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Achieving Maximum Crack Remediation Effect from Optimized Hydrotesting

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Working principle for crack growth control

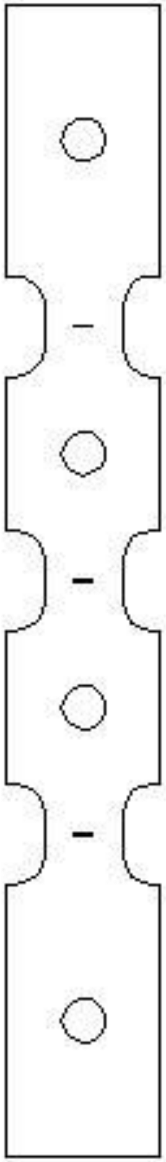
Crack growth or crack dormancy is a result of the following two competitive processes occurring at the crack tip:

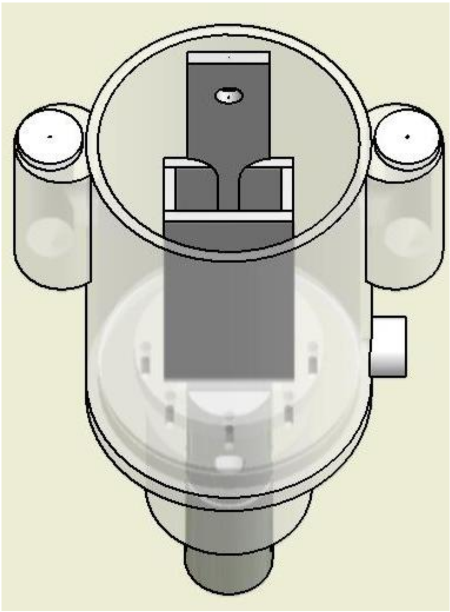
- **<u>Crack tip blunting</u>** driven by low temperature creep and hydrogen facilitated deformation

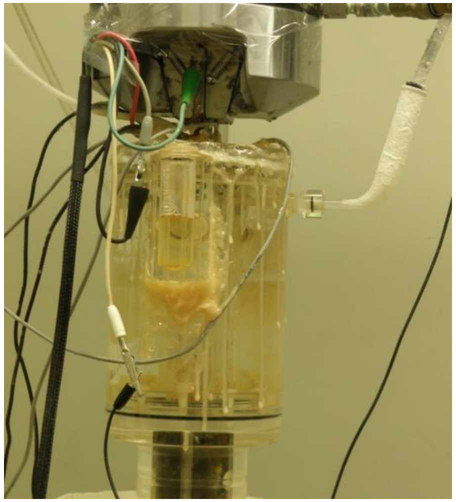
- **<u>Crack tip sharpening</u>** driven by fatigue and hydrogen embrittlement

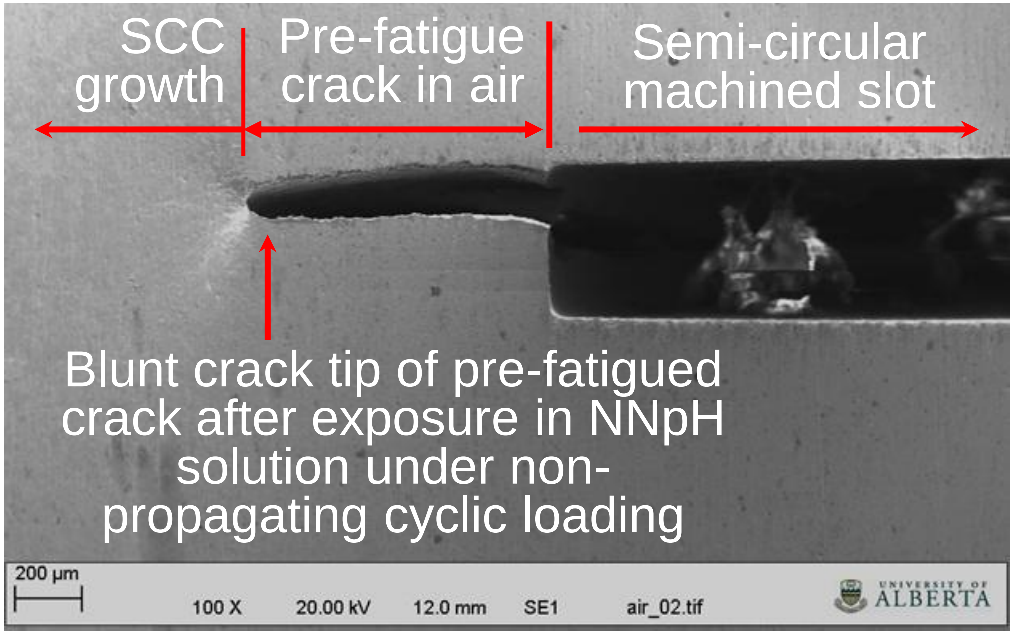
Note that: corrosion plays minor direct role in crack growth except for the initial stage and providing atomic hydrogen, a by-product of corrosion.

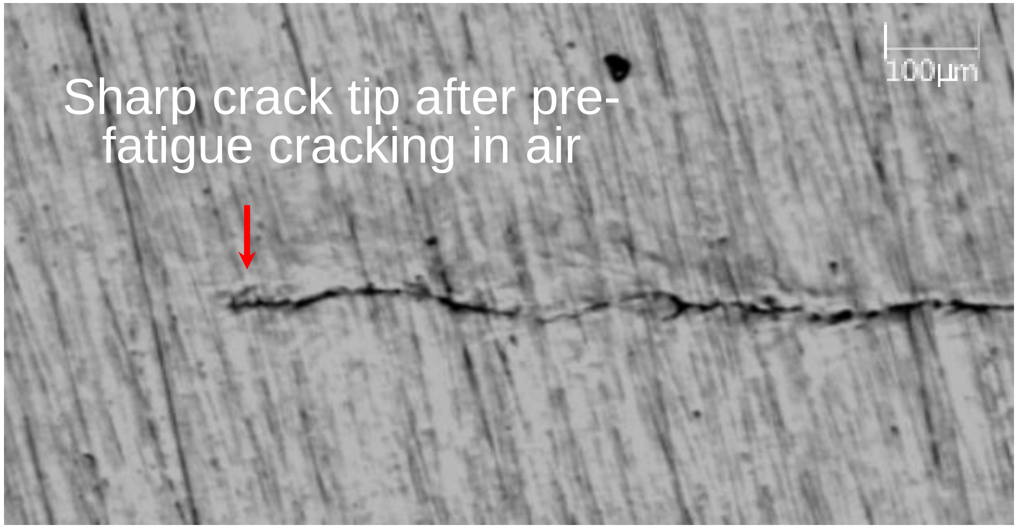
Working principle for crack growth control











