HE and CPT of ASTM A470 in VCI 337 and Ecoline 3690

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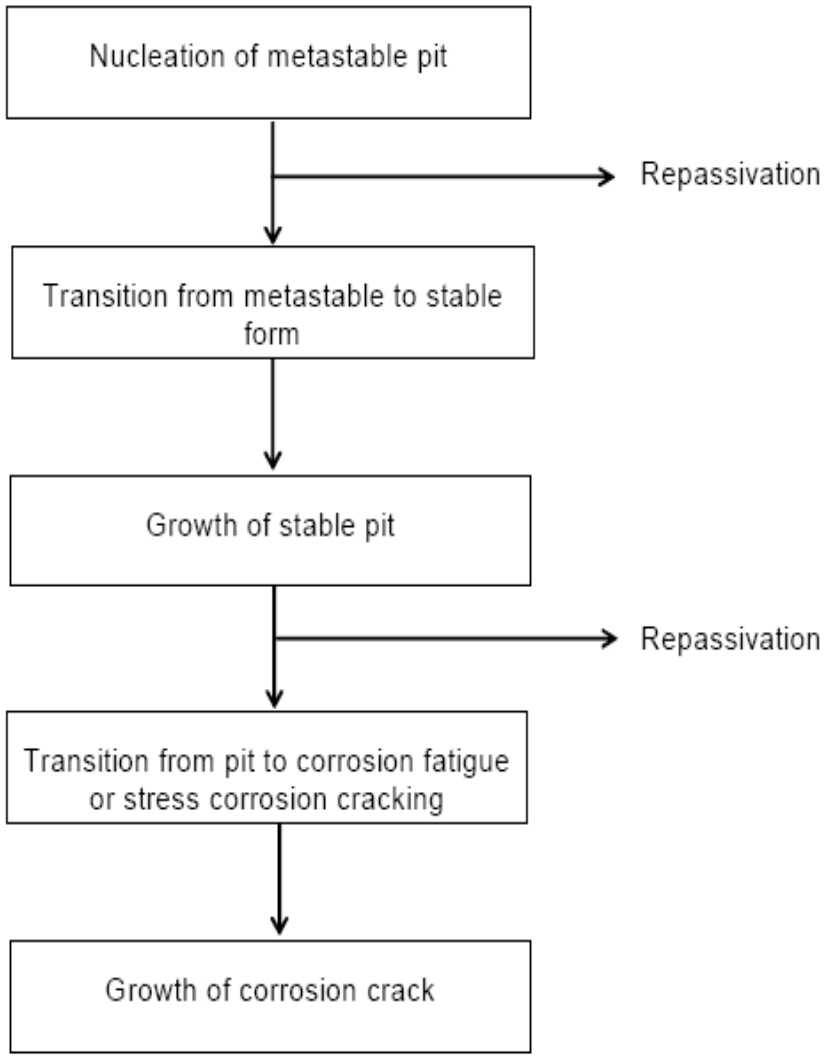
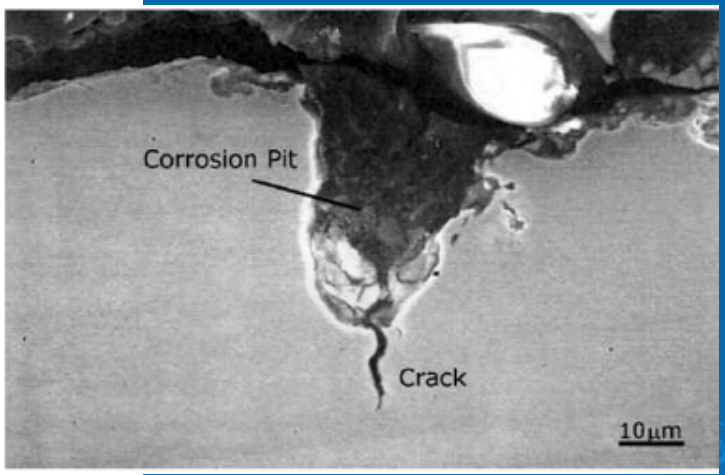
Steam Turbine Blade Failure Mechanisms

Failure Mechanism	Resultant Damage	Cause(s) of Failure
Corrosion	Extensive pitting of airfoils, shrouds, covers, blade root surfaces	Chemical attack from corrosive elements in the steam provided to the turbine
Creep	Airfoils, shrouds, covers permanently deformed	Deformed parts subjected to steam temperatures in excess of design limits
Erosion	Thinning of airfoils, shrouds, covers, blade roots	1) Solid particle erosion from very fine debris and scale in the steam provided in the turbine 2) Water droplet erosion from steam which is transitioning from vapor to liquid phase in the flowpath
Fatigue	Cracks in airfoils, shrouds, covers, blade roots	1) Parts operated at a vibratory natural frequency 2) Loss of part dampening (cover, tie wire, etc.) 3) Exceeded part fatigue life design limit 4) Excited by water induction incident – water flashes to steam in the flowpath
Foreign/Domestic Object Damage (FOD/DOD)	Impact damage (dents, dings, etc.) to any part of the blading	Damage from large debris in steam supplied to the turbine (foreign) or damage from debris generated from an internal turbine failure (domestic) which causes downstream impact damage to components
Stress Corrosion Cracking (SCC)	Cracks in highly stressed areas of the blading	Specialized type of cracking caused by the combined presence of corrosive elements and high stresses in highly loaded locations
Thermal Fatigue	Cracks in airfoils, shrouds, covers, and blade roots	Parts subjected to rapidly changing temperature gradients where thick sections are subjected to high alternating tensile and compressive stresses during heat-ups and cooldowns or when a water induction incident occurs where the inducted cool water quenches hot parts

