Comparisons of Periodic Unload and Hold Time Effects on SCC Growth Rates in Alloy 690

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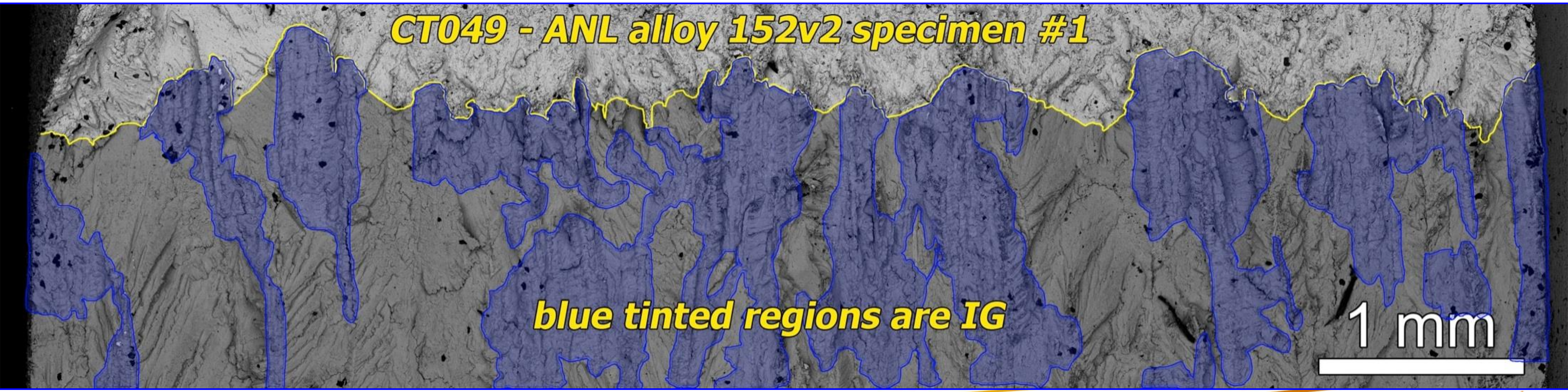
Presentation Outline

- *Background*
  - *Reason for usage*
  - *Review of usage in MRP-55 (alloy 600) & MRP-115 (alloy 182/82)*
  - *Hold time and periodic unloading descriptions*
  - *Usage for estimating constant K or constant load response*
- *Determination of when a PU is needed to estimate constant K response.*
- *Variation in CGR with hold time*
- *Comparison of results*
- *Summary and conclusions*

Reasoning for Periodic Unloading

- *Periodic unloading seen as helpful in breaking ligaments that may form as a result of branched cracking or poor grain boundary alignment relative to the target crack growth plane.*
- *However, a periodic unload does contribute to crack extension.*



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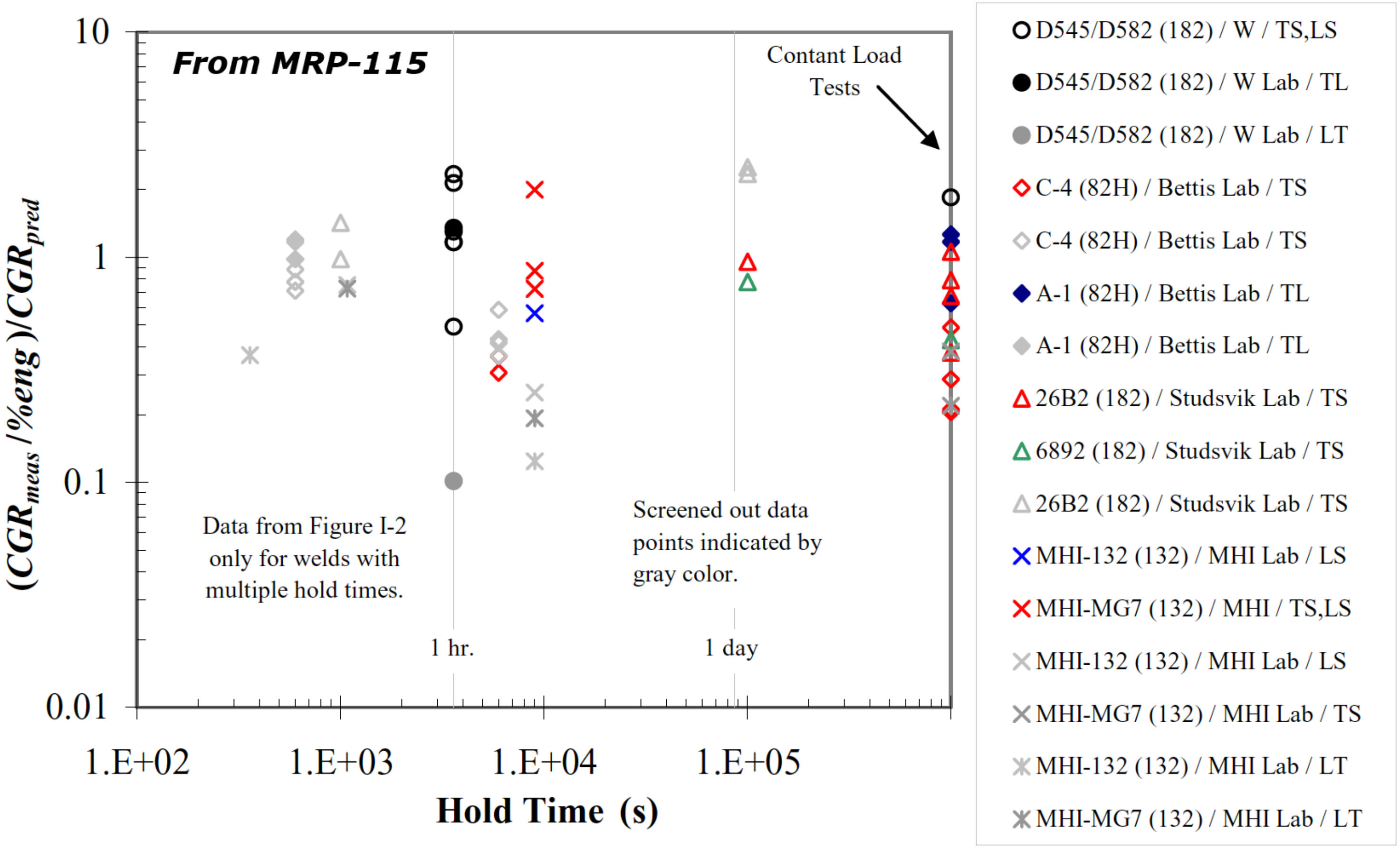
MRP-55 (Alloy 600) and MRP-115 (Alloy 182/82) Experience