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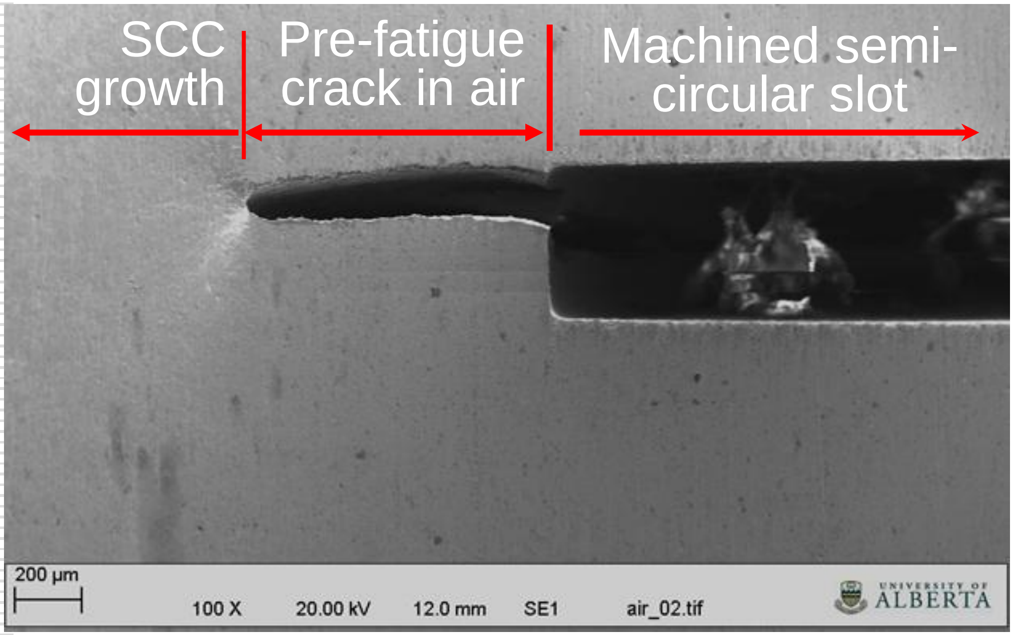

