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STRESS CORROSION CRACK GROWTH RATES FOR EN82H WELDS

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by Bechtel Bettis, Inc.

Stress Corrosion Crack Growth Rates for EN82H Weld

- SCC rates for EN82H in 360°C water (*Corrosion/96*, *Corrosion* 1999) exhibited excessive scatter,
  - with data from two specimens displaying unusually high rates.

- SCC rates were based on LVDT-measured CMOD;
  - CMOD has been used with reasonable success for wrought metals, but there appears to be a problem for welds.
  - CMOD values for specimens with unusually high SCC rates indicated a very long incubation period, followed by rapid cracking.
  - Believed that SCC started much earlier, but unbroken ligaments prevented measurable deflection.

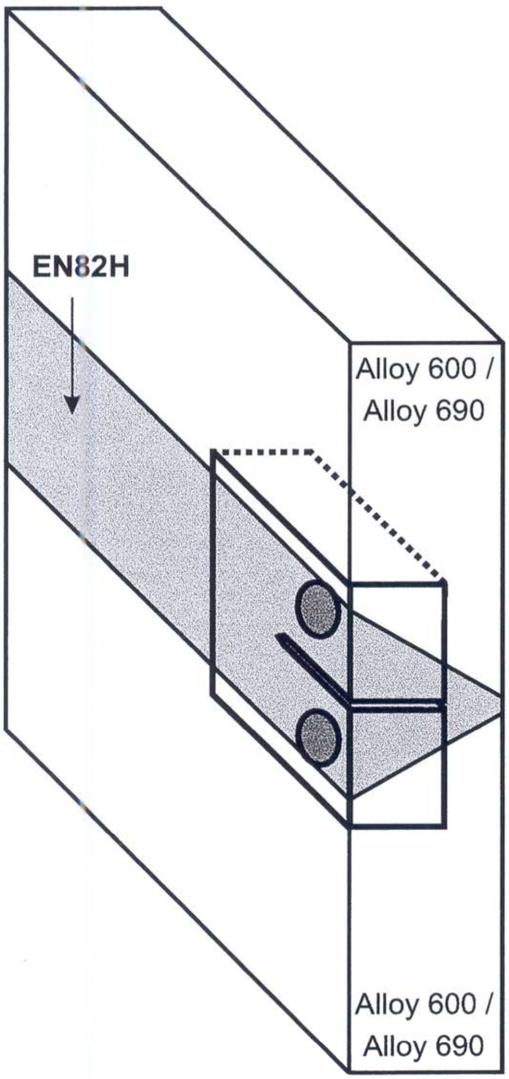
- EPD was unsuccessful in monitoring SCC due to: unbroken ligaments, nickel bridging and changes in resistivity.

- Test conditions remained constant throughout each test, so SCC rates could be calculated from total amount of crack extension ÷ total exposure time.
  - Potential problem: Significant change in K_I due to large Δa, but Amzallag has shown that da/dt is insensitive to K_I at high values of K_I.

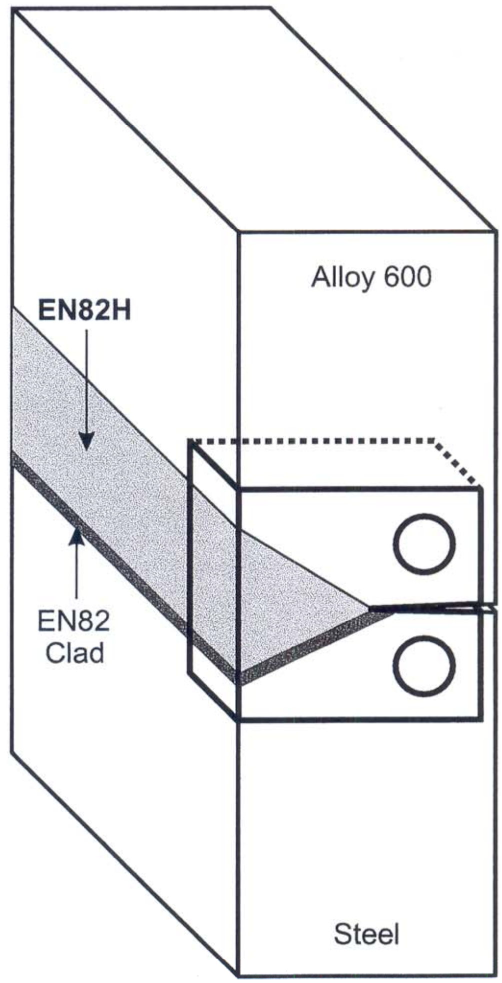
- Data from EN82H weld specimens (LVDT/EPD) were reanalyzed based on total crack extension (DE) ÷ total exposure time.
  - Exceptionally high da/dt obtained from CMOD appears to be an artifact due to large ligaments preventing deflection.
  - SCC rates for EN82H weld exhibit modest scatter.
  - SCC rates for EN82H are similar to Alloy 182 data.

- Significance:
  - Differences in weld composition do not significantly affect SCC rates.