- *MRP-55 (Alloy 600) does not assess hold time or periodic unload effects.*
  - *The only statement in the report is, "A review of the CGR database revealed that the potential accelerating effect of periodic unloading is relatively small, at least for susceptible materials."*
- *MRP-115 (Alloy 182/82) addresses hold times and periodic unloading.*
  - *When considering the entire MRP-115 dataset, the broad conclusion is that hold times >6000 s have no appreciable effect on CGR.*
  - *Hold times of <600 s may lead to a factor of 2x higher CGR.*
  - *Only a few datasets on specific materials where hold time is varied. In most cases, environmental factors may be affecting CGRs. Effect of hold time is mixed.*

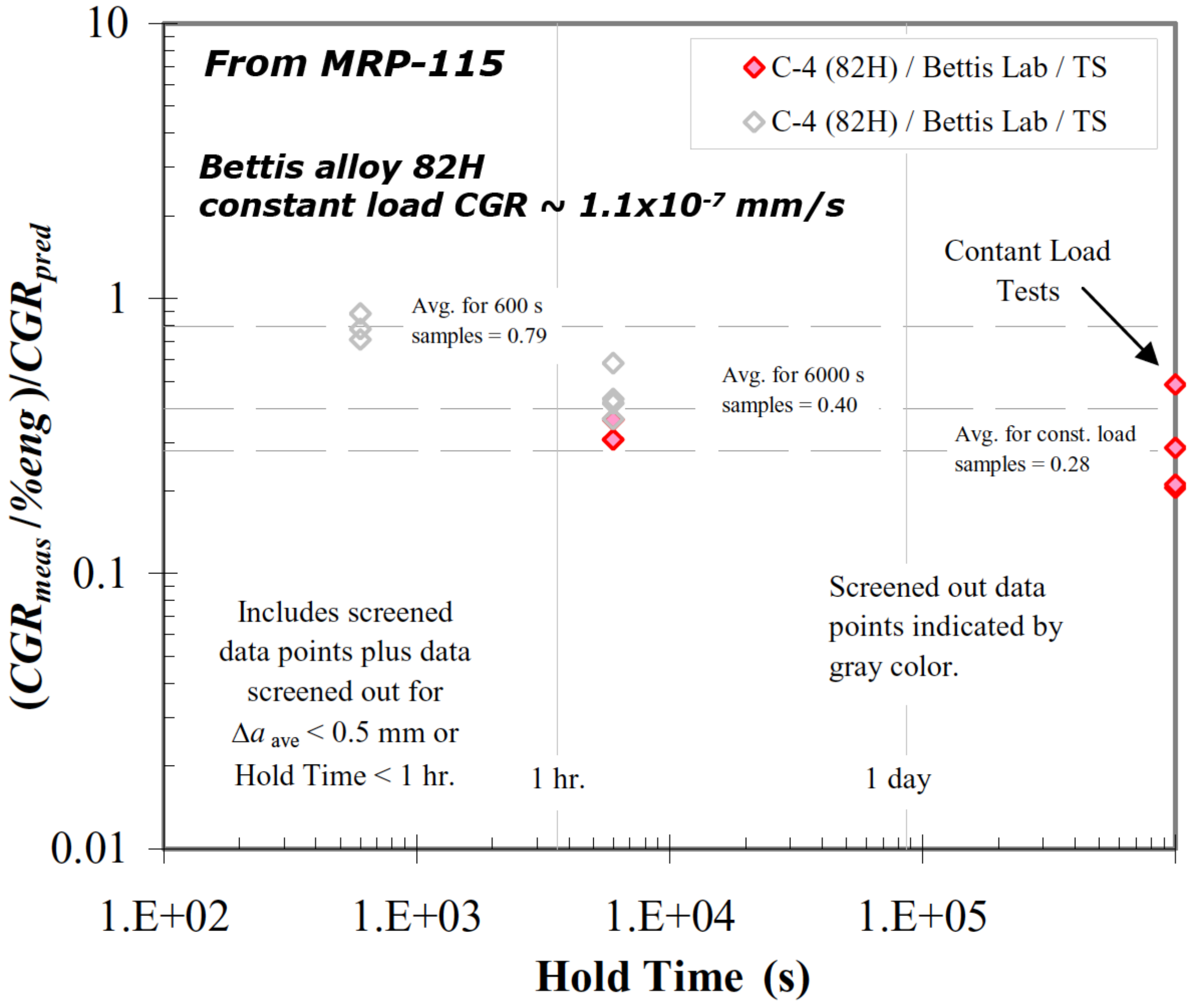
MRP-115 (Alloy 182/82) Hold Time Effects

- *MRP-115 (Alloy 182/82) hold time effects for multiple material data set (Figure I-3).*
  - *Many alloys/heats grouped together suggest <2x increase with decreasing hold time as indicated by the MRP report.*