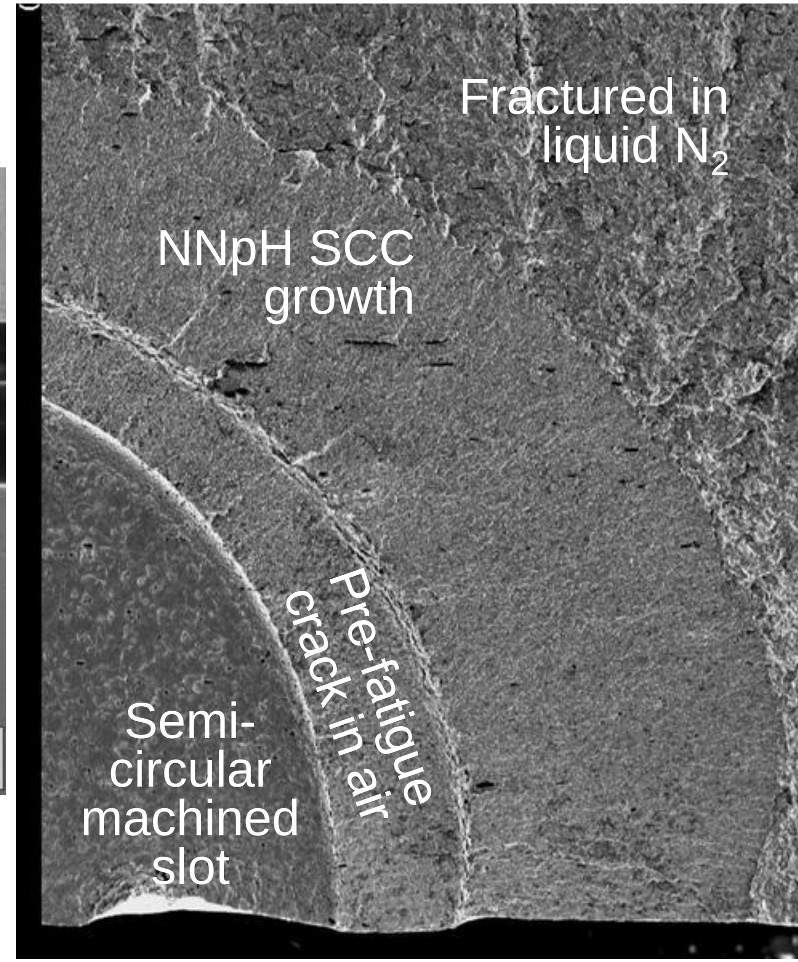

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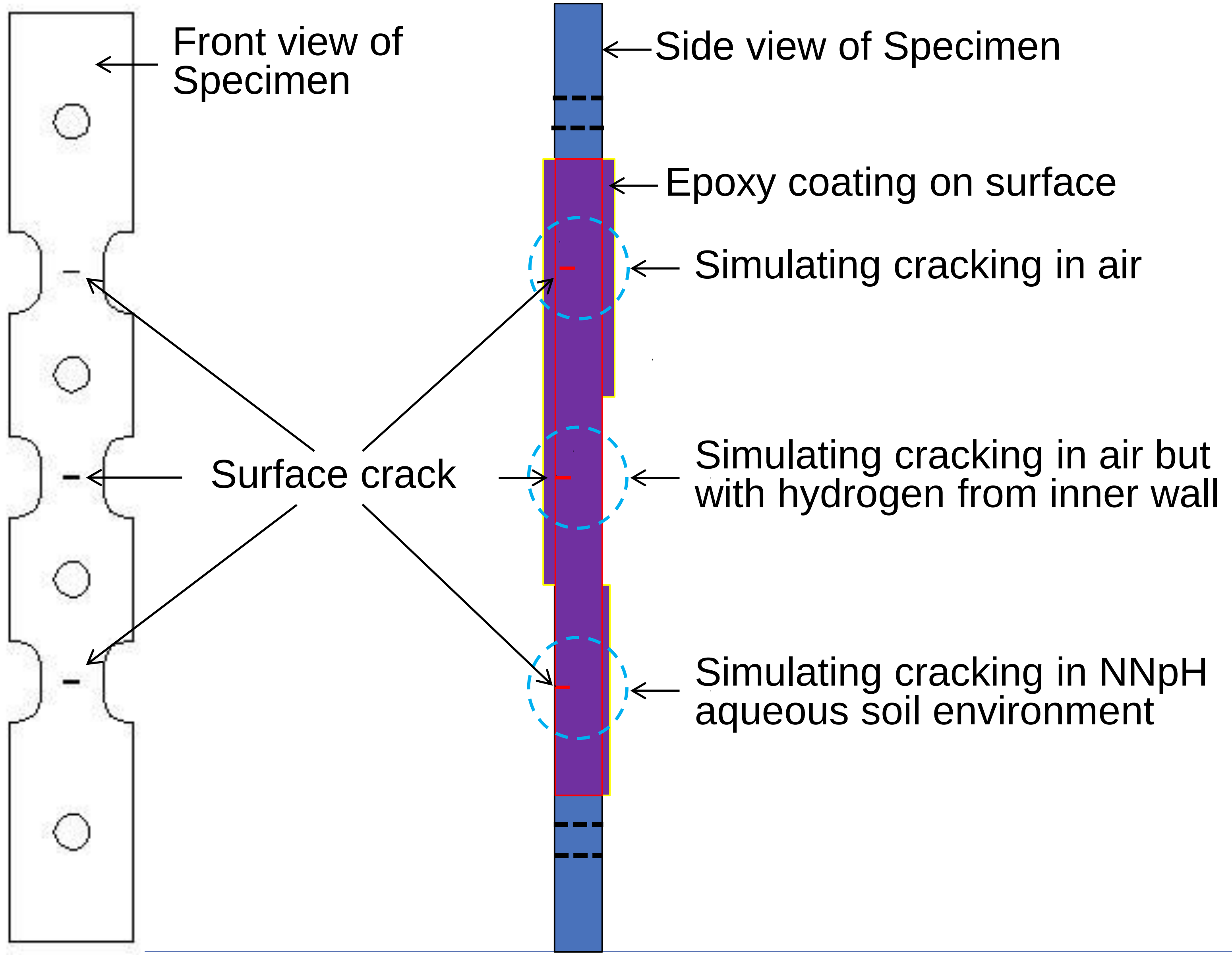
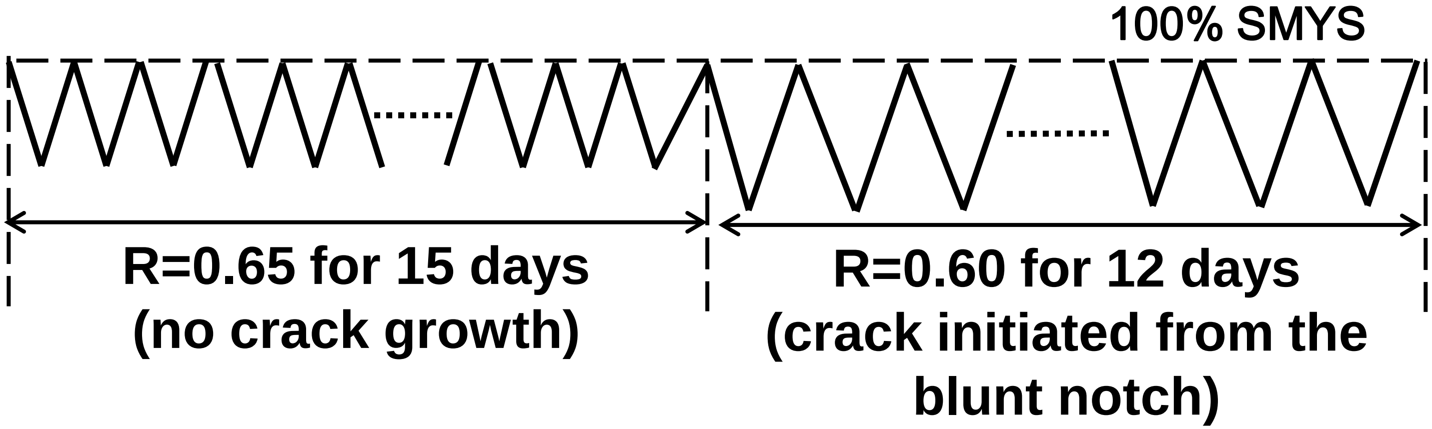


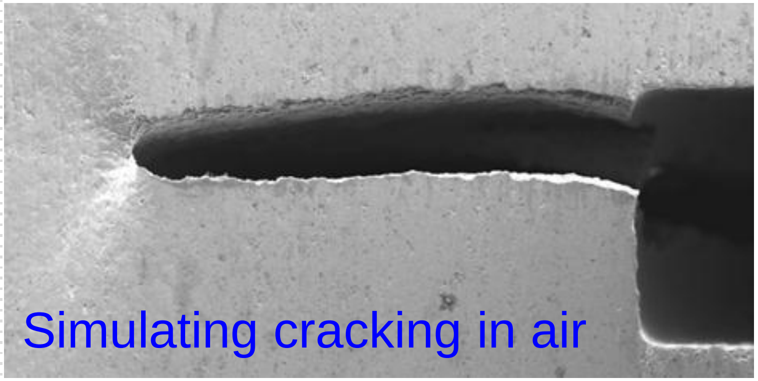
Working principle for crack growth control

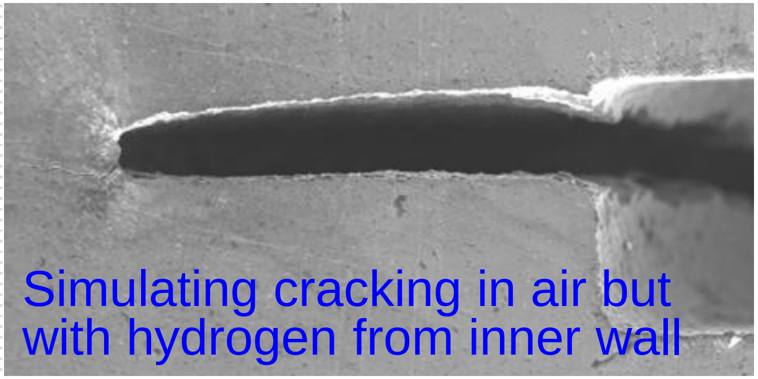
Test condition:

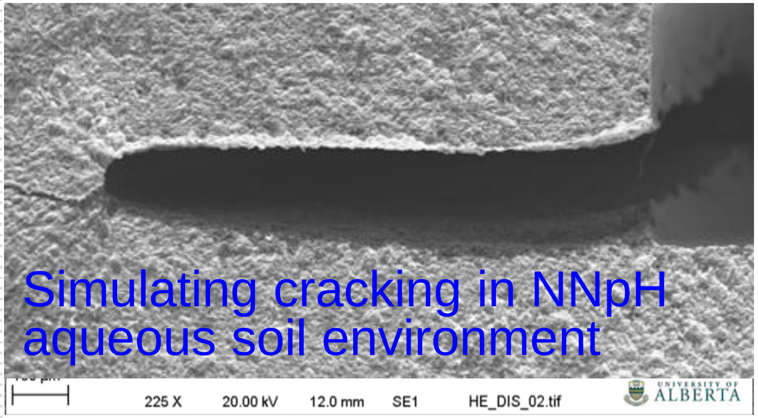
- Open circuit potential
- C2 solution purged with 20% CO_2 + N_2
- Frequency: 0.005 Hz
- X65 pipeline steel

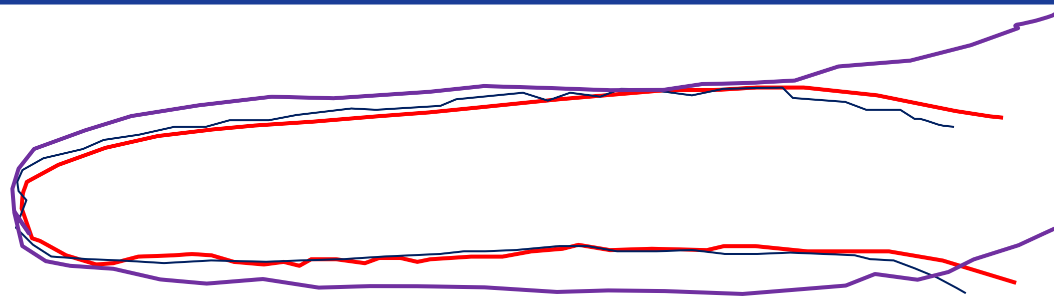


Working principle for control of crack growth









Red line

- Simulating cracking in air
- Effect of low temperature creep

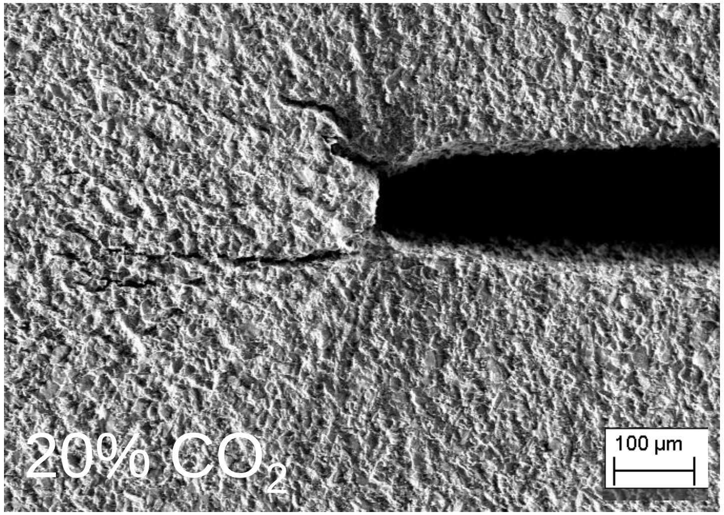
Blue line

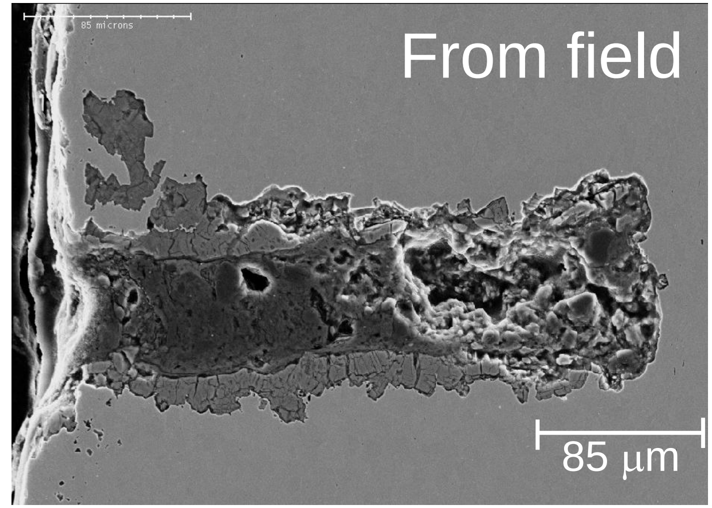
- Simulating cracking in air but with hydrogen from inner wall
- Effect of low temperature creep