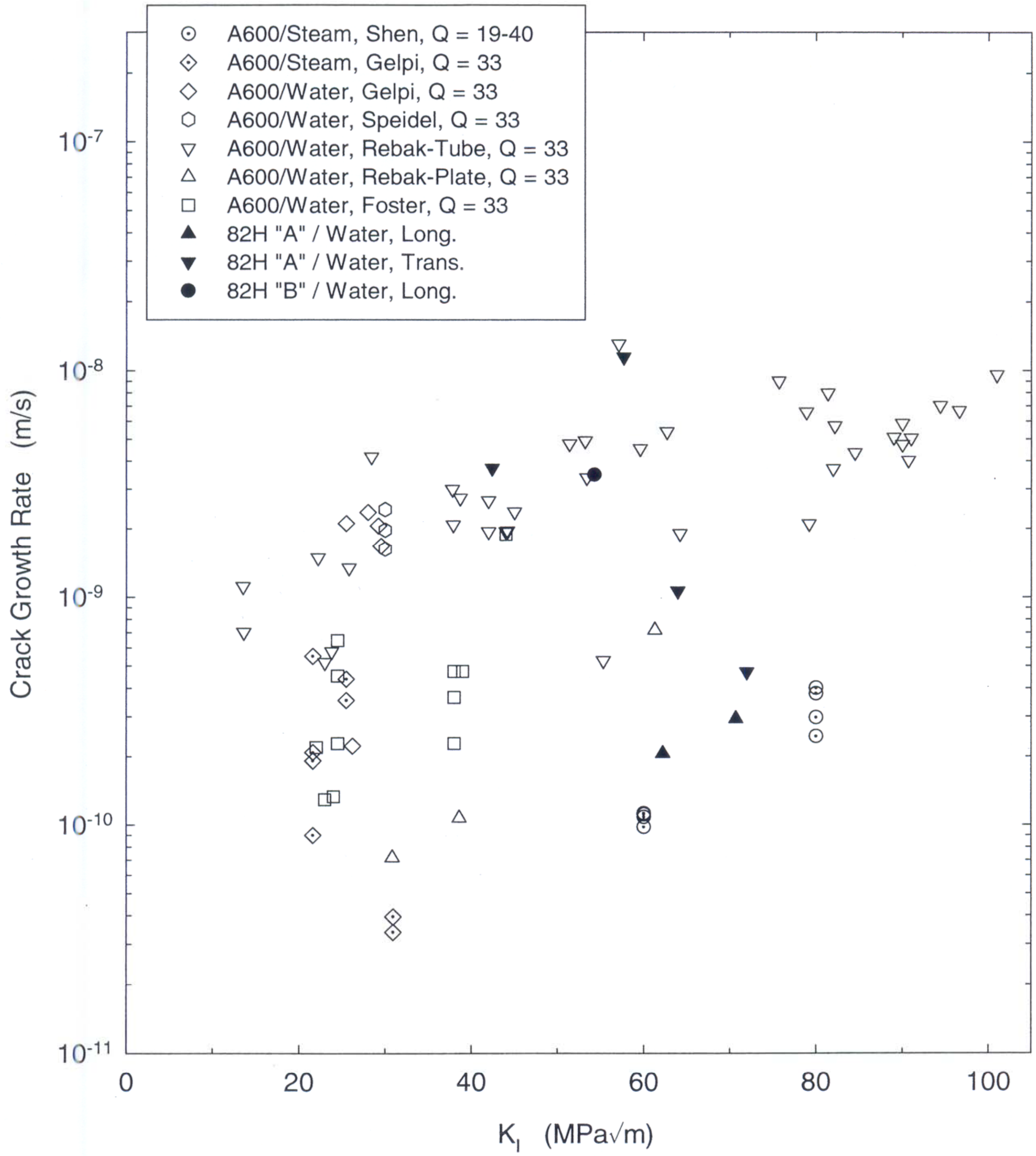
ORIENTATION OF WELD SPECIMENS



Longitudinal CT



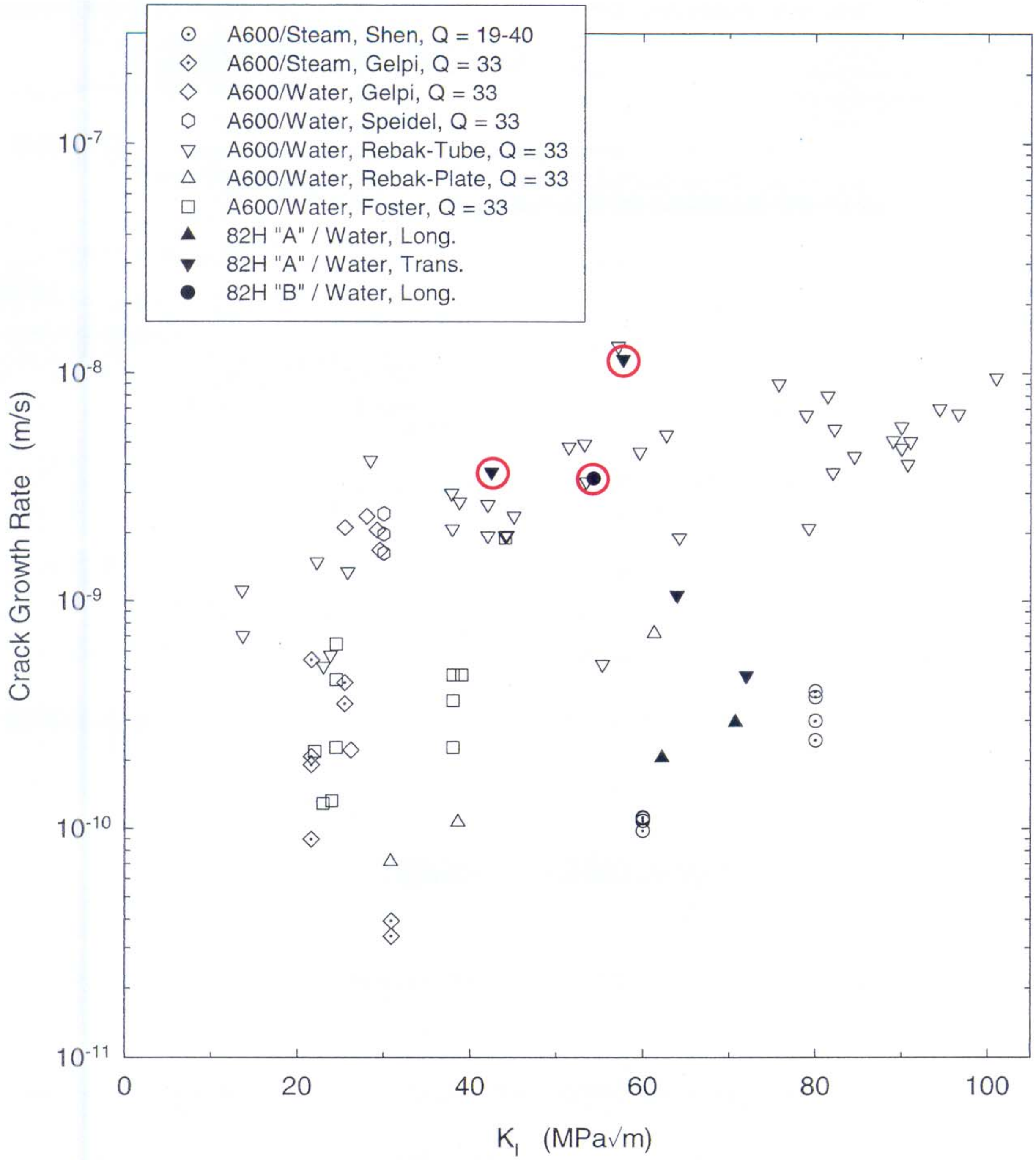
Transverse CT



Comparison of SCC Rates for EN82H Welds at 360°C with Literature Data Corrected for Temperature (Q)

- SCC rates for welds based on LVDT measured CMOD.
- Large scatter in weld data comparable to full range for A600.
- Large scatter was not unexpected because of variable microstructure & strength levels within welds.