History of Localized Corrosion Damages





Typical Locations of Disc Rim Cracking

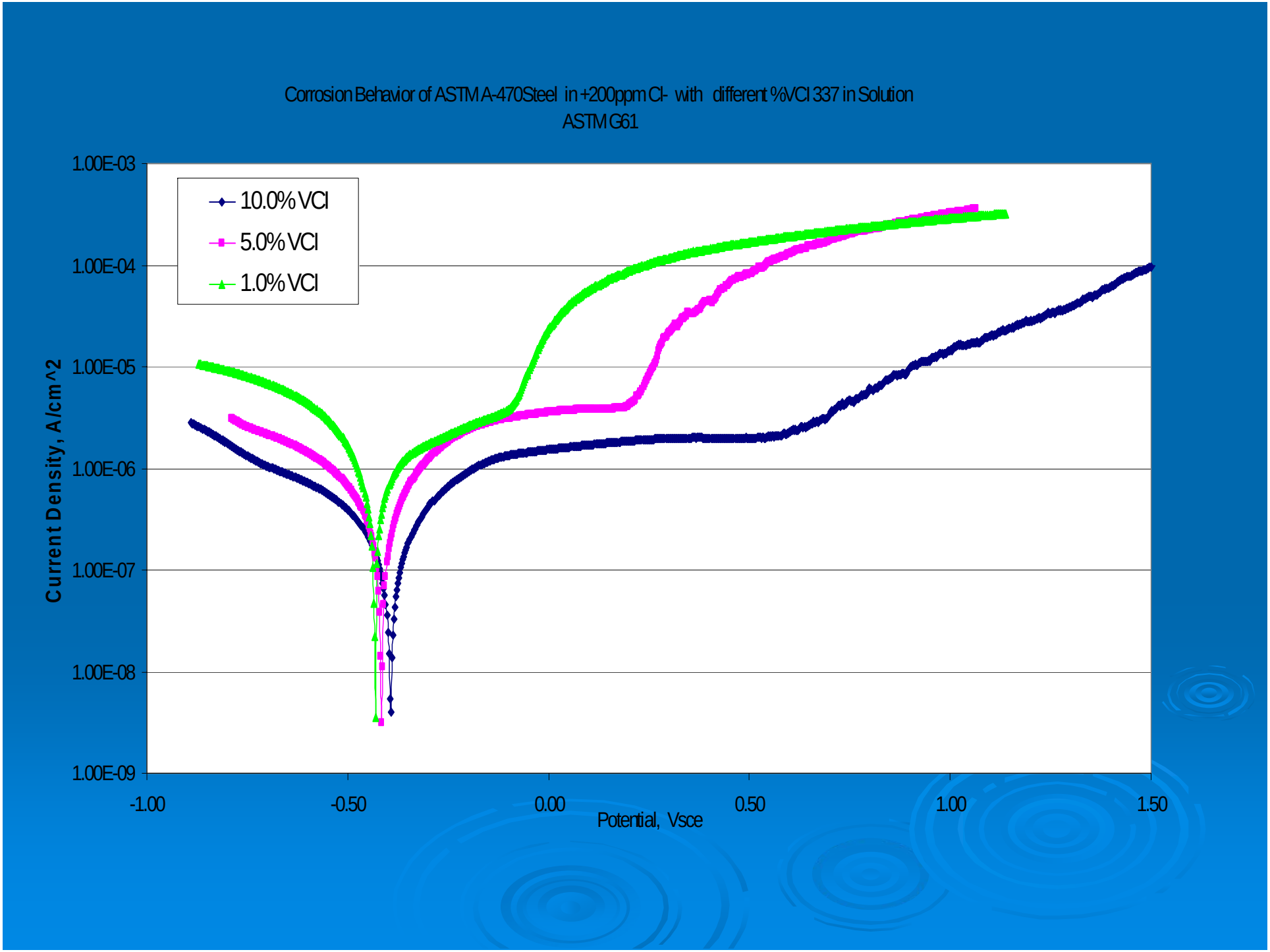
The buildup of damage due to localized corrosion, pitting, stress corrosion cracking and corrosion fatigue, in low pressure steam turbine blades, discs and rotors is a primary cause of most of turbine failures. Localized corrosion inhibitors can be used to protect steam turbines from the subsequent environment during shutdown and routine maintenance.

- Inhibition effectiveness of VCI 337 and Ecoline 3690 products was confirmed with electrochemical corrosion techniques in different concentrations of inhibitor and Stress corrosion cracking/Crevice corrosion tests in Anodic potential range.

- The Object of this phase Research:
  - 1. to investigate possible side effect VCI inhibitors to cause Hydrogen Embrittlement
  - 2. to define Critical Pitting Temperature

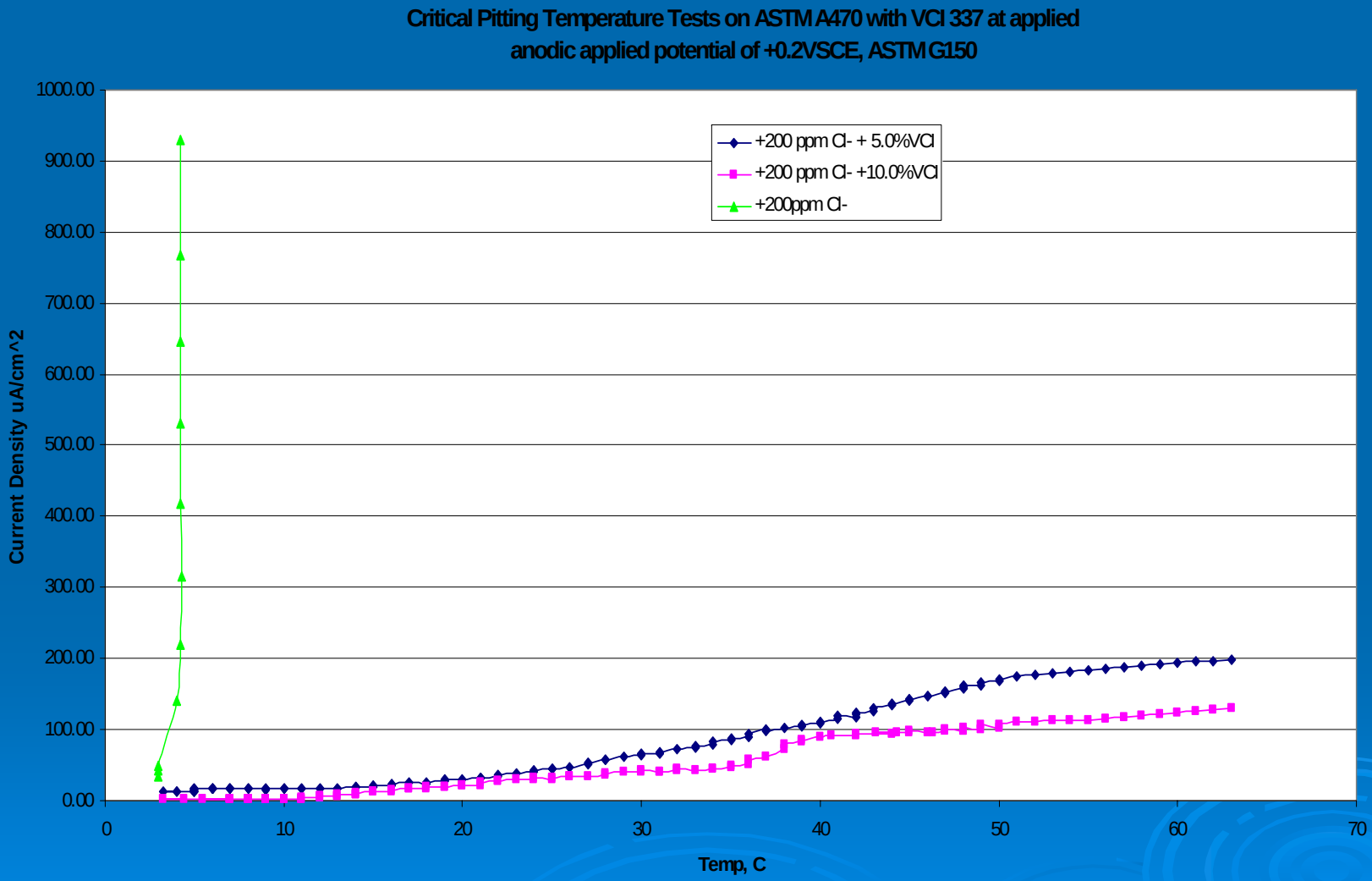
- Critical pitting Temperature (ASTM G150) Corrosion Tests on ASTM A470 in different solutions of VpCI 337 and Ecoline 3690