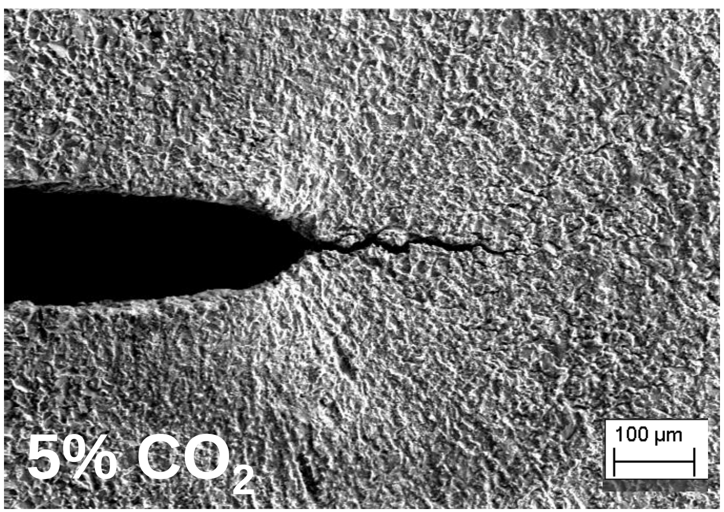
Purple line

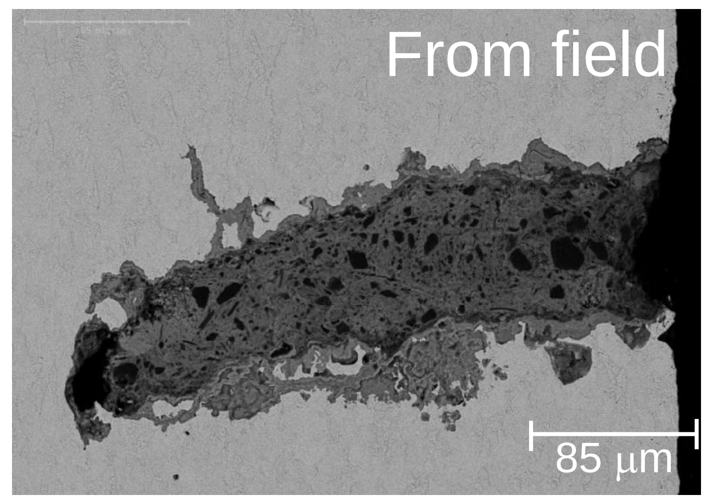
- Simulating cracking in NNpH aqueous soil environment
- Effect of low temperature creep and hydrogen-facilitated plastic deformation

