SAND2022-6103C

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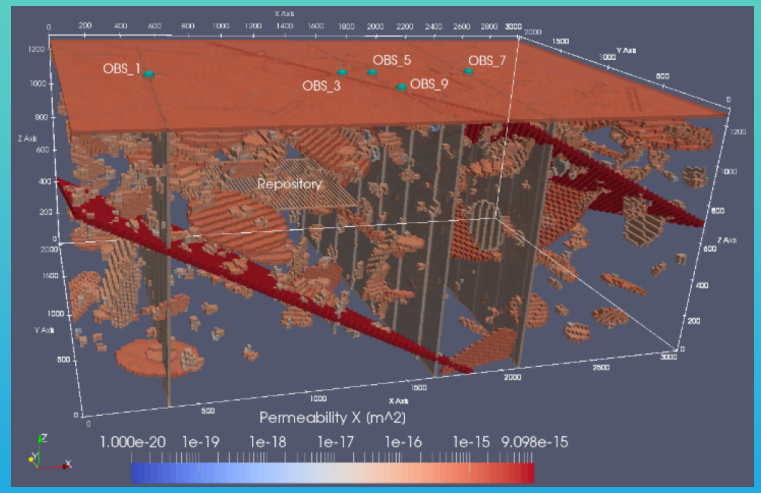
Spent Fuel and Waste Science and Technology (SFWST)



Stress Corrosion Cracking of Austenitic Stainless Steels in Concentrated Chloride Environments

Ryan M. Katona, J. Taylor, E. Karasz, B. Nation, A. W. Knight, C. R. Bryan, and R. F. Schaller

SWFST Annual Meeting

May 10th - 12th, 2022

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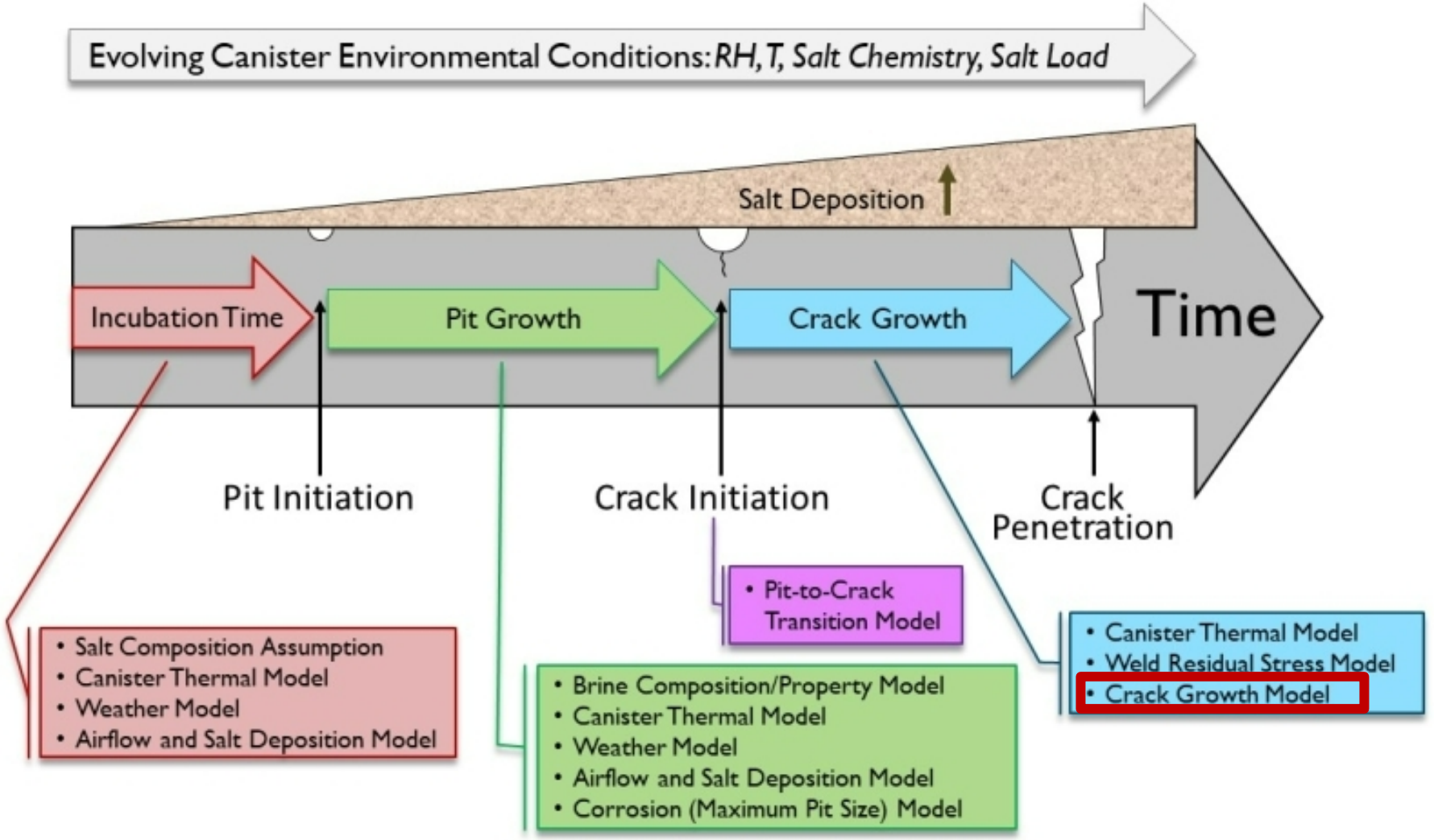
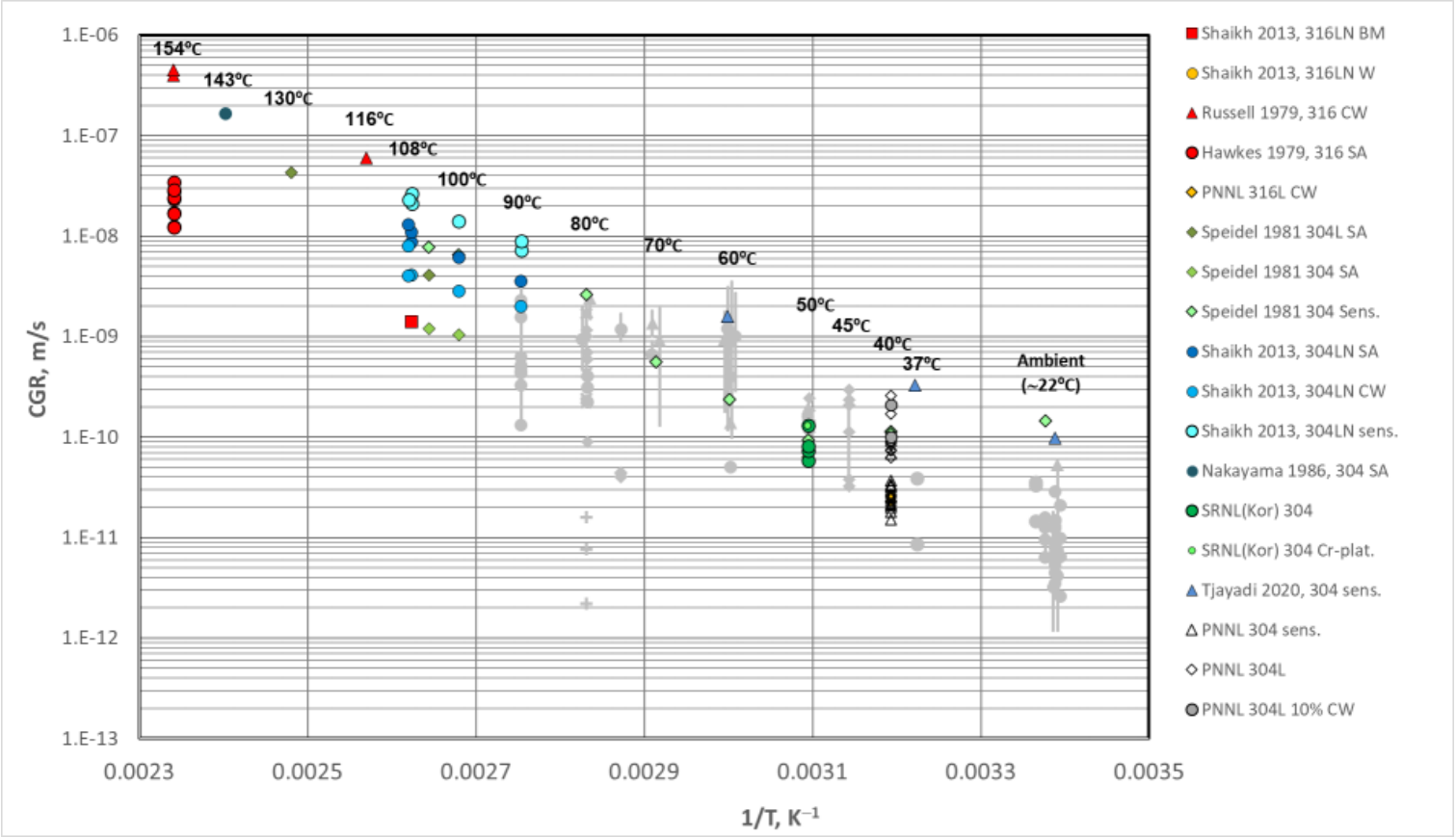
Integrated Mechanistic/Probabilistic Model for Canister SCC



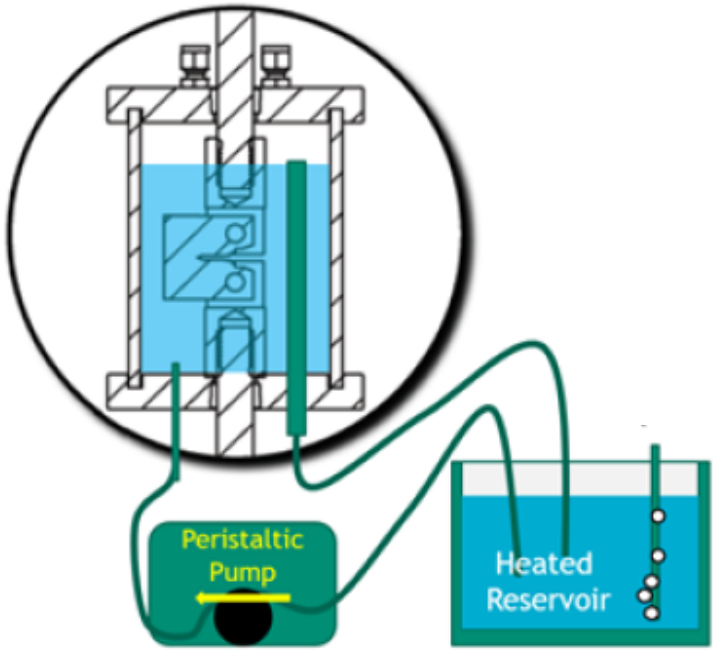
Arrhenius Temperature Dependence of Crack Growth



- Various collection methods, environments, lot of material, sensitization state, etc.

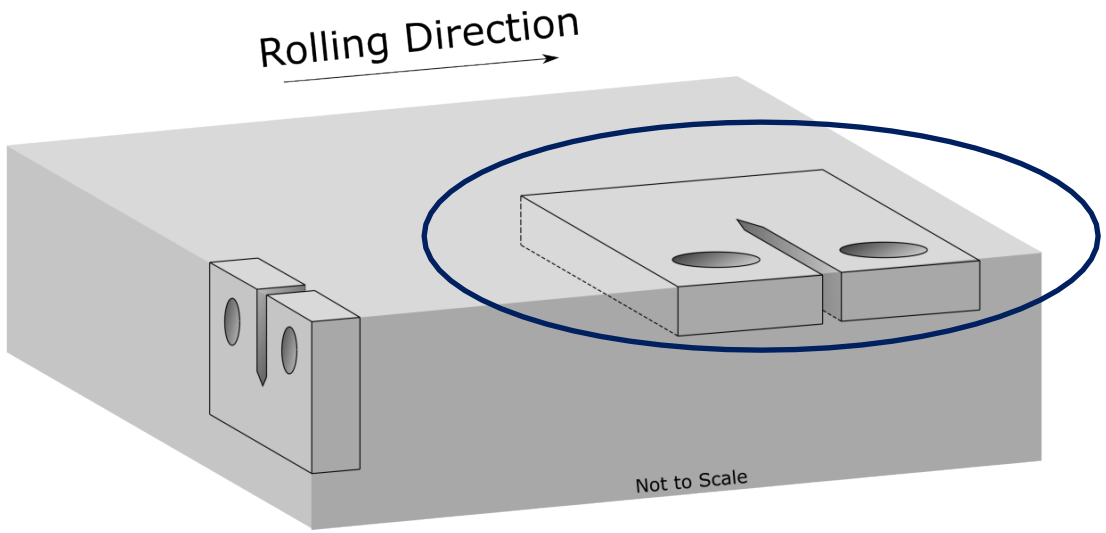
What are the governing factors and will certain factors cause accelerated growth?

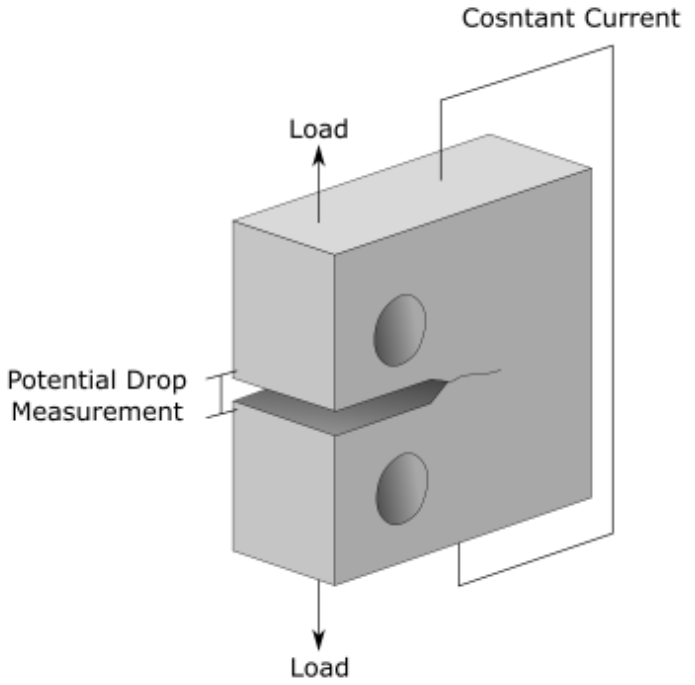
Capabilities

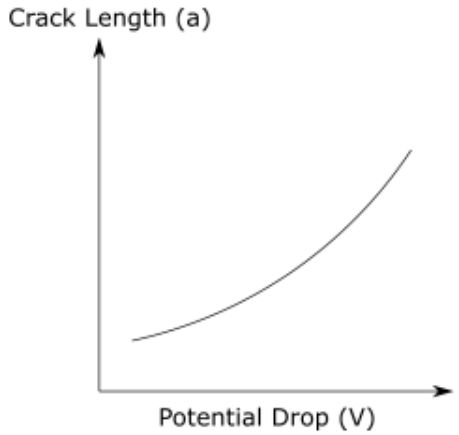


- Measure in-situ crack growth rate (~10^{-12} m/sec) in a corrosive solution under heated flow
- Development of atmospheric SCC set-up