LitData2.jnb

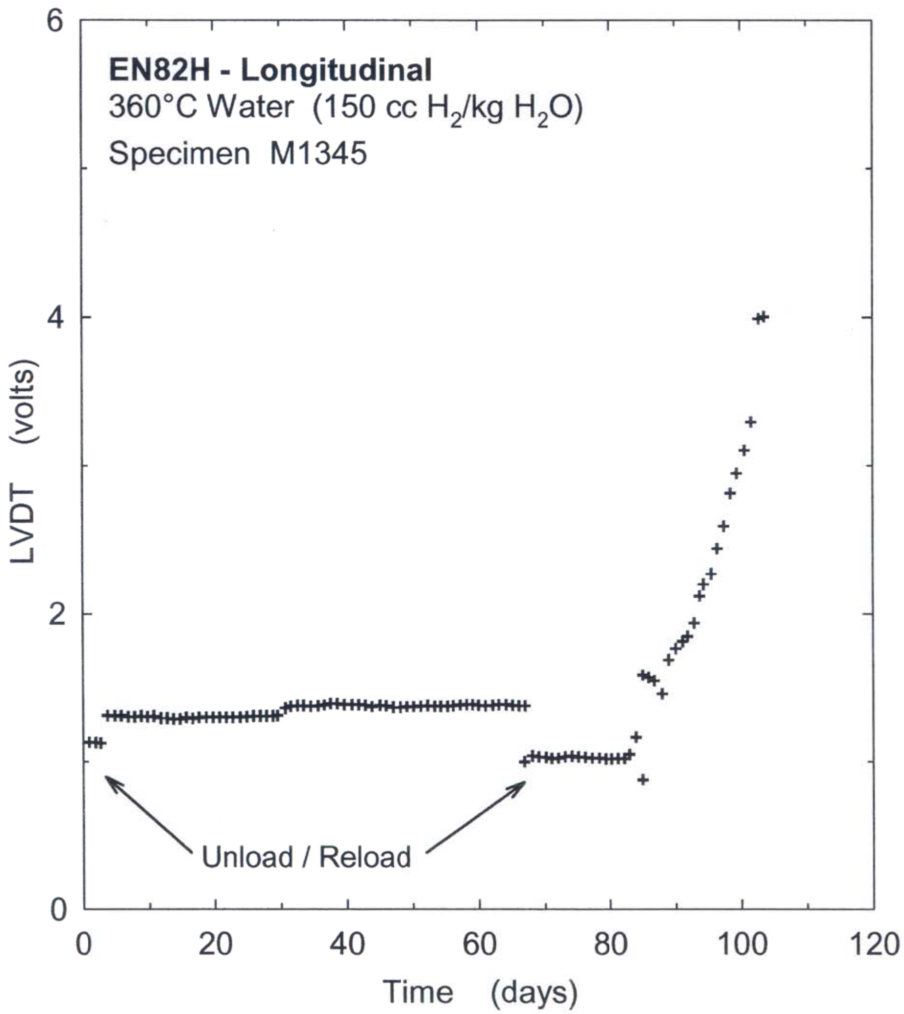


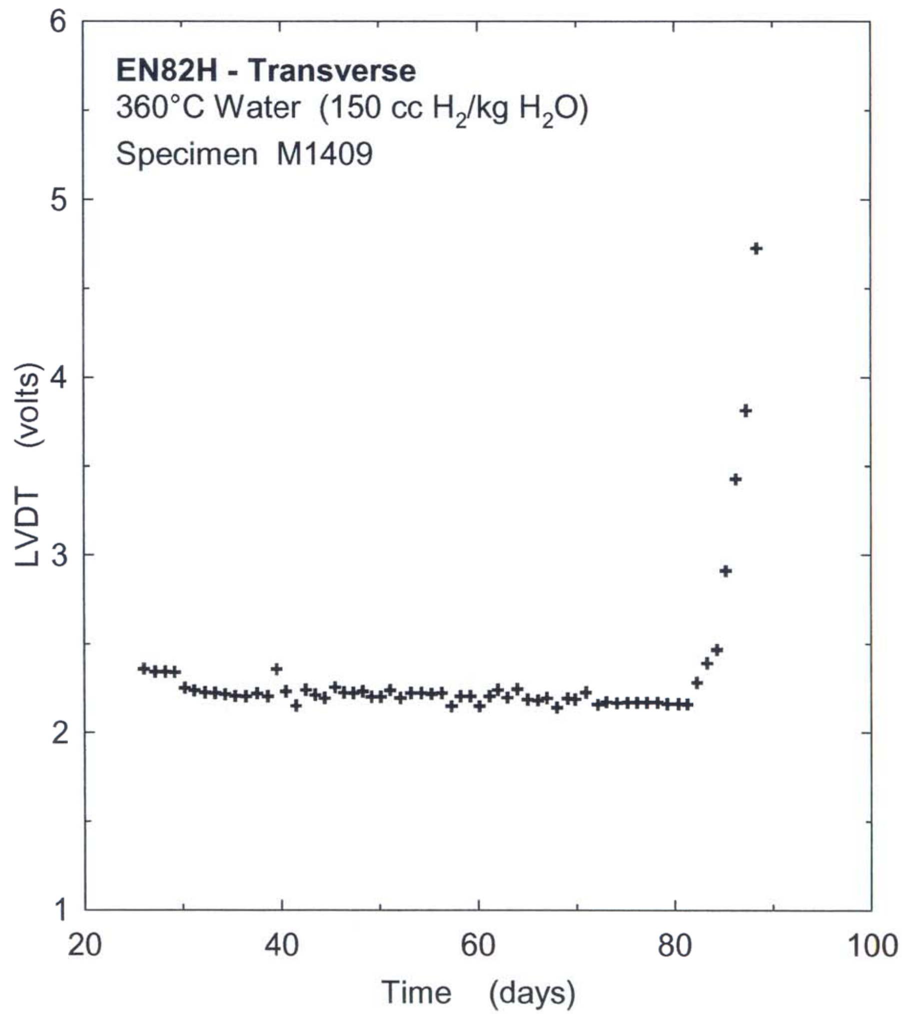
Comparison of SCC Rates for EN82H Welds at 360°C with Literature Data Corrected for Temperature (Q)

- LVDT-measured CMOD values for specimens with exceptionally high crack growth rates (ie, circled data points) indicated very long crack incubation times (81 - 85 days) followed by rapid crack growth.
- SCC probably started early in these tests, but large ligaments in the wake of the crack prohibited significant deflection.
- As cracks grew, stress intensities in ligaments increased and eventually the ligaments began to crack.
- The high cracking rates inferred from LVDT measurements reflect ligament separation, not the overall SCC rate.