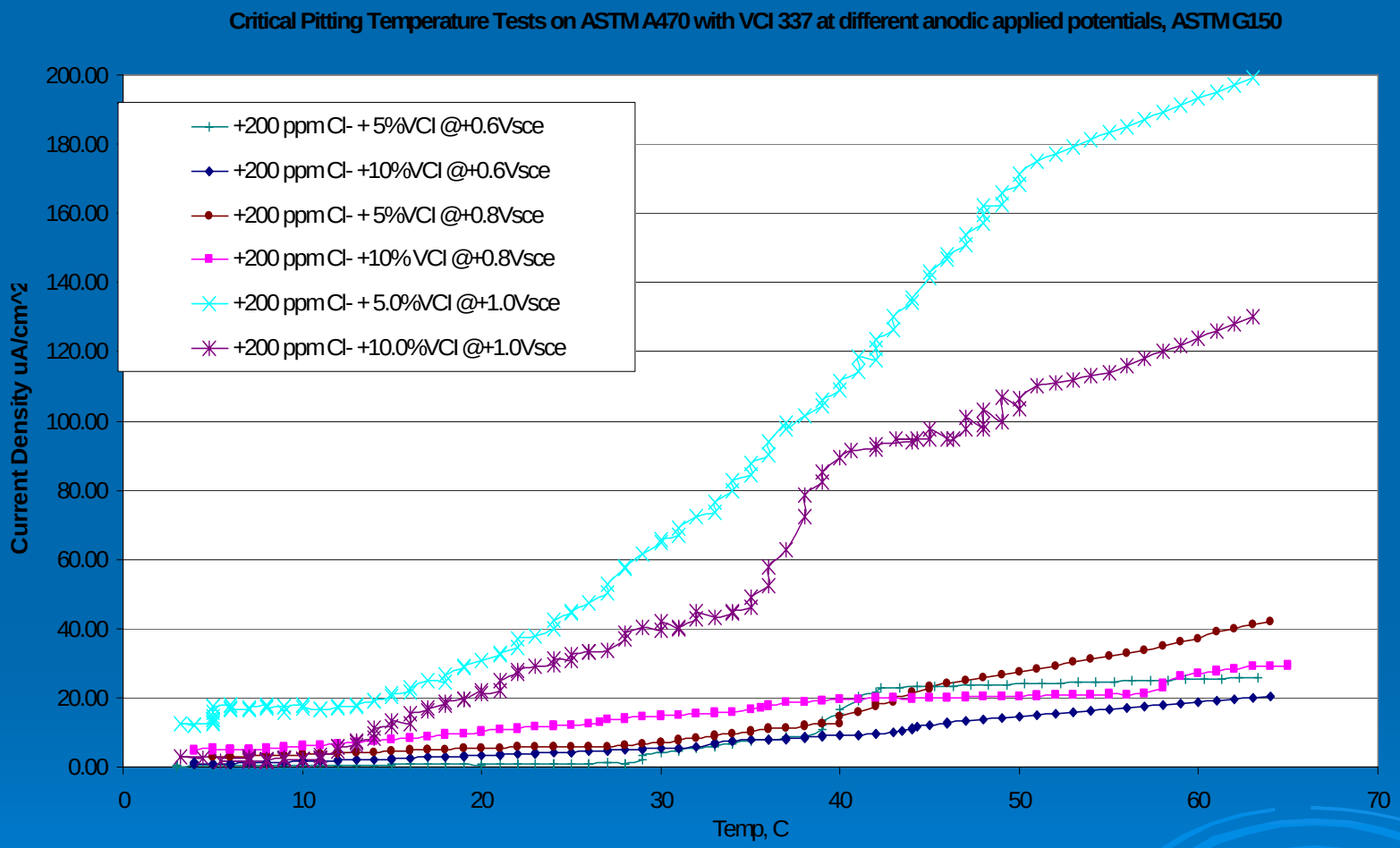
Environment	Inhibitor Concentration, %	# of Tests
water +200 ppm Cl-	1.0	4
water +200 ppm Cl-	5.0	4
water +200 ppm Cl-	10.0	4
water +200 ppm Cl-	50.0	4

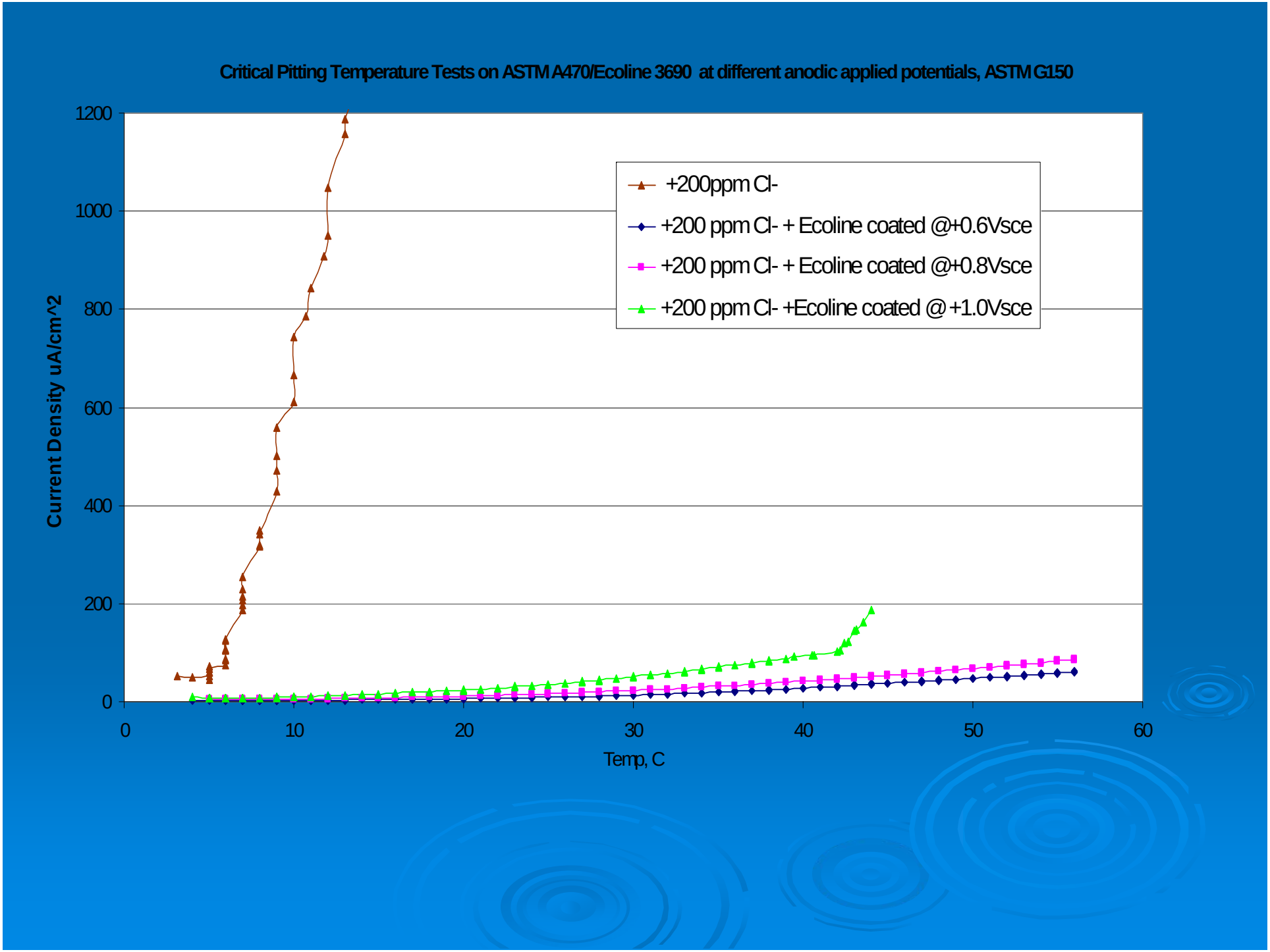

Corrosion Behavior of ASTM A-470 Steel in +200ppm Cl- with different %VCI 337 in Solution
ASTM G61
10.0% VCI
5.0% VCI
1.0% VCI
Current Density, A/cm^2
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
-1.00
-0.50
0.00
0.50
1.00
1.50
Potential, Vsce