Sample Orientation and *In-Situ* Testing Methodology

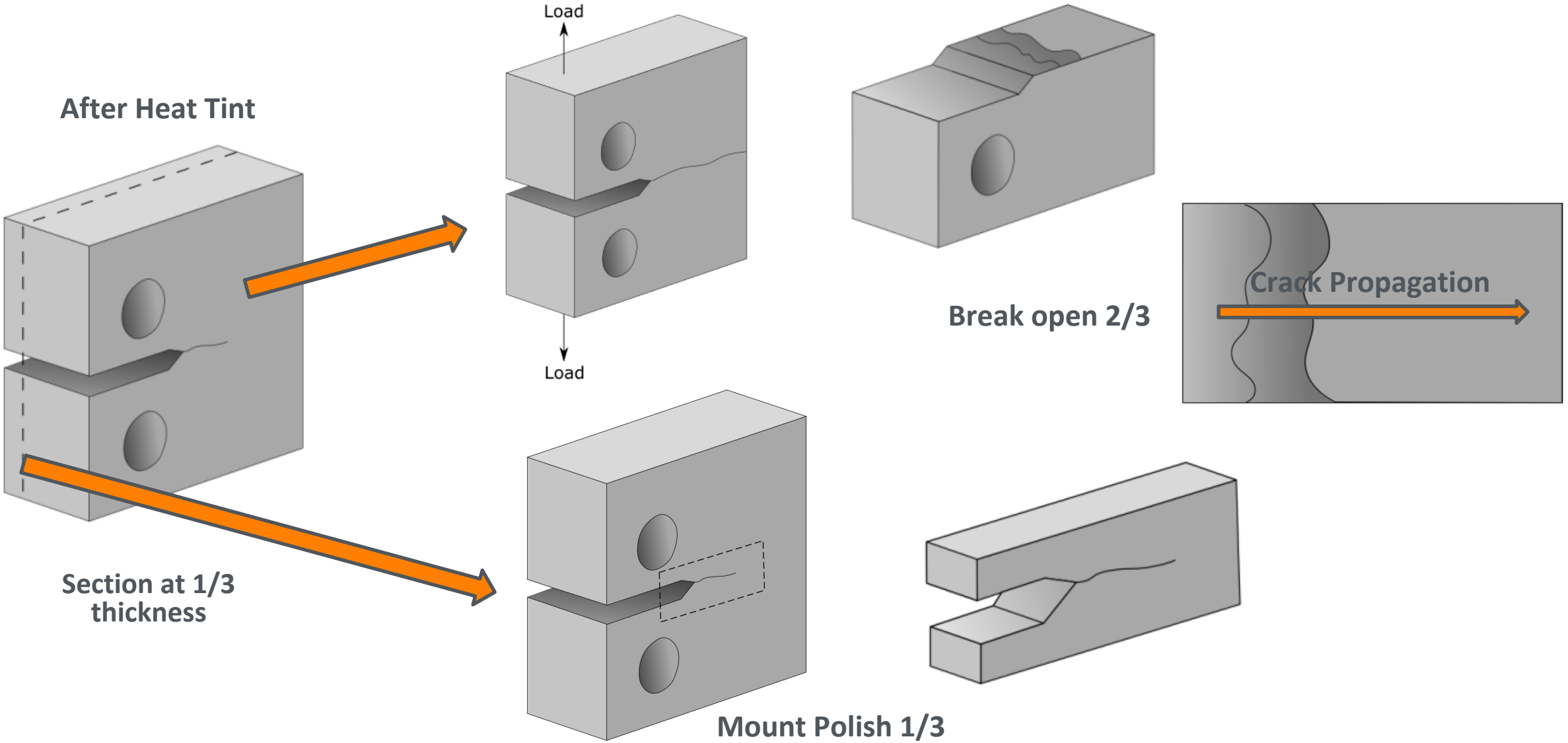




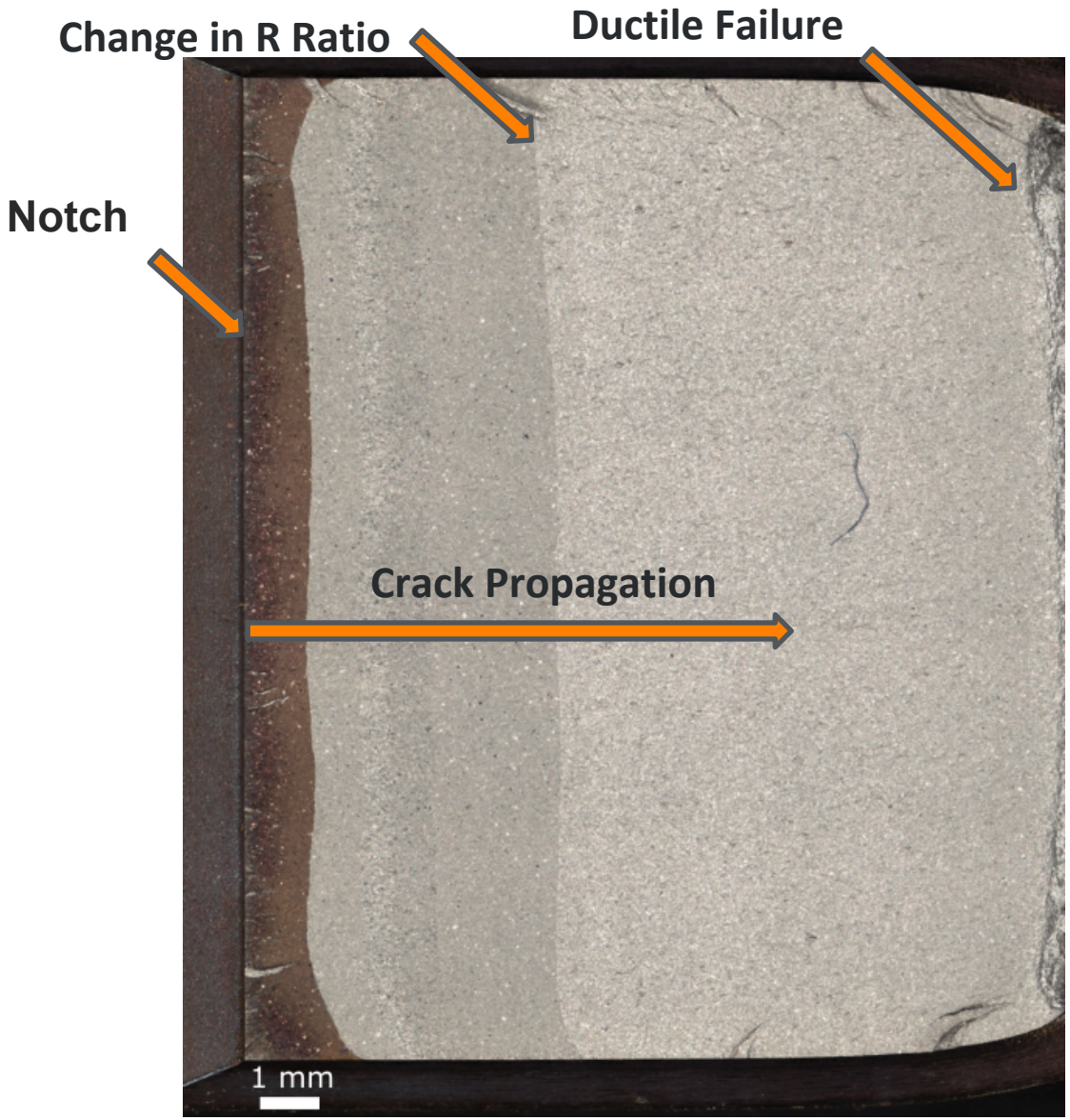


- Majority of samples presented will be in the L-T orientation
- Annealed ASTM SS304L (information in supplemental)
- Utilizing Direct Current Potential Drop (DCPD)

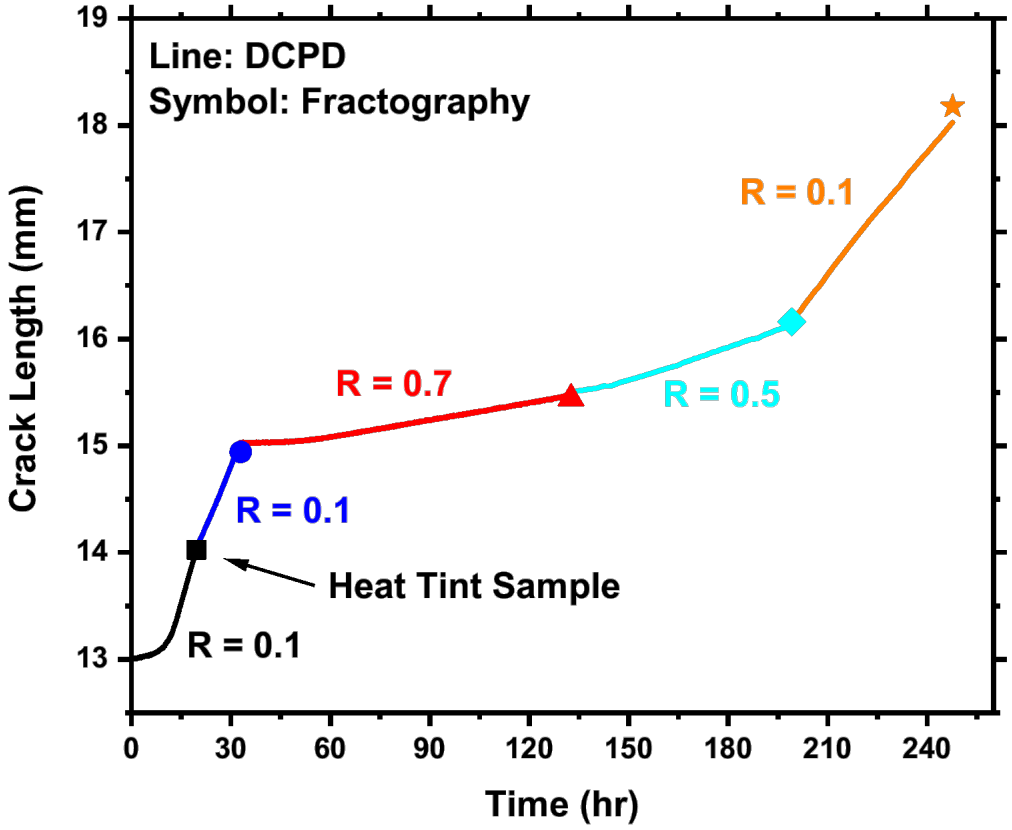
Methods for Post Test Sample Analysis



Calibration of DCPD Set-up

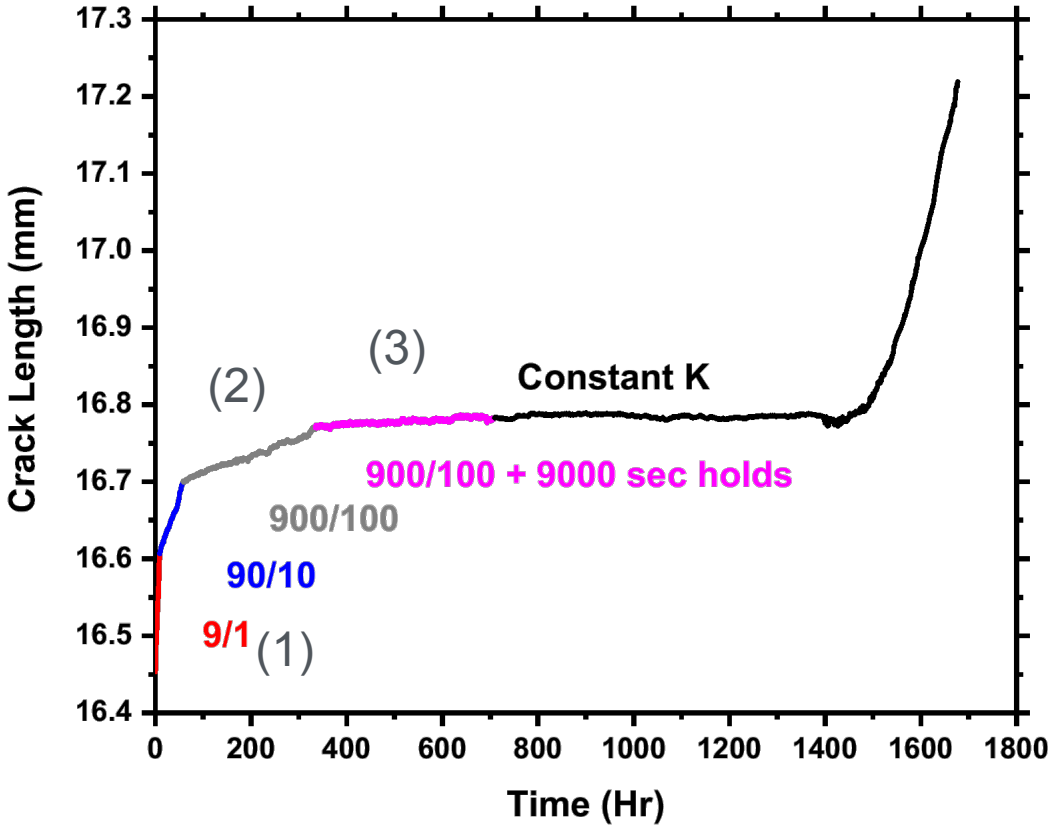


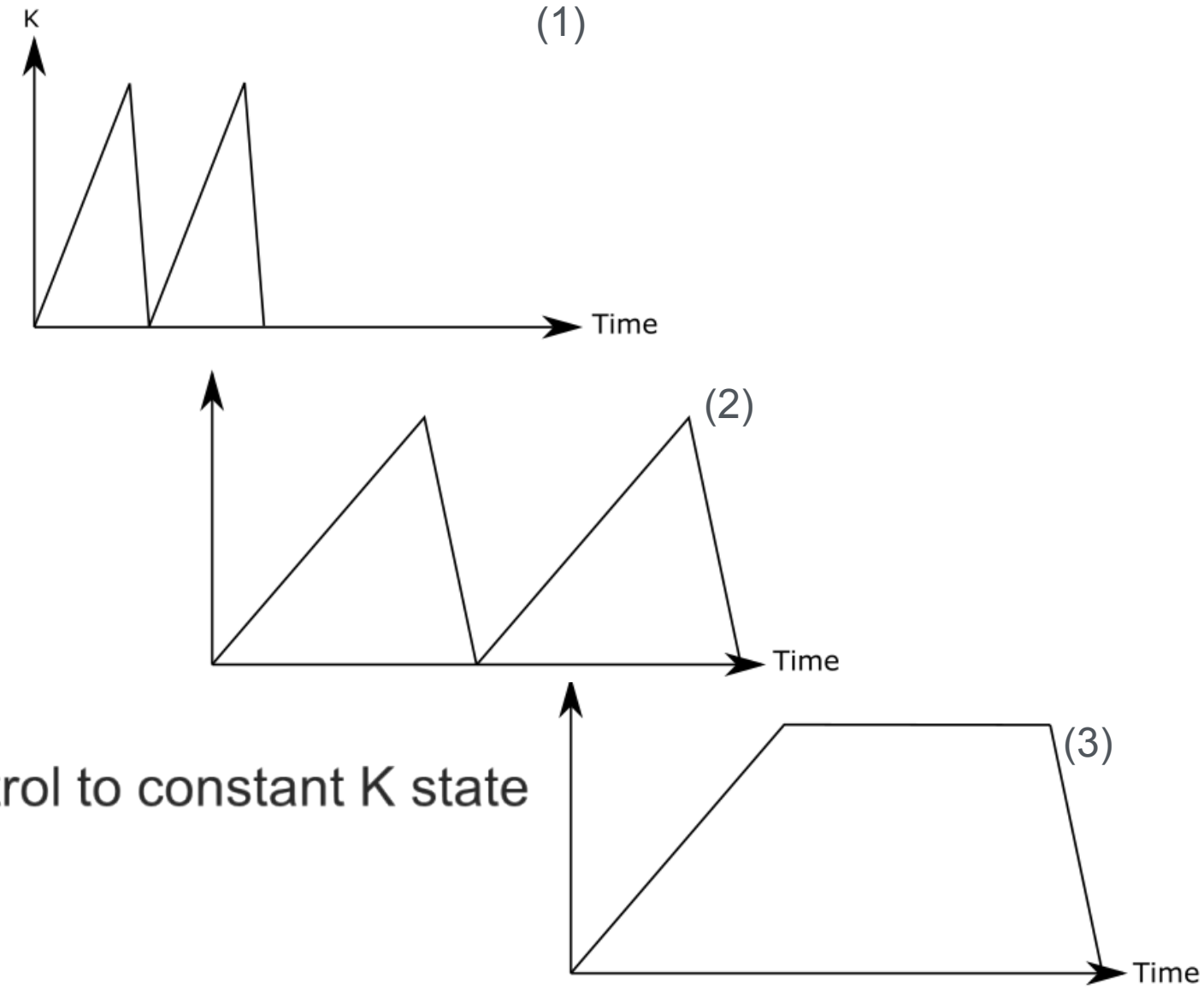
Calibration of DCPD Set-up



- Performed on two different load frames
- Confidence DCPD system is set-up correctly

