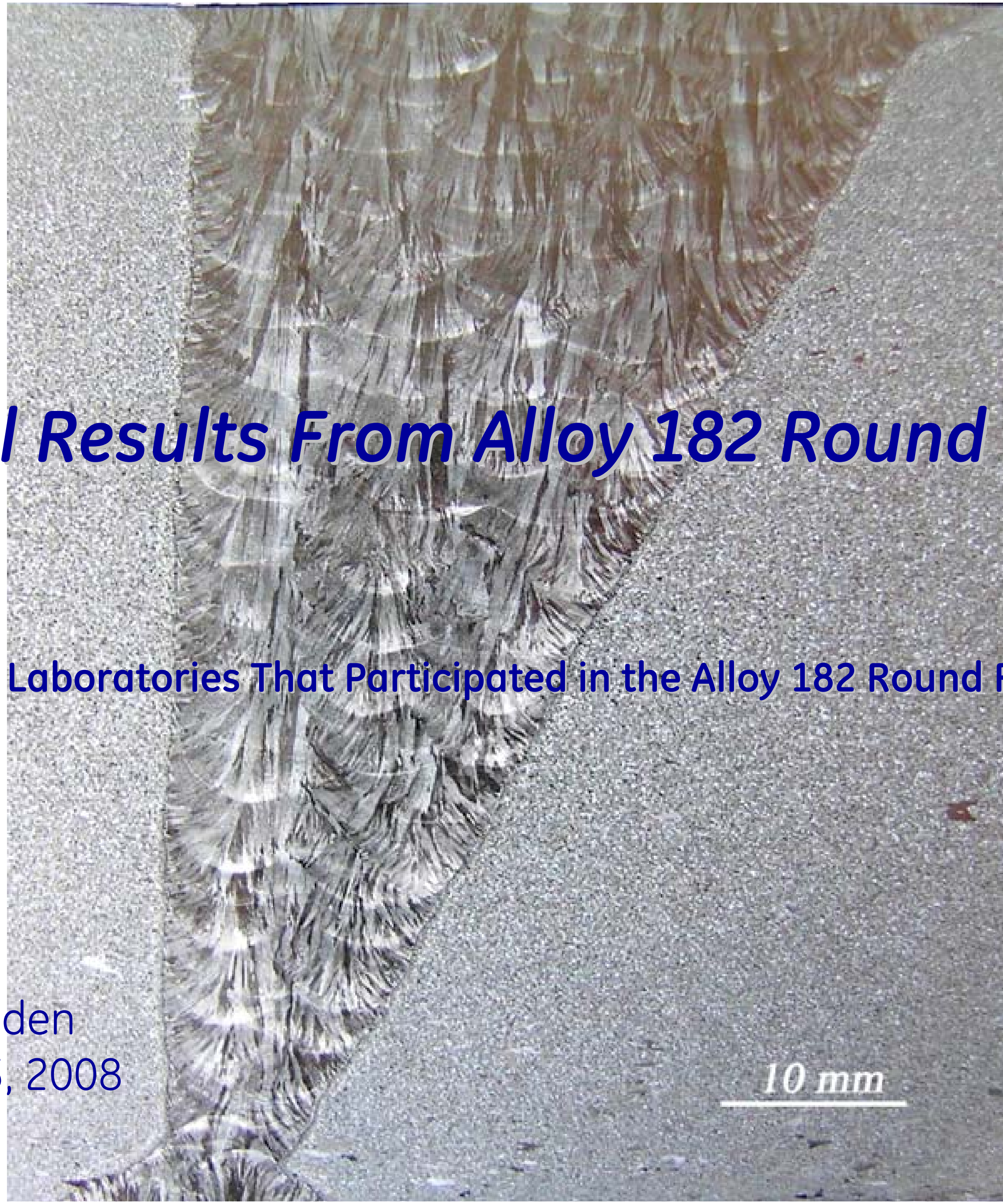
Final Results From Alloy 182 Round Robin

All Laboratories That Participated in the Alloy 182 Round Robin



ICG-EAC
Båstad, Sweden
April 20 – 25, 2008

imagination at work

Many thanks for the patience and time invested by participating laboratories:

ANL, AREVA, CEA, CIEMAT, EDF, GEGR, NRI, PNNL, PSI, SCKCEN, Serco Assurance, Toshiba, Studsvik, and VTT

Updates

- 33 weld samples were sent out, including 2 replacements:

  19 specimens were tested – 5 weld top and 14 weld root
  12 under BWR test conditions
  7 under PWR test conditions.

- 14 Laboratories ran tests for which data was reported

- New BWR data, pure water (2 ppm O_2) and 30 ppb SO_4^{2-} added.

Review – Material Issues:

- A combination of a highly difficult material in which to sustain SCC growth and related sensitivity to managing SCC growth during testing led to a large variation in CGRs.
- The alloy 182 was not highly prone to propagation possibly due to large unidirectional oriented dendrites with similarly oriented NbC carbides densely precipitated along dendrite cores.
- Sulfate additions in BWR water increased growth rates.
- Large variation in crack growth rates not associated with weld root versus weld pool top.

Review – Test Issues – Post Pre-Crack IG Engagement:

- Failure to transition to 100% IG engagement leads to crack front unevenness and associated ambiguities in:
  - determining crack growth rate (using max depth, average depth of "engaged areas", averaged depth over entire front...?)
  - monitoring in-situ crack advance versus time
  - the reduction in "local K" in at the tip of SCC cracks because the load is carried by the intact (pinned) areas
  - ambiguities in estimating the nominal K to use for reporting data.
- Many investigators did achieve 100% IG engagement, with a greater "average crack advance" than "crack front unevenness".

> • Need to employ a uniform method of measuring post fracture crack length from highly uneven crack fronts.
>
> • 3-D crack crack front more relevant description for weld metals

Review – Pre-Cracking:

Issues with test procedures:

- Investigators used variations on the recommended methods for pre-cracking and SCC transitioning, Steps 6 through 9 or 11 generally replicated.

