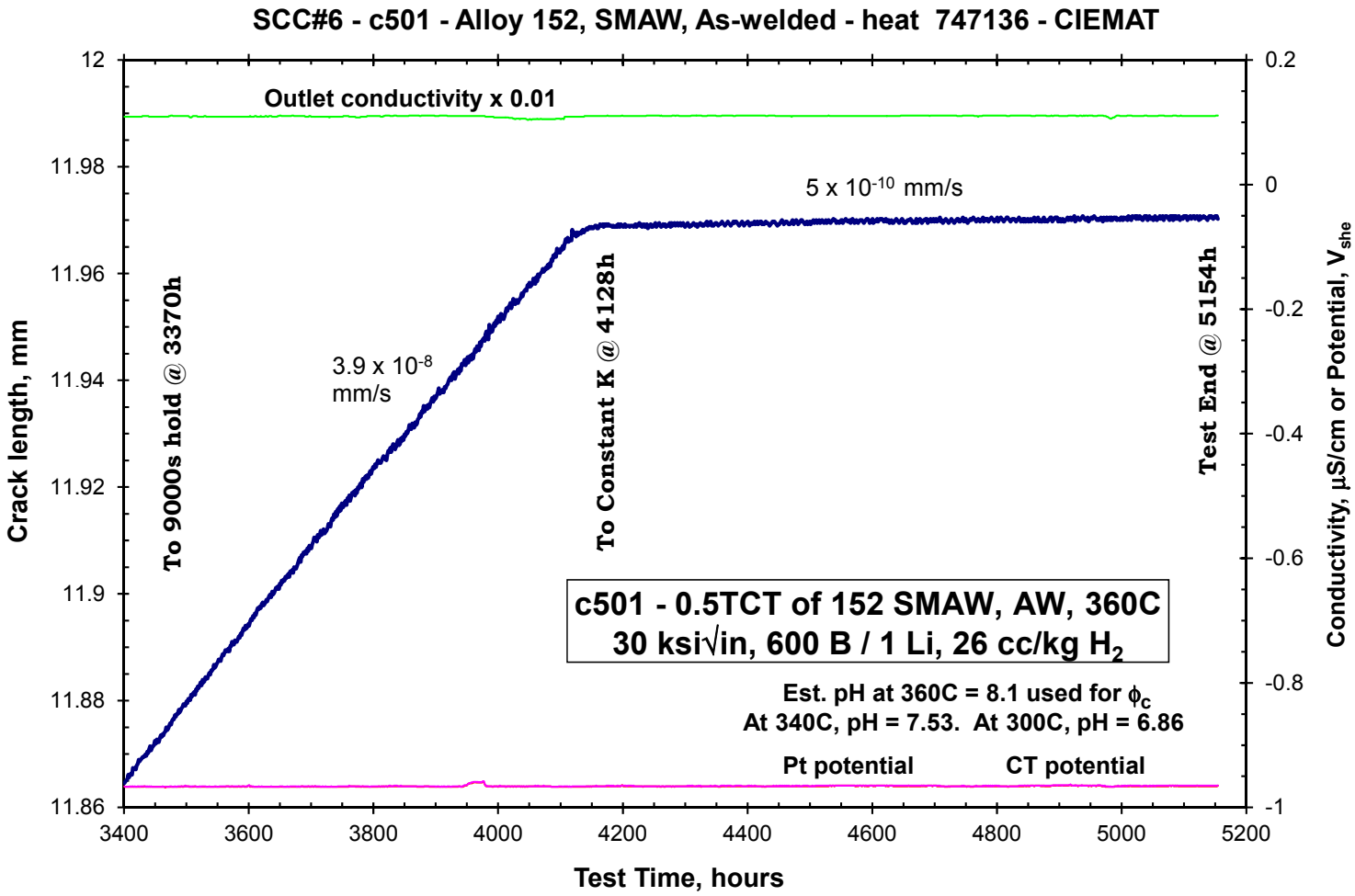
## 152 Weld – CIEMAT




*Medium growth rate with 9000s hold time*

# Specimen c501

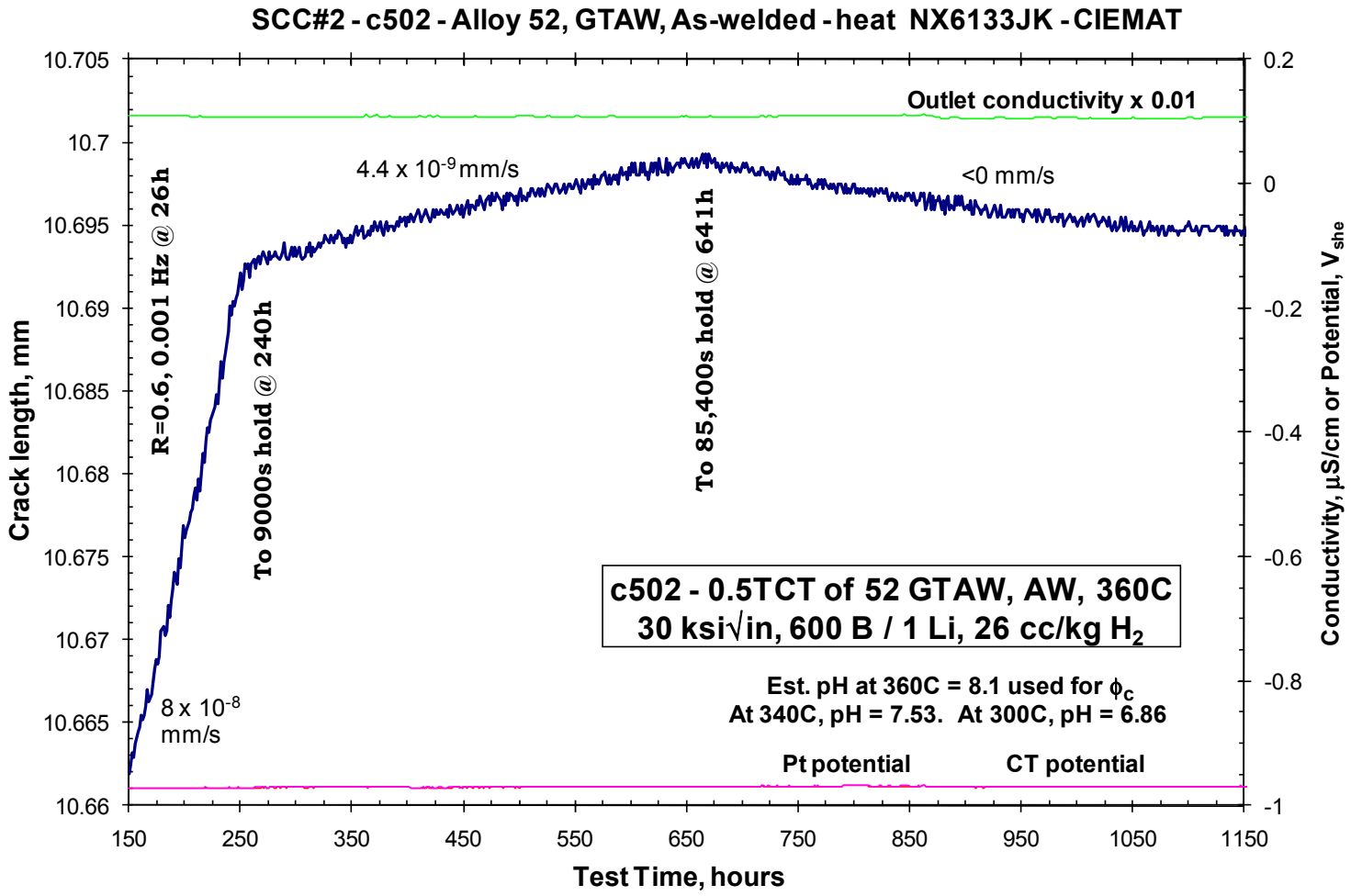
## 152 Weld – CIEMAT




*Medium growth rate with 9000s hold time*

# Specimen c502

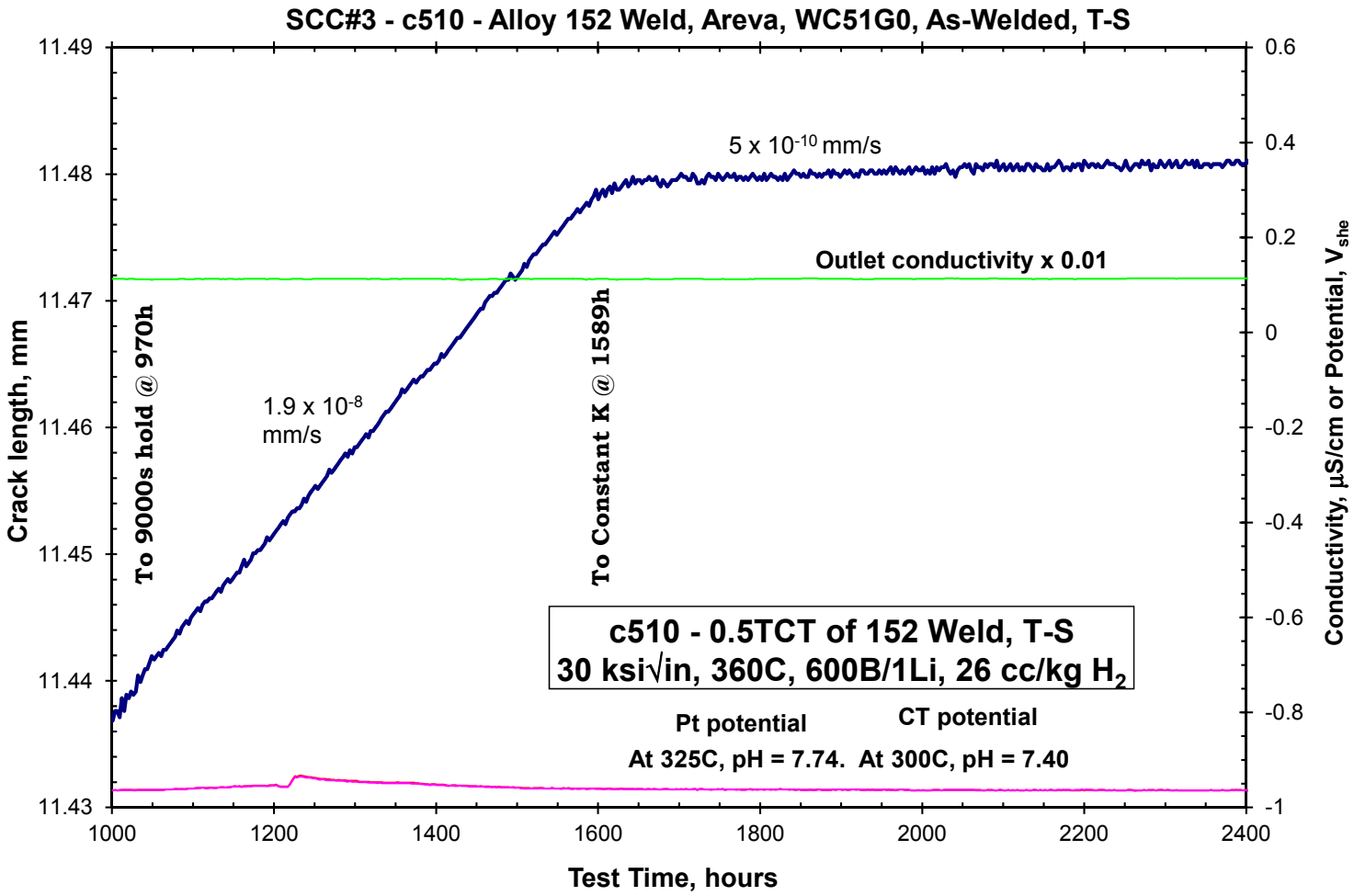
## 52 Weld – CIEMAT




*Low growth rate even when cycling with 9000s hold time*

## Specimen c510

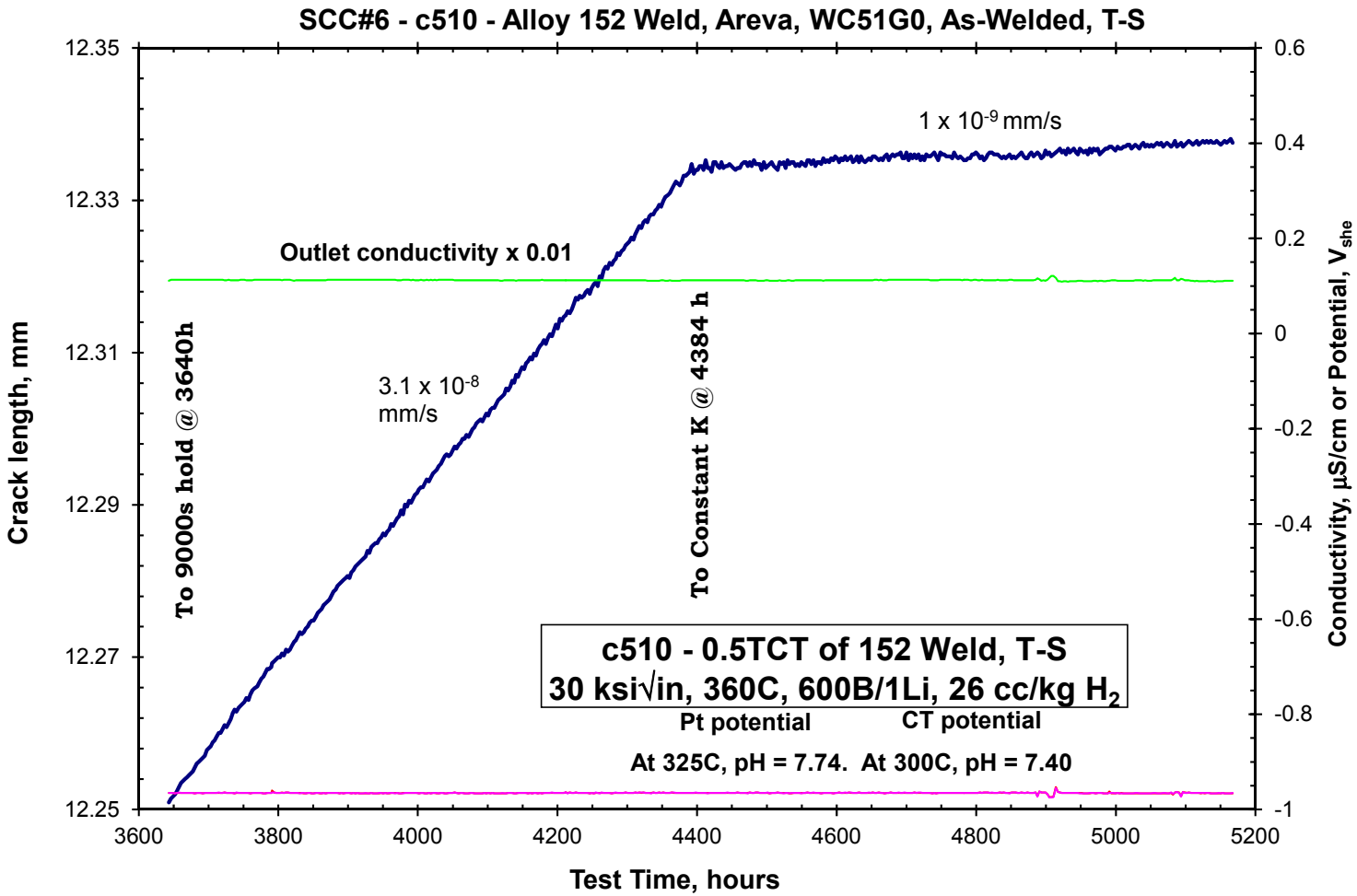