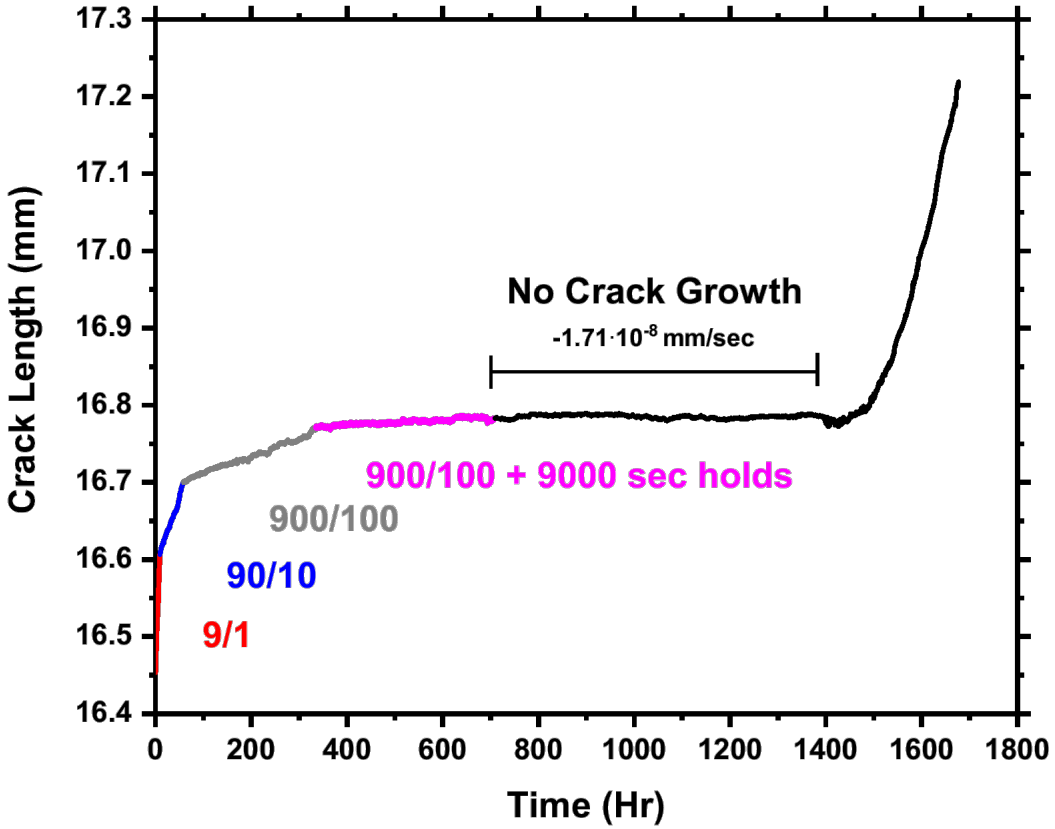
Testing Methodology





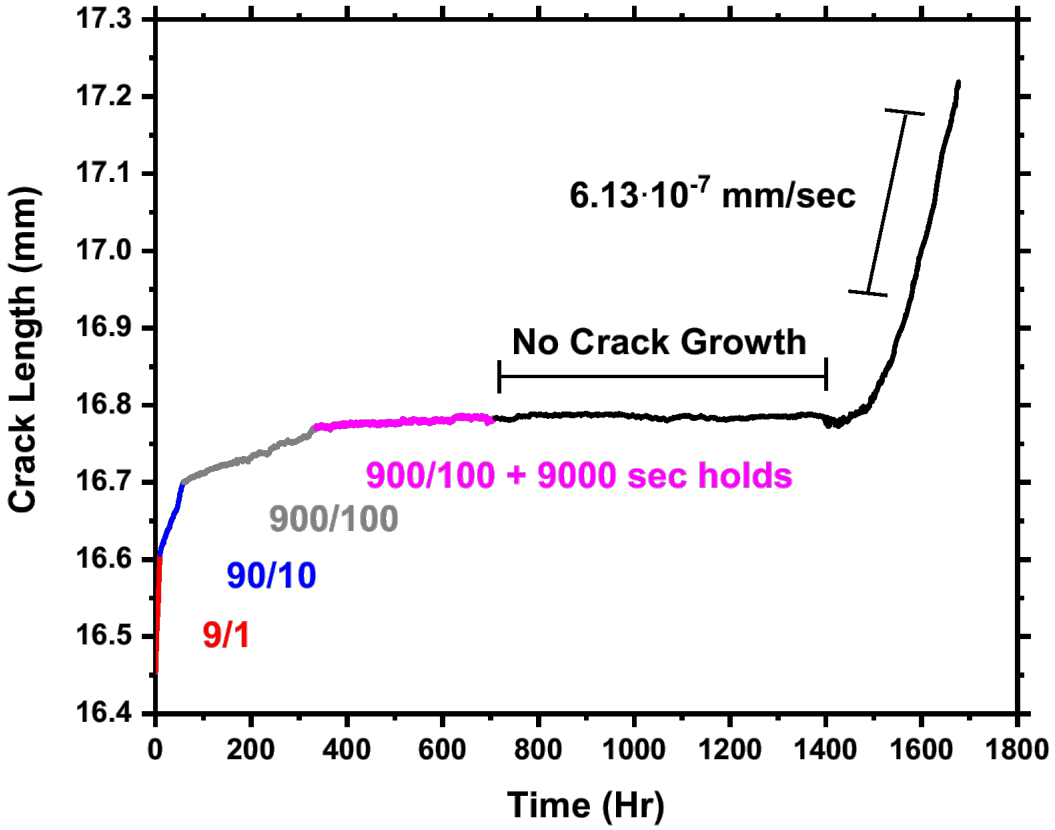
- Decreasing frequency under K control to constant K state
  - 'True' crack plane for constant K SCC
- $K_{max} = 20\ MPa\sqrt{m}$

SS304L Exhibits Delayed Crack Growth Under Constant K in $MgCl_2$ at 55 ˚C

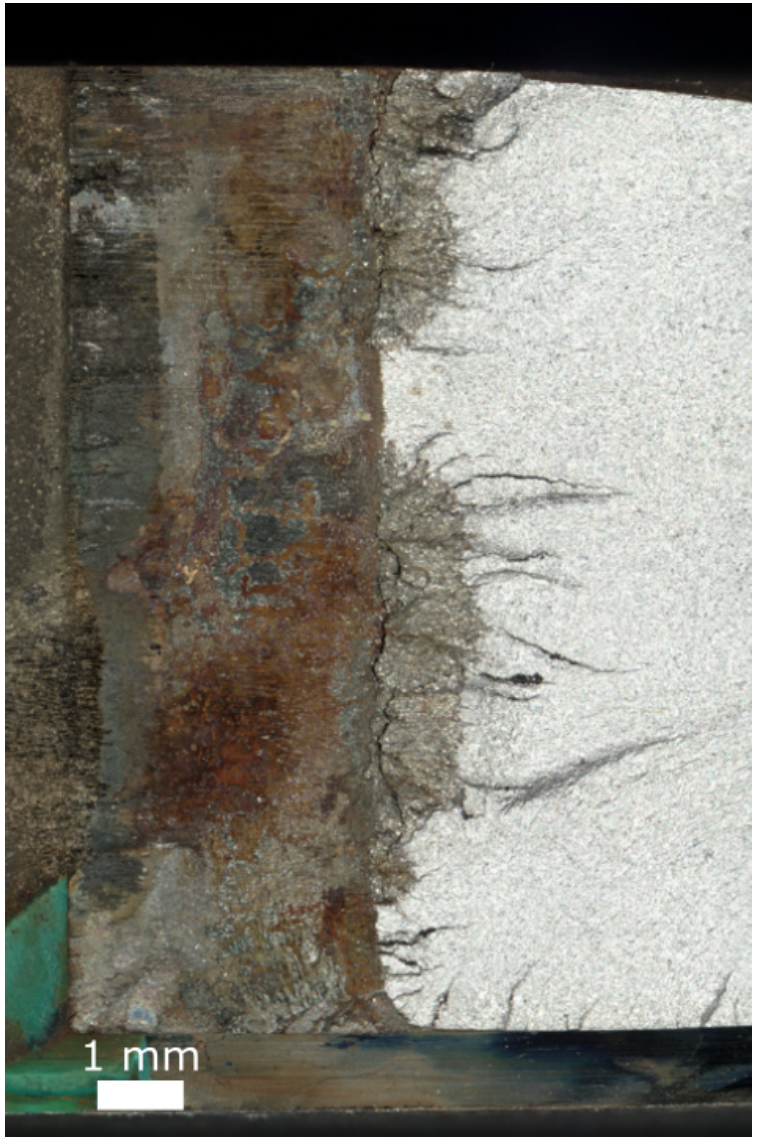


- No growth for ~ 700 hours

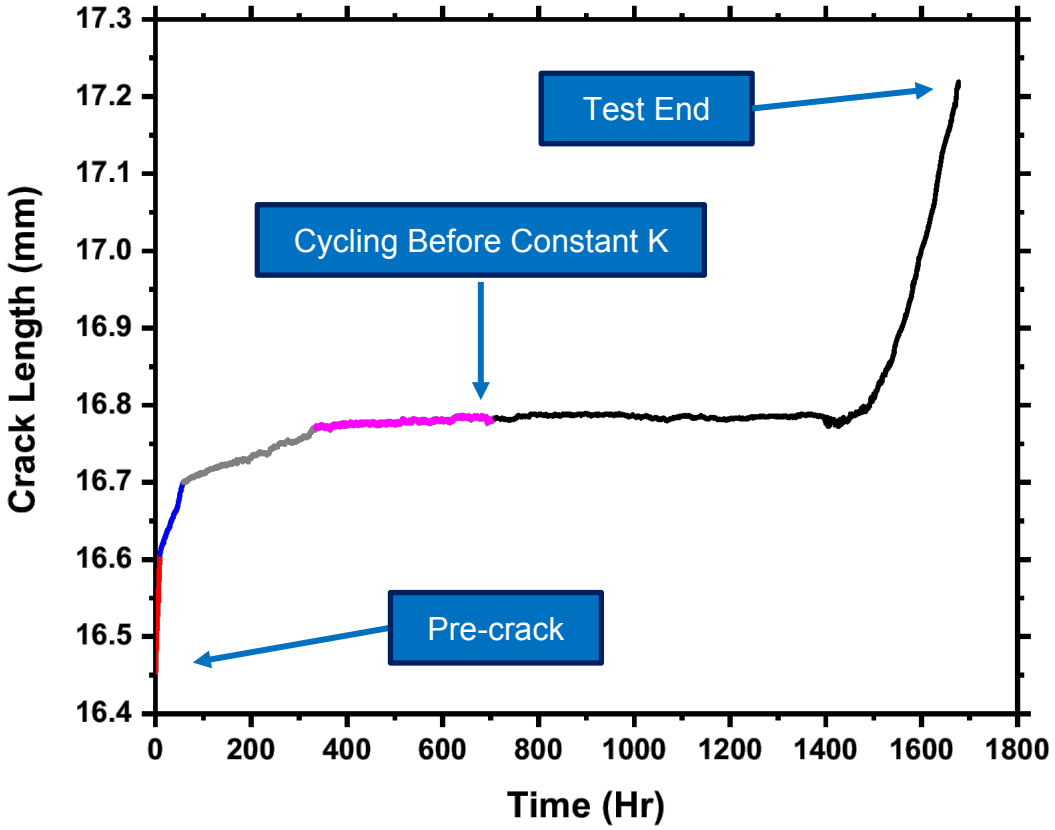
SS304L Exhibits Irregular Crack Front in Saturated $MgCl_2$ at 55 °C

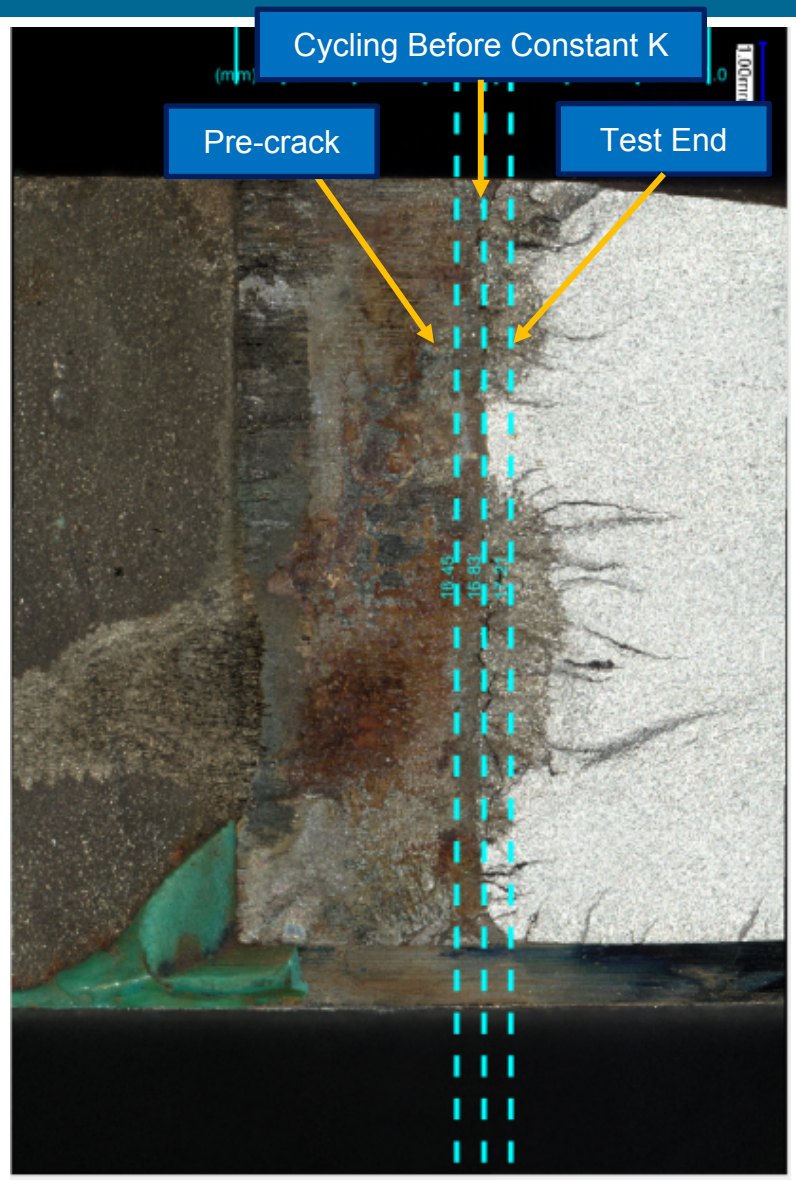


- After roughly 1500 hours of total test time, cracking ensues
- Sample was cut at 1/3 of thickness



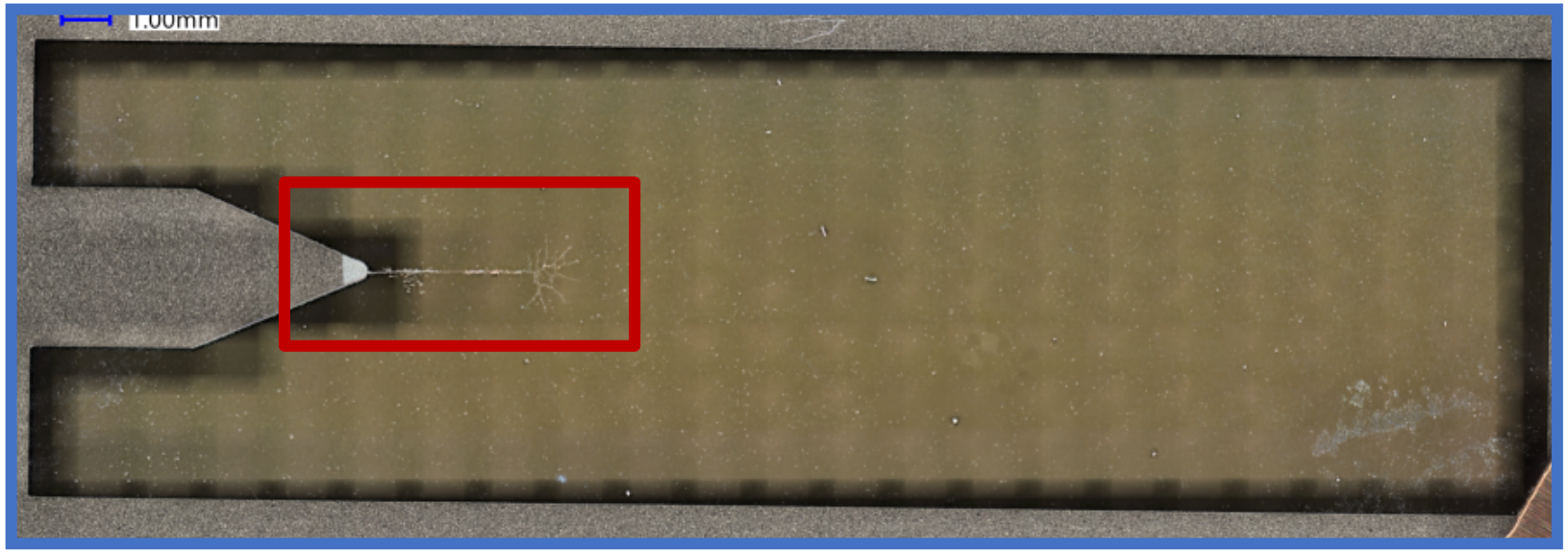
SS304L Exhibits Irregular Crack Front in Saturated $MgCl_2$ at 55 °C