Step	K_{max}, MPa√m	Load ratio, R	Frequency	Crack increment
1	25	0.3	1 Hz sine	0.5 mm
2	28	0.5	1 Hz sine	0.3 mm
3	30	0.6	1 Hz sine	0.3 mm
4	30	0.7	1 Hz sine	0.3 mm
5	30	0.7	0.1 Hz sine	0.2 mm
6	30	0.7	0.01 Hz sine	0.2 mm
7	30	0.7	0.001 Hz triangle	0.2 mm
8	30	0.7	" + 9ks hold	0.1 mm
9	30	Constant load	Constant load	≥1 months
10	30	0.7	0.001 Hz + 9ks	≥0.1 mm & ≥2 wks
11	30	Constant load	Constant load	≥1 months

Review – Test Issues – Experience with IG Transitioning:

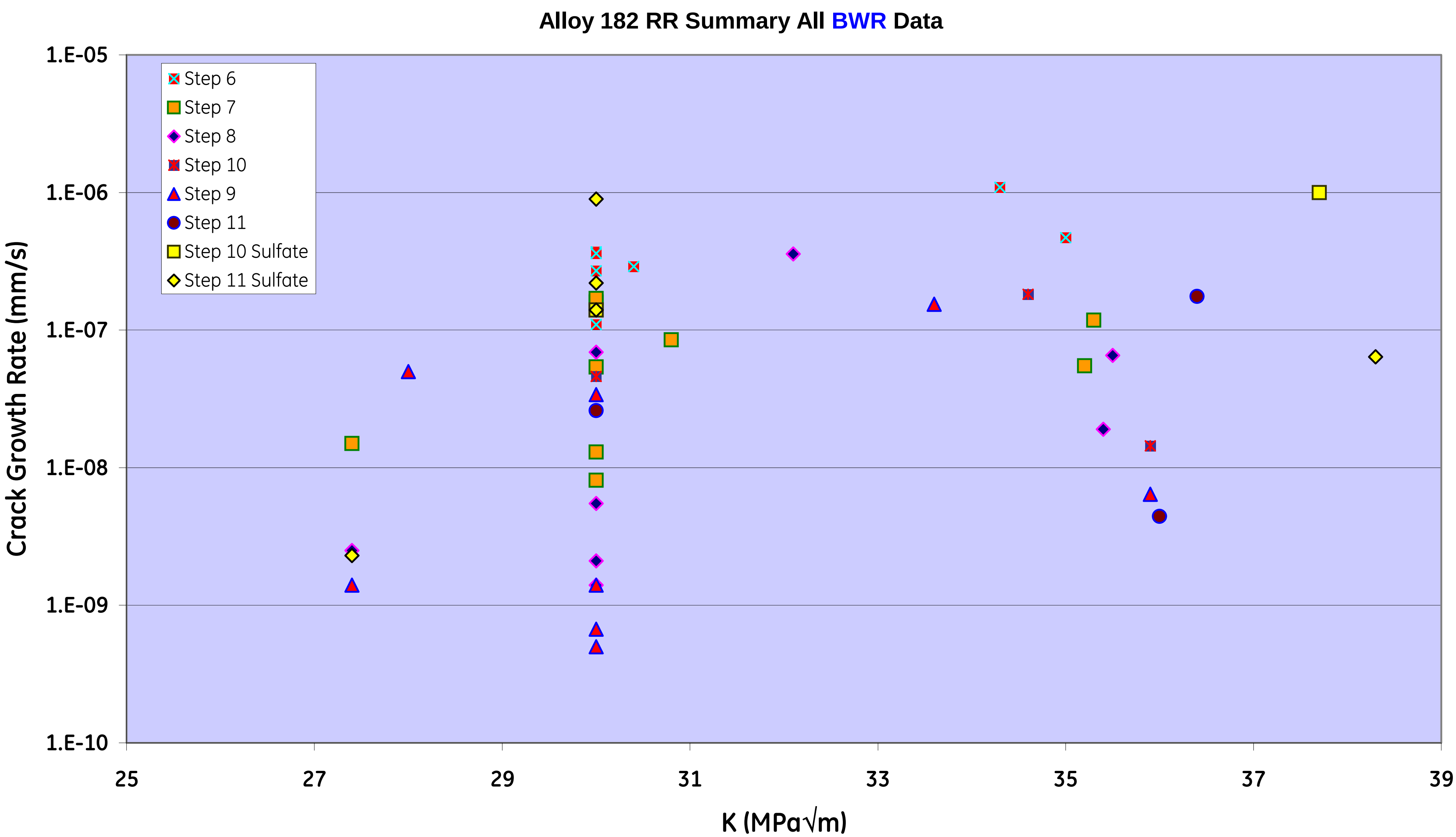
- Fatigue precracking produces a fatigue hardened plastic zone and a transgranular crack that is, on average, ½ grain diameter from a GB
- Transitioning is designed to produce full engagement of an IG SCC crack whose plastic zone is similar to a monotonic crack that was always SCC
- Transitioning is most important for low growth rate situations – resistant materials, less aggressive water chemistry, low K, low temperature…
- Should ideally be done based on crack growth increment, not time
- Must be done by monitoring crack, not following a "recipe"
- No growth should always be followed with repeated attempts to re-activate the crack with "gentle cycling"

Review – Test Issues – Experience with IG Transitioning:

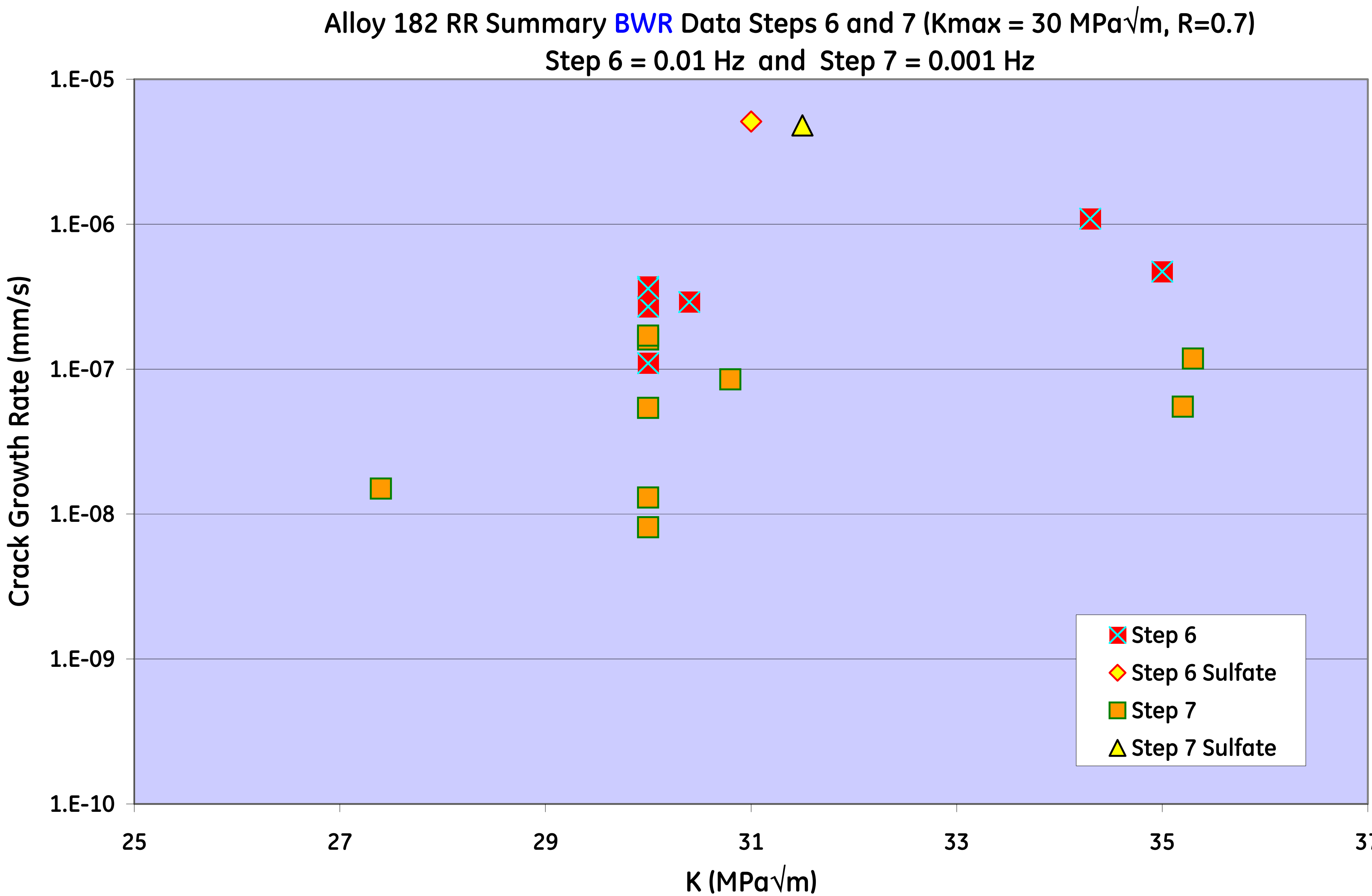
- Low R tends to activate the crack but also promotes TG SCC
- High R tends to have no effect; even R=0.7 doesn't always work;
  This is apparently related to crack tip closure, which eliminates the cyclic deformation at the crack tip.
- R=0.7, 0.001 Hz, then adding 9000s hold is the best place to start, but:
- At low K_{max} (< ~20 ksi√in), R=0.5 is often needed
- At high K_{max} (> ~40 ksi√in), R=0.8 is often adequate and preferred

- R=0.9, 5 Hz often observed to have no effect on CGR
- R=0.3, 0.1 Hz sometimes found not to re-activate cracks
- Formulas and recipes provide guidance but no guarantee