Electrochemical Polarization Behavior of ASTM A470 in Different Solutions

Sample	Ec,	Ic	Eb,	CR,	Passive range	Ipss
	mVsce	uA/cm^2	mVsce	mpy	mVsce	uA/cm^2
200ppm Cl- +0.0%VCI	-675	1.47	-450	0.63	none	NA
200ppm Cl- +1.0%VCI	-460	0.389	+45	0.17	-300 to +20	3.12
200ppm Cl- +5.0%VCI	-415	0.304	+240	0.13	-200 to +200	3.22
200ppm Cl- +10.0%VCI	-392	0.0832	+1060	0.04	-100 to +950	1.92

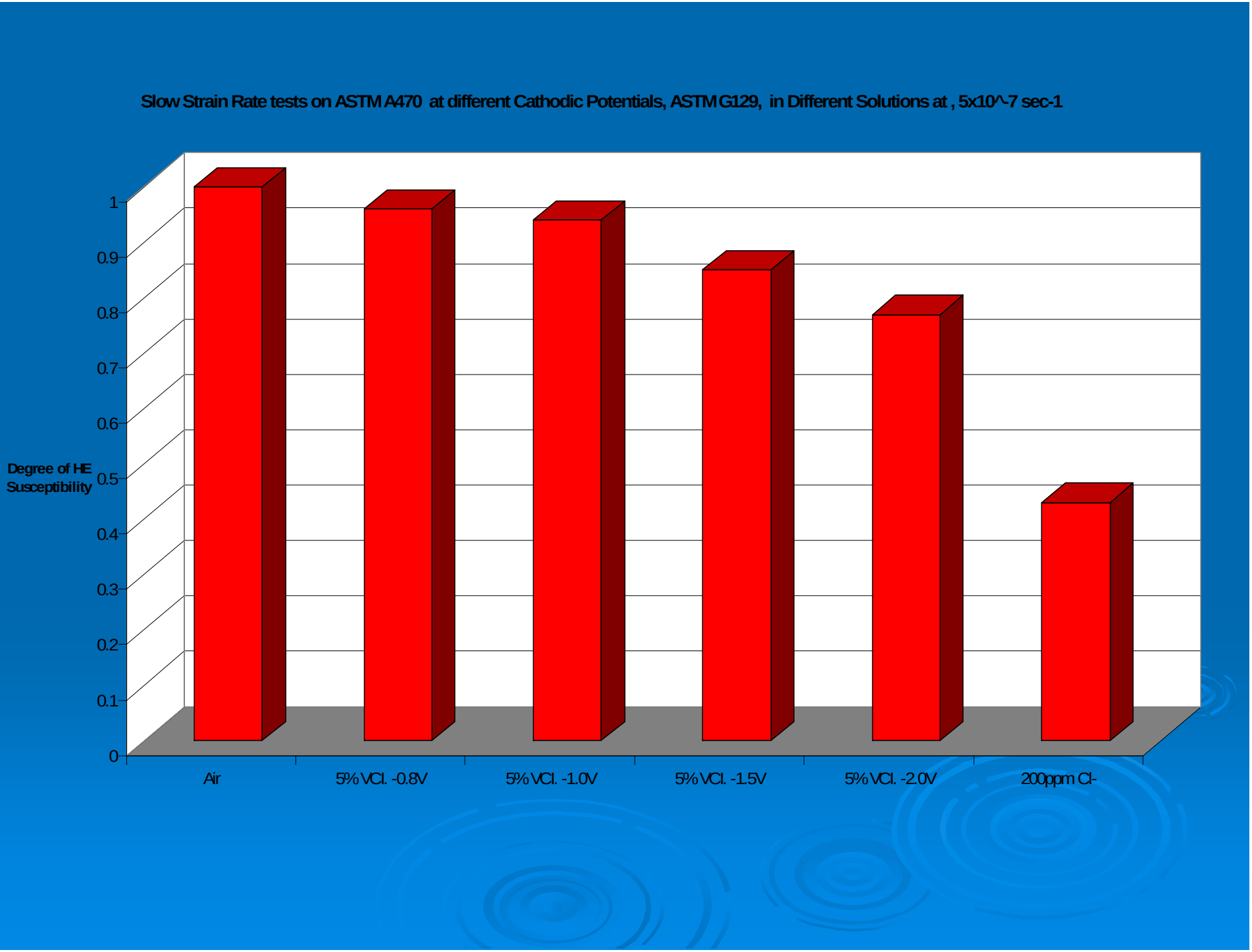

Critical Pitting Temperature Tests on ASTM A470 with VCI 337 at applied anodic applied potential of +0.2VSCE, ASTM G150
Current Density uA/cm^2
1000.00
900.00
800.00
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
0
10
20
30
40
50
60
70
Temp, C
+200 ppm Cl- + 5.0%VCI
+200 ppm Cl- +10.0%VCI
+200ppm Cl-


Critical Pitting Temperature Tests on ASTM A470 with VCI 337 at different anodic applied potentials, ASTM G150
Current Density uA/cm^2
200.00
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0
10
20
30
40
50
60
70
Temp, C
+200 ppm Cl- + 5%VCI @+0.6Vsce
+200 ppm Cl- +10%VCI @+0.6Vsce
+200 ppm Cl- + 5%VCI @+0.8Vsce
+200 ppm Cl- +10% VCI @+0.8Vsce
+200 ppm Cl- + 5.0%VCI @+1.0Vsce
+200 ppm Cl- +10.0%VCI @+1.0Vsce