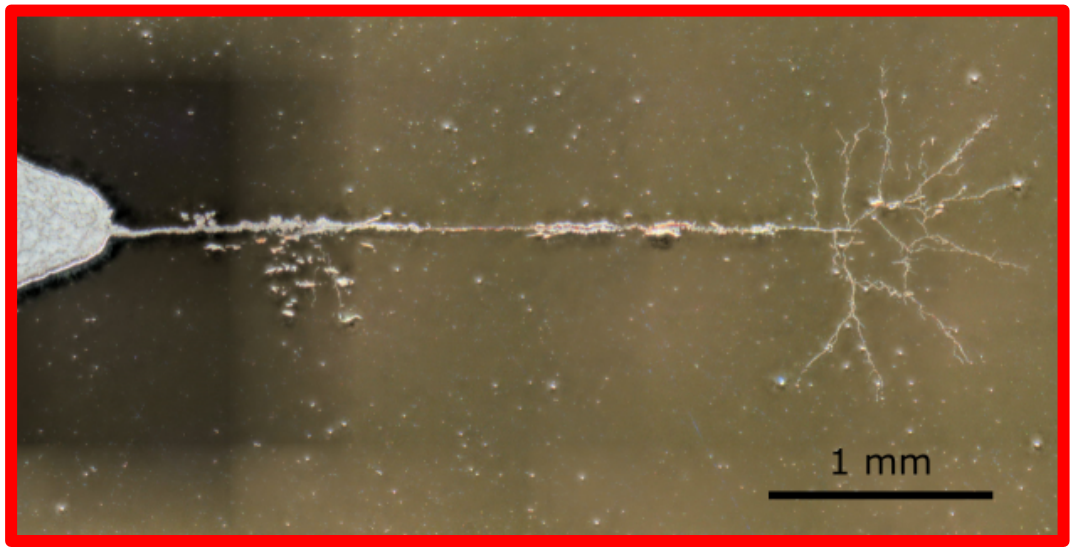




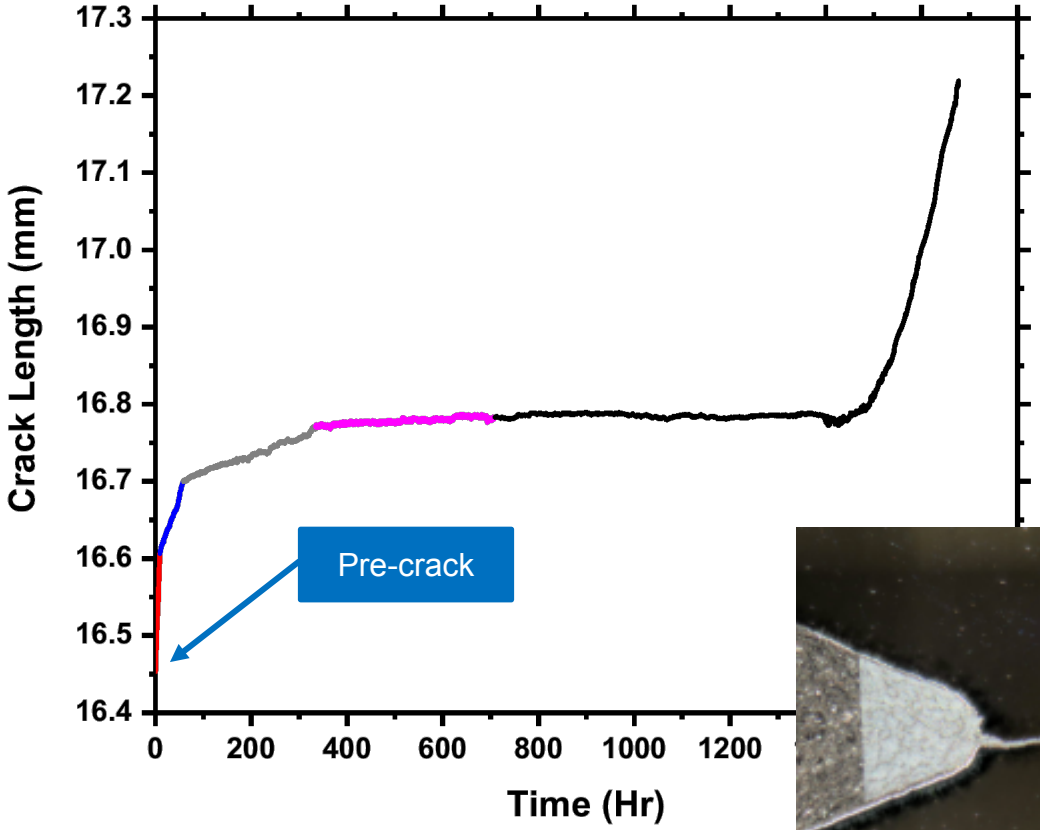
- Overlay of DCPD on fractography potentially suggests cracking halted at the uniform 'ledge'

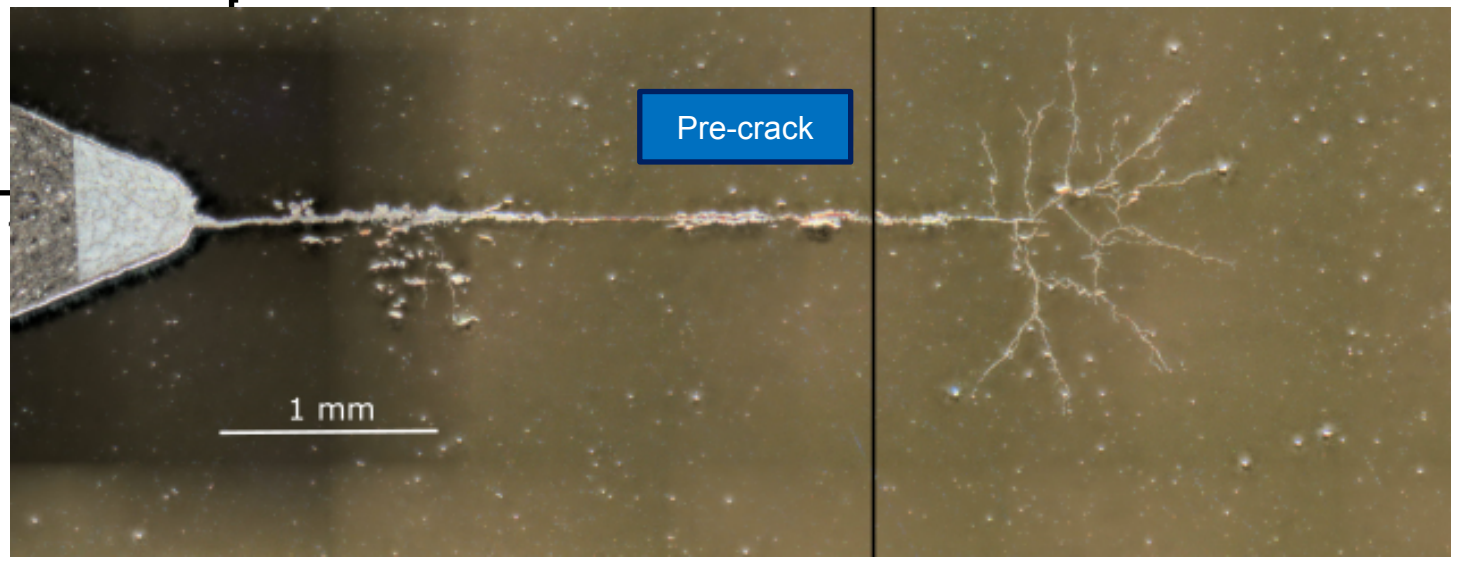
SS304L Exhibits Crack Branching in Saturated $MgCl_2$ at 55 ˚C





SS304L Exhibits Crack Branching in Saturated $MgCl_2$ at 55 ˚C





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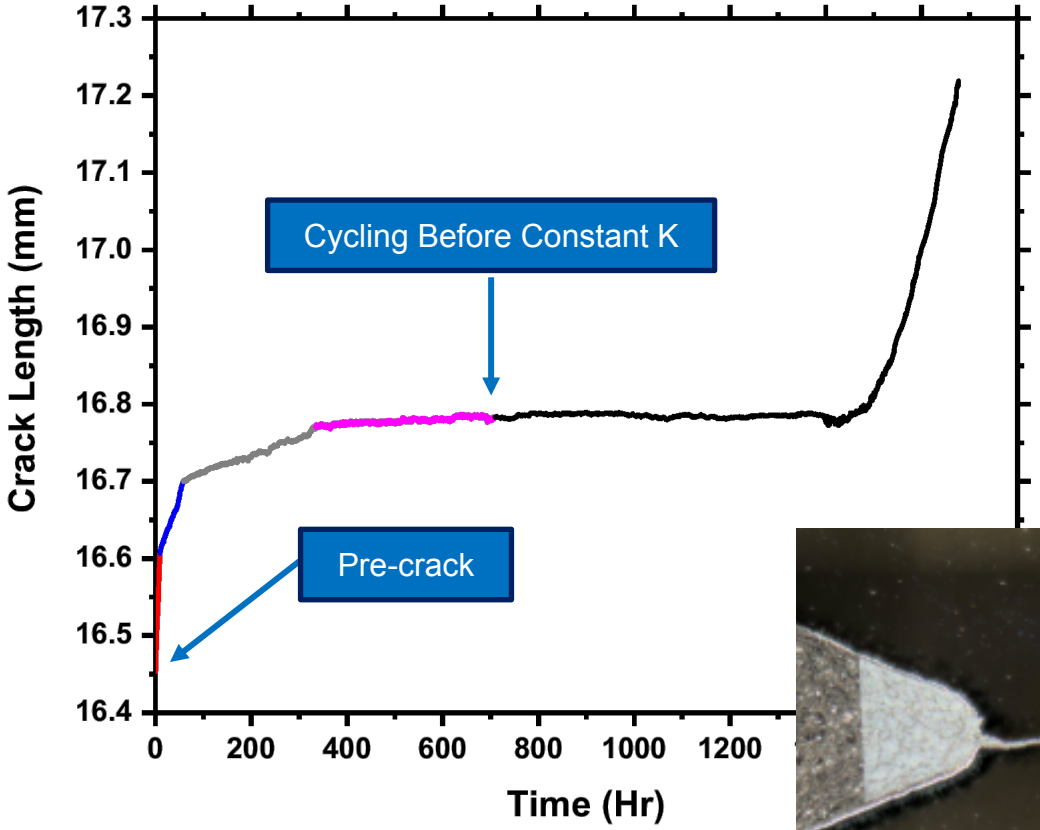