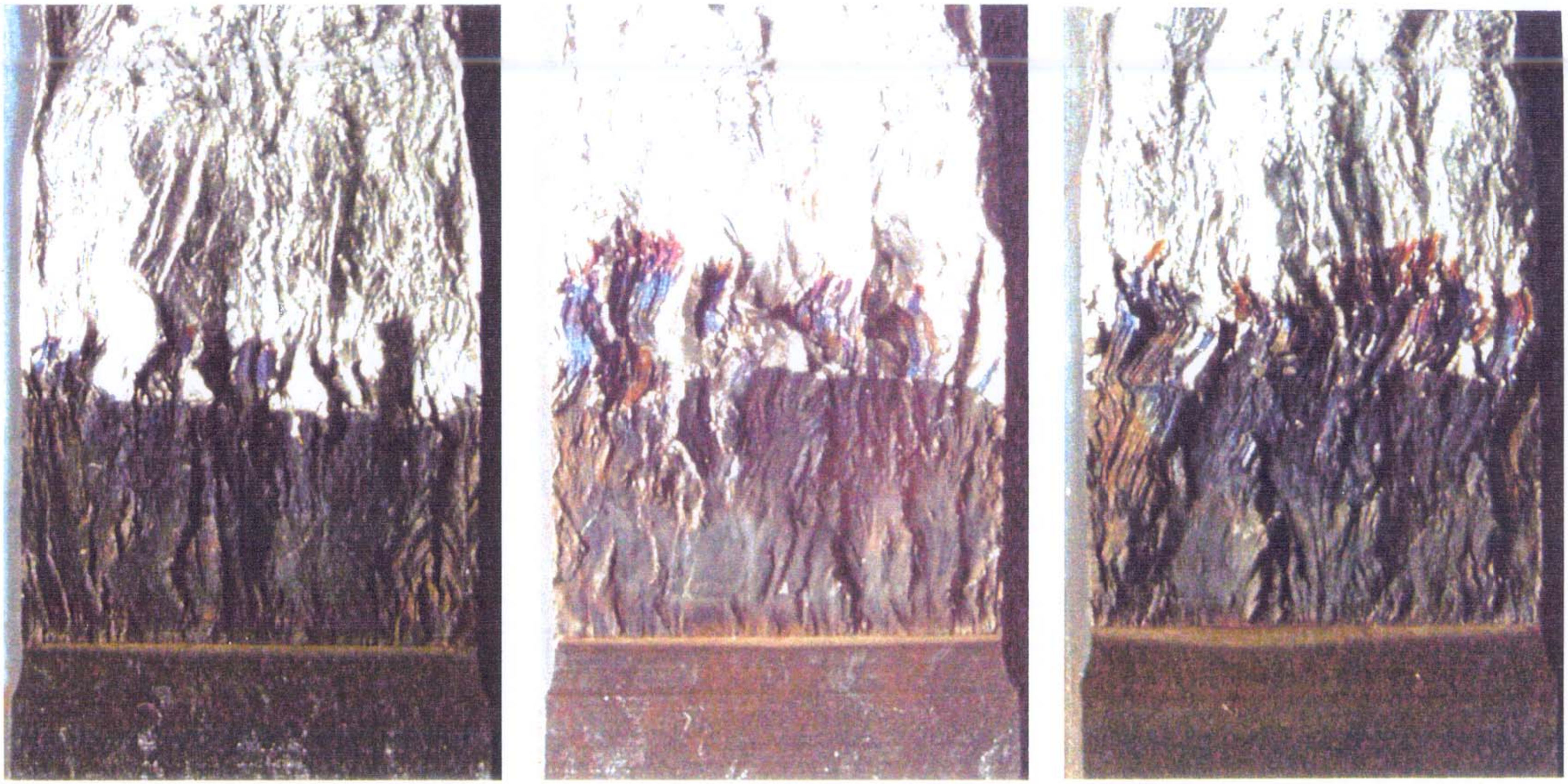
LVDT-Measured CMOD for Constant-Load SCC Tests

LVDT measurements indicate long incubation times (81 & 85 days) followed by rapid crack growth.
SCC probably occurred early in test, but large ligaments prevented deflection.
After extensive SCC, high stress intensity factor in ligaments caused them to crack.
High SCC rates inferred from LVDTs reflect ligament separation, not actual SCC rates.