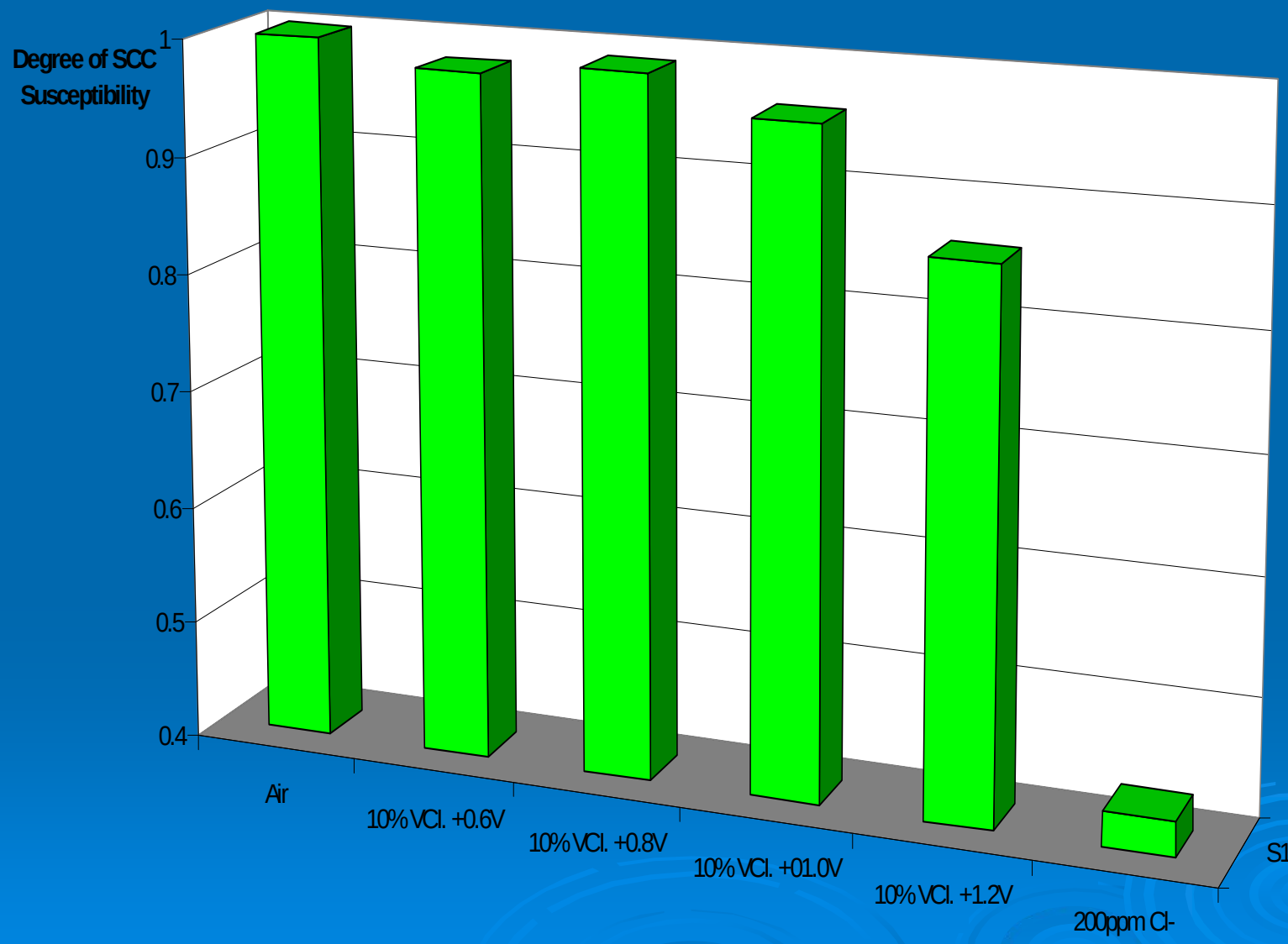

Critical Pitting Temperature Tests on ASTM A470/Ecoline 3690 at different anodic applied potentials, ASTM G150
Current Density uA/cm^2
1200
1000
800
600
400
200
0
0
10
20
30
40
50
60
Temp, C
+200ppm Cl-
+200 ppm Cl- + Ecoline coated @+0.6Vsce
+200 ppm Cl- + Ecoline coated @+0.8Vsce
+200 ppm Cl- +Ecoline coated @ +1.0Vsce

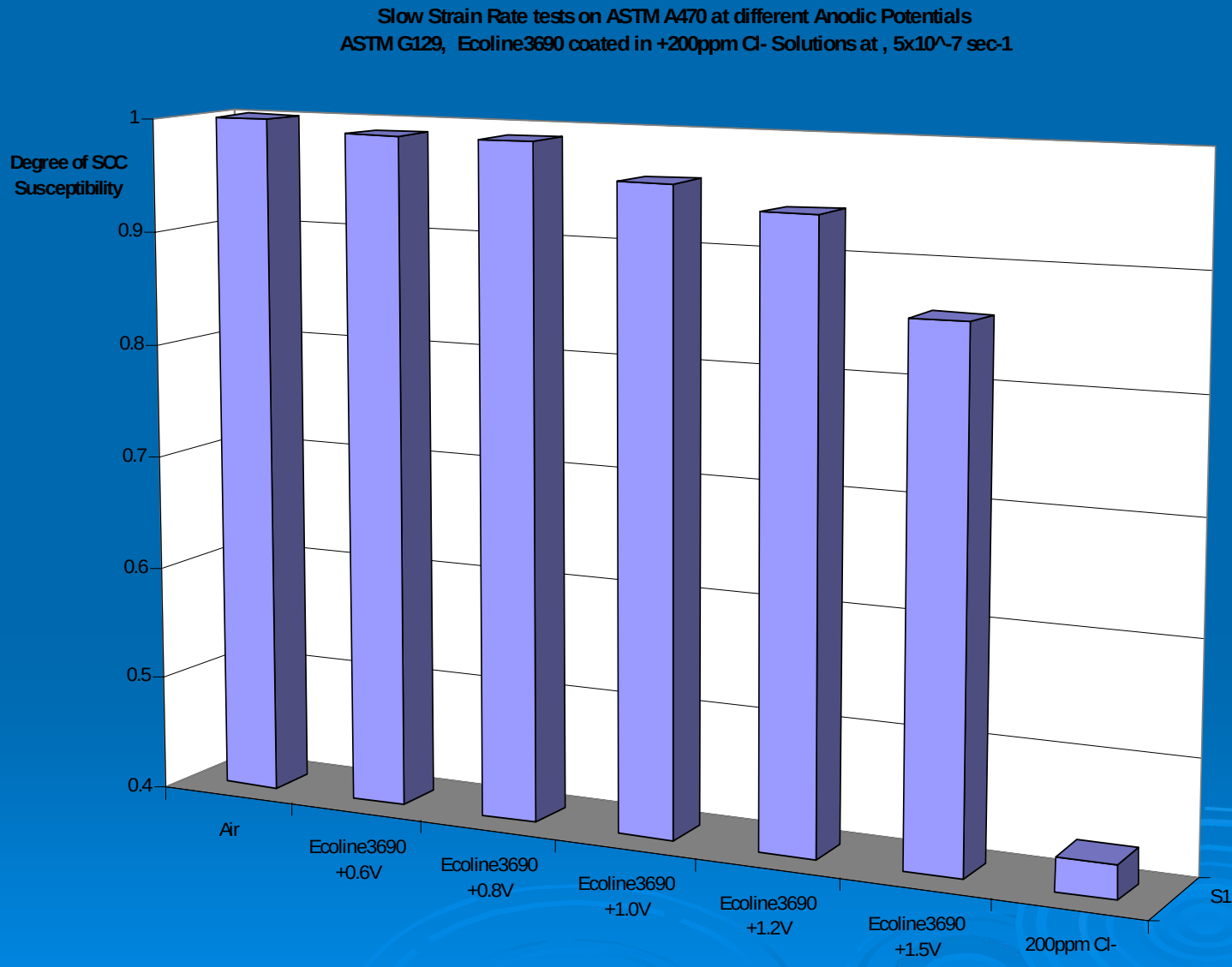
- HE Corrosion Tests on ASTM A470 using the slow strain rate techniques in 5% VCI 337 solutions, Strain Rate = 5x10-7 cm-1.