# 152 Weld – Areva




*Low growth rate even when cycling with 9000s hold time*

## Specimen c510

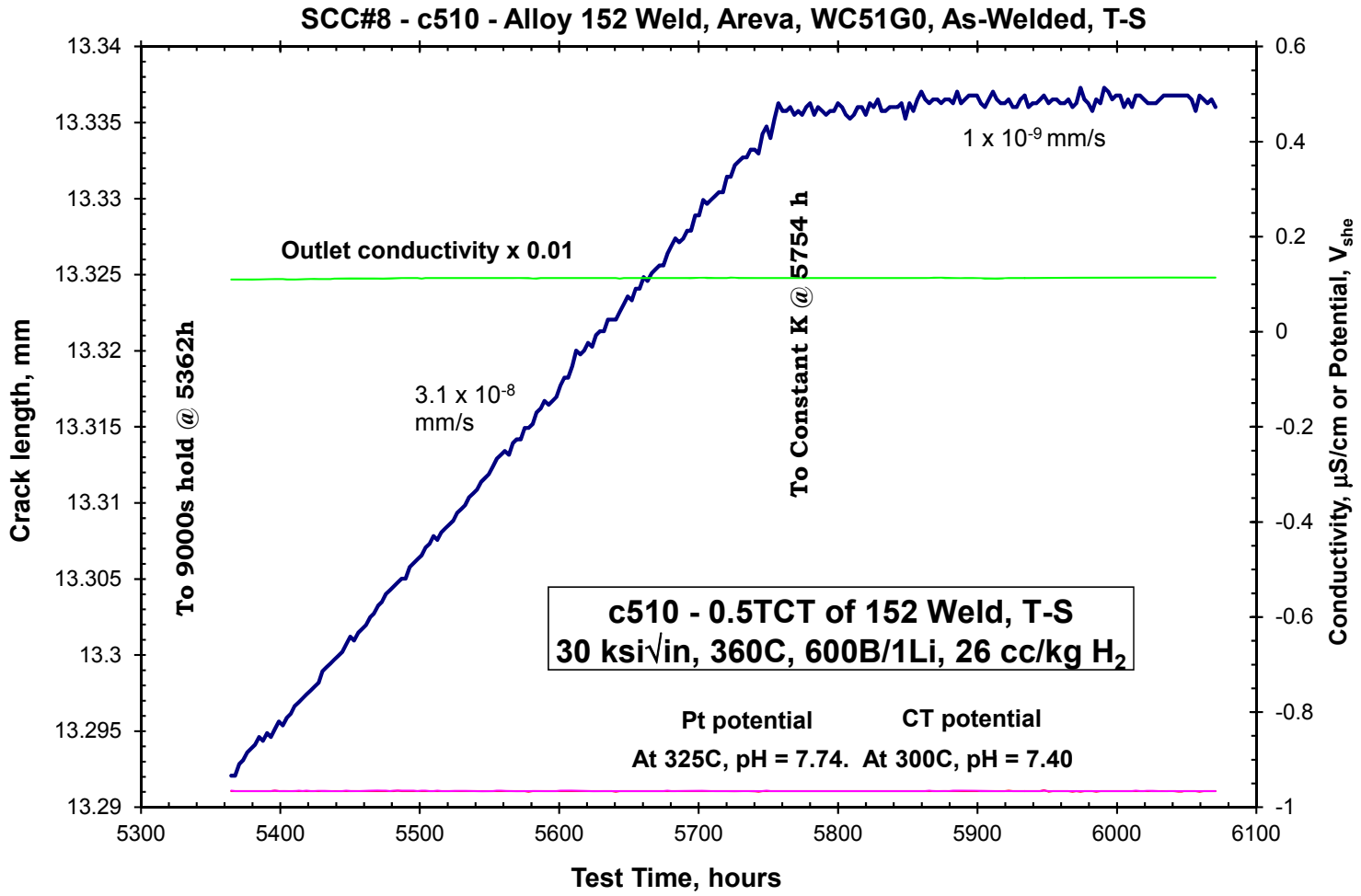
# 152 Weld – Areva




*Low growth rate even when cycling with 9000s hold time*

# Specimen c510

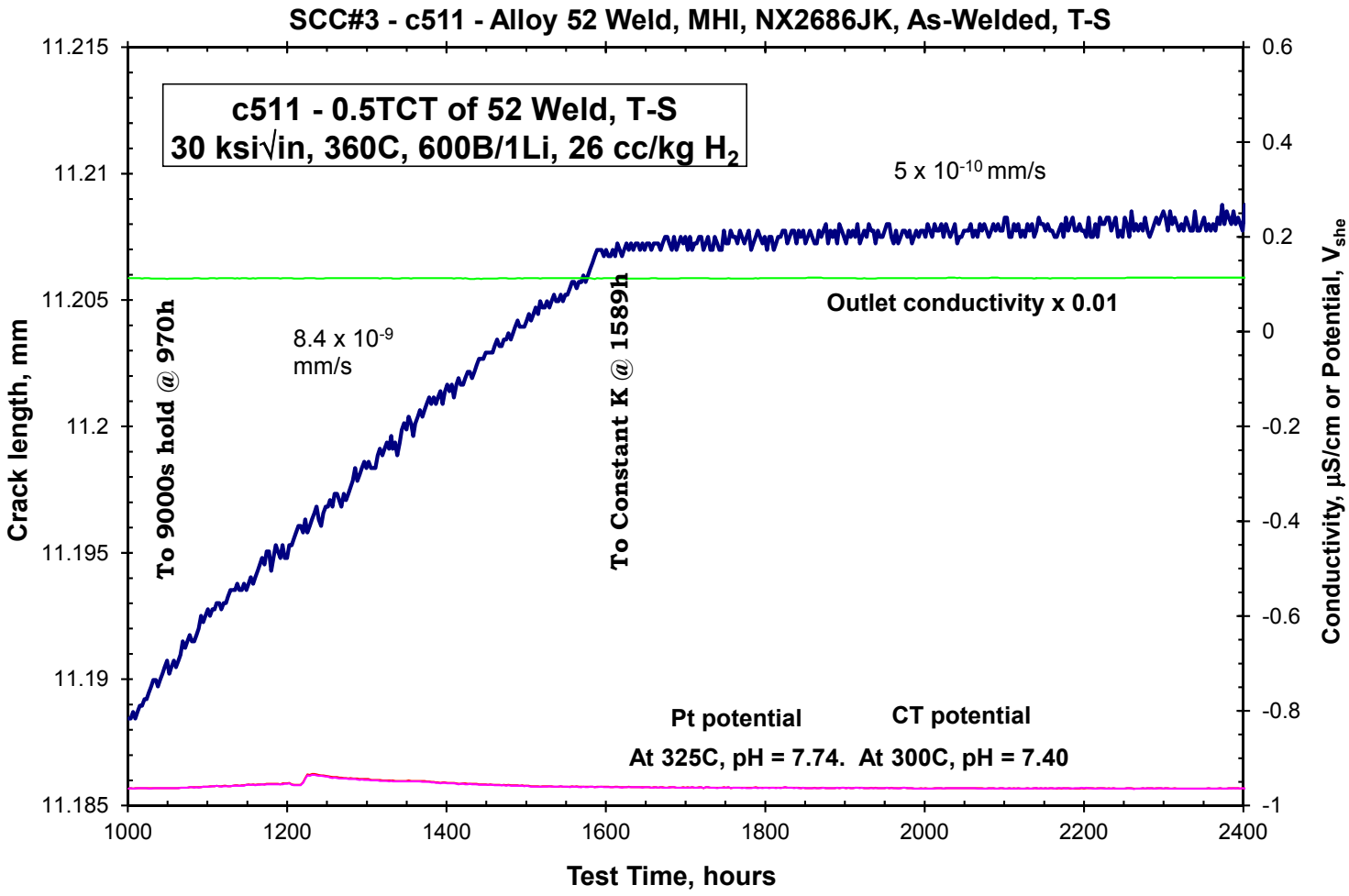
## 152 Weld – Areva




*Low growth rate even when cycling with 9000s hold time*

## Specimen c511

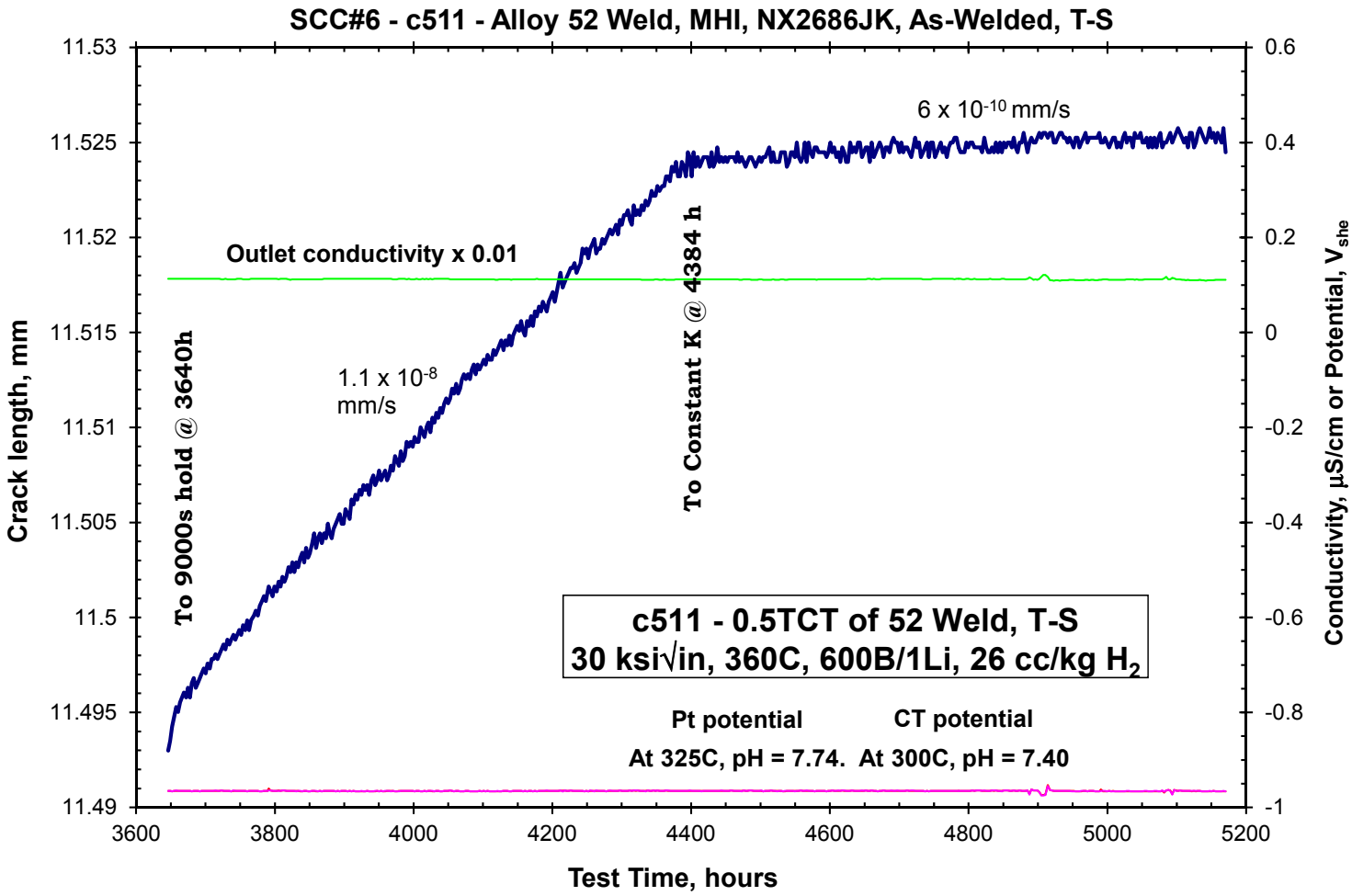