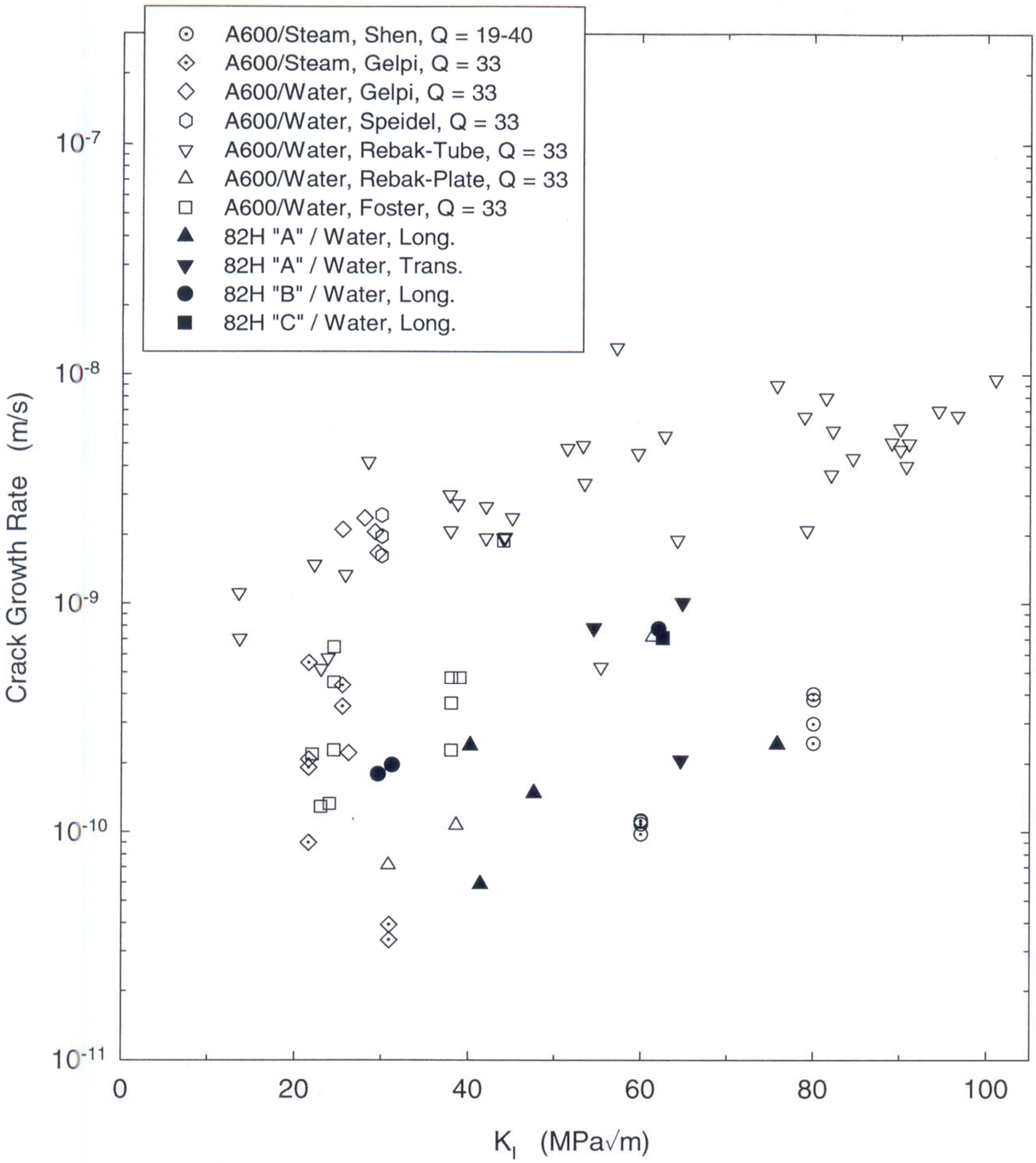
LVDT_CMOD2.jnb



(a) (b) (c)

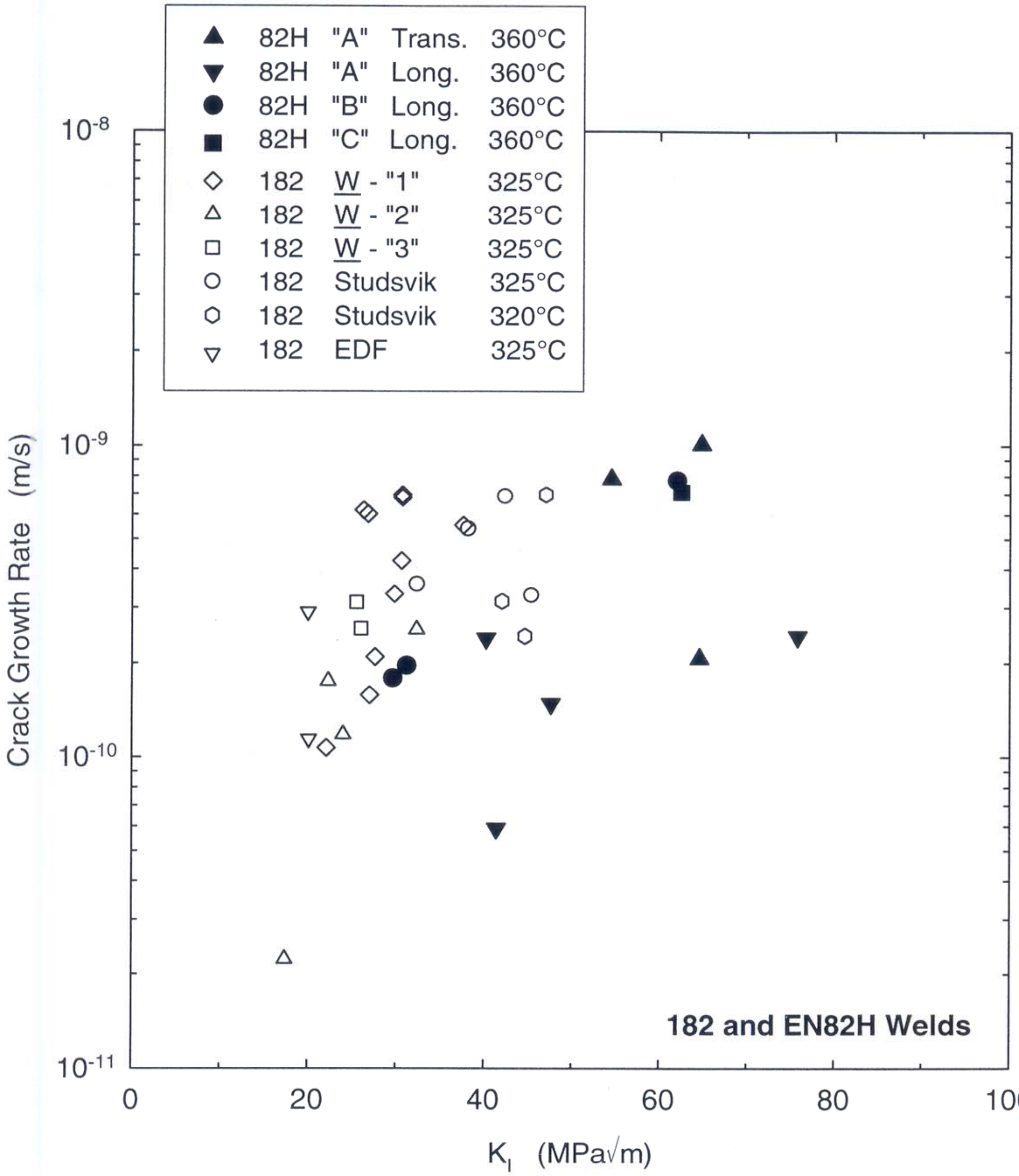
Fracture Surface Appearance for EN82H Welds

(a) SCC typically initiates in localized regions and proceeds along favorably oriented dendritic grain boundaries.
(b) In some welds large unbroken ligaments exist behind the advancing crack front.
(c) Even when crack extension is rather uniform, unbroken ligament typically remain well behind the crack tip.



Comparison of SCC Rates for EN82H Welds at 360°C with Literature Data Corrected for Temperature (Q)