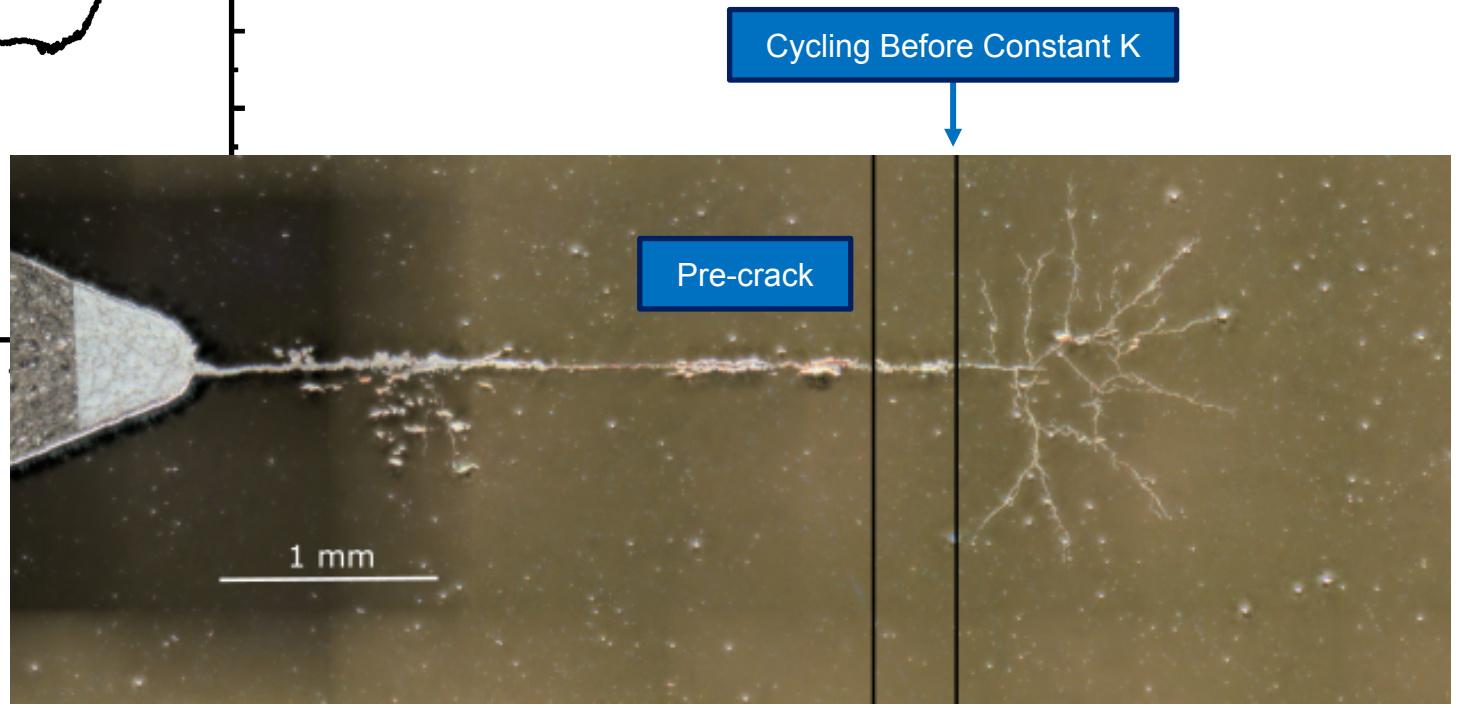

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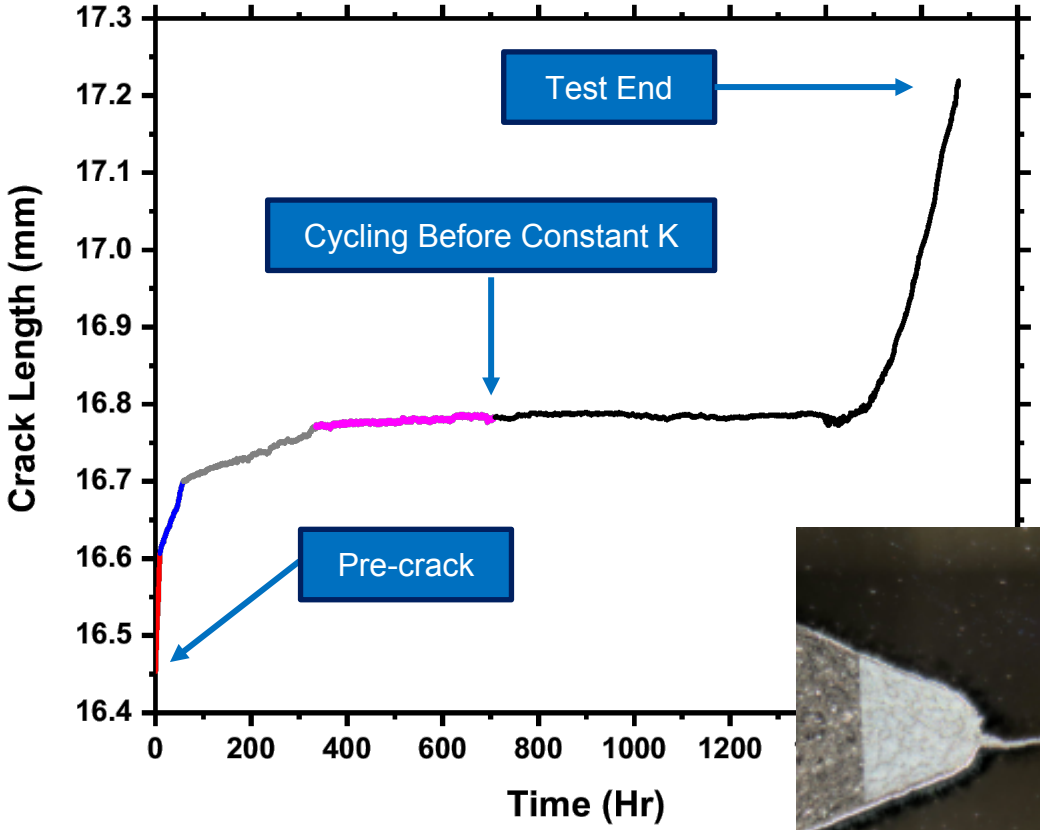
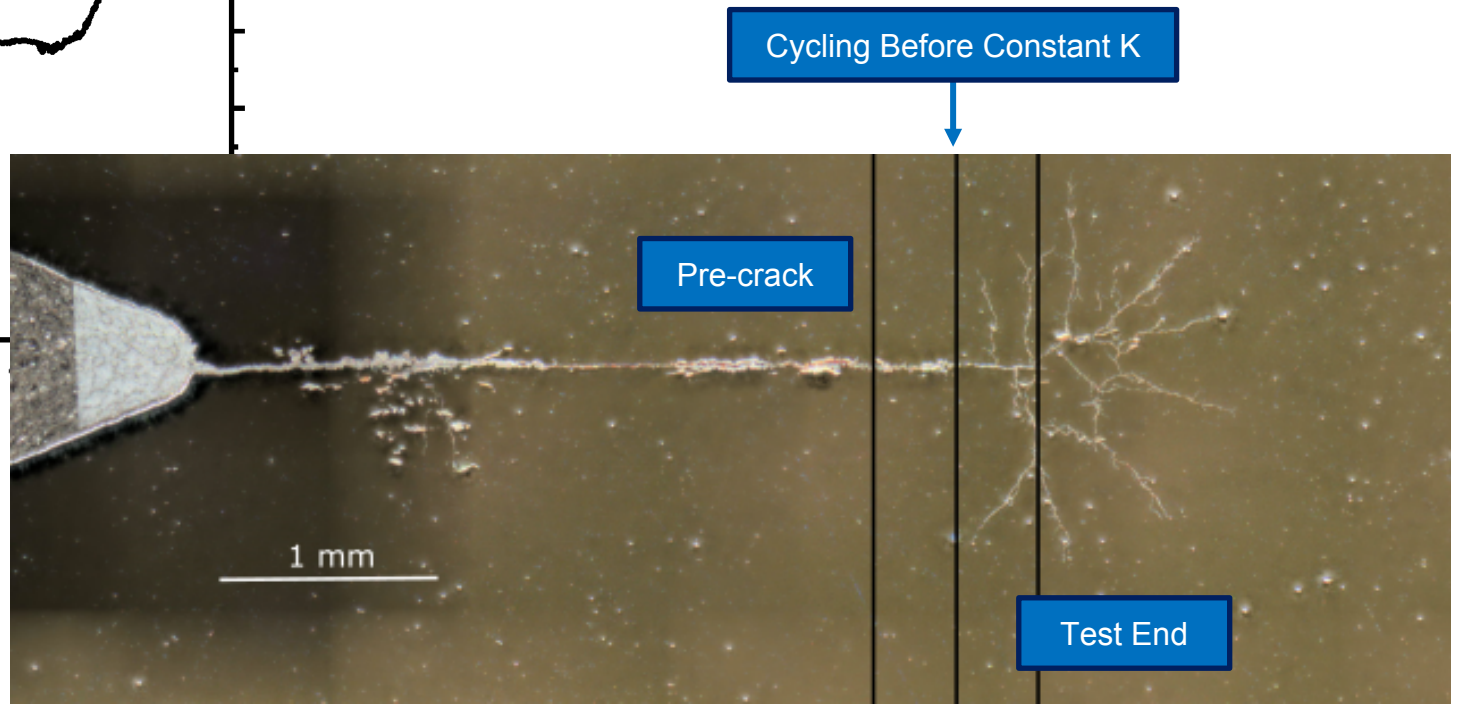
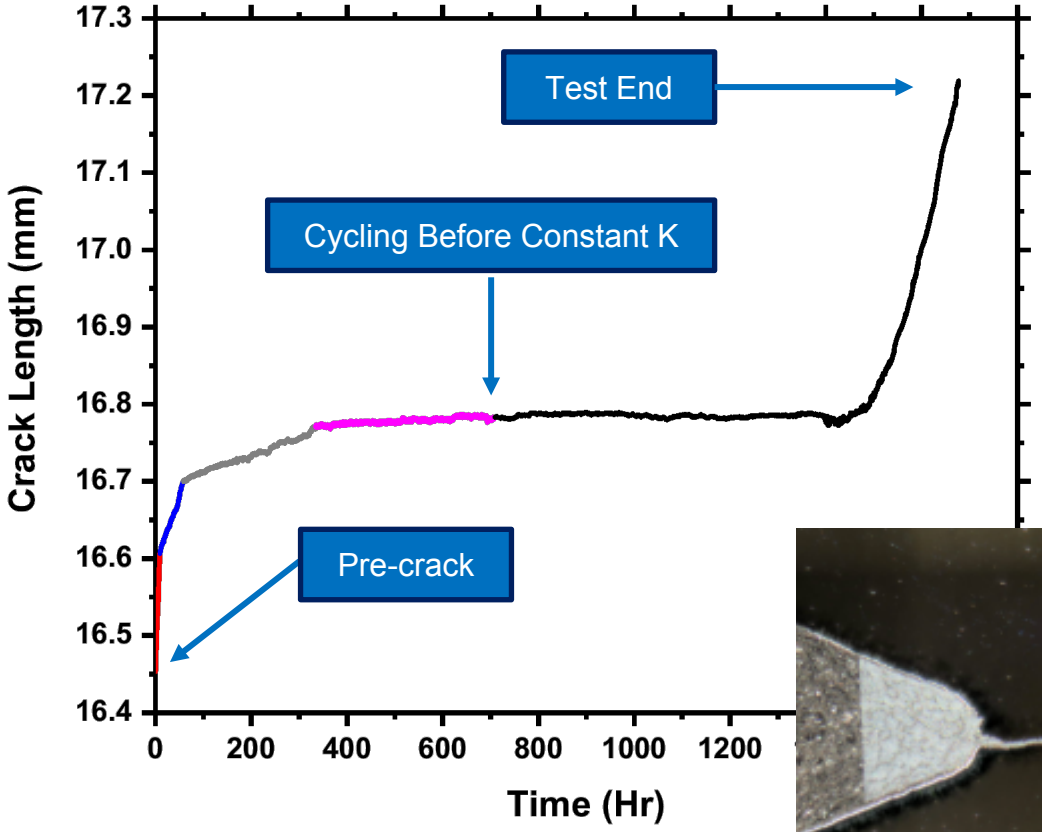
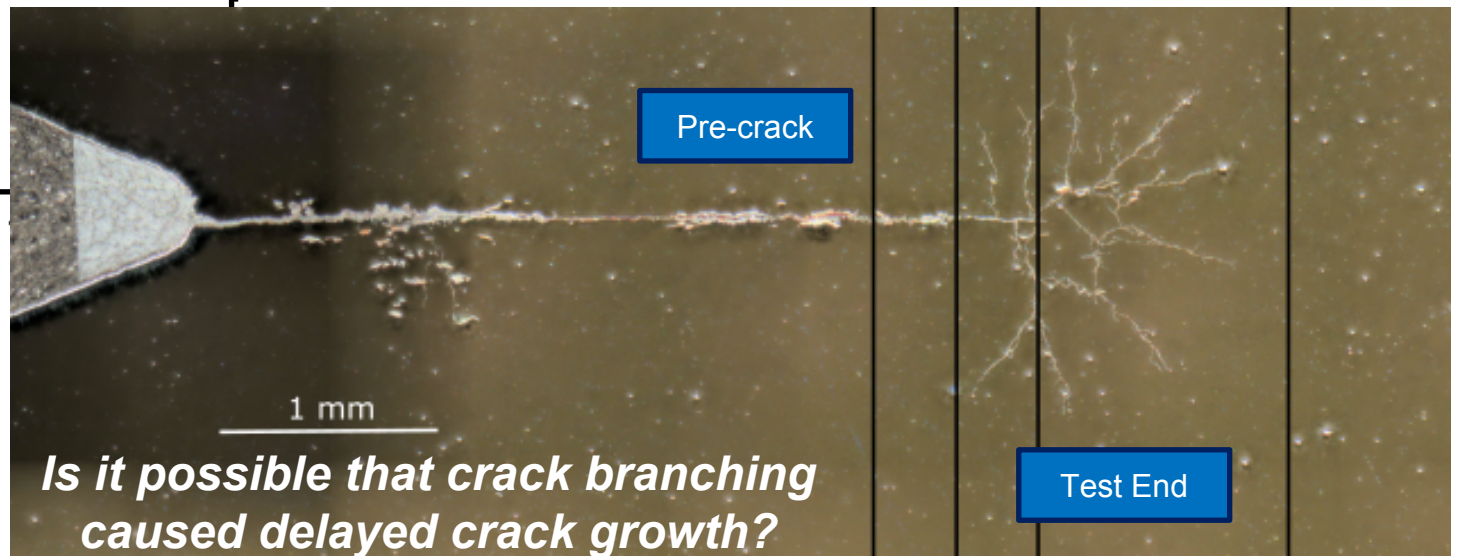




SS304L Exhibits Crack Branching in Saturated $MgCl_2$ at 55 ˚C

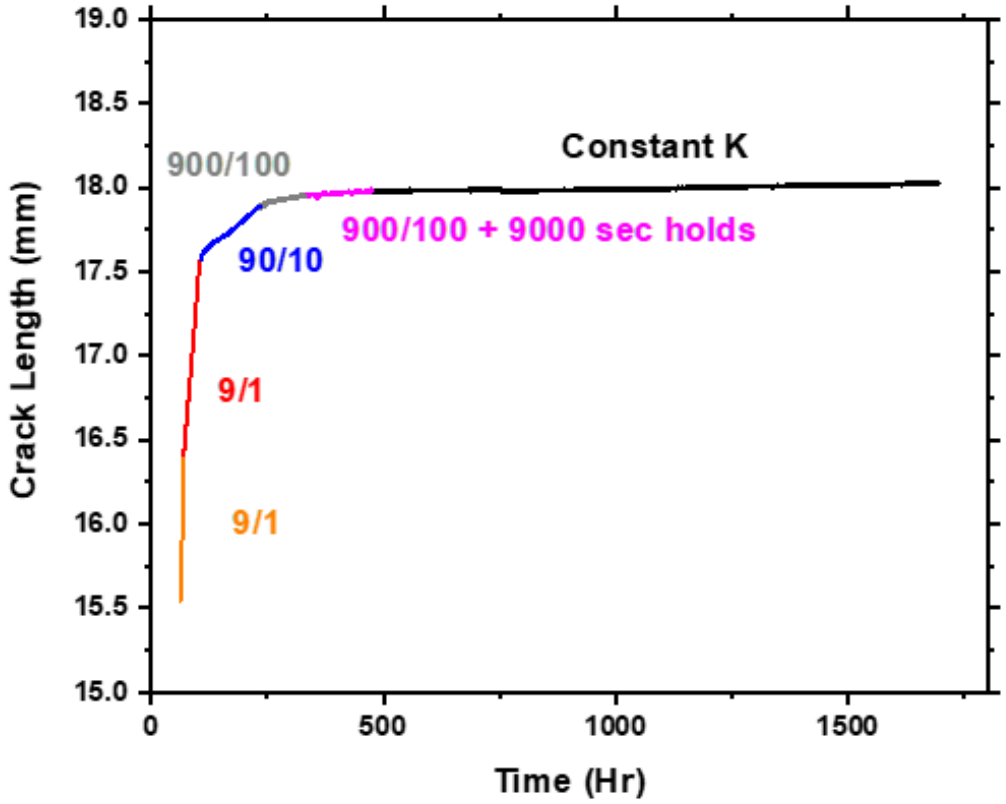


Cycling Before Constant K

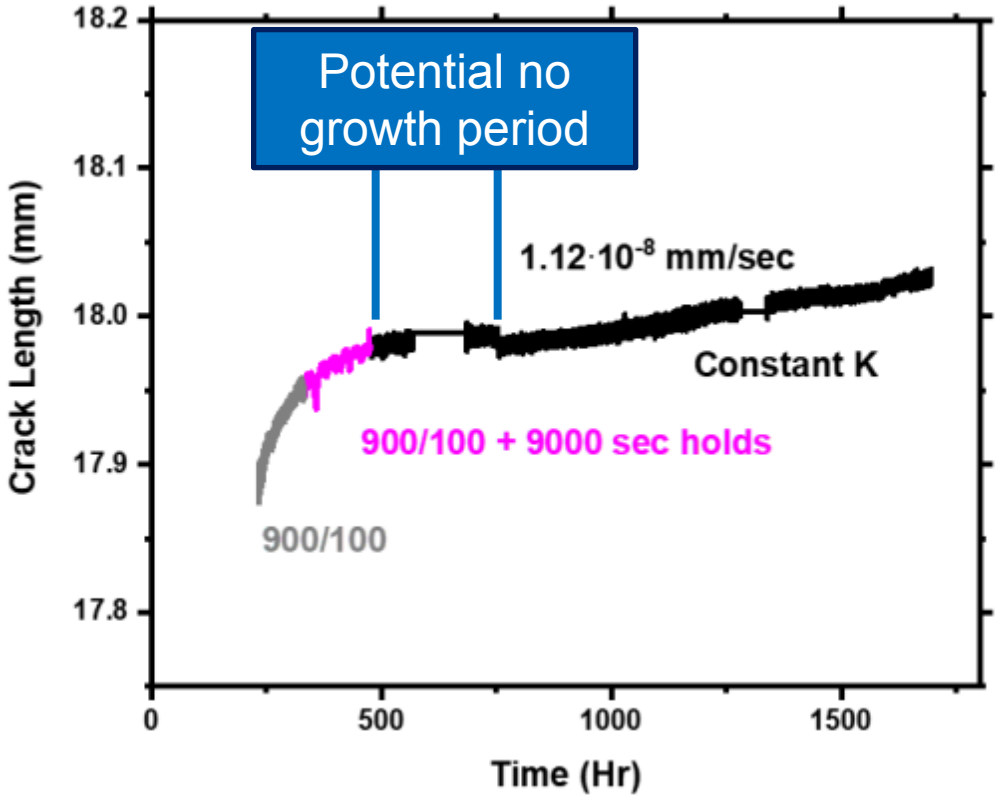


Is it possible that crack branching caused delayed crack growth?

Low Crack Growth Rate for in Saturated $MgCl_2$ at 25 ˚C

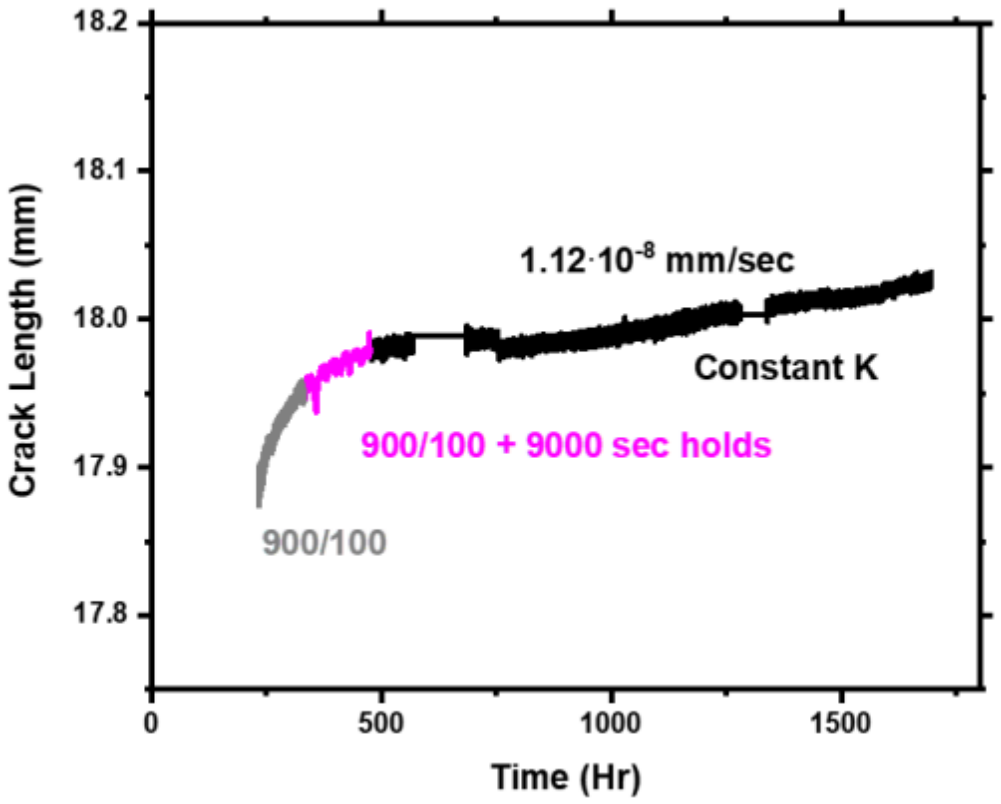


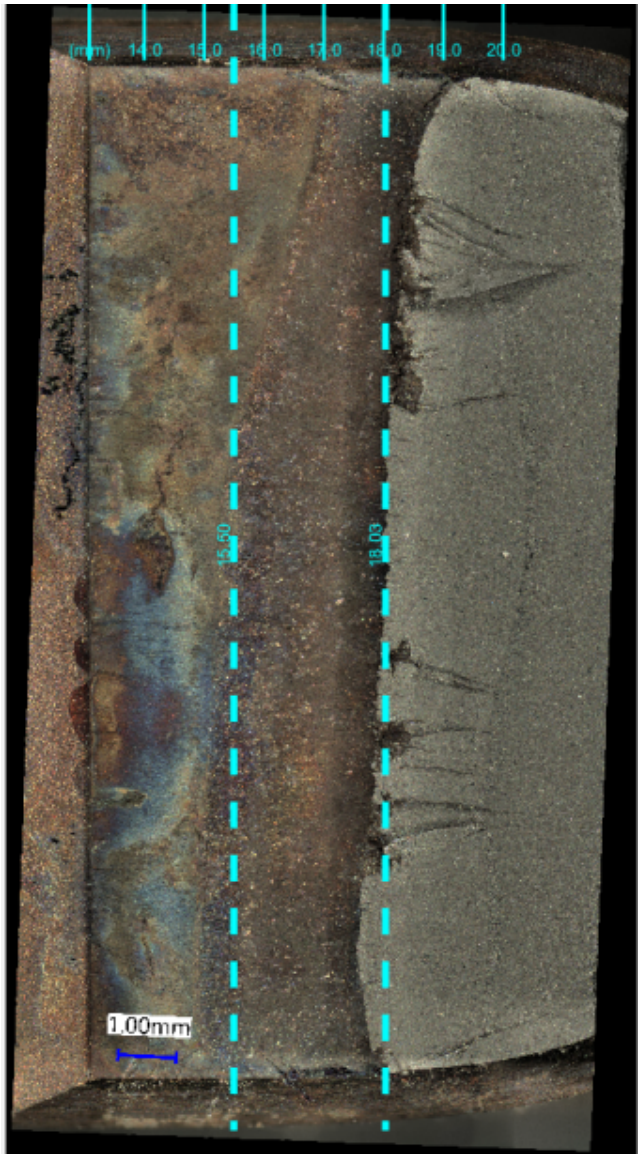
Low Crack Growth Rate for in Saturated $MgCl_2$ at 25 ˚C Exhibited Localized Cracking