# 52 Weld – MHI, NX2686JK




*Low growth rate even when cycling with 9000s hold time*

## Specimen c511

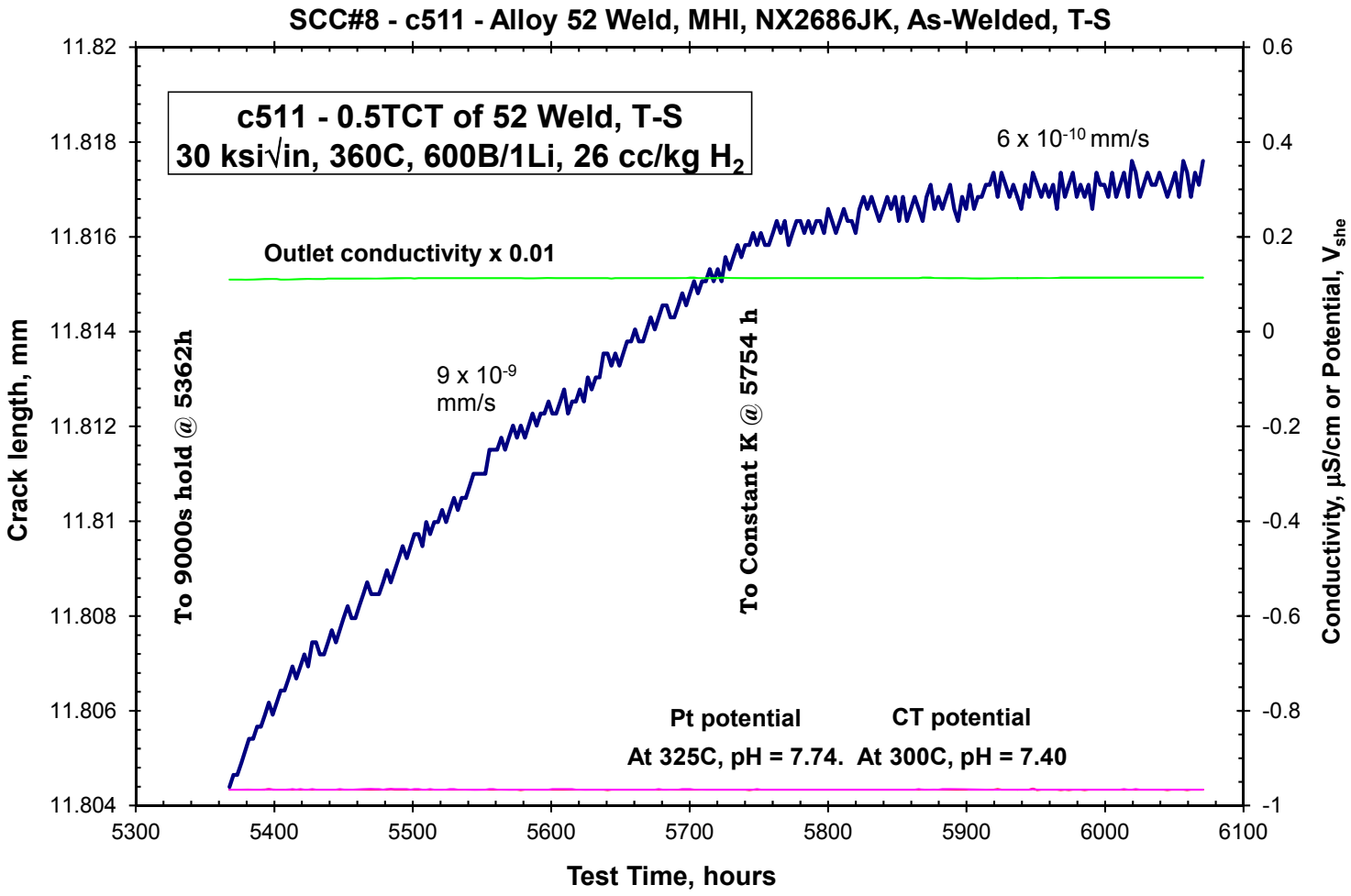
# 52 Weld – MHI, NX2686JK




*Low growth rate even when cycling with 9000s hold time*

# Specimen c511

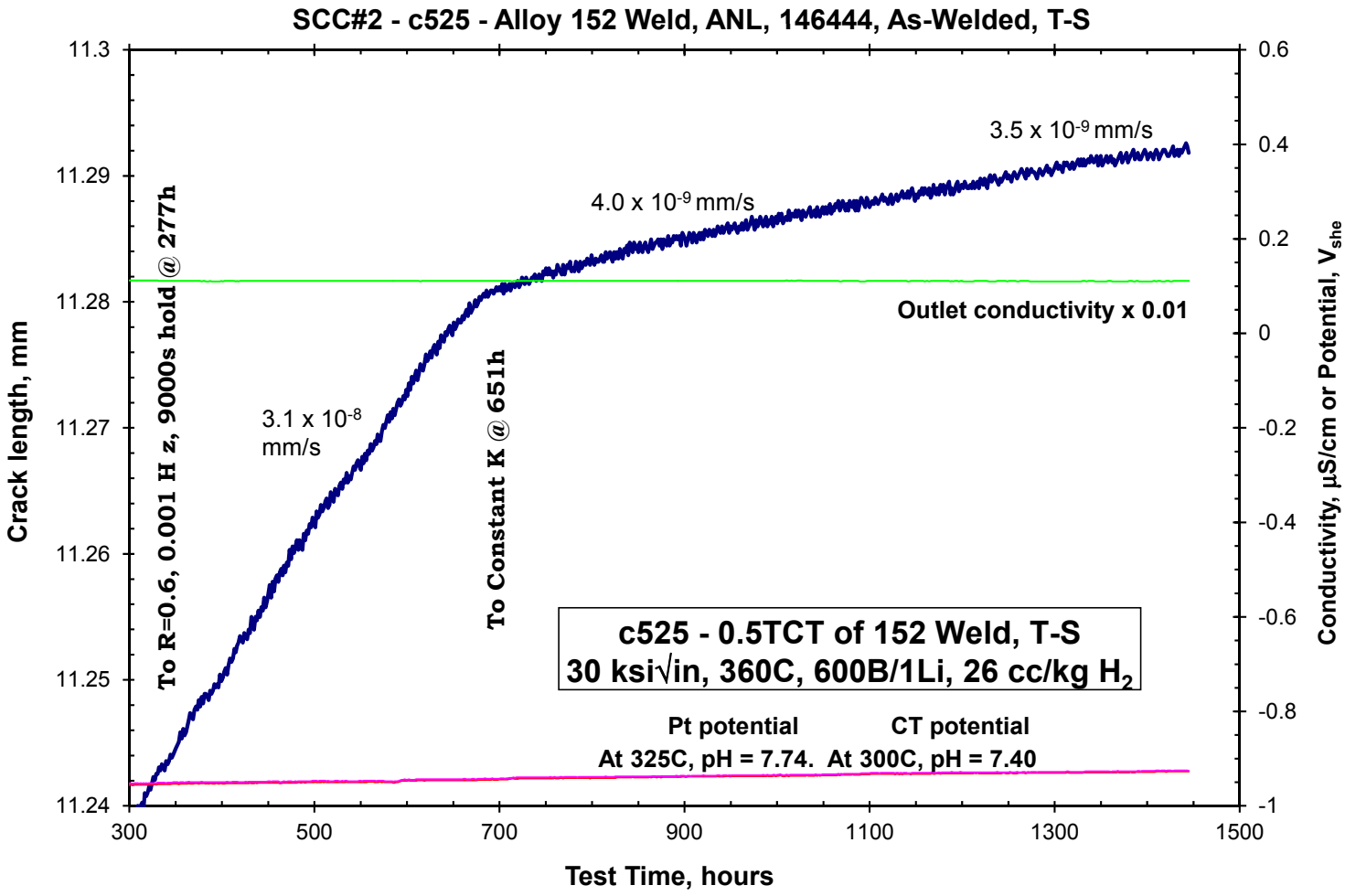
## 52 Weld – MHI, NX2686JK




*Low growth rate even when cycling with 9000s hold time*

# Specimen c525

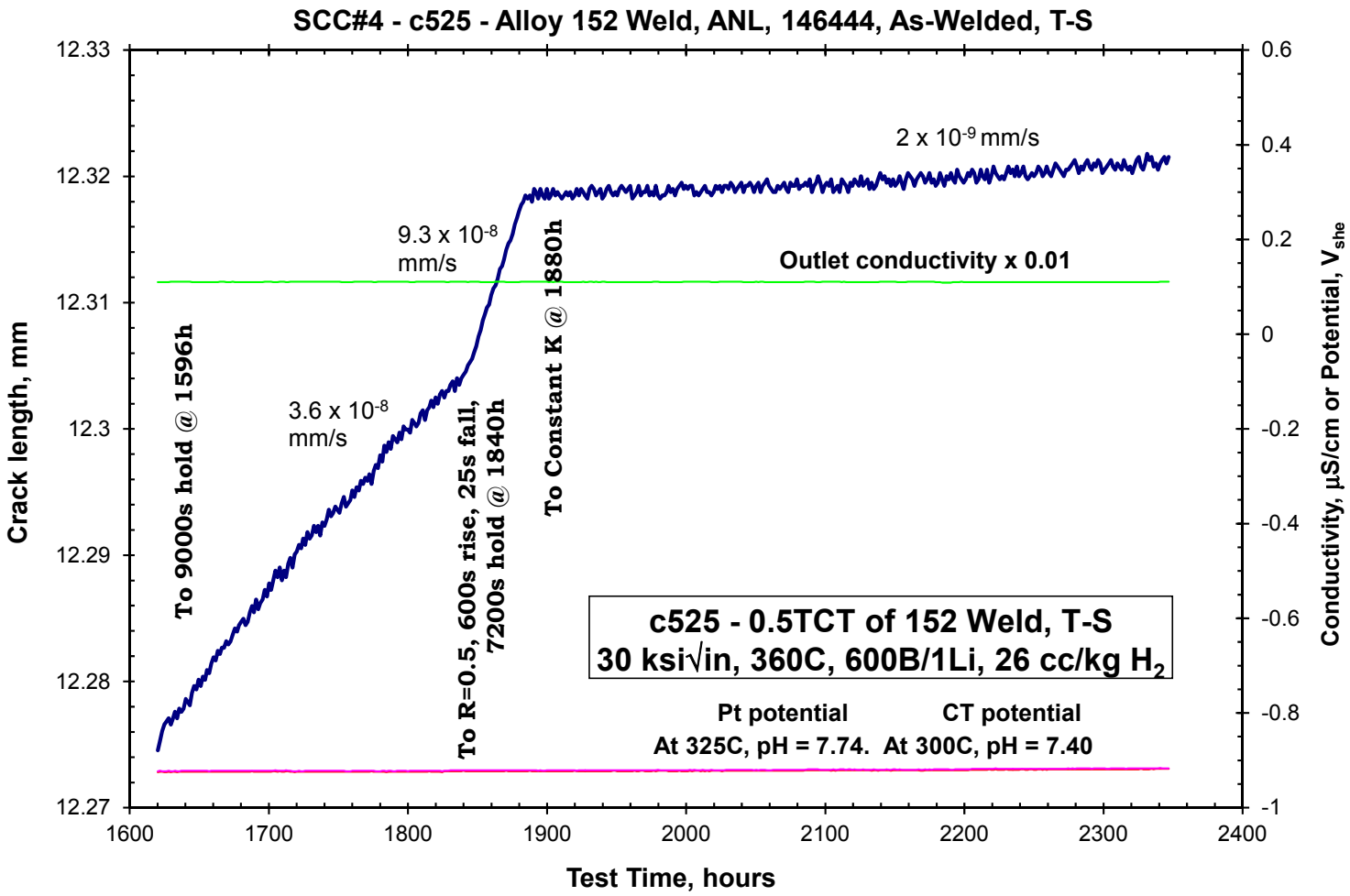