Review – All BWR data

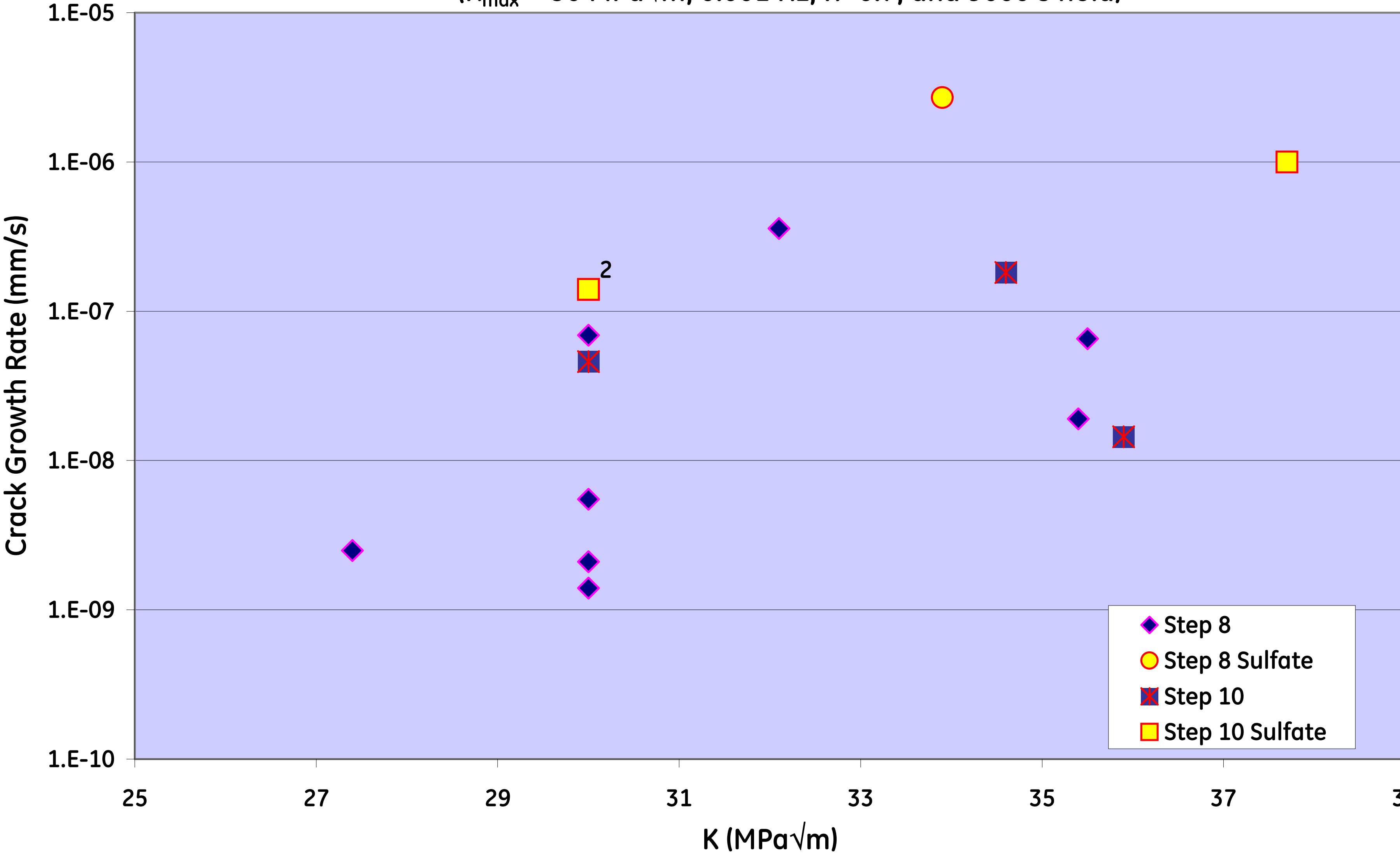


imagination at work

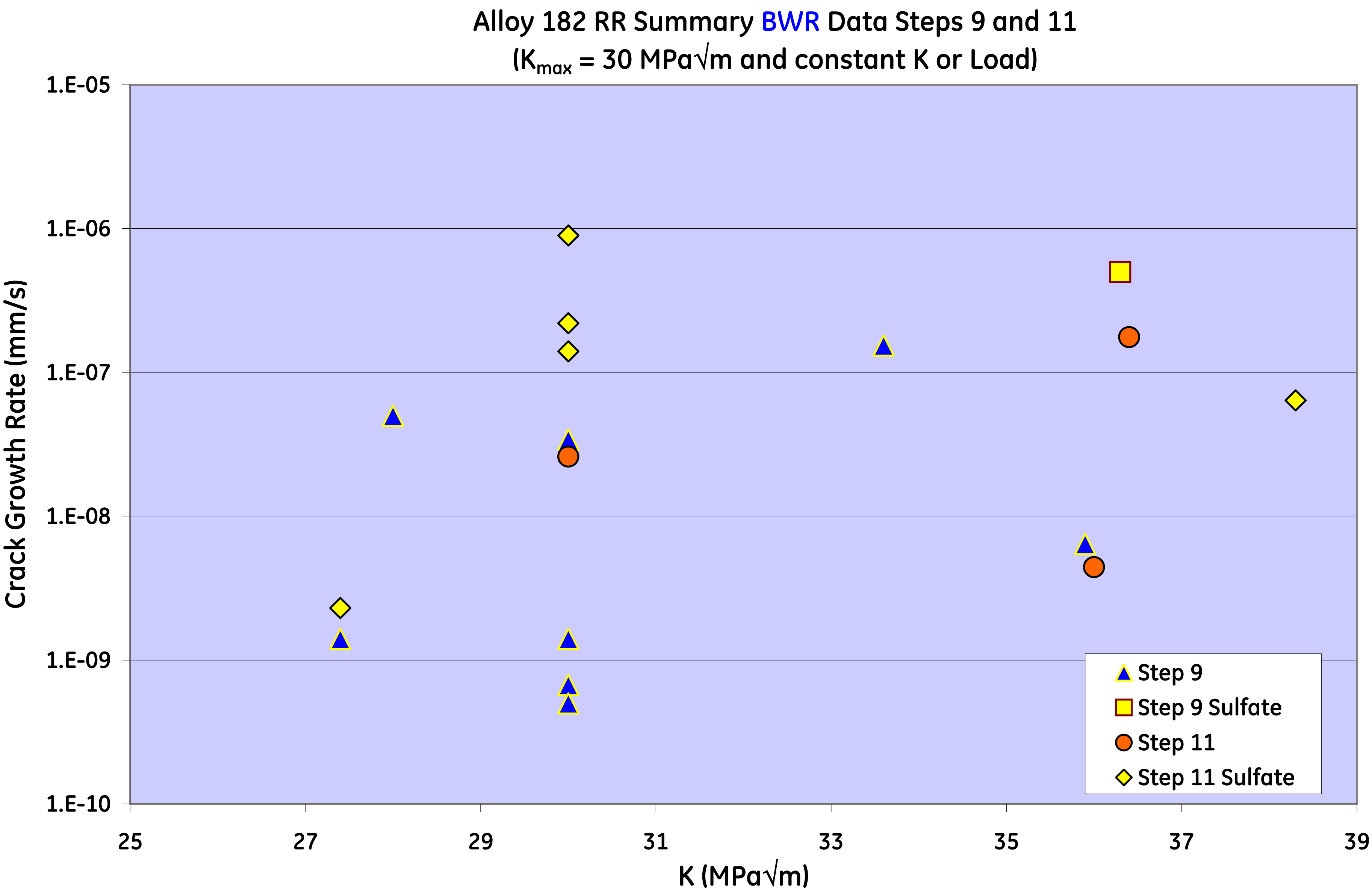


imagination at work