Environment	Applied Potential, Vsce	# of Test each alloy
water +200 ppm Cl-	-0.80	2
water +200 ppm Cl-	-1.00	2
water +200 ppm Cl-	-1.50	2


Slow Strain Rate tests on ASTM A470 at different Cathodic Potentials, ASTM G129, in Different Solutions at , 5x10^-7 sec-1
Degree of HE Susceptibility
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Air
5% VCl. -0.8V
5% VCl. -1.0V
5% VCl. -1.5V
5% VCl. -2.0V
200ppm Cl-

Slow Strain Rate tests on ASTM A470 at different Anodic Potentials
ASTM G129, in 10%VCl 337 Solutions at , 5x10^-7 sec-1



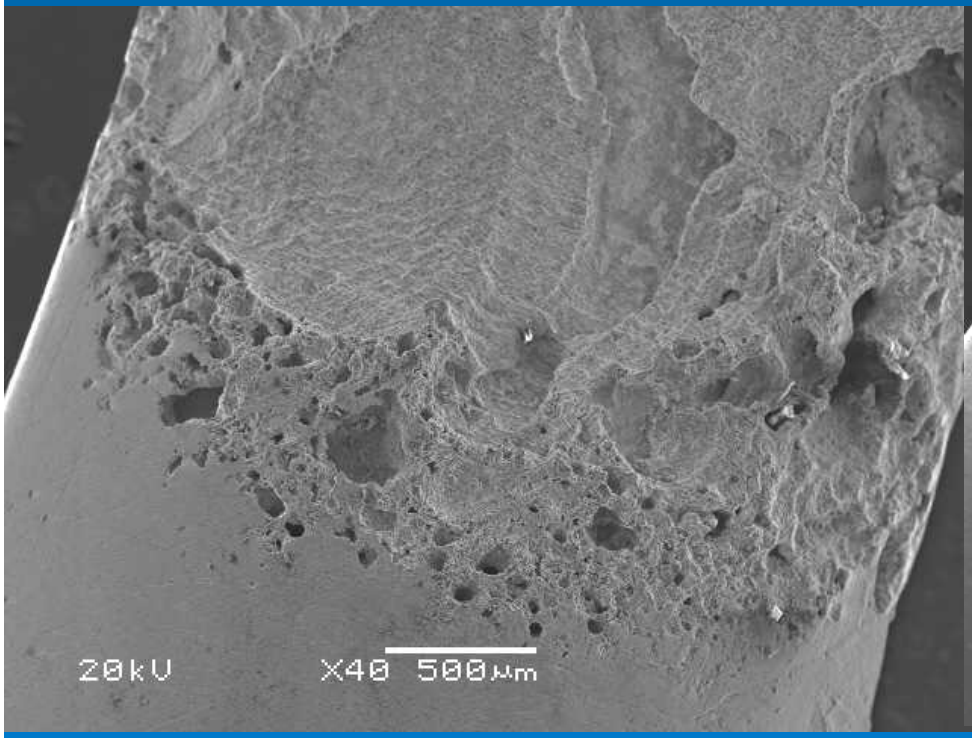

Slow Strain Rate tests on ASTM A470 at different Anodic Potentials
ASTM G129, Ecoline3690 coated in +200ppm Cl- Solutions at , 5x10^-7 sec-1
Degree of SCC Susceptibility
1
0.9
0.8
0.7
0.6
0.5
0.4
Air
Ecoline3690 +0.6V
Ecoline3690 +0.8V
Ecoline3690 +1.0V
Ecoline3690 +1.2V
Ecoline3690 +1.5V
200ppm Cl-
S1

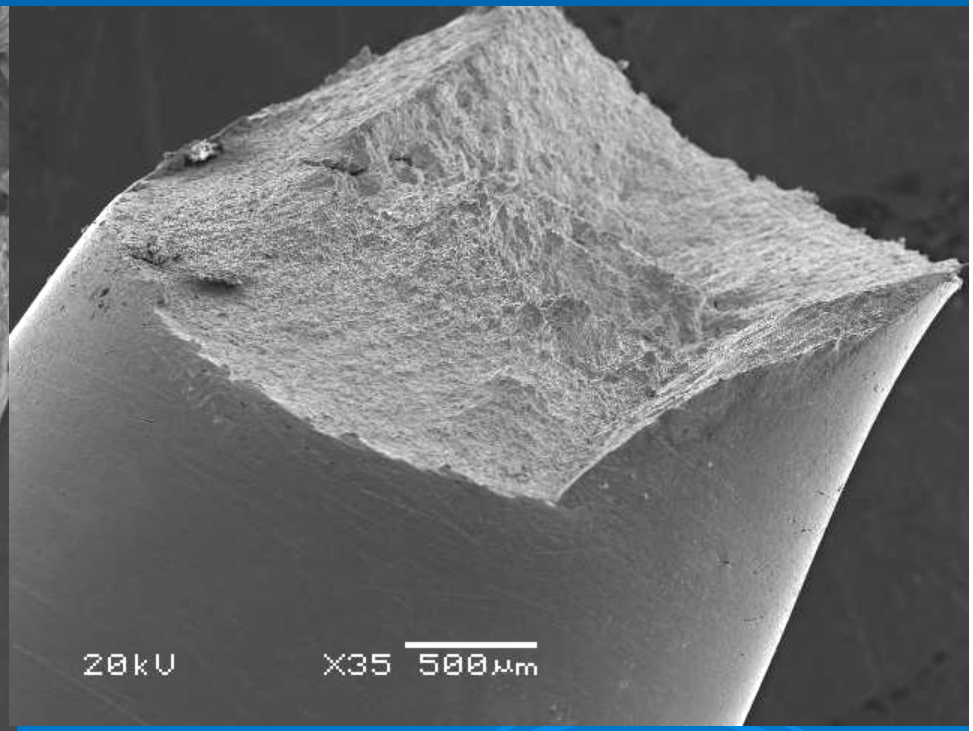
- SCC Corrosion Tests on ASTM A470 using the slow strain rate techniques in Ecoline 3690 coated samples, Strain Rate = 5x10-7 cm-1.

Environment	Applied Potential, Vsce	# of Test each alloy
water +200 ppm Cl-	-0.80	2
water +200 ppm Cl-	-1.00	2
water +200 ppm Cl-	-1.50	2

SCC of ASTM A470

- +200ppm Cl- (-0.2 Vsce)
- +10.0% VCl, (+1.0Vsce)