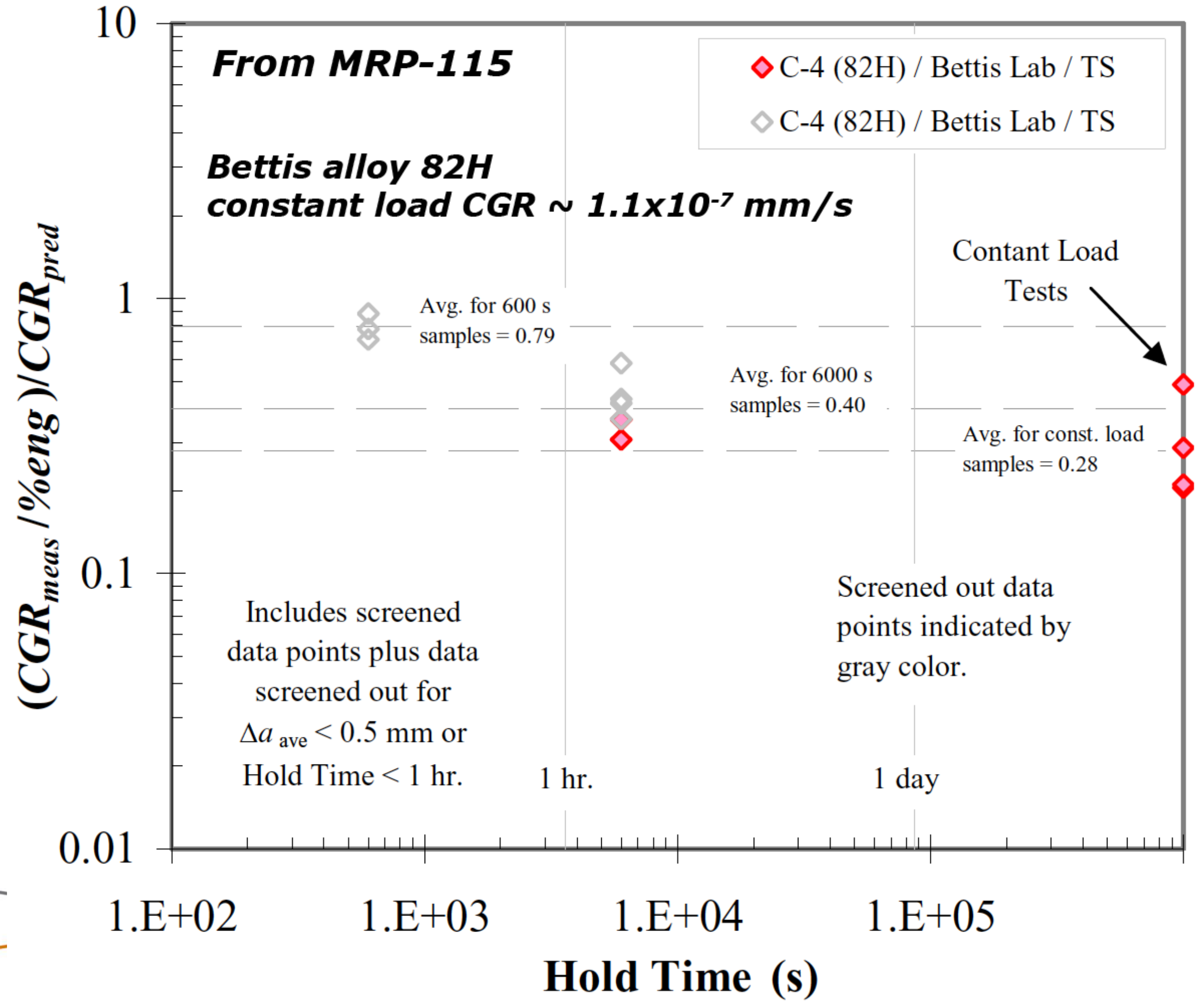
MRP-115 (Alloy 182/82) Hold Time Effects

- *Hold time effects from Bettis C-4 alloy 82H (Fig. I-6).*
  - *Data from a single set of identical specimens show ~2x higher CGR at 600 s hold.*



MRP-115 (Alloy 182/82) Hold Time Effects

- *Hold time effects from Bettis C-4 alloy 82H (Fig. I-6).*
  - *No difference in CGR between constant load and 600 s hold. Note high constant load CGR.*



Estimations of Effect of Periodic Unload on Crack Growth Rate

- *In concept, the effect of a periodic unload on crack growth rate can be calculated by a time weighted average of the cyclic loading CGR and constant K CGR.*

$$CGR_{PU} = \frac{t_{hold} CGR_{CK} + t_{cycle} CGR_{cycle}}{t_{cycle+hold}}$$

- *Ignores the effect of load cycle on crack morphology*

Calculated PU CGR for a 12s/12s load cycle using approximate CGRs measured from high, moderate, and non-CW alloy 690

Example	CGR_{CK} (mm/s)	CGR_{cycle}	hold time	calc CGR_{PU}	increase
high CW	7×10^{-8}	5×10^{-6}	9000 s (2.5 h)	1.1×10^{-7}	1.6x
mod CW	1.6×10^{-8}	3×10^{-6}	9000 s (2.5 h)	1.8×10^{-8}	1.1x
non CW	1×10^{-9}	3×10^{-6}	9000 s (2.5 h)	9.0×10^{-9}	9.0x

- *Results suggest that the CGR of susceptible materials will be only slightly affected by a PU, but the PU CGR of resistant materials will be more strongly increased.*

Types of Periodic Unload

- *Neither MRP-55 nor MRP-115 specify the type of PU.*
- *Two types of periodic unloads considered*
  - *Fast pure fatigue unload/reload cycle. Purpose is to break ligaments. Will not drive a crack TG in a susceptible material.*
  - *Slow reload cycle that can have an SCC component. Often referred to as a cycle+hold. Perhaps more applicable in a moderately resistant material where a fast cycle could drive a crack TG.*

Selected Comparisons of Fast and Slow Cycle PU CGRs for a Total Cycle Time of 2.78 h (10000 s). R = 0.5.

CT	Material	CGR_{CK}	CGR_{PU} @ 12s/12s	CGR_{PU} @ 980s/20s	slow/fast ratio
CT100	A690 21%CF	$1.6x10^{-8}$	$3.3x10^{-8}$	$4.4x10^{-8}$	1.3x
CT102	A690 21%CF	$1.6x10^{-8}$	$5.2x10^{-8}$	$6.0x10^{-8}$	1.2x
CT093	A690 20%TS	$4.9x10^{-9}$	$1.8x10^{-8}$	$2.2x10^{-8}$	1.2x
CT101	A690 21%CF	$3.1x10^{-9}$	$1.7x10^{-8}$	$2.7x10^{-8}$	1.6x

- *Slow cycle produces slightly higher CGRs as expected. Prefer slow reload to minimize possible TG in resistant matrials.*