- Possible delay in indicated crack growth similar to 55 ˚C
- Sample was not sliced but fractured open
- Similar crack morphology to 55 ˚C however are thinner regions

SS304L Exhibits Irregular Crack Front in Saturated $MgCl_2$ at 25 °C





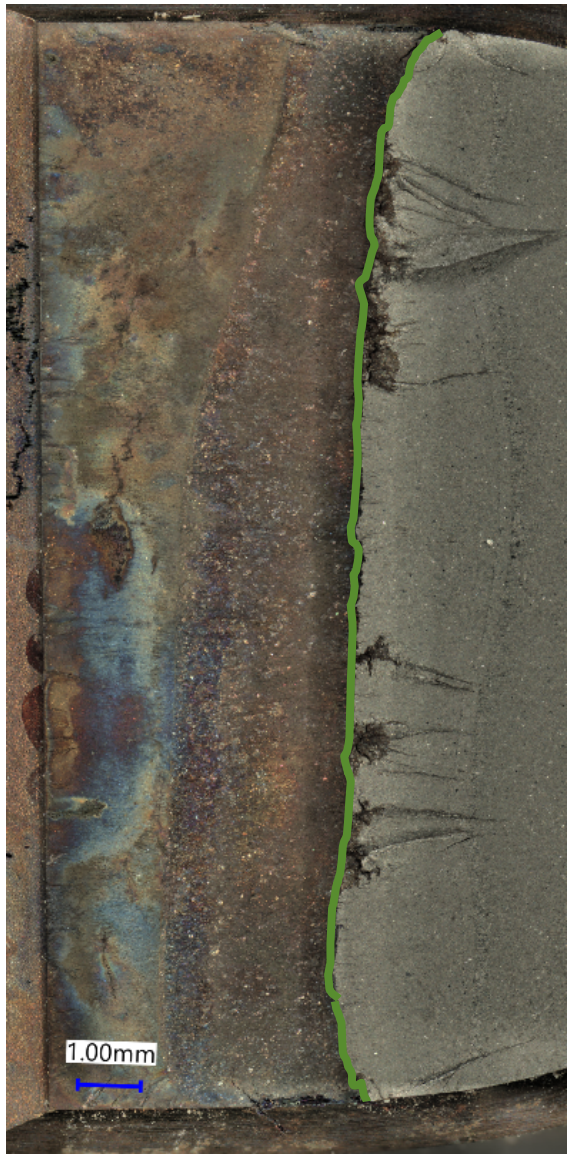
- Slightly curved crack front makes overlay of DCPD difficult

SS304L Exhibits Irregular Crack Front in Saturated $MgCl_2$ at 25 °C

- Measured 100 points of extension from the drawn blue line and averaged
  - Integration of crack extension by hand
  - Similar to area integration

Method	Δa
DCPD	53.8 mm
Fractography	60.1 mm

- Compared to total crack extension during constant K portion
- Possible that growth in ‘protrusions’ ahead of blue line occurred during the constant K portion



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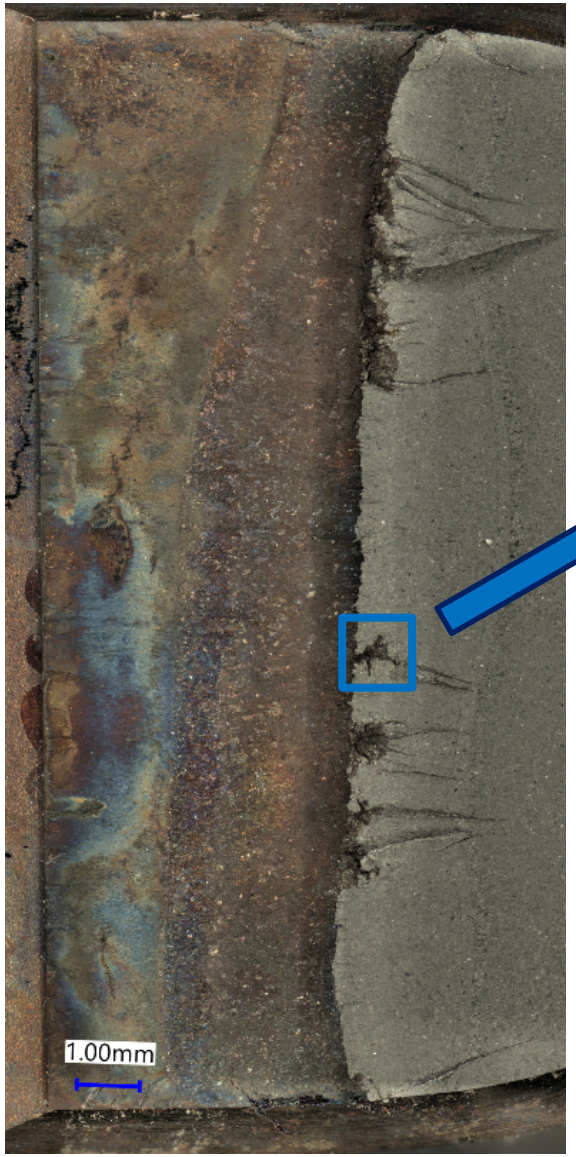

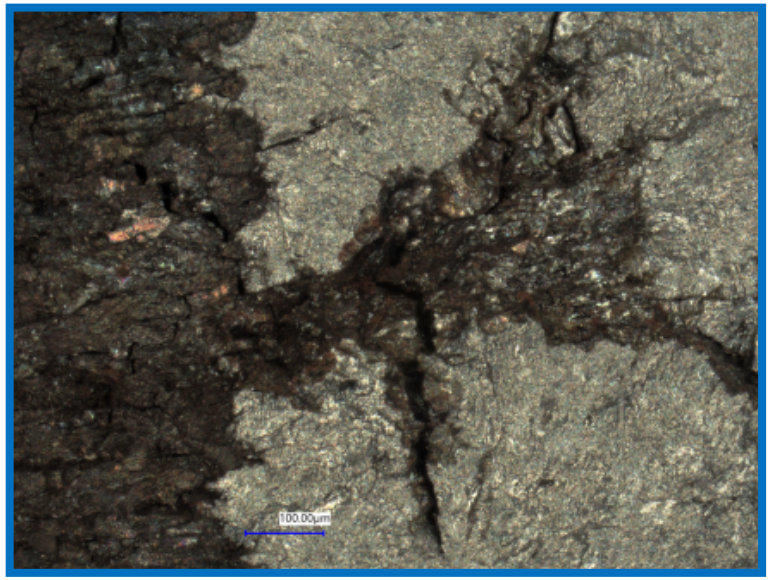

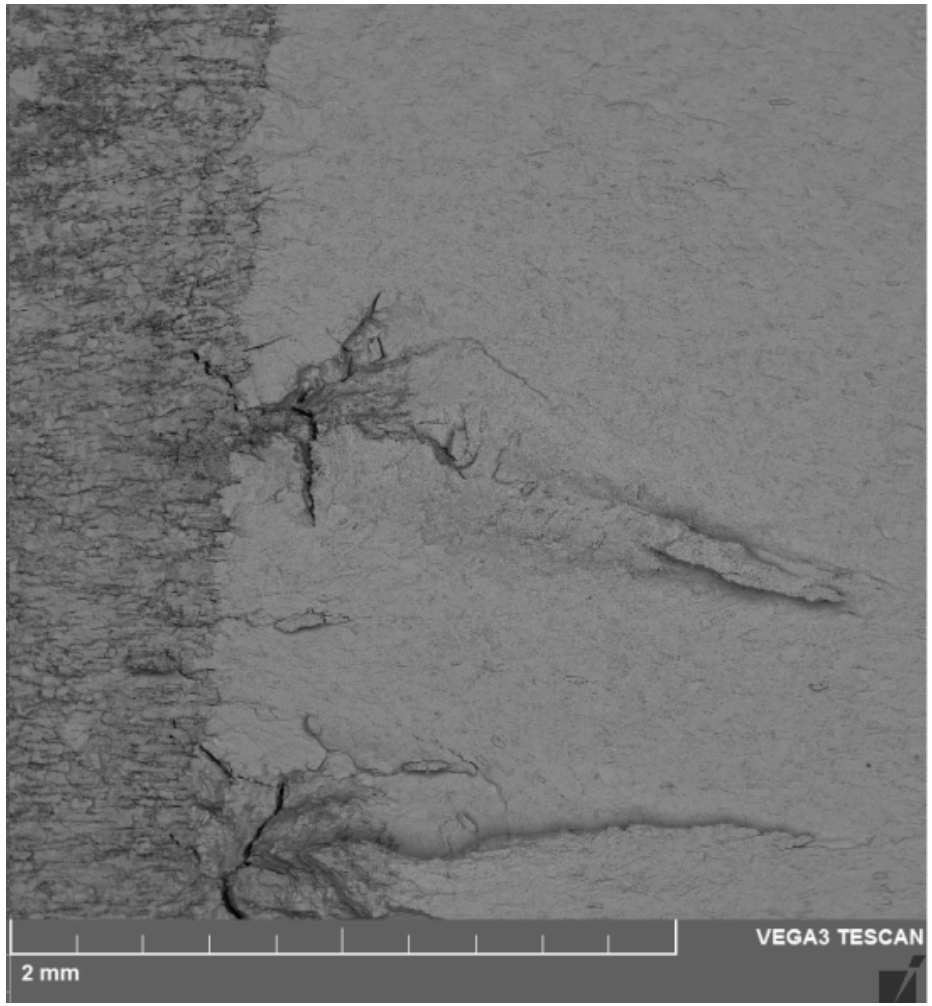

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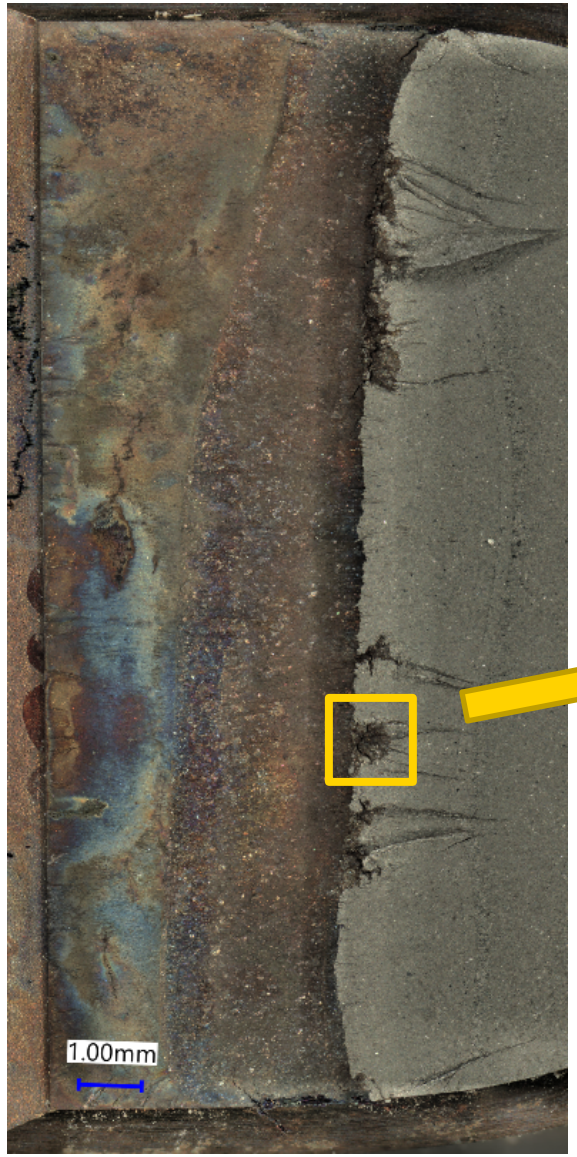
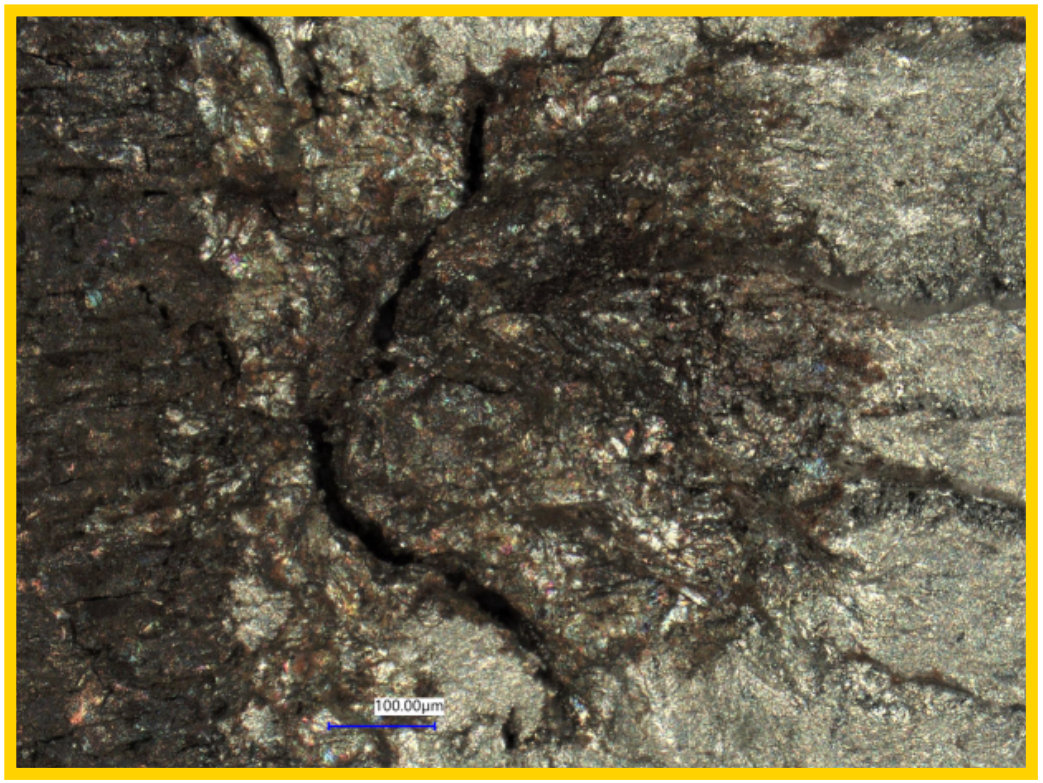
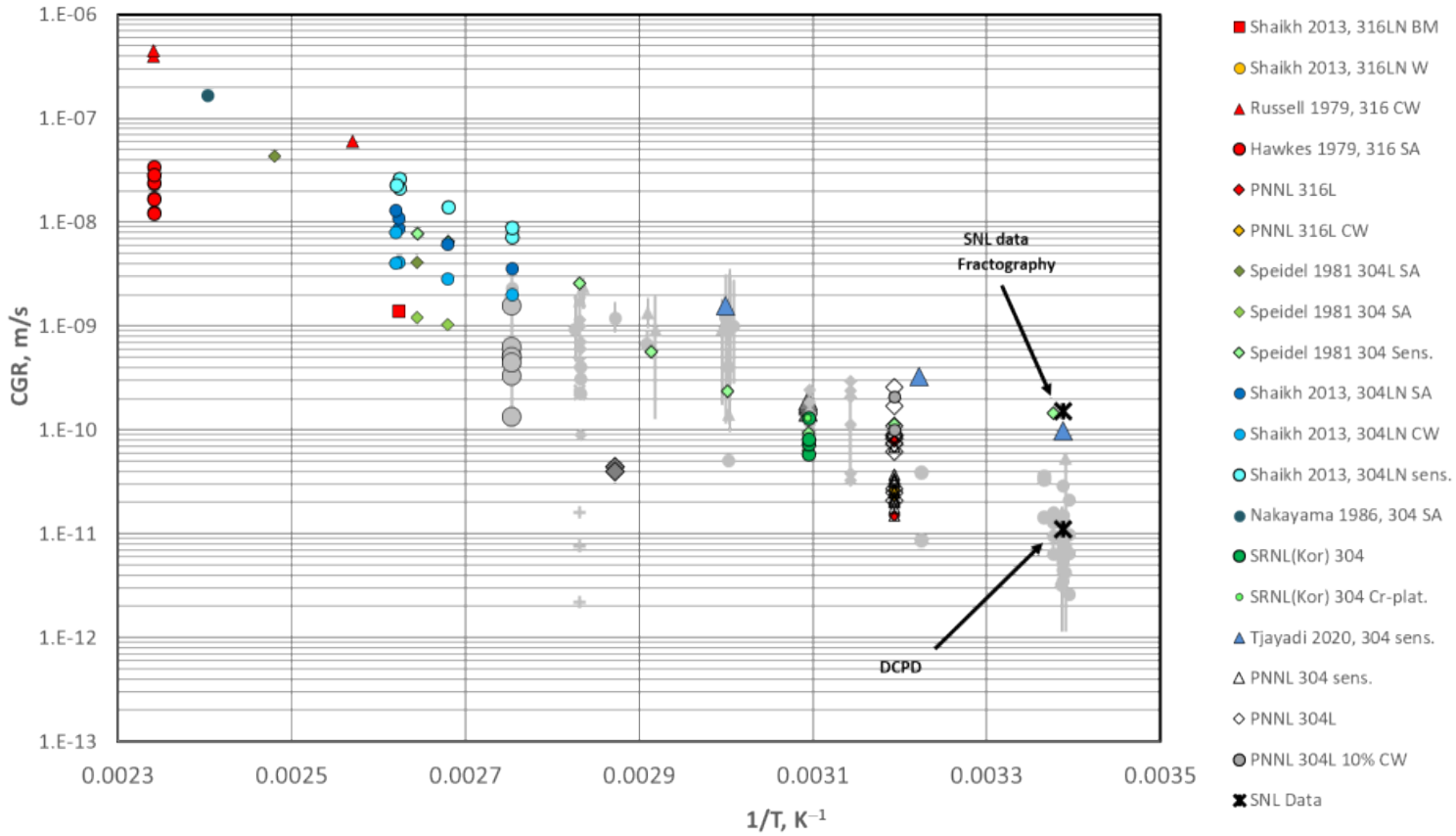