Working principle for control of crack growth

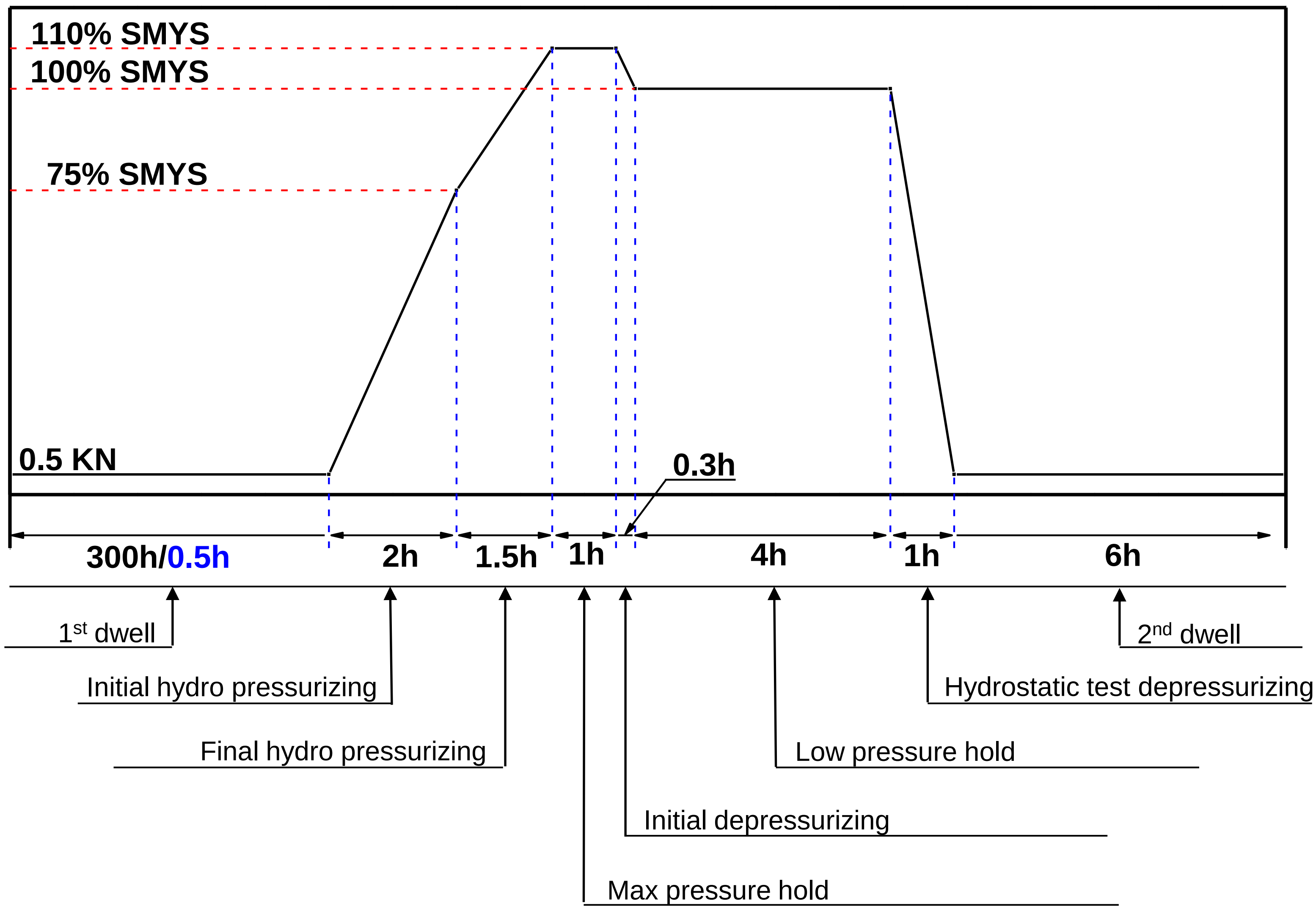








Simulating crack growth during hydrostatic loading



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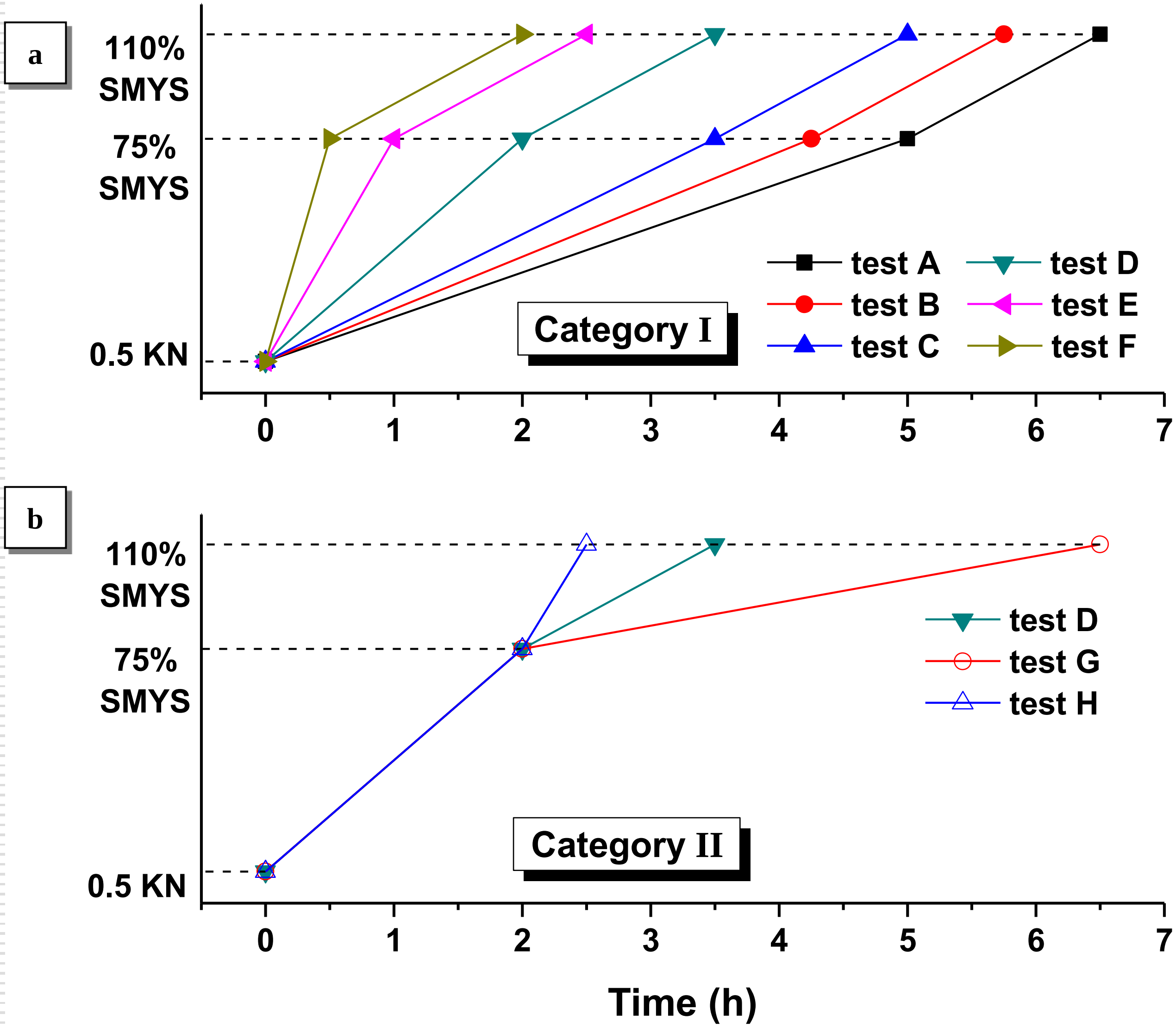