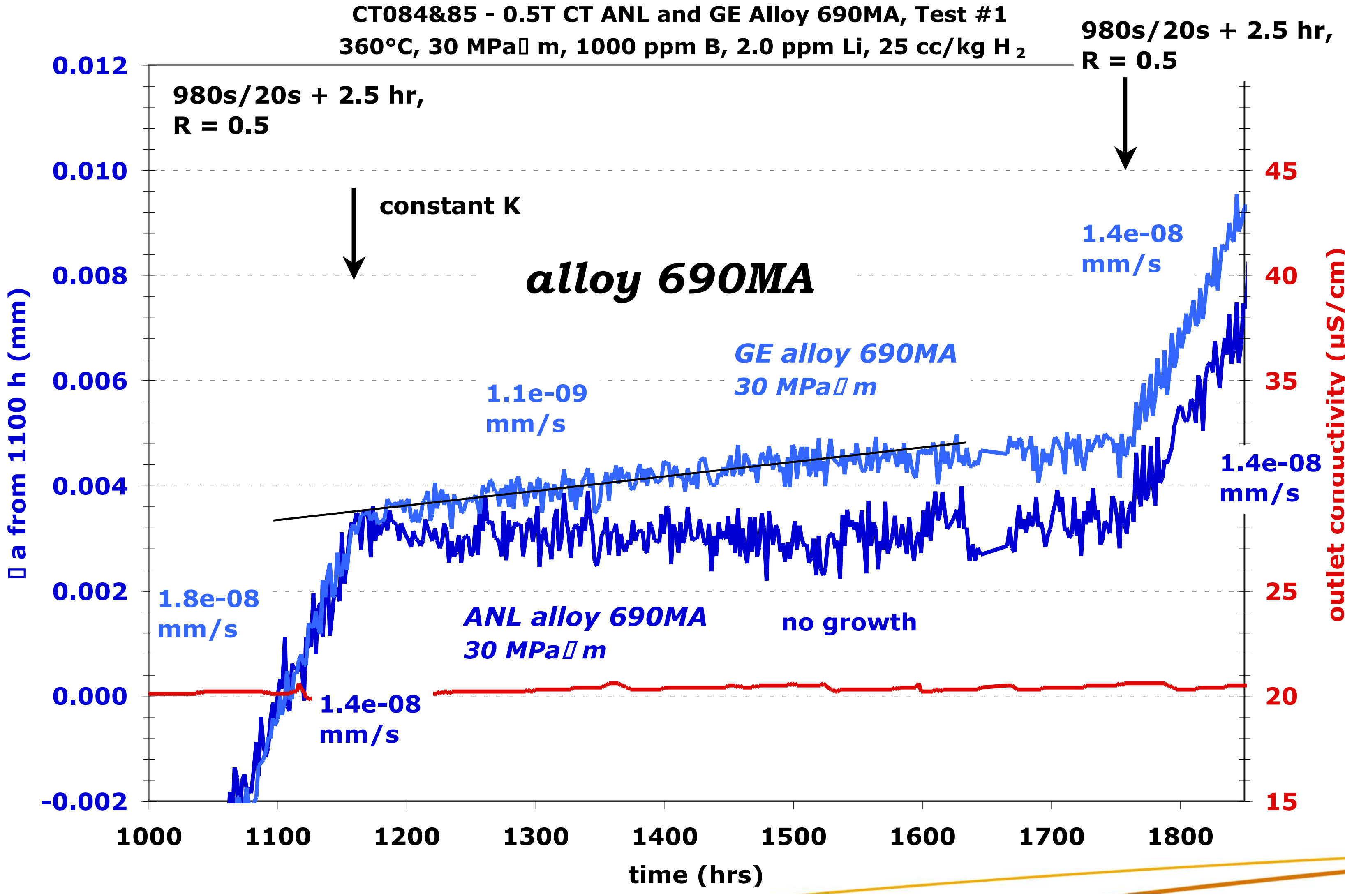
Comparison of PU CGR to Constant K

Periodic unload CGR for alloy 690 using a 980s/20s PU at R = 0.5. CGRs are in mm/s.

ID	CW	CGR_{CK}	hold	CGR_{PU}	increase
CT098	31%CF	7.4×10^{-8}	2.5 h	4.1×10^{-7}	5.5x
CT099	31%CF	6.4×10^{-8}	2.5 h	1.4×10^{-7}	2.2x
CT100	21%CF	1.6×10^{-8}	2.5 h	2.5×10^{-8}	1.6x
CT102	21%CF	1.6×10^{-8}	2.5 h	4.7×10^{-8}	2.9x
CT084	MA	5×10^{-10}	2.5 h	1.4×10^{-8}	28x
CT085	MA	1.1×10^{-8}	2.5 h	1.8×10^{-8}	16x