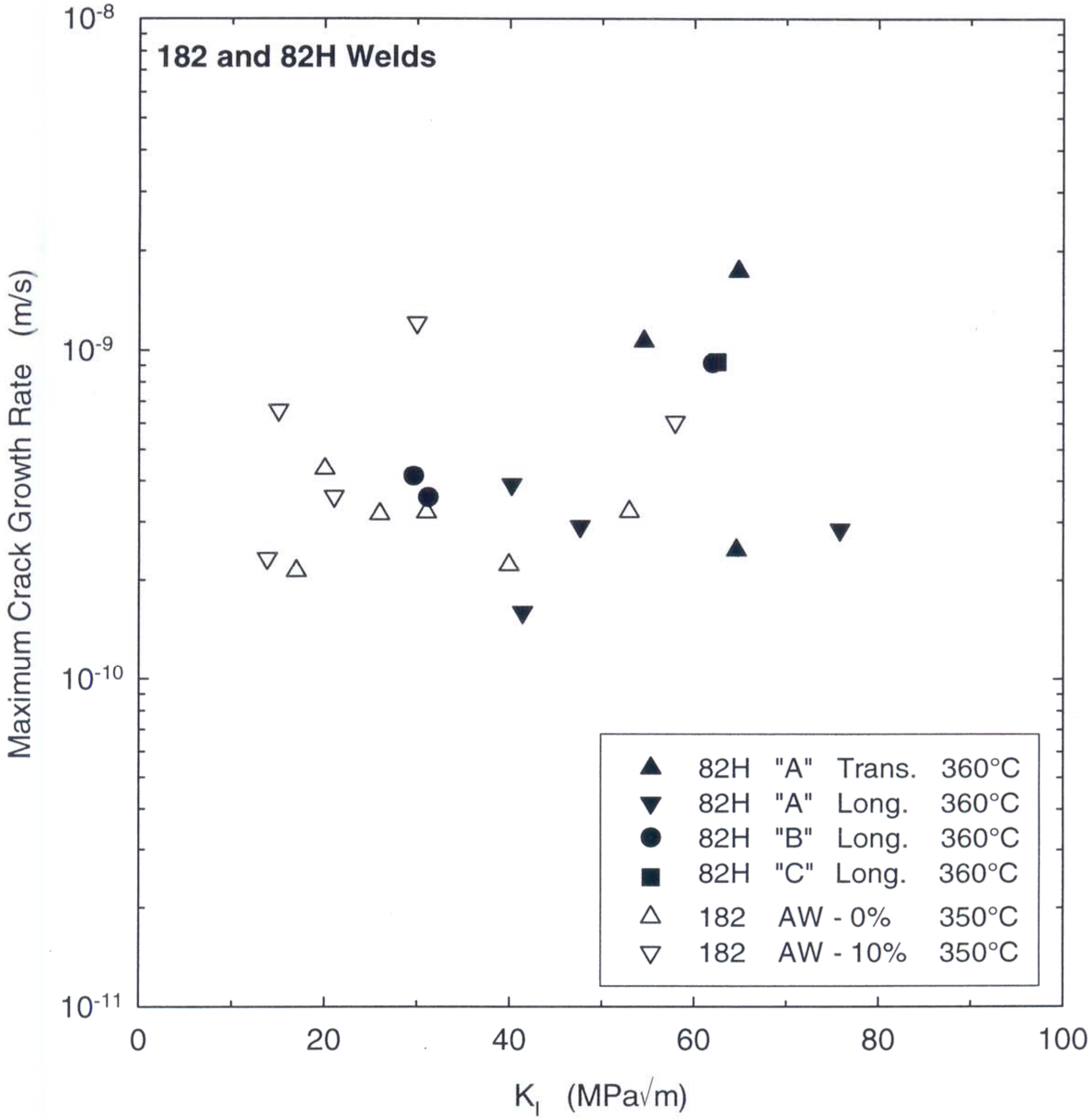
- SCC rates based on crack extension ÷ total exposure time (assumes crack incubation times are much less than test time).
- Exposure times (for all but one test) ranged from 70 to 280 days; hence, incubation times should be much less than test times.
- Test time for specimen with highest SCC rate was only 11 days, but LVDT indicated that SCC initiated during the first day.
- Modest scatter in SCC rates for weld specimens.



CGRs for EN82H Welds in 360°C Water & Alloy 182 Welds in 325°C Water
(Bamford et al, 10th Internat'l Conf. on Environmental Degradation, 2001)

- Range of CGRs for EN82H in 360°C water appears to be similar to range of data for Alloy 182 welds in 325°C water.
  (CGRs were based on average crack extension values.)

SCC_82H_16f.jnb



CGRs for EN82H Welds in 360°C Water & Alloy 182 Welds in 350°C Water

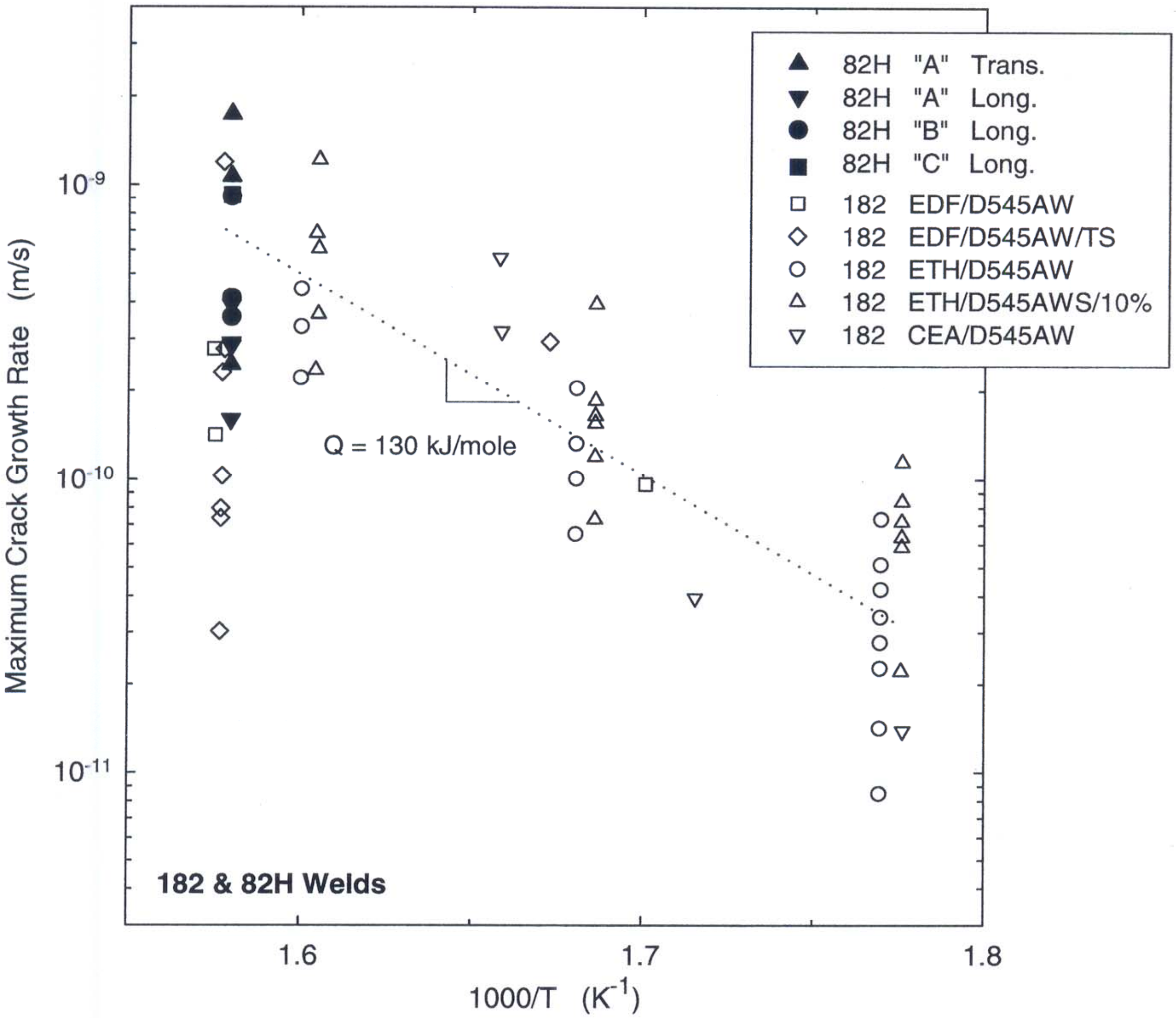
(Le Hong et al, 10th Internat'l Conf. on Environmental Degradation, 2001)

- CGRs for EN82H in 360°C water agree reasonably well with data for Alloy 182 welds in 350°C water.