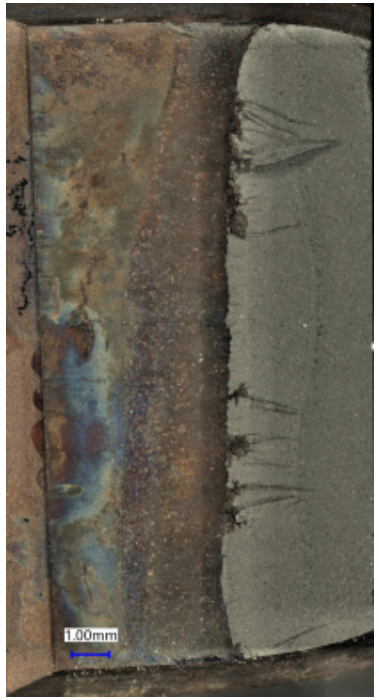
- Significant corrosion products on the surface
  - Enhanced cleaning needed, however, crack wake corrosion could be eliminating features of interest
- Looking for intergranular/transgranular fracture

Crack Growth of Furthest ‘Protrusion’ Potentially Order of Magnitude Higher Than DCPD



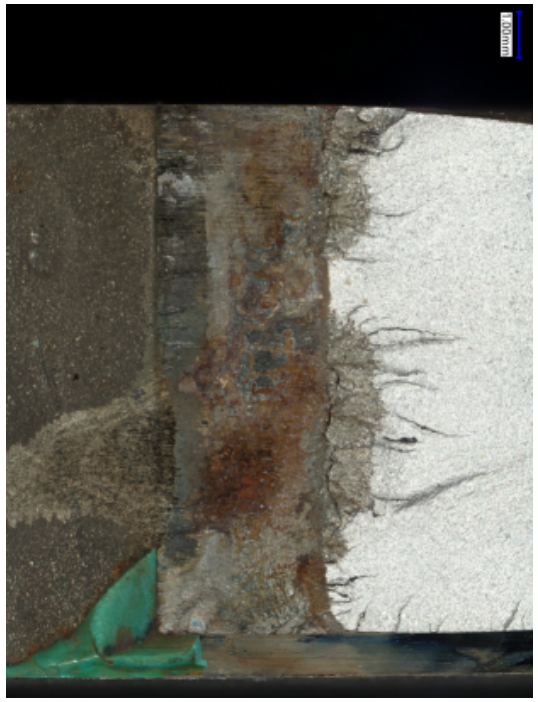
- Considering protrusion occurs during constant K portion of the test, an increased crack growth rate is calculated
  - *measured from deepest point of protrusion

Overview of $MgCl_2$ Samples



Lot 1 – RT

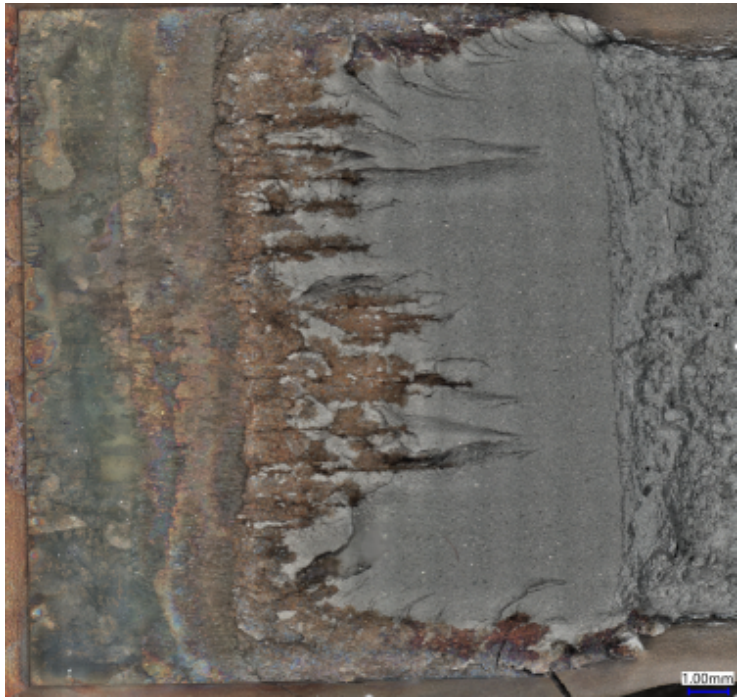
(1218 hours)



Lot 1 – 55 ˚C

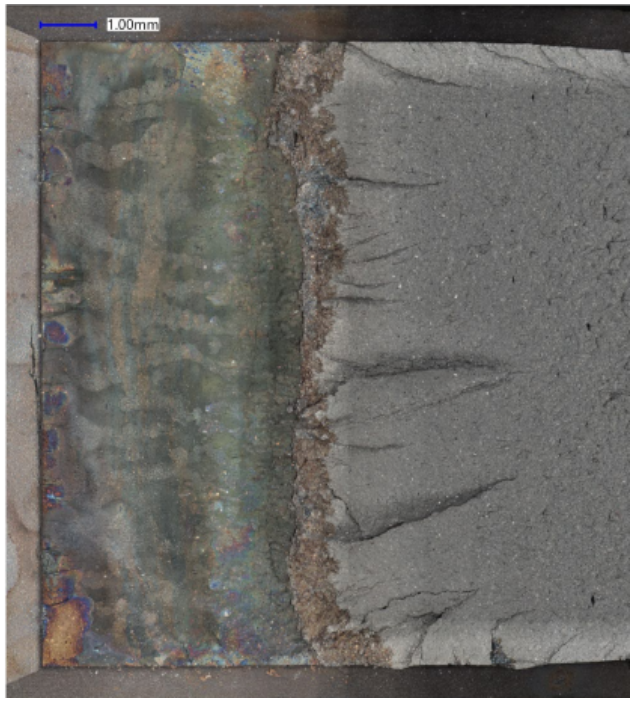
(709 Hours)

(450 hours of growth)



Lot 3 – 55 ˚ C

(650 Hours)



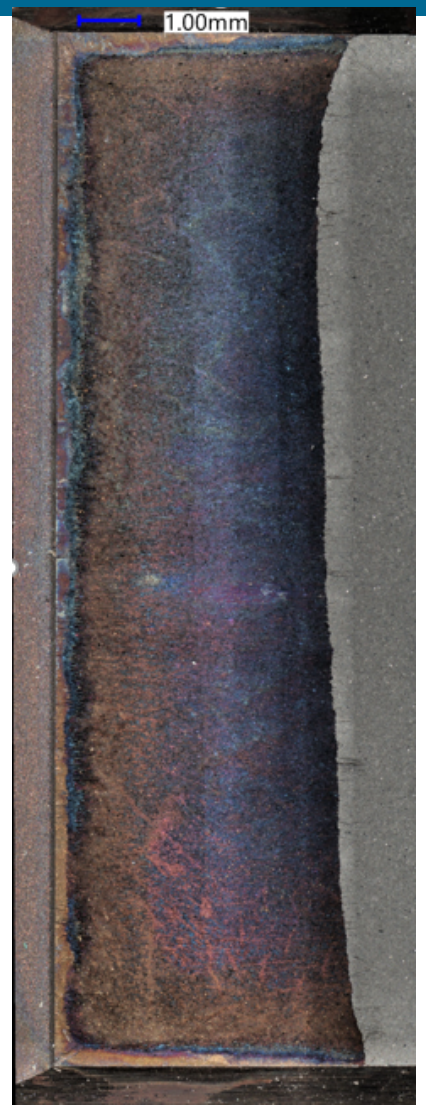
Lot 3 – 55 ˚ C (T-S)

(800 Hours)

(Time under Constant K)

- Crack morphologies show influence from temperature, lot, and direction

Overview of Saturated NaCl Samples



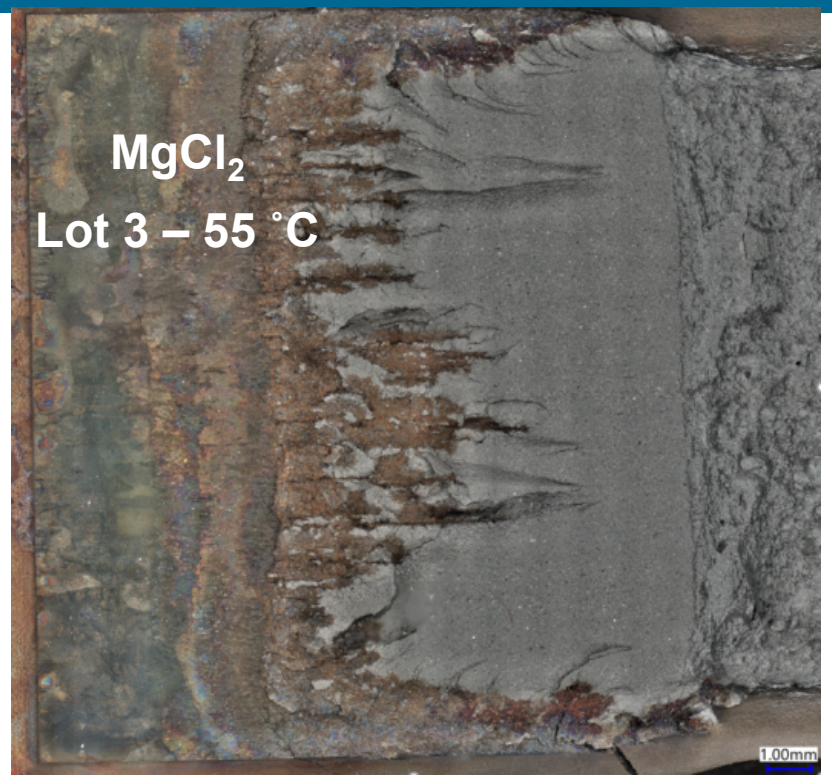
Lot 1 – 22 ˚C

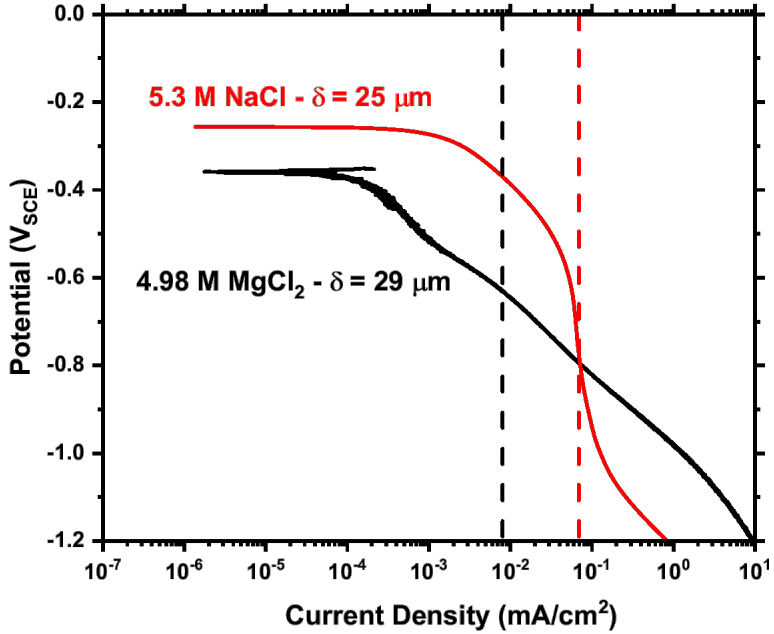
No indicated crack growth

Lot 3 – 60 ˚C

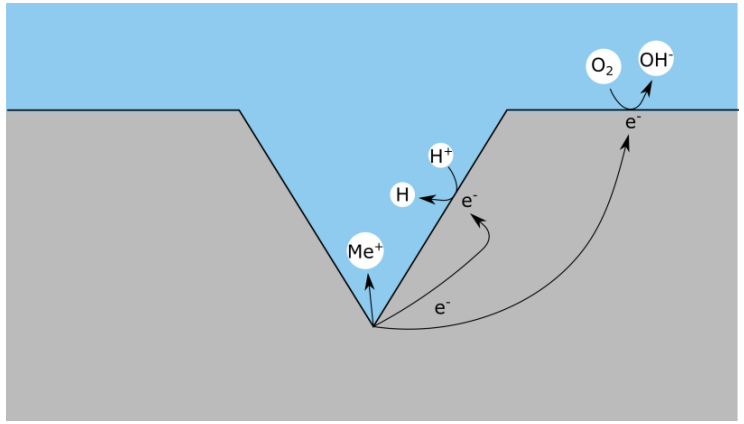
Roughly 50 μm of crack extension during constant K