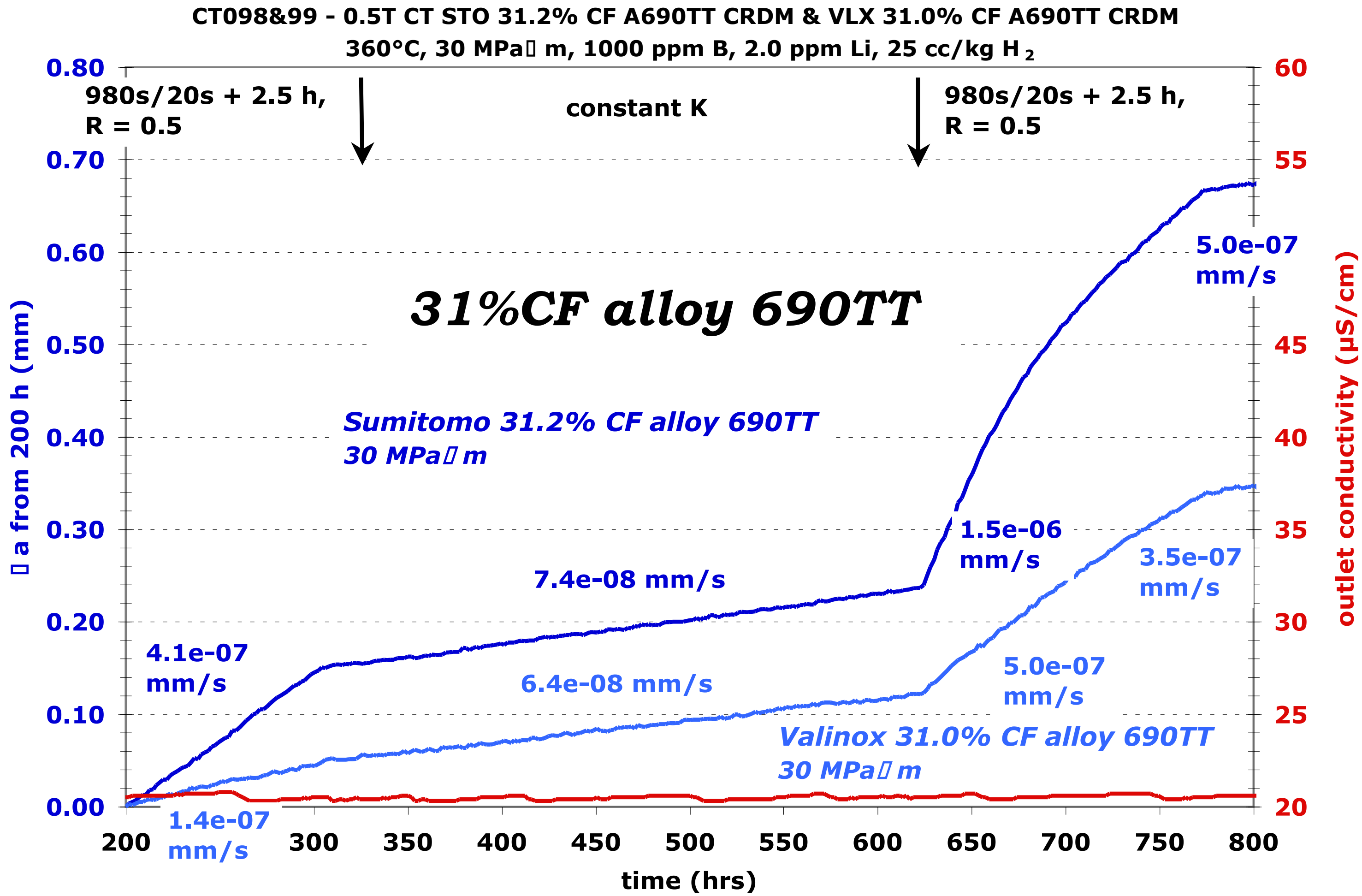
- *A 2.5 h hold produces a ~2-5x higher CGR in moderate to high susceptibility materials.*
- *~20-25x higher CGR in resistant materials.*
- *Results are consistent with EPRI MRP-55/115, but highlight the inaccuracy of using a PU to estimate CGR in a resistant material.*

Effect of Ligaments/Bridging on DCPD Crack Length Measurement



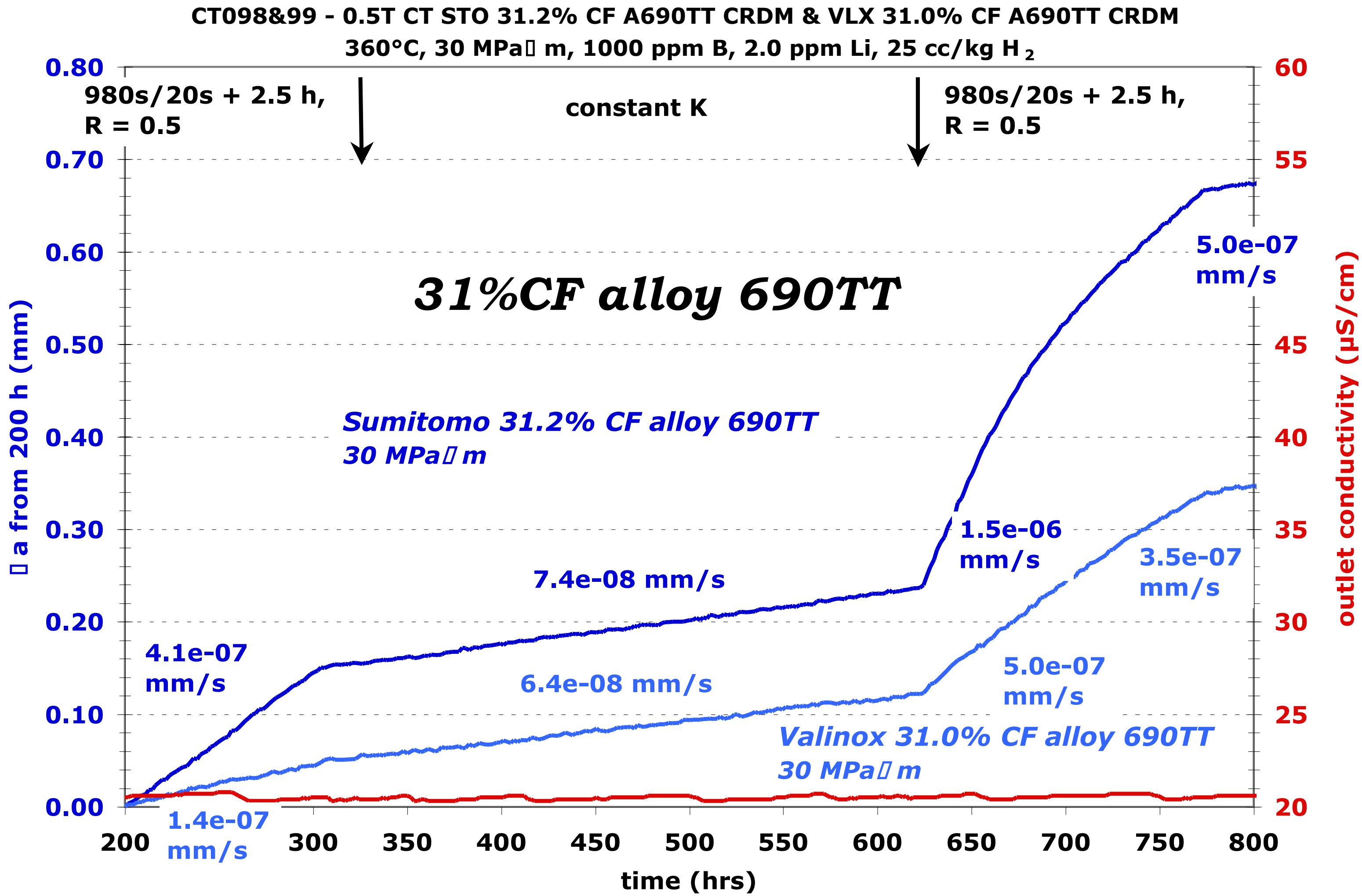
*In a **resistant alloy 690**, cycle+hold (PU) CGR is the same before and after constant K exposure showing lack of ligament/bridge formation.*