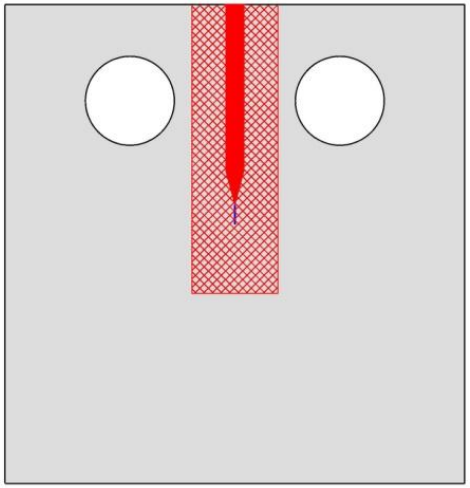

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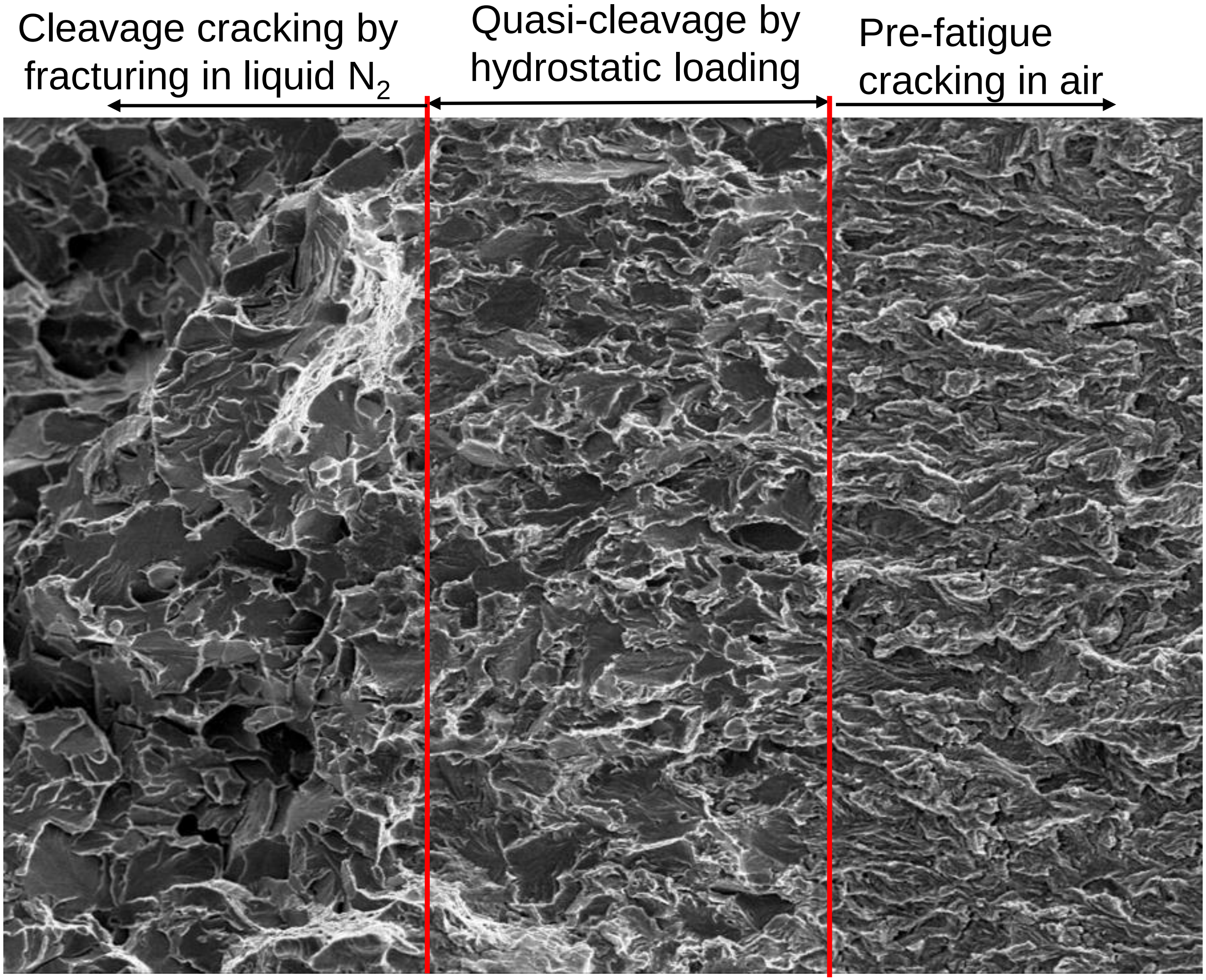
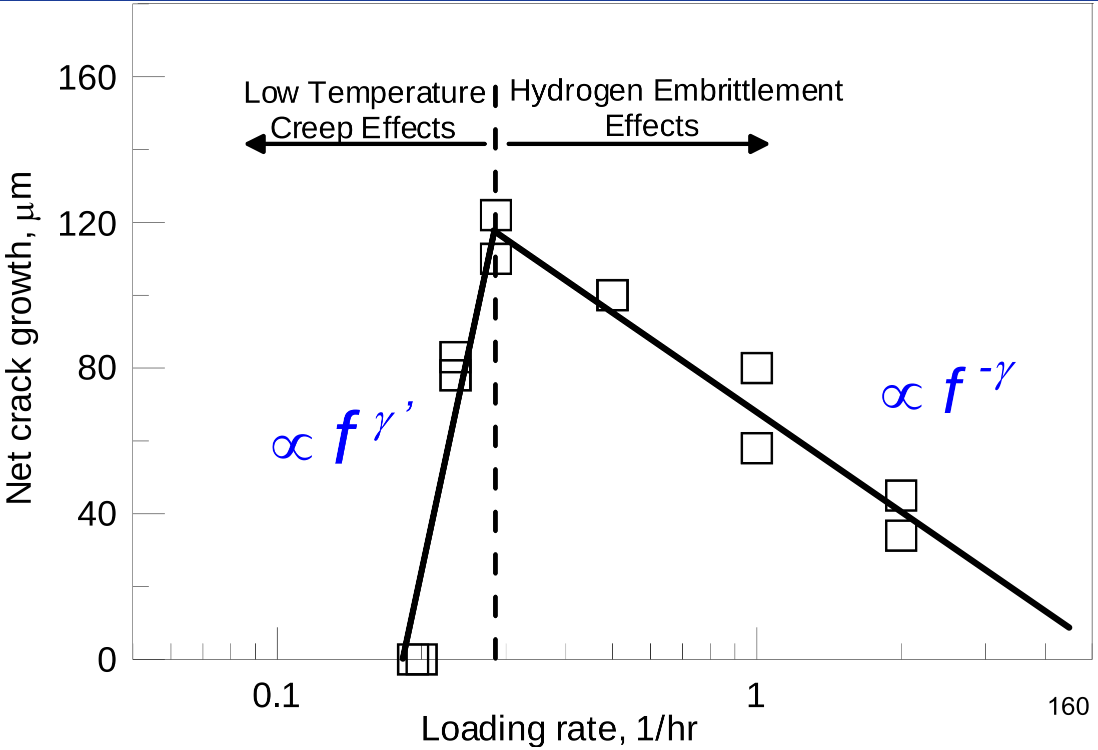
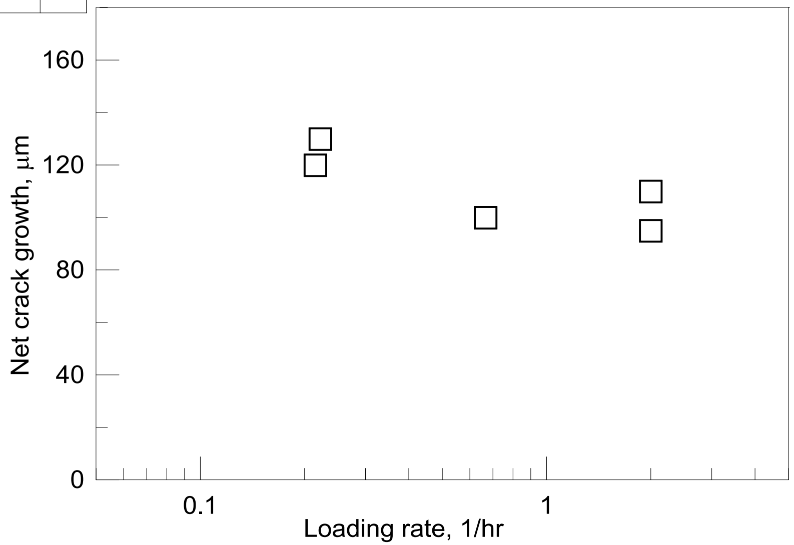