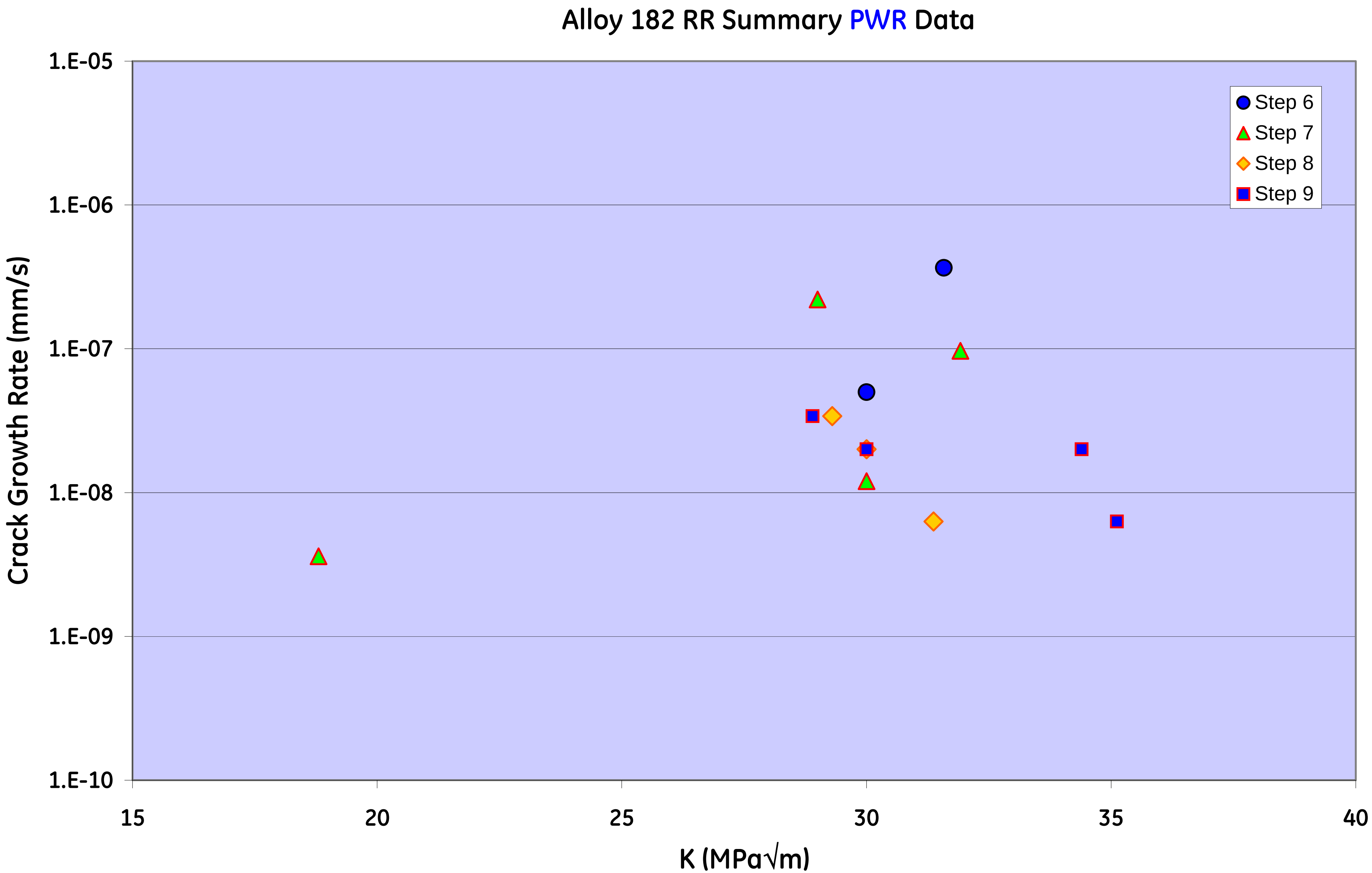
Alloy 182 RR Summary BWR Data Steps 8 and 10
(K_{max} = 30 MPa√m, 0.001 Hz, R=0.7, and 9000 s hold)