Effect of Ligaments/Bridging on DCPD Crack Length Measurement



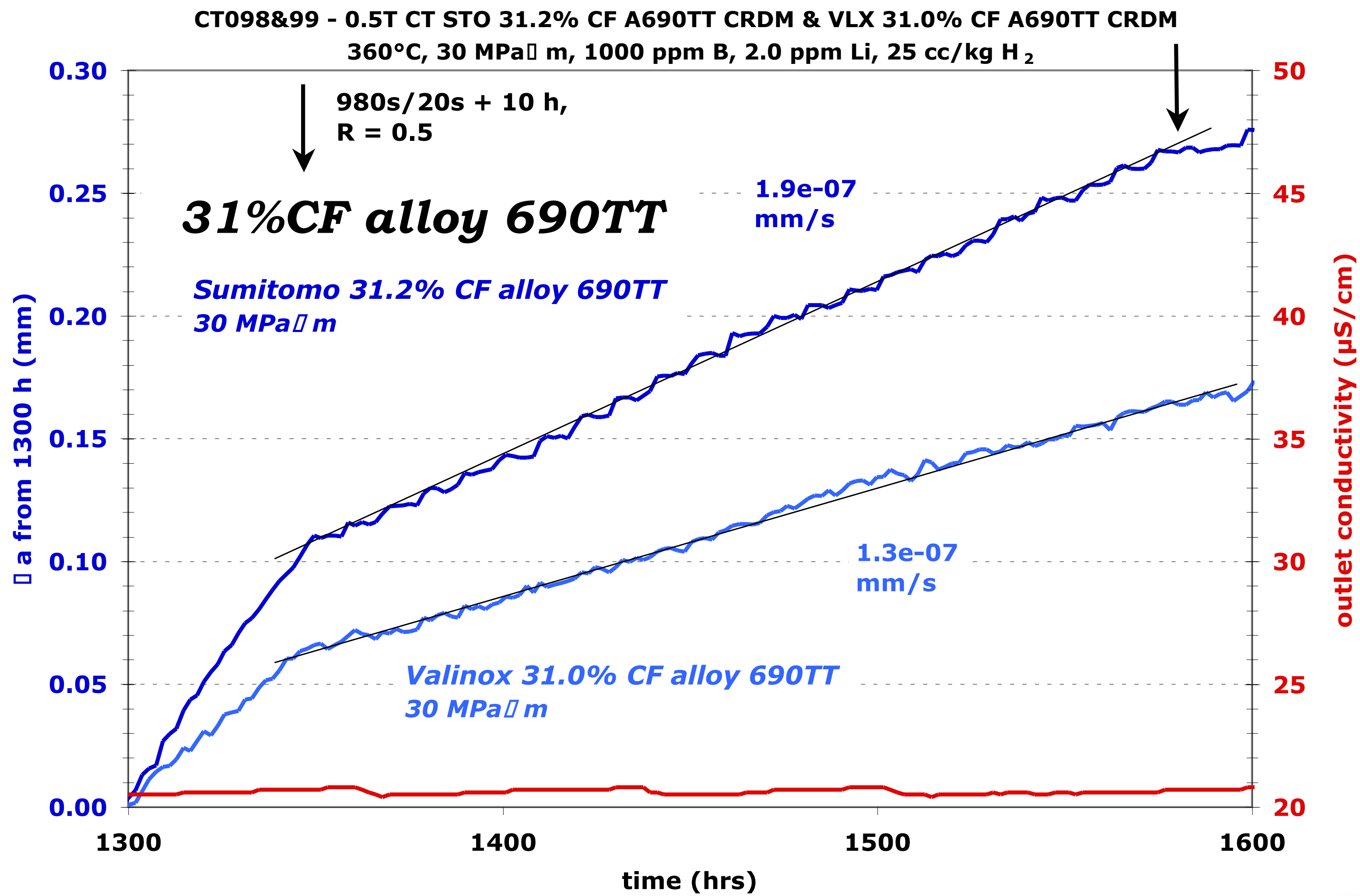
- In a ***susceptible alloy 690***, *a spike in cycle+hold (PU) CGR is observed after constant K suggesting ligament/bridge formation.*
- *DCPD-based CGR during constant K is underestimating actual crack extension. This is the basis for use of PU.*