## 152 Weld – ANL, 146444




*Low growth rate even when cycling with 9000s hold time*

# Specimen c525

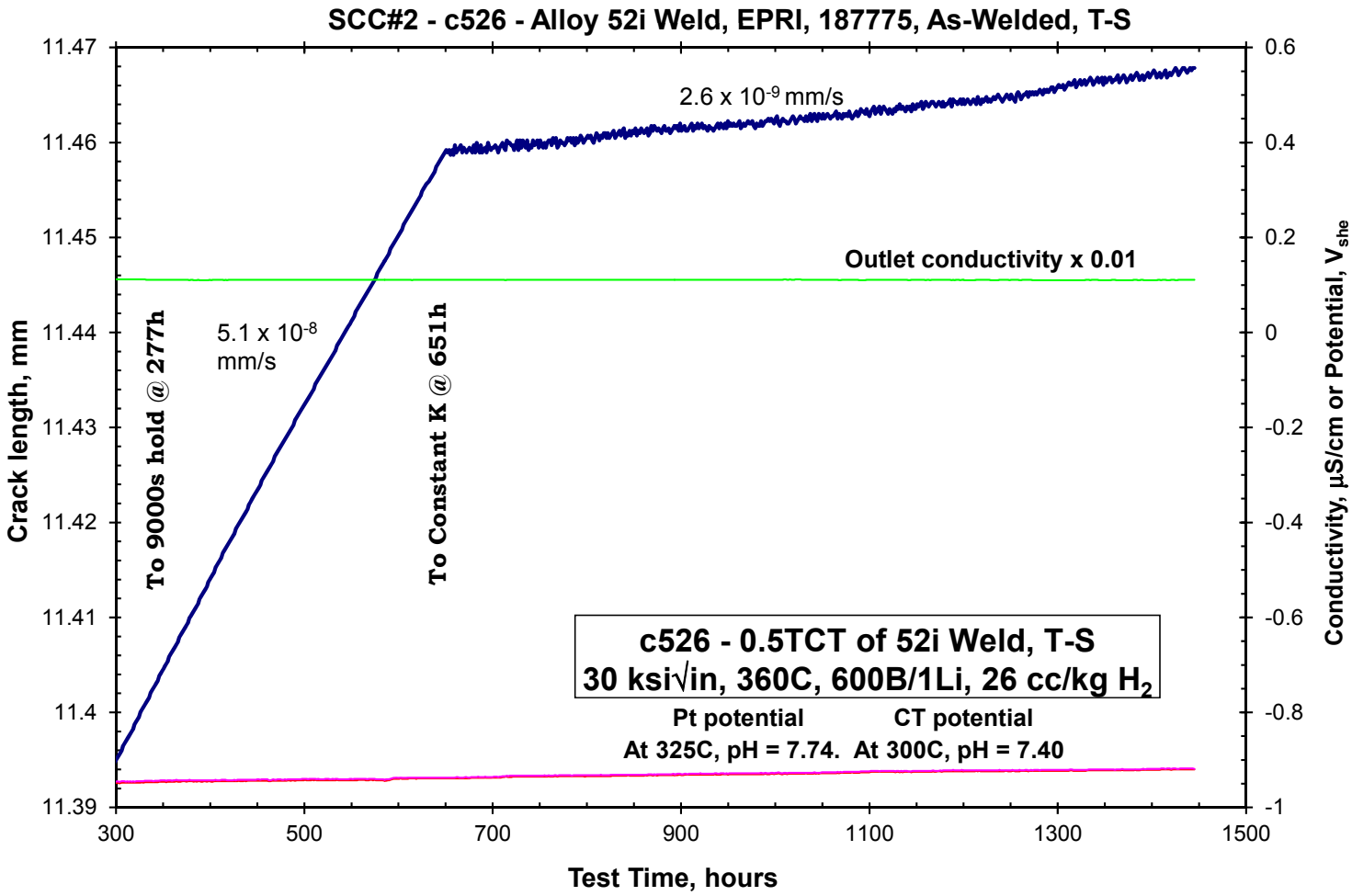
## 152 Weld – ANL, 146444




*Low growth rate even when cycling with 9000s hold time*

## Specimen c526

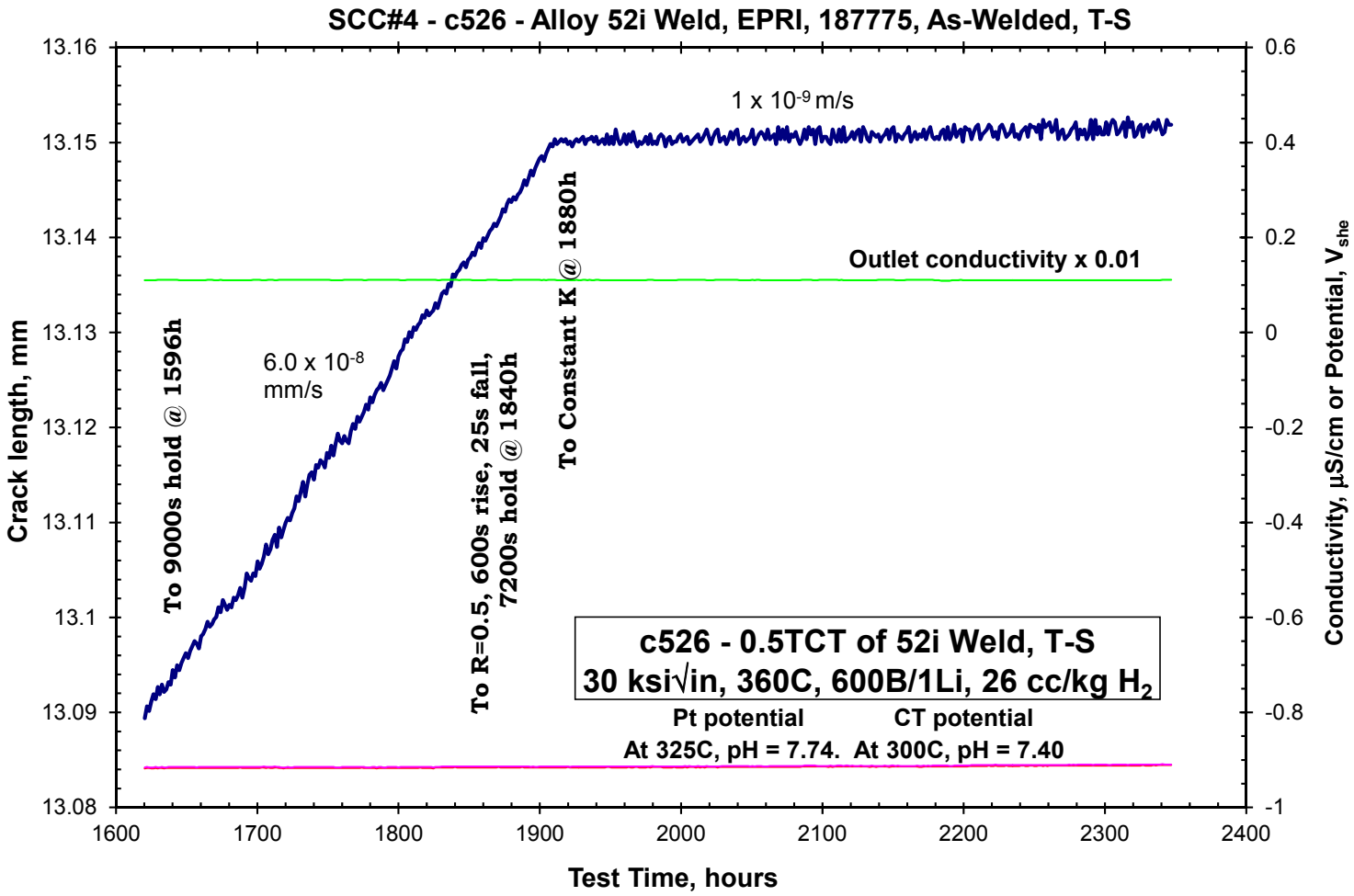
# 52i Weld – EPRI, 187775




*Low growth rate even when cycling with 9000s hold time*

# Specimen c526

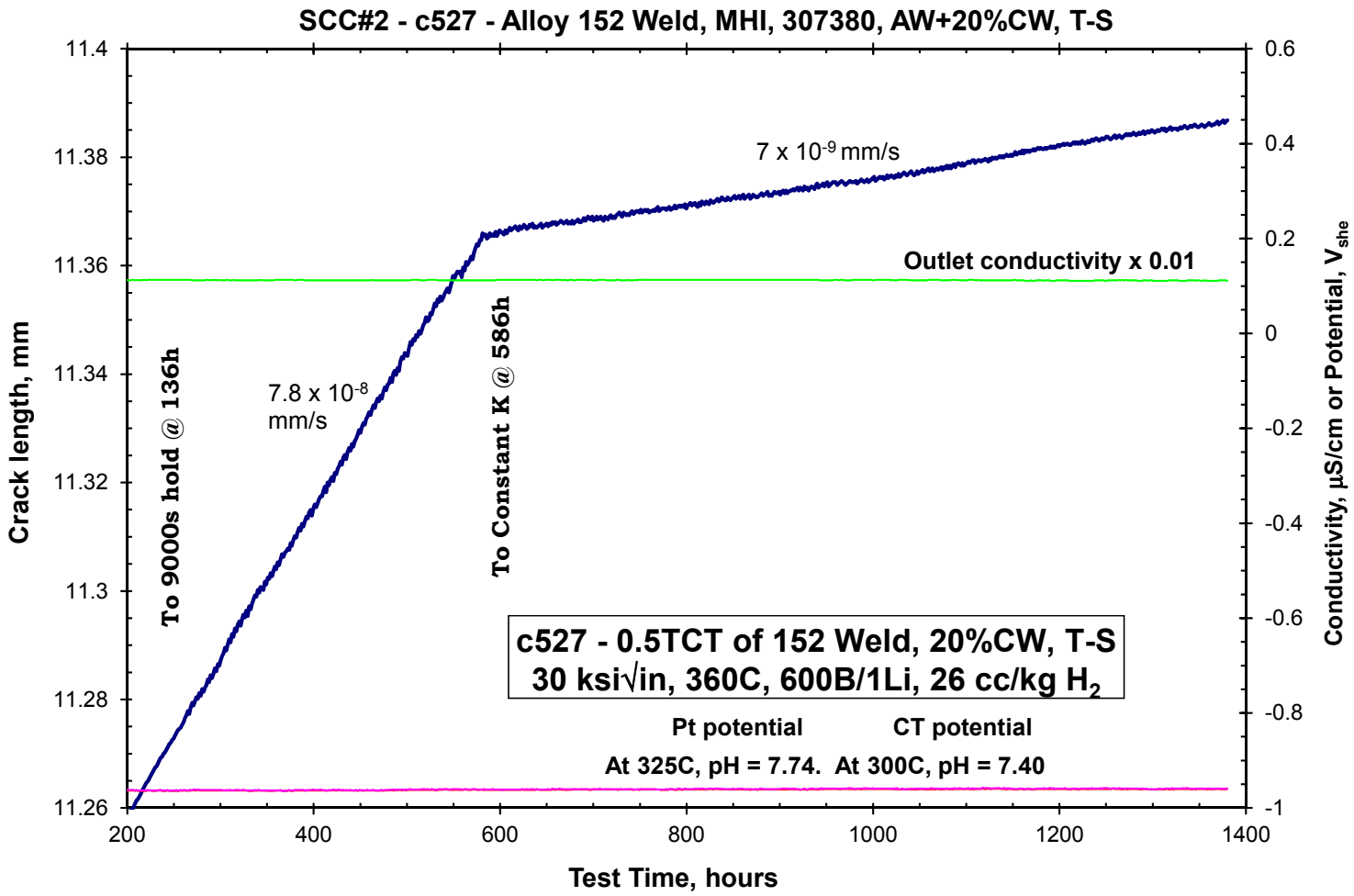