imagination at work

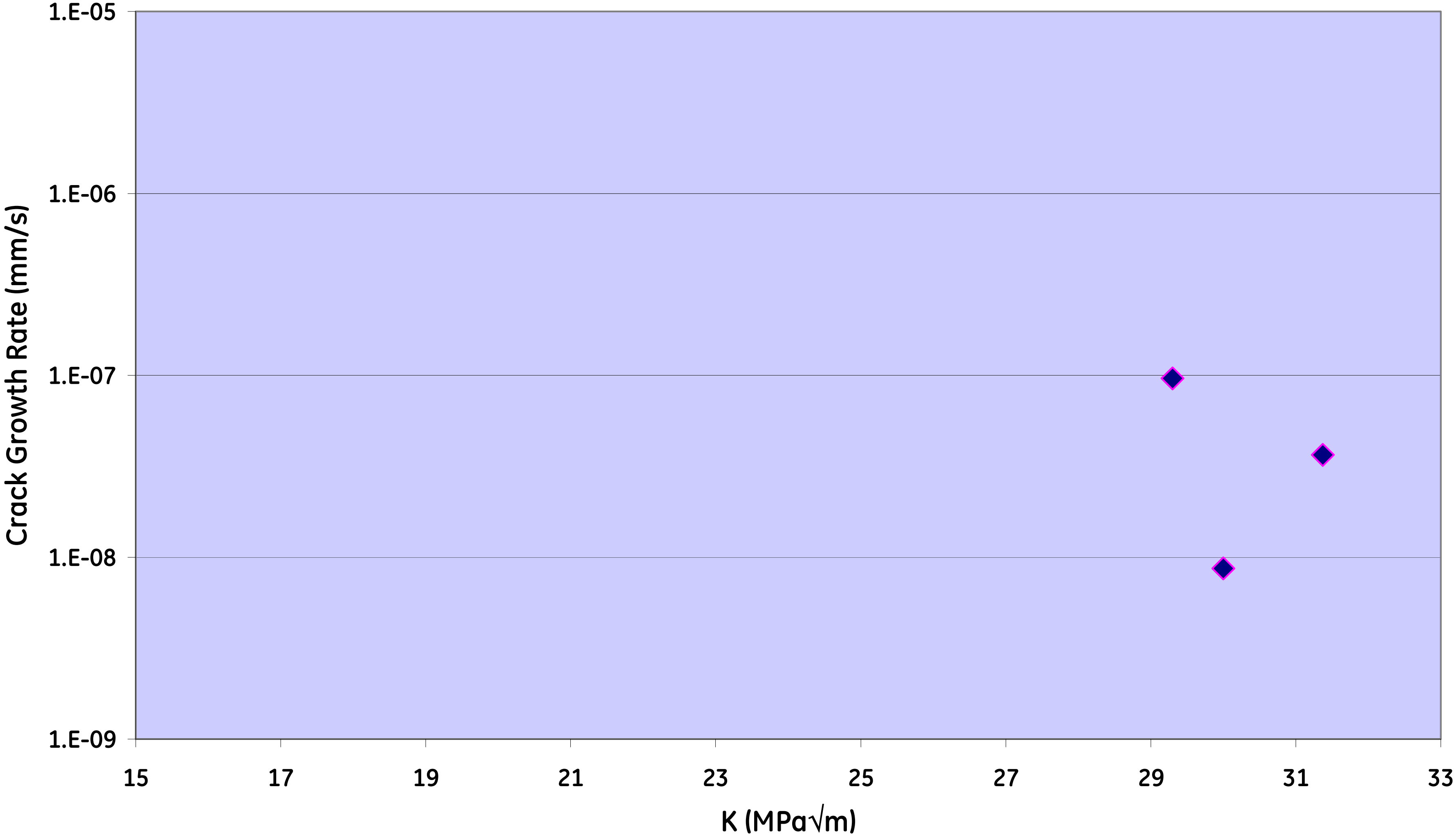


imagination at work



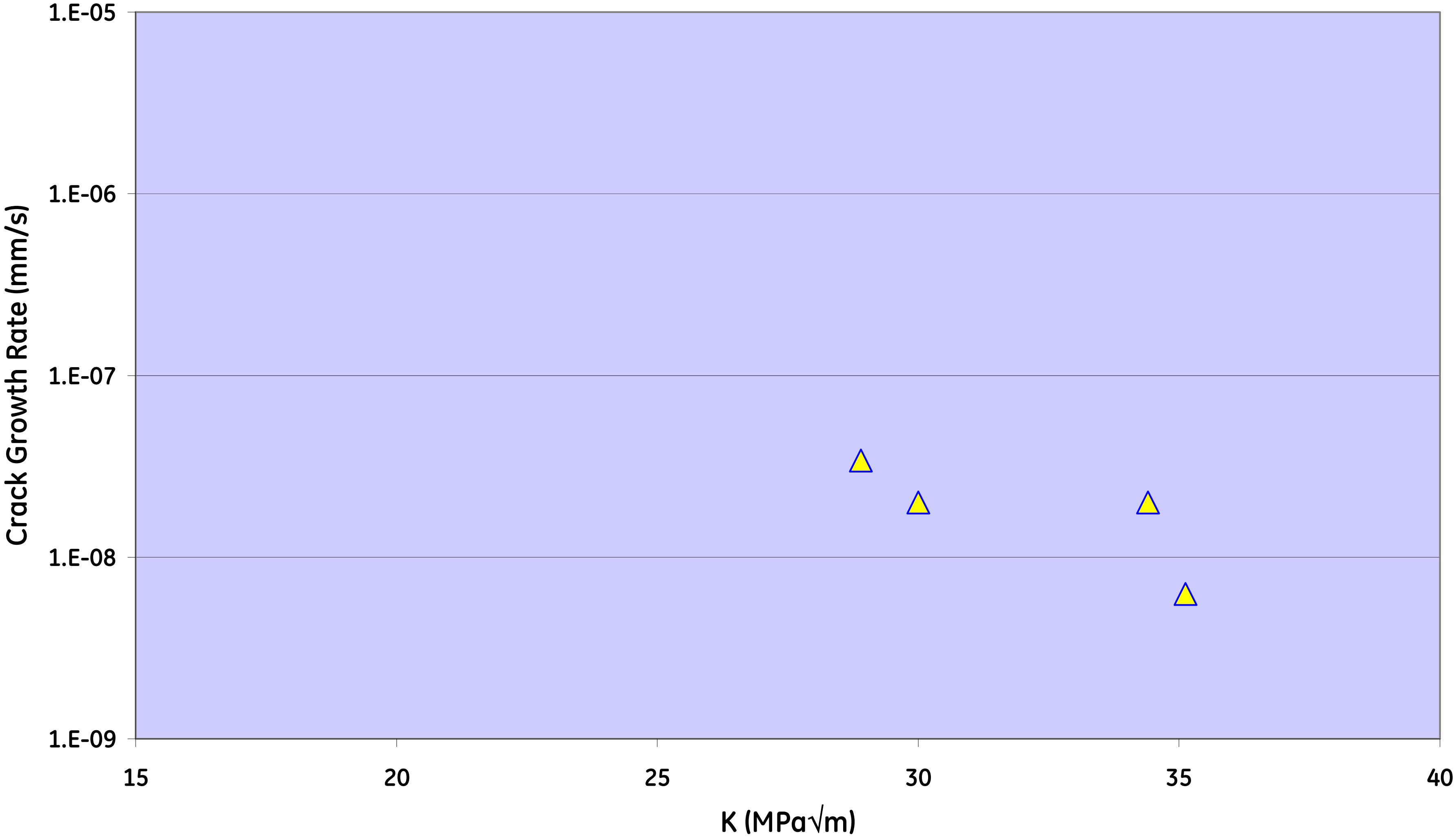
imagination at work

Alloy 182 RR Summary PWR Data Step 8
(K$_{max}$ = 30 MPa√m, 0.001 Hz, R=0.7, and 9000 s hold)



imagination at work

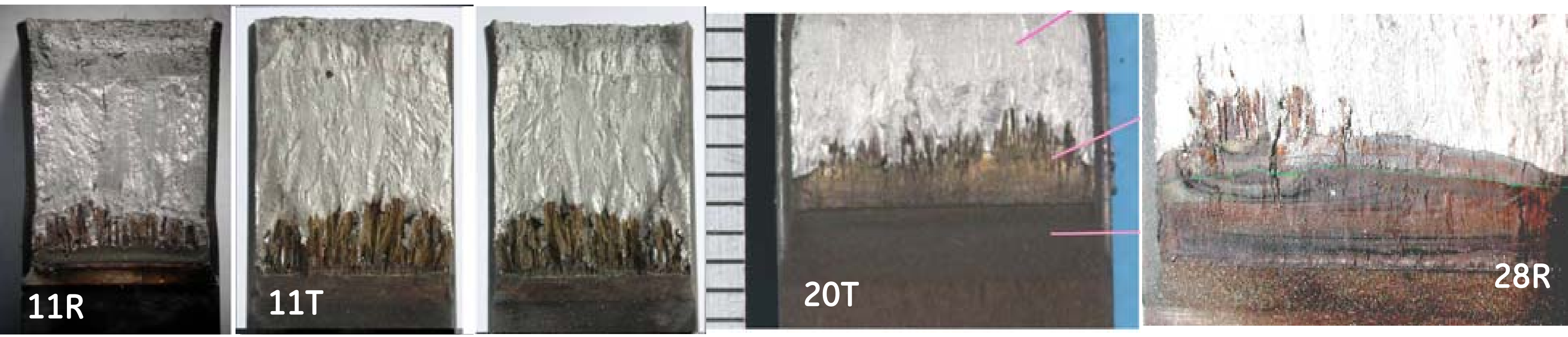
Alloy 182 RR Summary PWR Data Step 9
(K_{max} = 30 MPa√m and constant K or Load)



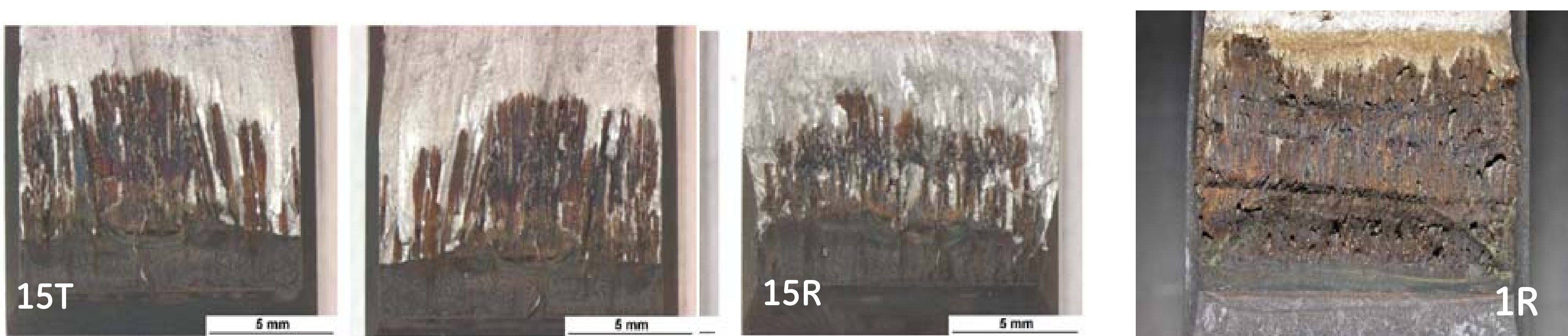
2. Conclusions – Post Pre-Crack IG Engagement:

Issues with test procedures:

- The extent of "IG engagement" from the TG fatigue pre-crack varied markedly due to used variations for pre-cracking and SCC transitioning.
- Very long dendrite lengths in the crack growth direction

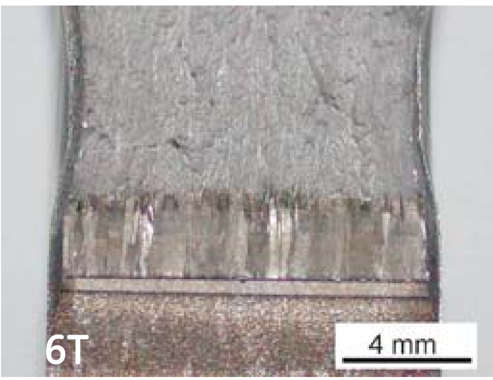


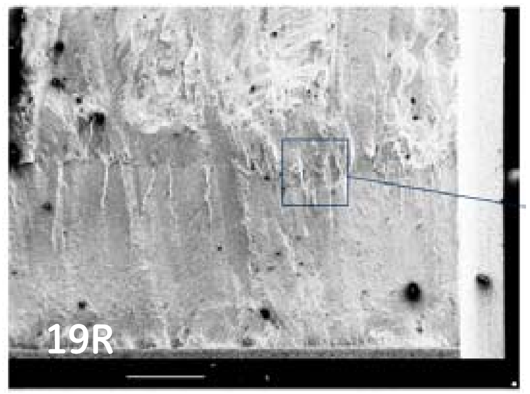
BWR test crack fronts observed.

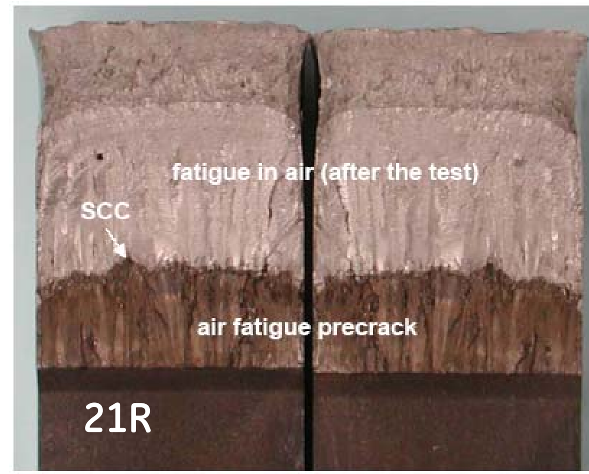


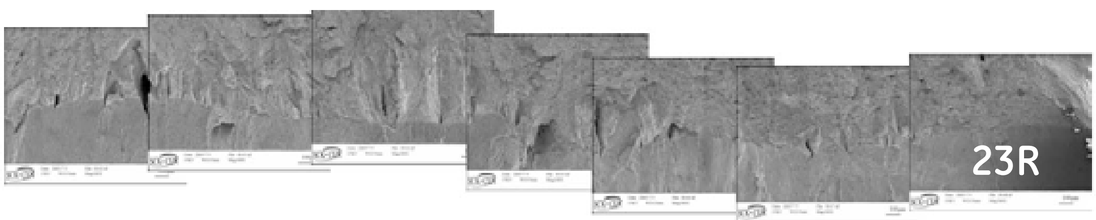
2. Conclusions - *Post Pre-Crack IG Engagement:*

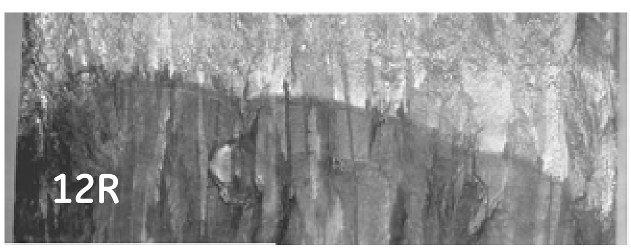
PWR testing generally showed uniform crack fronts with some irregular crack front morphologies.