Selection of Hold Time for PU CGR Observations



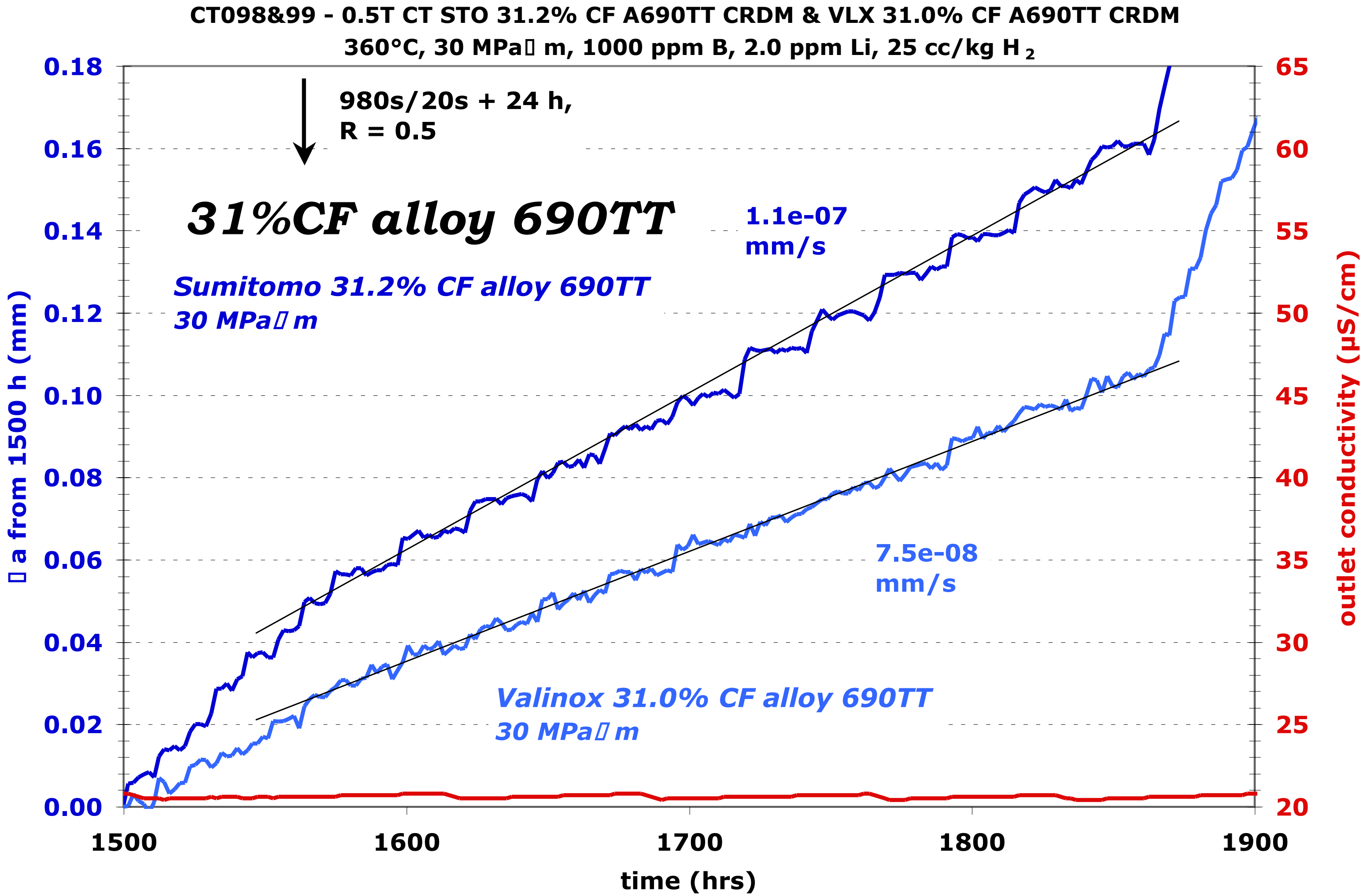
- *A 2.5 h hold PU is 2-5x higher than DCPD-based constant K CGR.*
- *Are these CGRs representative of the actual constant K CGR?*
- *Explore application of longer hold times.*

10 h hold PU CGR Observation



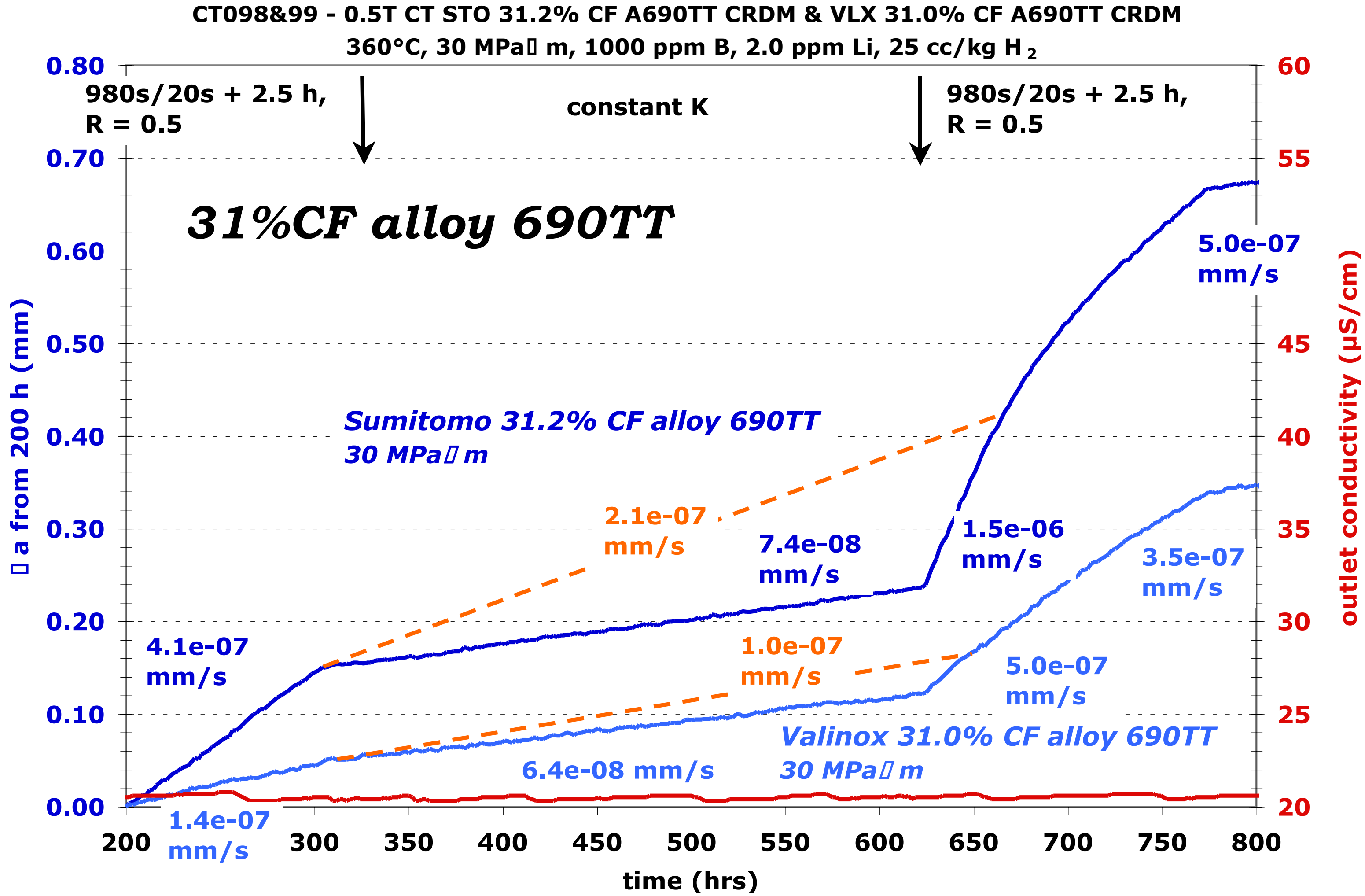
- *Small steps in crack growth traces, but overall steady crack extension.*
- *Steps too large to be due to corrosion fatigue, suggests that extension is due to breaking ligaments/bridges.*