Crack growth rate of $2.1 \cdot 10^{-8}$ mm/sec



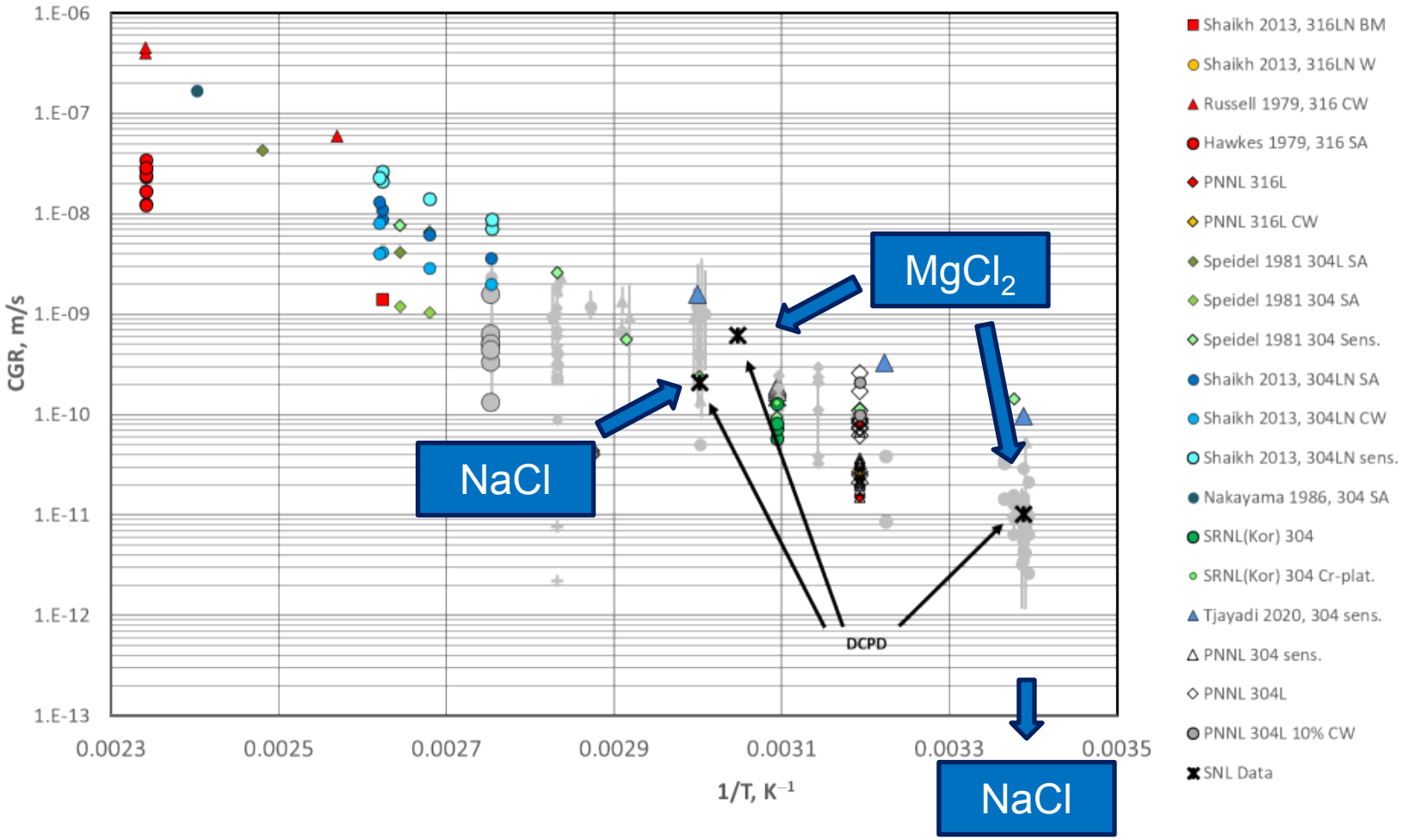


- Similar to differences in morphologies from corrosion exposures
- Potentially due to differences in cathodic reduction reaction
- Possibility for different crack tip chemistry changing pH and embrittlement



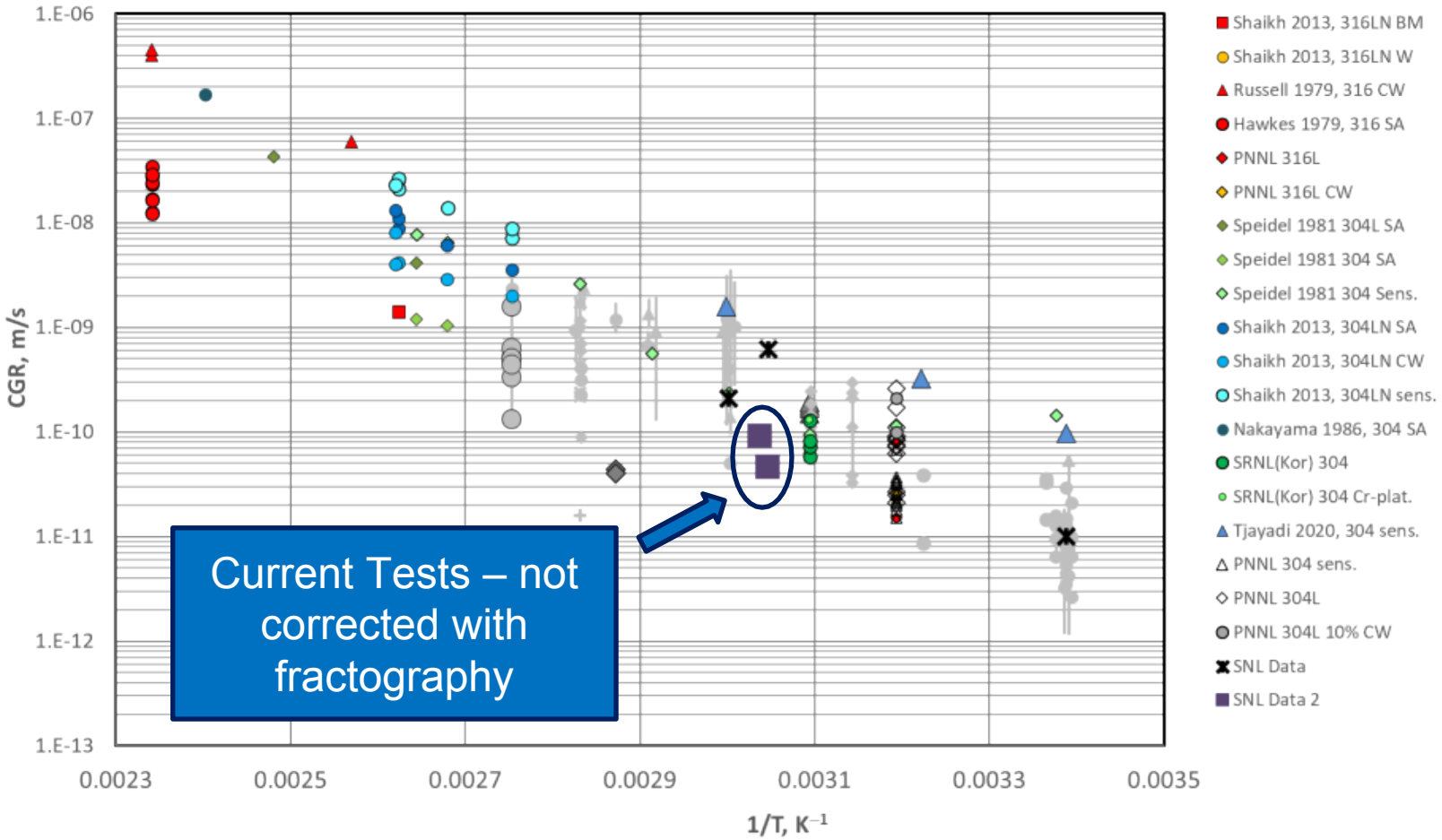
R.M. Katona et al., Journal of The Electrochemical Society, 168 (2021) 031512.
R.M. Katona et al., Corrosion Science, 177 (2020) 108935.

Measured Crack Growth Agrees with Literature Trends



- Similar crack growth rate trend with temperature to other studies in literature
- Potential influence of solution composition on crack growth rate but does influence morphology

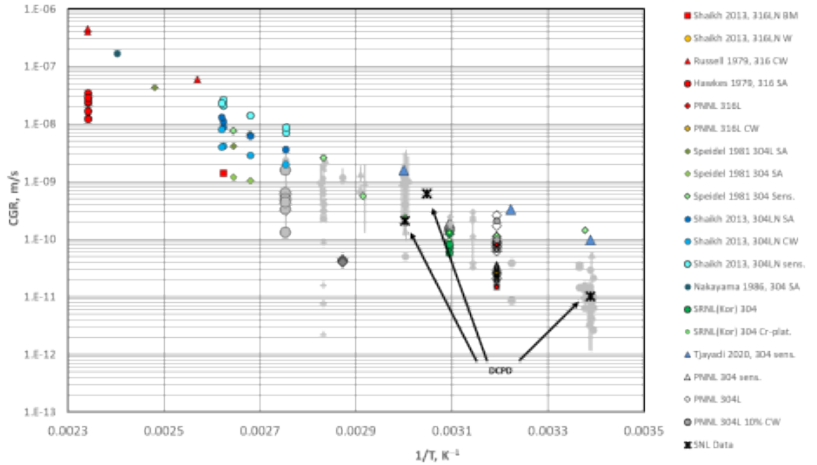
Measured Crack Growth Agrees with Literature Trends

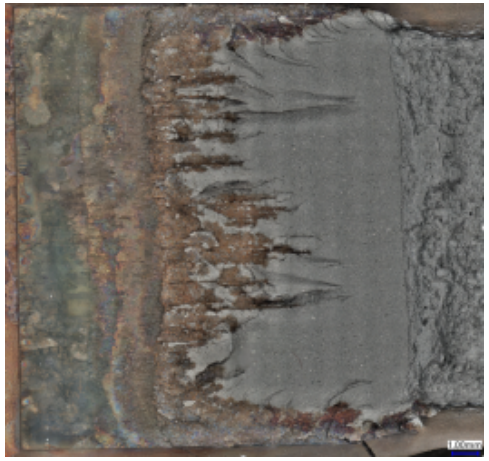


- Replicated tests show fairly good agreement

Key Take-a-ways and Gaps

- Temperature has an impact on crack growth and current experiments agree with literature trends
- Importance of fractography combined with DCPD
- Solution, sample orientation, and material lot appear to impact crack growth and crack morphology
- Key Gaps:
  - Crack growth rate can be vastly different if using DCPD average or growth of furthest protrusion
  - Can multiple tests be performed on the same sample given the ‘weird’ fracture morphologies?
  - Is scatter due to these morphologies, **environment**, material, measurement technique, etc.?
- Next Steps:
  - Further investigation of solution effects
  - Testing various sample directions
  - Atmospheric testing (thin brine layers)





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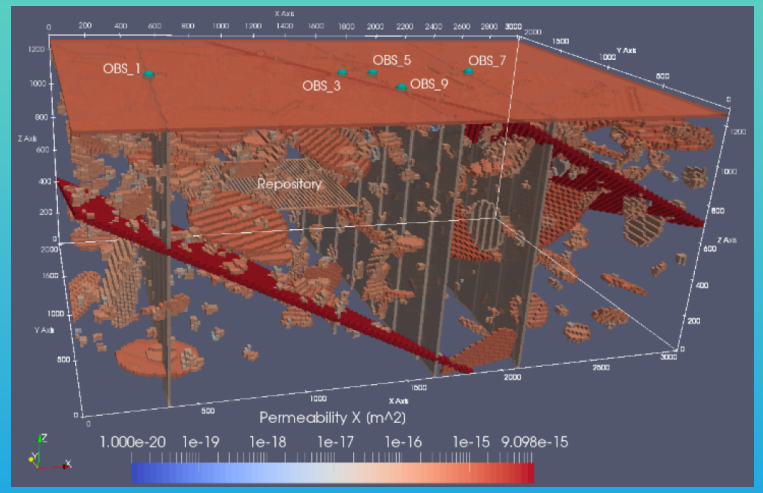

Stress Corrosion Cracking of Austenitic Stainless Steels in Concentrated Chloride Environments

Ryan M. Katona, J. Taylor, E. Karasz, B. Nation, A. W. Knight, C. R. Bryan, and R. F. Schaller

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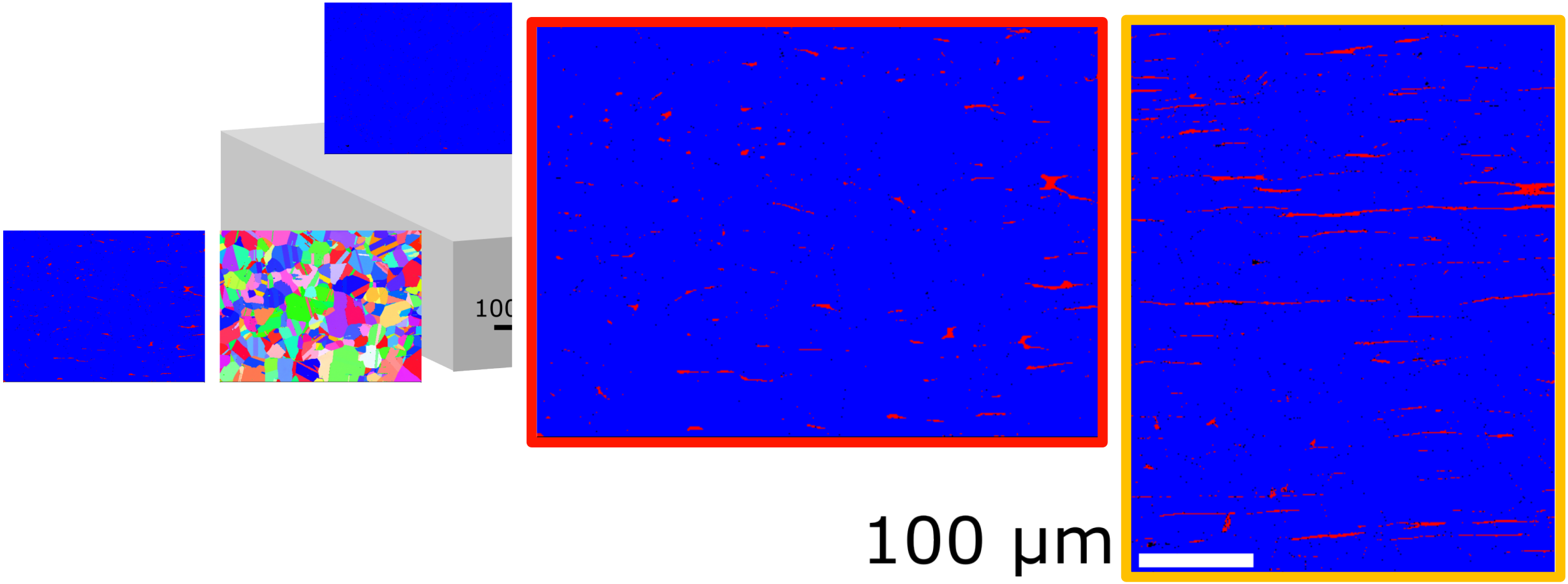
Lot ID	Plate #	Heat #	PNNL Reference #	UTS (Mpa)	YS 0.2% (Mpa)	Elong.(%)	HRB
LT001	206972	SD23822	n/a	647	267.516653	57.6	82.2
LT003	213104	04E28VAA	P304L1	623	292	62.9	81

	Composition													
	C	Co	Cr	Cu	Mn	Mo	N	Nb	Ni	P	S	Si	Ti	Fe
LT001	0.02	0.2	18.14	0.25	1.7	0.08	0.07	-	8.04	0.031	0.004	0.4	0.001	bal
LT003	0.017	0.234	18.1	0.412	1.782	0.414	0.08	0.014	8.03	0.037	0.001	0.236	0.002	70.7


100 µm

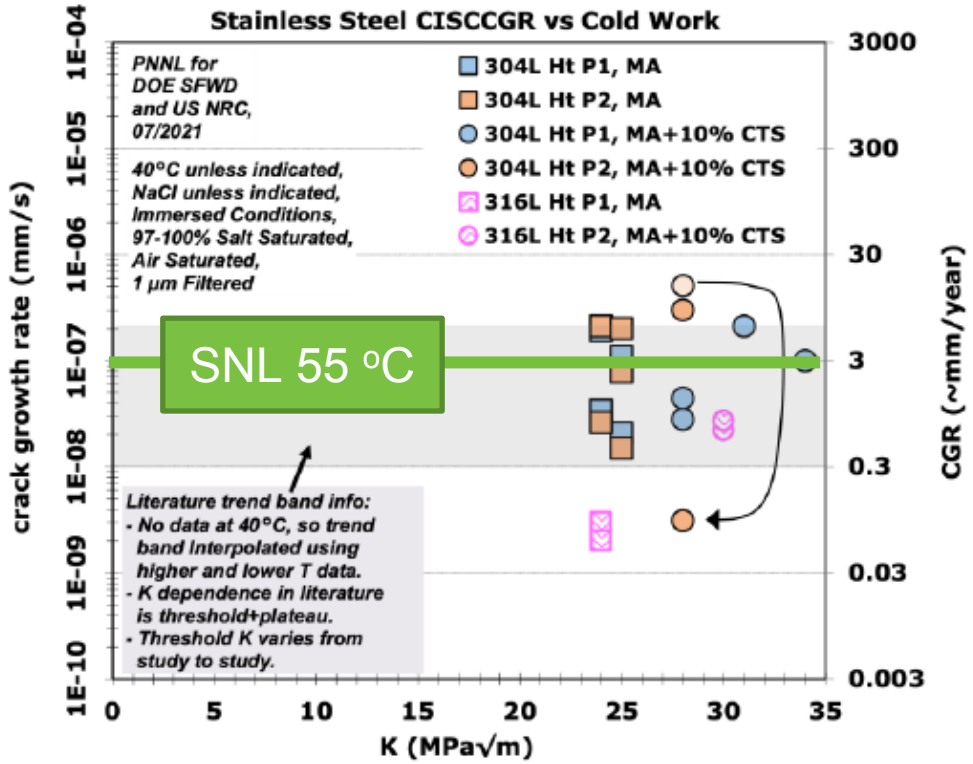


Figure 23. Effect of 10% cold work on CISCCGR of two heats of 304L.