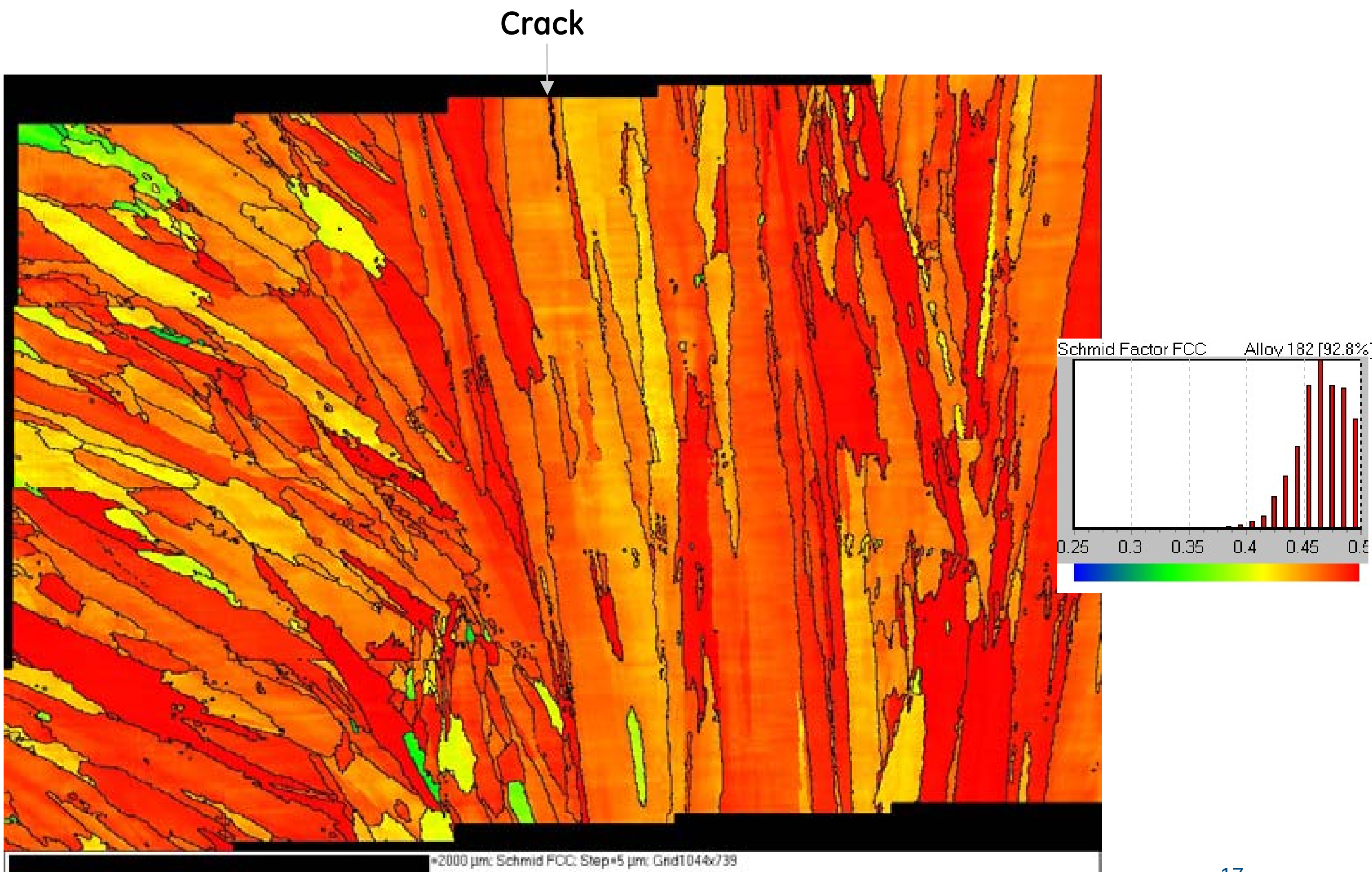


2. Conclusions – Post Pre-Crack IG Engagement:

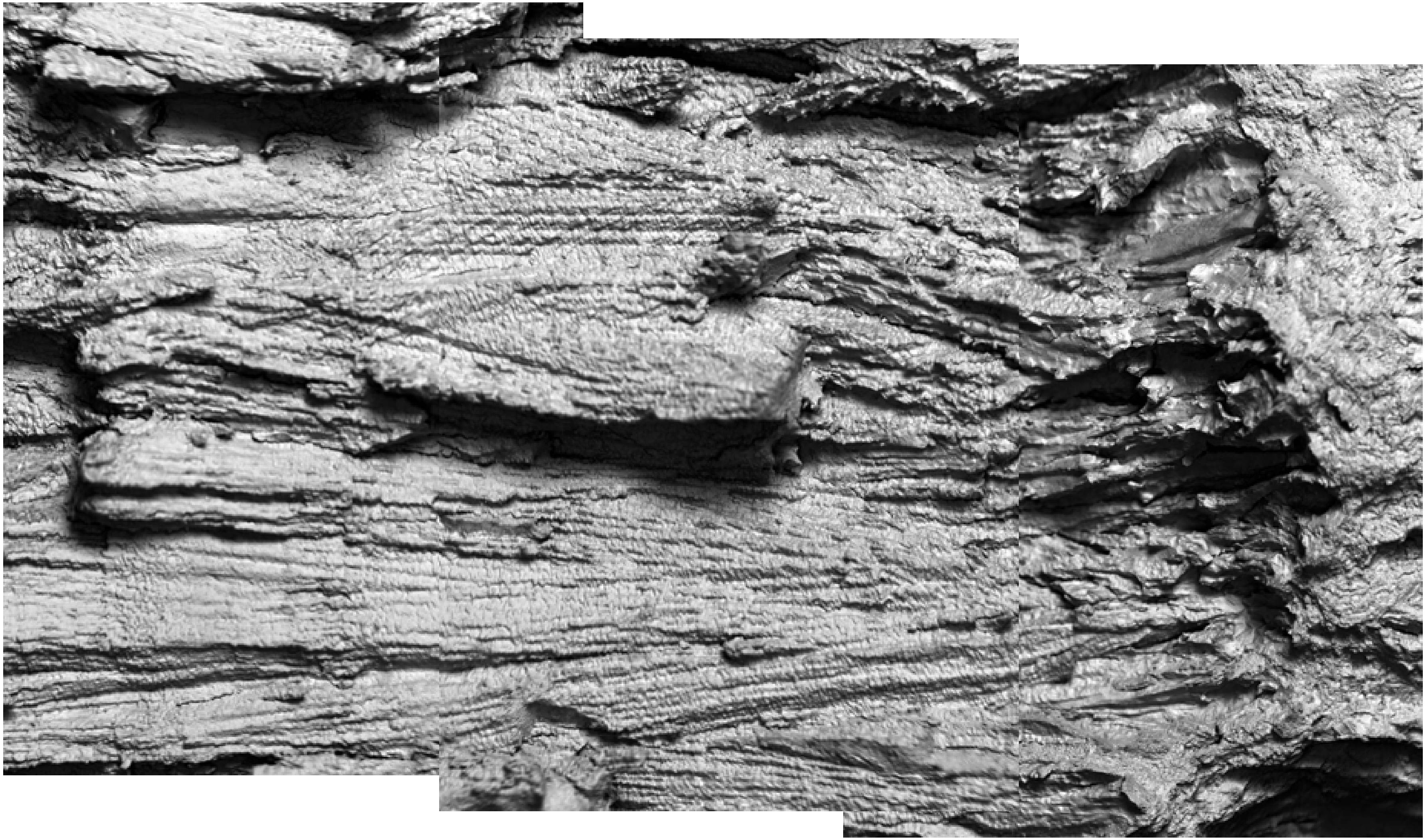
Issues with test material:

- Very long dendrite lengths in the crack growth direction.

- Limited change in crystallographic orientation along potential crack paths



SEM fractography along crack growth direction in sample C296



Crack Advance

imagination at work

Conclusions

Focus of Future Round Robins:

- Benchmark experimental capabilities using well-characterized materials whose SCC response has been demonstrated to be reproducible.
    - Previously tested
    - Sufficient quantity
    - Smaller, 2 to 5 laboratory round robin efforts should be considered in some cases, particularly for the latter (unusual material) case.

- Possible evaluation of specific heats or conditions of materials that exhibit good SCC response.

- Generated a larger data set consider a hybrid PWR/BWR water chemistry – higher temperature to accelerate BWR rates.