  Alloy 182 welds were tested in both the as-welded and 10% cold worked conditions.

  (CGRs were based on maximum crack extension values.)

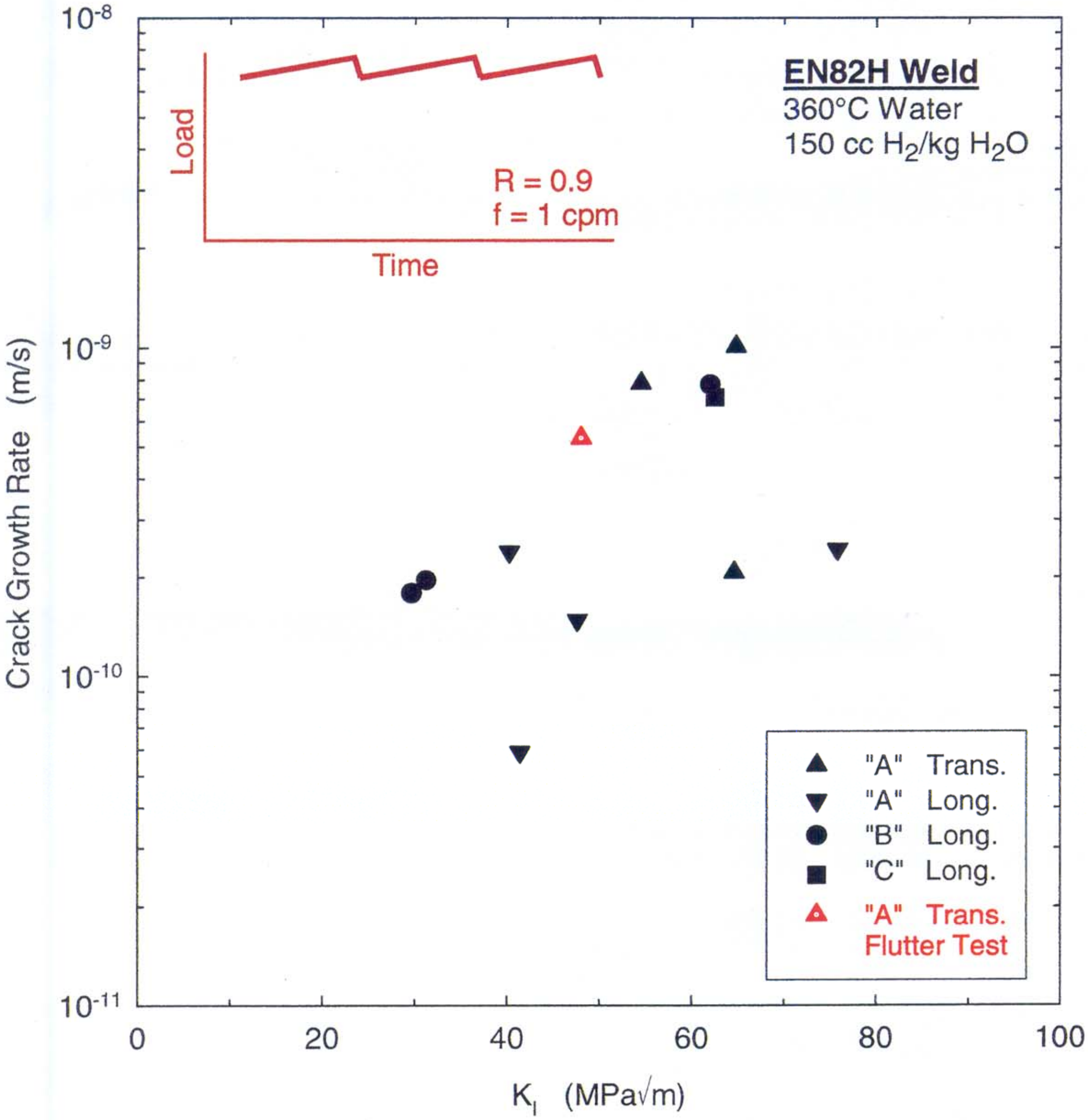
SCC_82H_38Amz_Max_f.jnb



Effect of Temperature on Crack Growth Rates for EN82H & 182 Welds

(Le Hong et al, 10th Internat'l Conf. on Environmental Degradation , 2001)

- CGRs for EN82H welds in 360°C water are consistent with Arrhenius behavior exhibited by Alloy 182 welds.
  Data are consistent with an activation energy of 130 kJ/mol.
  (CGRs were based on maximum crack extension values.)



Effect of Flutter Fatigue Loading on Environmental Cracking Rate

Flutter fatigue loading (R = 0.9, f = 1 cpm) did not severely accelerate CGR, relative to constant-load SCC rates.

SCC_82H_13f.jnb

Stress Corrosion Crack Growth Rates for EN82H Weld

Conclusions:

Limited CGR data for EN82H welds are consistent with data for Alloy 182.

Flutter fatigue loading (low amplitude, very high R) does not severely accelerate CGRs.

References:

1. C. M. Brown and W. J. Mills, "Fracture Toughness, Tensile and Stress Corrosion Cracking Properties of Alloy 600, Alloy 690 and their Welds in Water," *Corrosion / 96*, Paper #90, NACE, 1996.