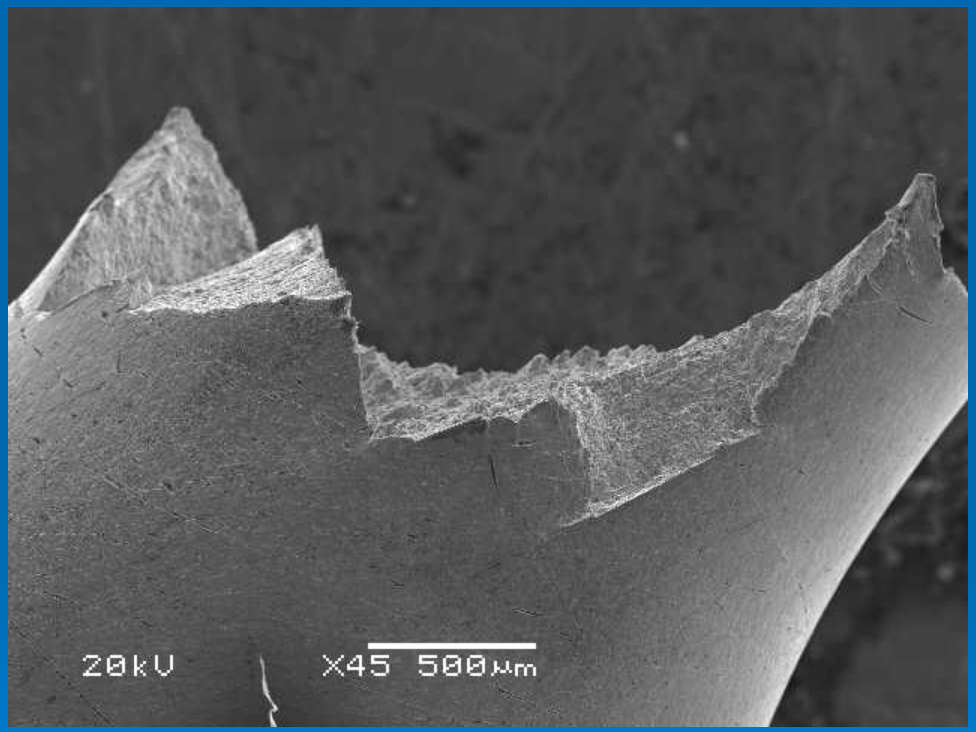




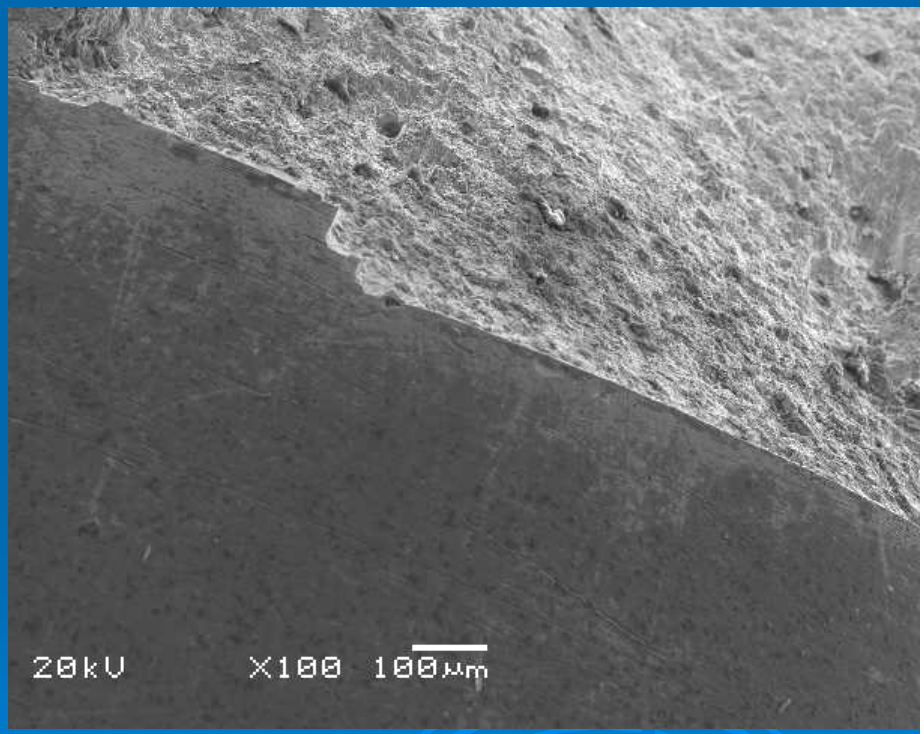
SCC of ASTM A470

E= +1.0 Vsce

- +200ppm Cl-

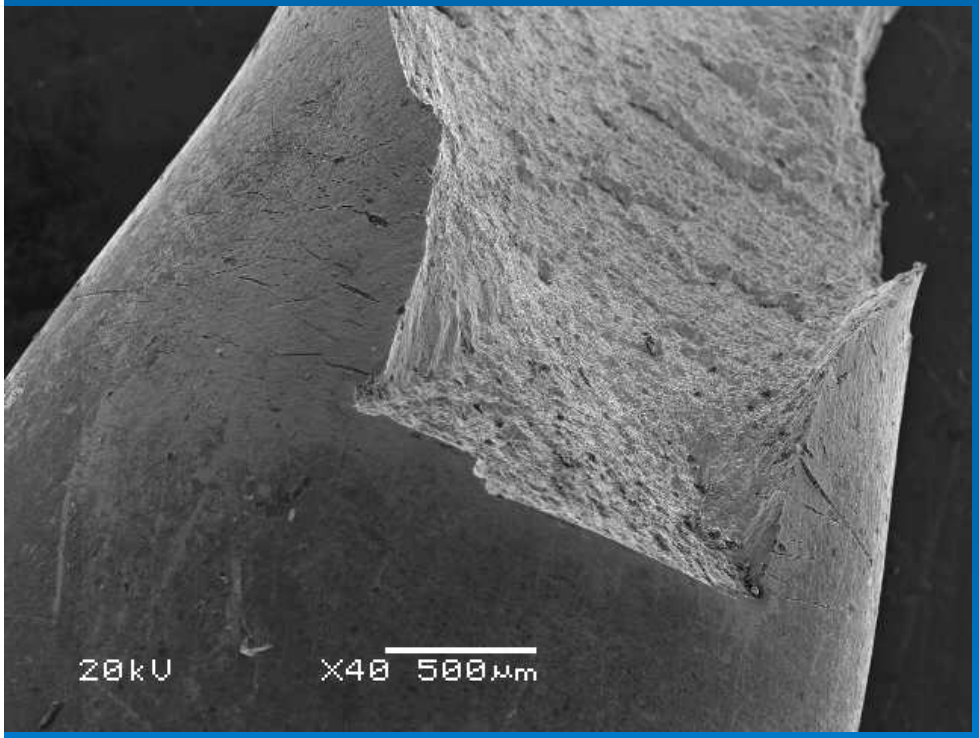


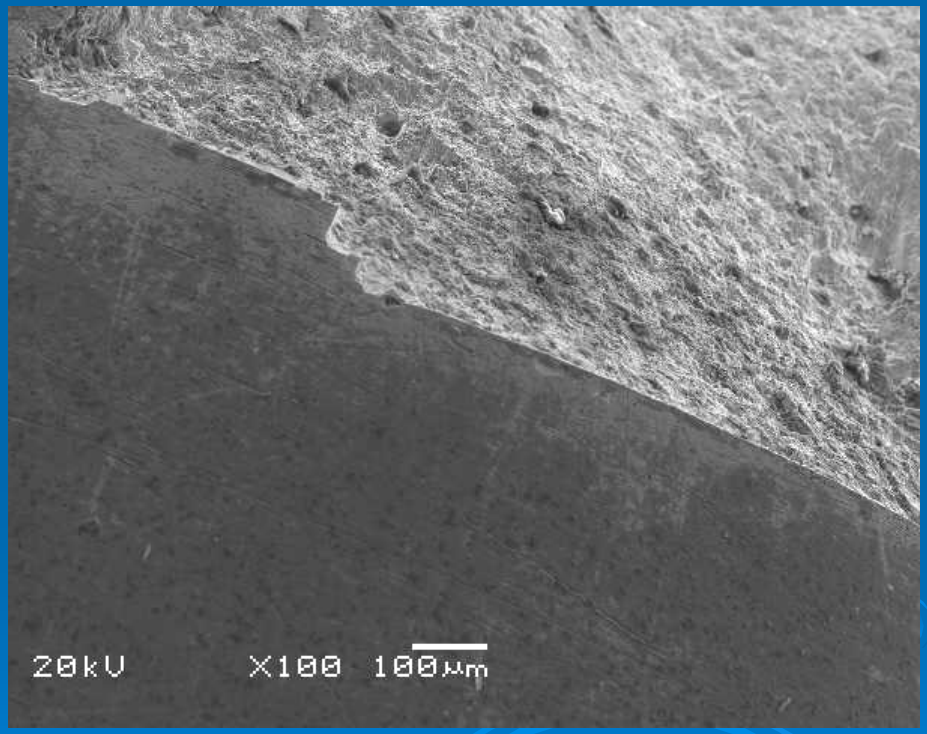
- +10.0% VCI