24 h hold PU CGR Observation



- *CGR is ~1/2 of the 10 h hold.*
- *Steps are more pronounced in the Sumitomo consistent with the idea that a slow cycle contributes primarily to breaking ligaments/bridges.*

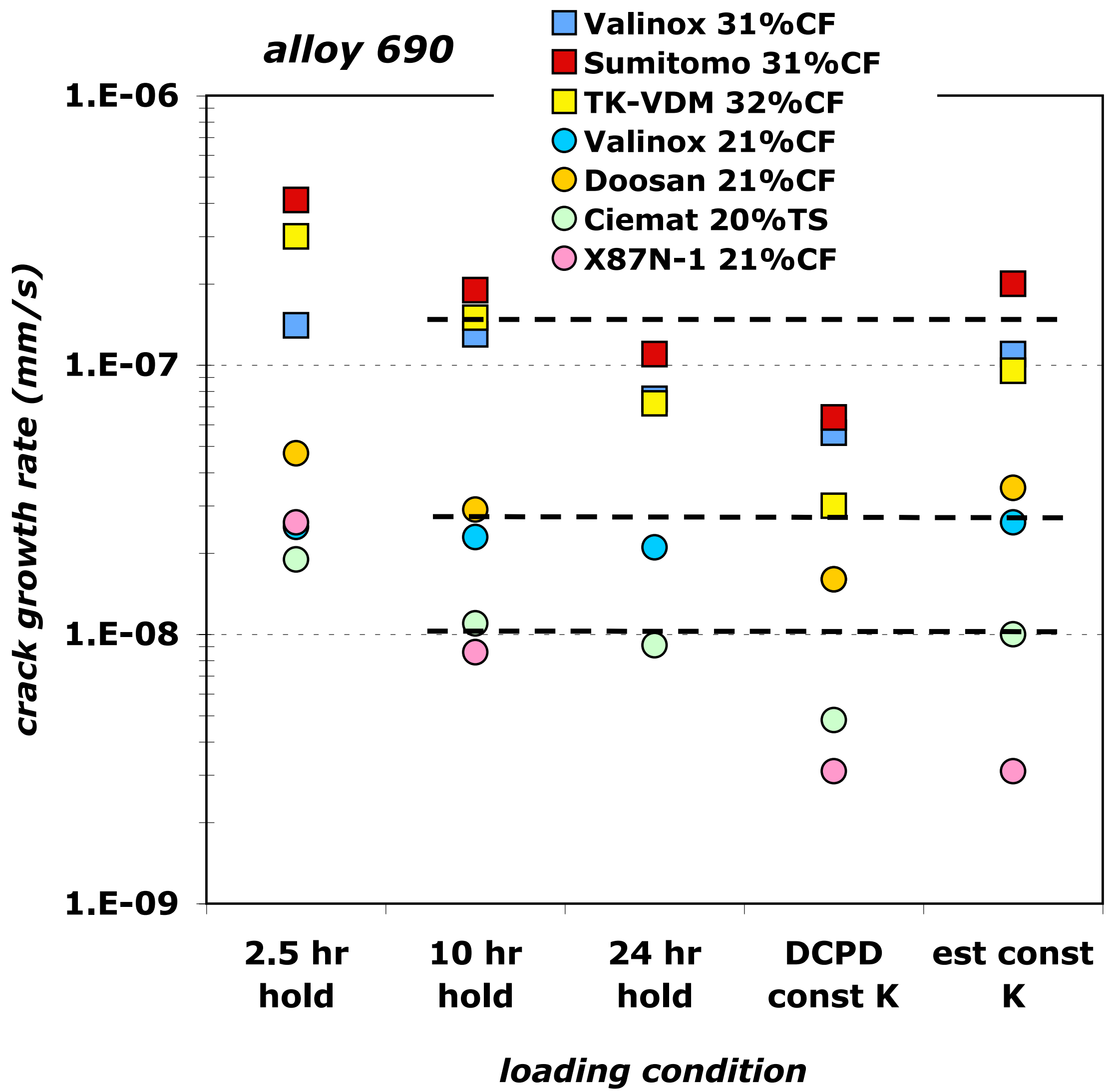
Estimation of Constant K Response From Speciment Response



- *Use break point in crack growth response during 2.5 h hold after constant K to produce an estimated constant K CGR.*
- *Estimated values are ~1.5-3x higher than DCPD-based CGR.*

Comparison of CGR Measurements

- *Compare a variety of hold times to DCPD-based constant K and adjusted constant K.*
- *High to low susceptibility materials on the plot.*
- *For materials that exhibit evidence of ligament/bridge formation after constant K, the 10 h hold and the adjusted constant K values are similar.*
- *Determining the estimated value requires interpretation of response.*
- *10 h measurement requires no interpretation.*



PNNL Summary of Use of Periodic Unloading for Constant K Estimation

- *MPR-55/115 suggest that a periodic unload can be used to break ligaments/bridges for susceptible materials.*
  - *PU CGR is ~2x higher than constant K for susceptible materials.*
- *Alloy 690 and its welds can possess a range of susceptibility indicating a need to reassess the usage of a PU.*
- *A 980s/20s cycle PU was used to assess alloy 690.*
  - *Slow reload preferred over fast reload to limit TG formation.*

1. *Assess whether a PU is needed. Results suggest that a PU is needed only when evidence of ligament/bridge formation is detected after constant K loading.*
   - *Resistant alloy 690 exhibits no evidence of ligaments/bridges.*
2. *In this study, a 10 h hold was in agreement with estimated constant K CGRs for materials that exhibited bridge/ligament formation*
   - *Values were ~1.5-5x higher than constant K CGRs depending on the degree of ligament/bridge formation.*
3. *Application of a PU to resistant materials produces artificially CGRs. Can range from 3-20x higher than constant K CGR.*