## 52i Weld – EPRI, 187775




*Low growth rate even when cycling with 9000s hold time*

## Specimen c527

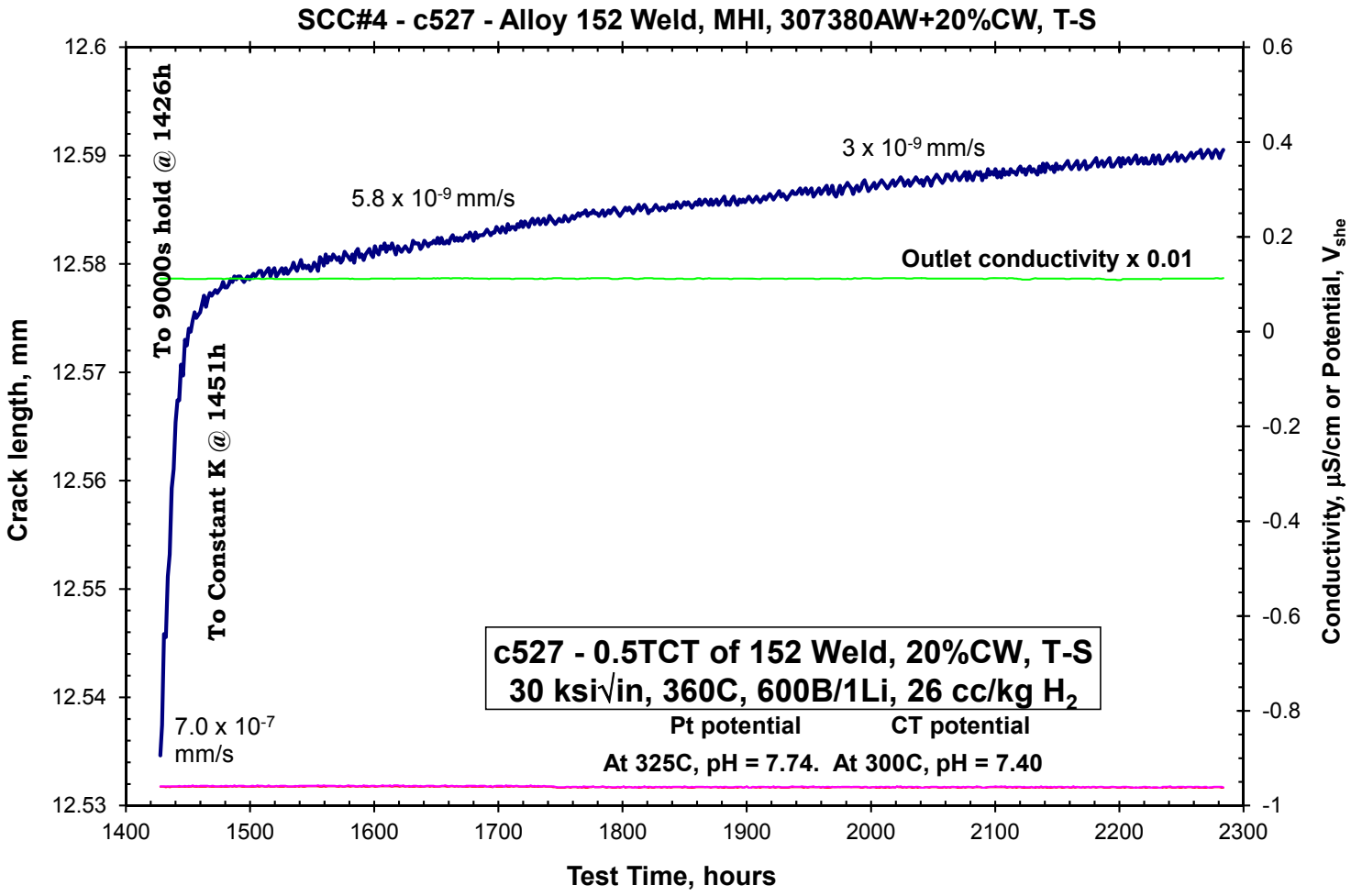
# 152 Weld – MHI, 307380 + 20% CW




*Low growth rate even when cycling with 9000s hold time*

## Specimen c527

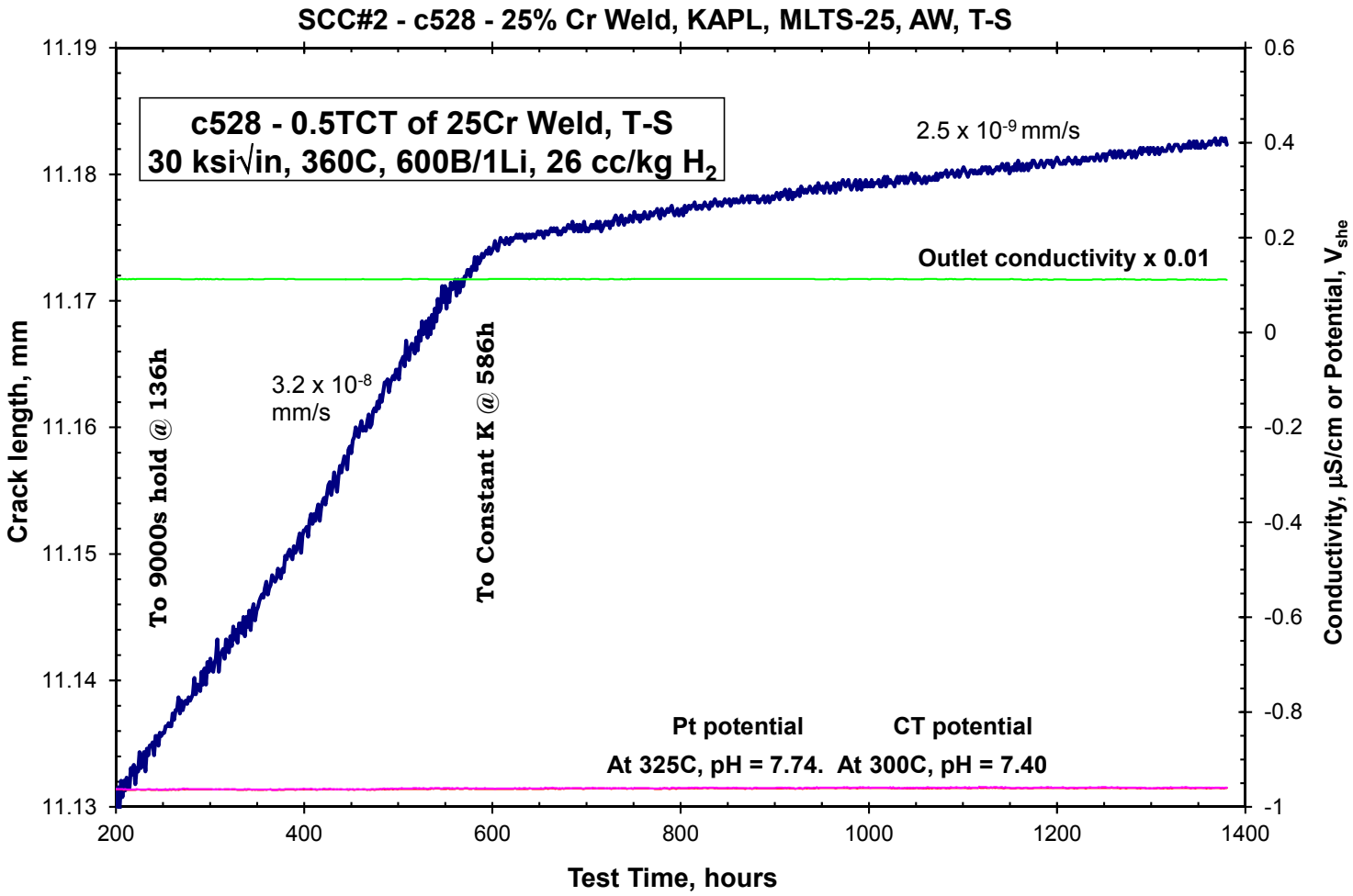
# 152 Weld – MHI, 307380 + 20% CW




*Low growth rate even when cycling with 9000s hold time*