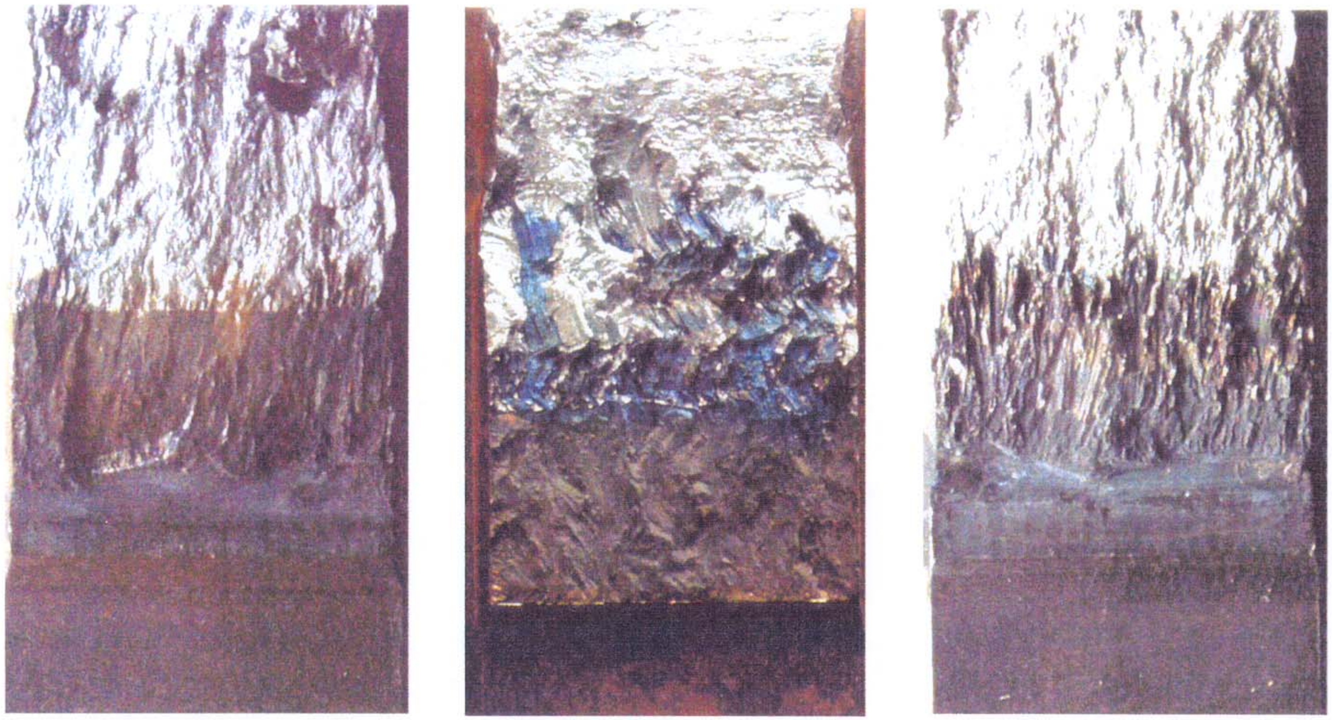
2. C. M. Brown and W. J. Mills, "Effect of Water on Mechanical Properties and Stress Corrosion Behavior of Alloy 600, Alloy 690, EN82H Welds, and EN52 Welds, *Corrosion*, Vol. 55, 1999, p. 173.

3. W. H. Bamford, K. R. Hsu, L. Tunon-Sanjur, J. Foster and A. McIlree, "Alloy 182 Weld Crack Growth, and Its Impact on Service-Induced Cracking in Operating PWR Plant Piping," *Tenth International Symposium on Environmental Degradation of Materials in Nuclear Power Systems-Water Reactors,* NACE, 2001 (in press).

4. S. Le Hong, J. M. Boursier, C. Amzallag and J. Daret, "Measurements of Stress Corrosion Cracking Growth Rates in Weld Alloy 182 in Primary Water of PWR," *Tenth International Symposium on Environmental Degradation of Materials in Nuclear Power Systems-Water Reactors,* NACE, 2001 (in press).

Appendix

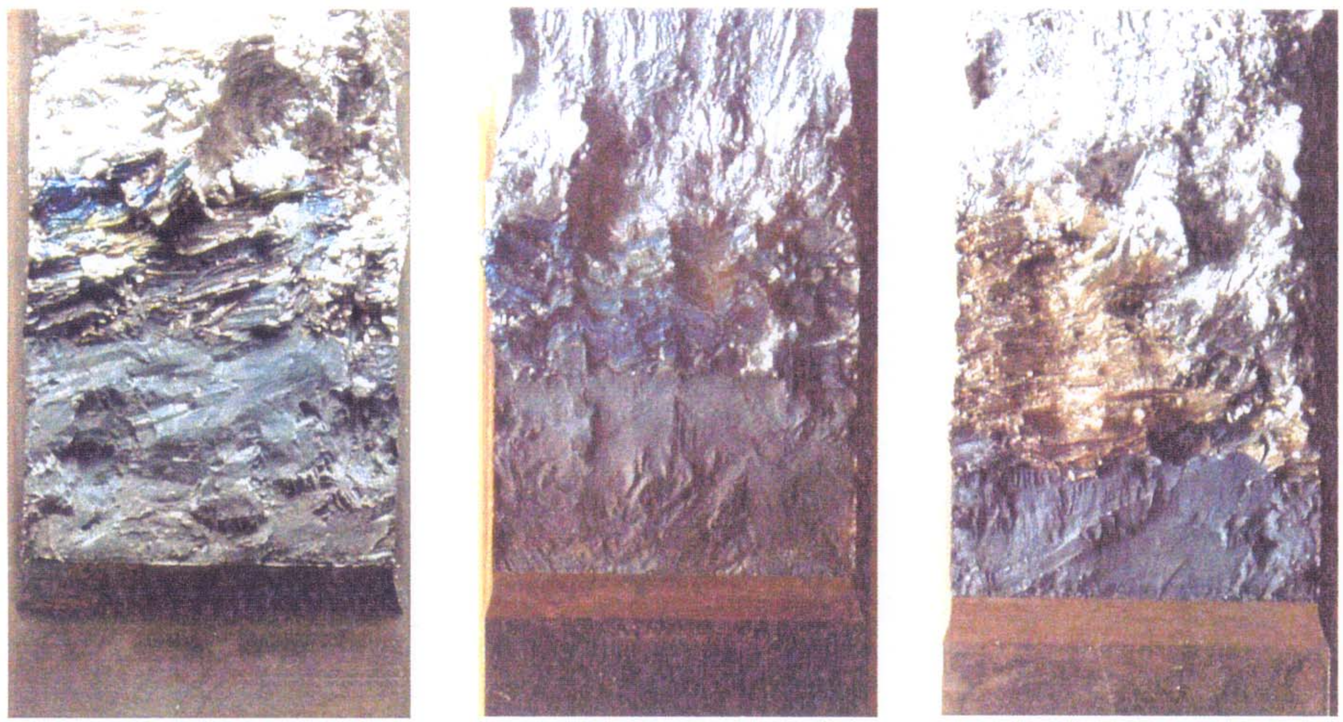
Fracture Surface Appearance for EN82H Welds



(a) (b) (c)

Fracture Surface Appearance for EN82H Welds

Trans_SCC1.cdr



(a) (b) (c)

Fracture Surface Appearance for EN82H Welds

Long_SCC1.cdr