Simulating crack growth during hydrostatic loading

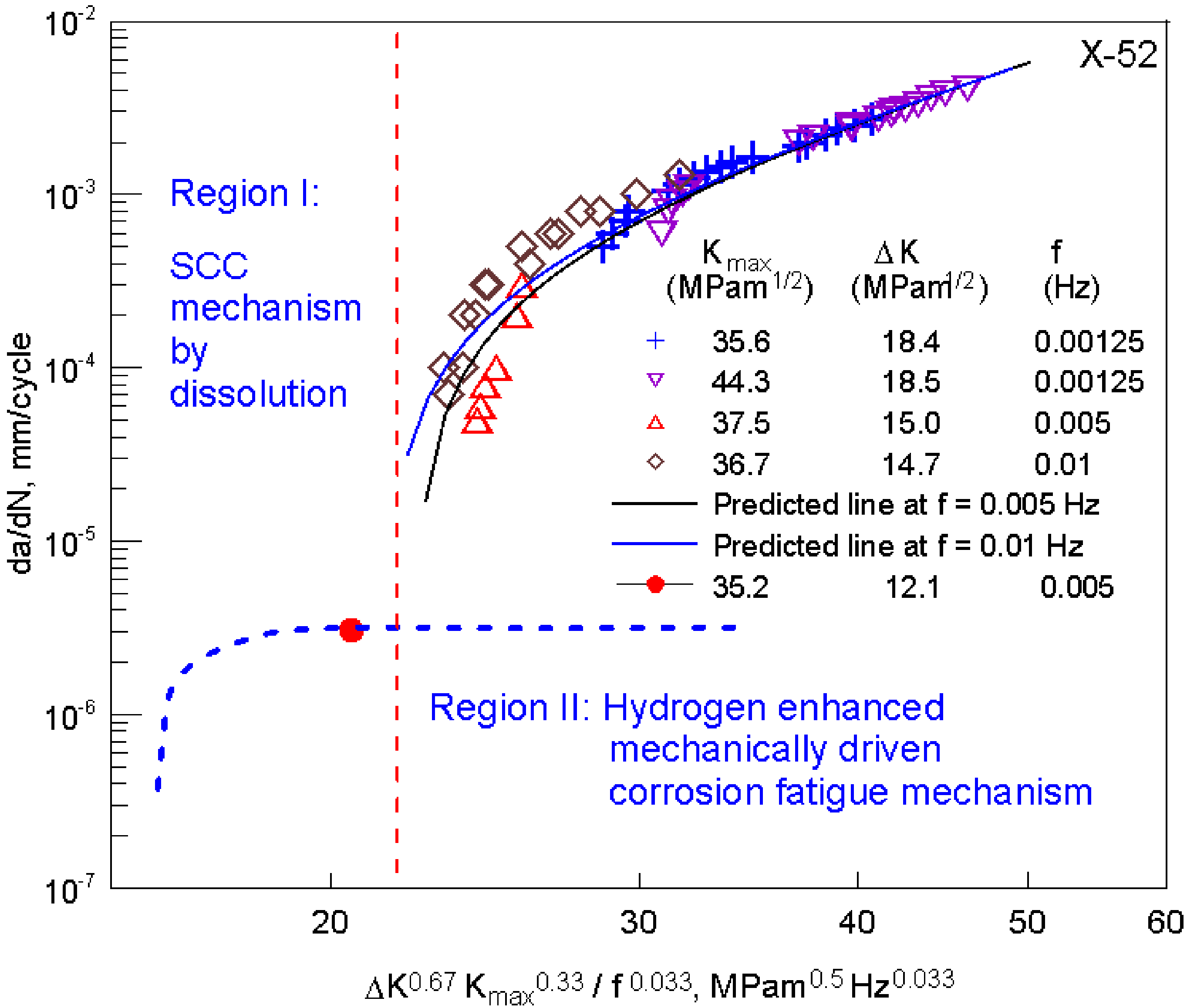


Effect of loading rate in Stage I on crack growth

Effect of loading rate in Stage II on crack growth



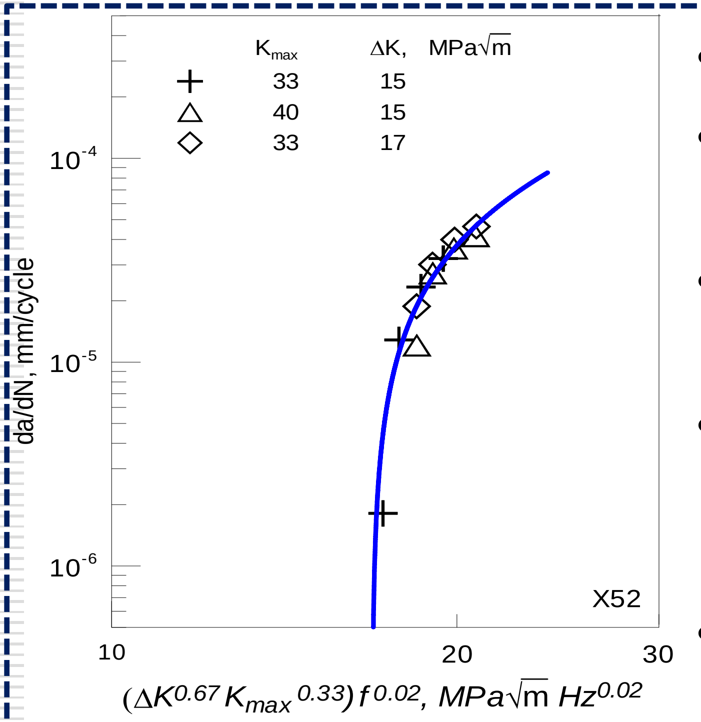
Predictive crack growth model



Predictive crack growth model

$$\left(\frac{da}{dN}\right)_{tot.} = \left[(HEF)\left(\frac{da}{dN}\right)_{air}\right]_{CF} + \frac{1}{f}\left(\frac{da}{dt}\right)_{SCC}$$

Can be neglected



- An intrinsic behavior of pipeline steels
- Low temperature creep dependent and therefore loading frequency is important
- Material & process-dependent – future direction of pipeline steel research
- Threshold of corrosion fatigue – therefore materials' susceptibility to cracking can be different – future studies
- *[HEF]* does not affect the thresholds but is a growth rate-raiser – further studies

Predictive crack growth model

REGION I SCC Mechanism

- ❑ What is the crack growth rate in Region I?
- ❑ What determines the crack growth rates in Region I?
- ❑ Can the SCC growth rate in Region I be added to the corrosion fatigue growth rate in Region II?
- ❑ To what crack depth would Region I mechanism be predominant?
- ❑ Is the SCC growth rate in Region I constant, and what would be the SCC growth rate as a function of crack depth?

Predictive crack growth model

REGION II Hydrogen enhanced mechanically driven

Crack Growth Rate Modelling Consideration

- Most cycles are non-propagating because of low temperature creep
- Crack growth is discontinuous and can take place when a critical condition is met.
- Both the retardation and the enhancement need to be considered.

How to perform hydrotesting

Best strategies of hydrostatic testing

1) Producing the least crack growth during hydrostatic loading

2) Avoiding over-estimate of the remaining life, which could occur when crack tip remains at a sharp state

3) Achieving maximum post-test benefits (crack growth retardation)

Recommendations

- Conditioning pipelines achieving crack tip blunting
- Guideline for shallow crack grinding
- Control of pressure fluctuations achieving maximum pipeline safe operating lifetime
- Generalized experimental approaches for assessing the susceptibility of pipeline steels to environmentally-assisted cracking
- Modelling crack growth in all cracking stages – practical approach for field application
- New considerations for developing pipeline steels with improved resistance to environmentally-assisted cracking
- Investigating high pH cracking of pipeline steels using similar approaches described in this report.

Thank you for your time!

Questions?