## Specimen c528

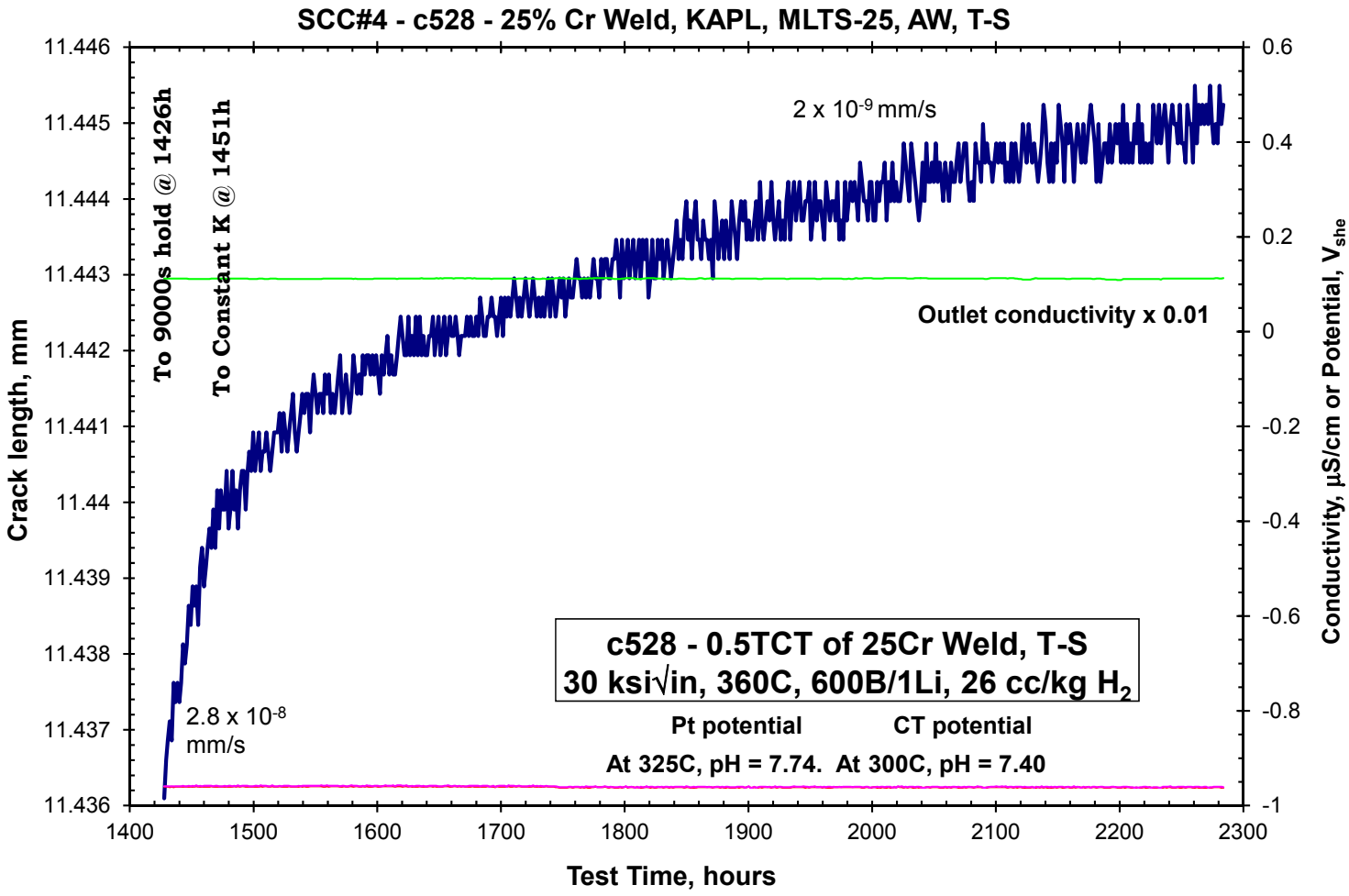
# 25% Cr Weld – KAPL, MLTS 25




*Low growth rate even when cycling with 9000s hold time*

## Specimen c528

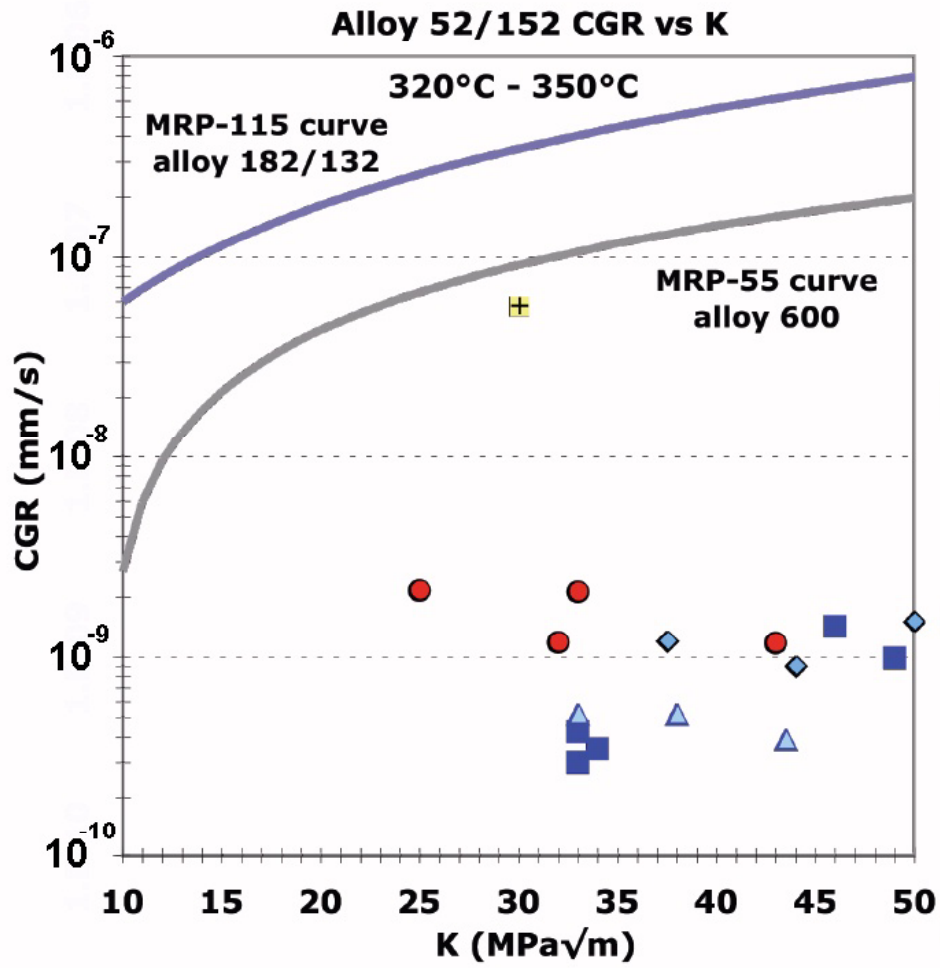
# 25% Cr Weld – KAPL, MLTS 25




*Low growth rate even when cycling with 9000s hold time*

PNNL Plot – Dec 2010

# Summary of Recent 52/152 Weld Metal




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

- PNNL tests on alloy 152, 52 and 52M weld metal show limited IGSCC and very low growth rates, $\leq 2 \times 10^{-9}$ mm/s at constant K.
- Fractography indicates engaged (IG) CGR for alloy 152 is up to 3x the ***average*** CGR. The ***maximum*** CGR is up to 6x the ***average*** CGR. Even the "conservative maximum" rates are $<\sim 2 \times 10^{-8}$ mm/s.
- Constant K SCC data on alloy 152/52/52M remains very limited.

*Alloy 52/152 weld metal is clearly not immune but, with one exception, grows at slow rates in PWR primary water.*

# Conclusions

- *Many re-attempts to promote crack advance using extensive transitioning. CGR data at long hold time or constant K is low or very low.*
- *KAPL 52i and 152i with 27% Cr, and 25% Cr MLTS-25 also show very low CGR.*
- *Apart from weld with additional 20% cold work, no weld has exhibited a growth rate above ~4 x $10^{-9}$ mm/s*