SCC of ASTM A470

E= +1.0 Vsce, 10.0% VCI A

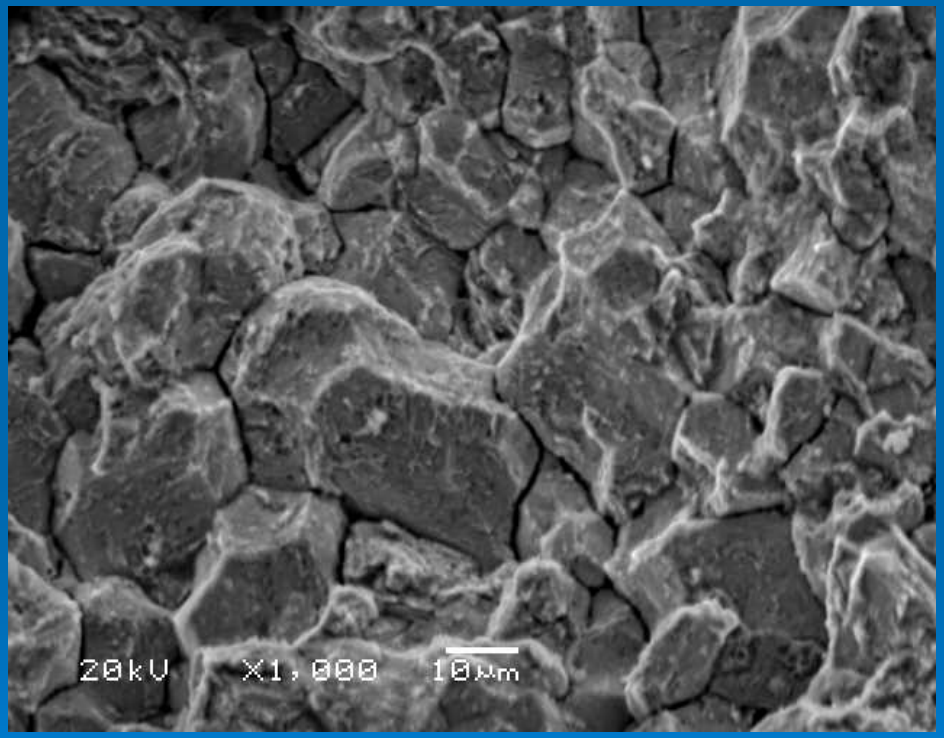




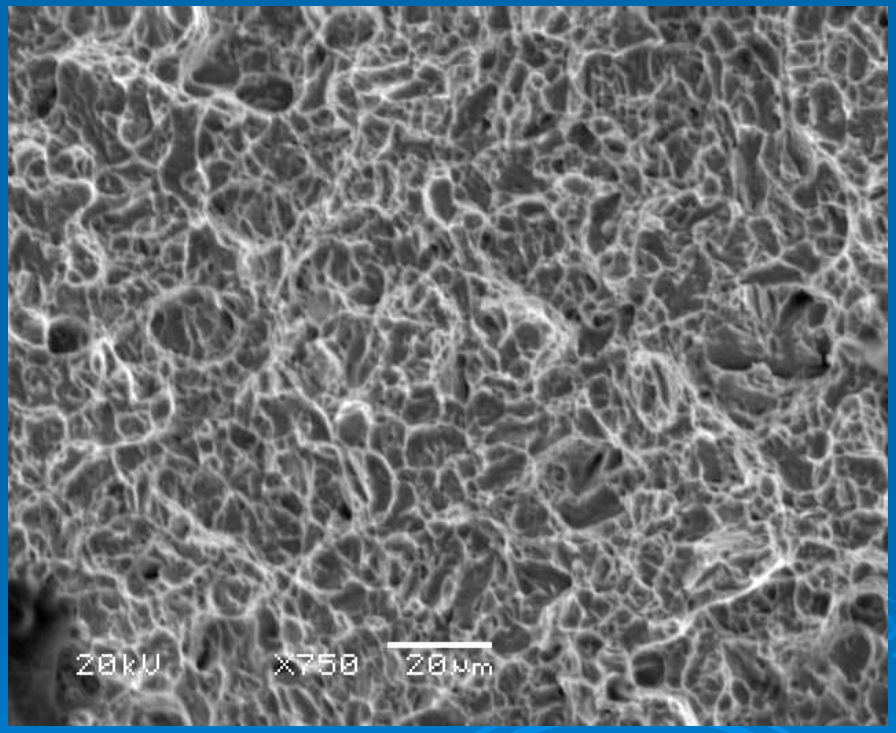
SCC of ASTM A470

E= -0.2 Vsce

- +200ppm Cl-



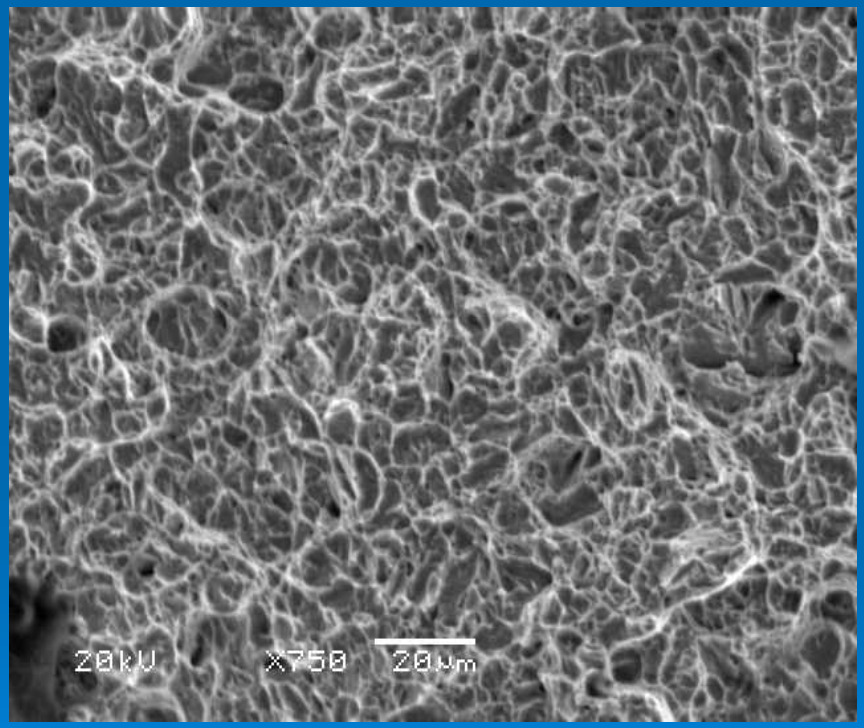
- 5.0% VCI



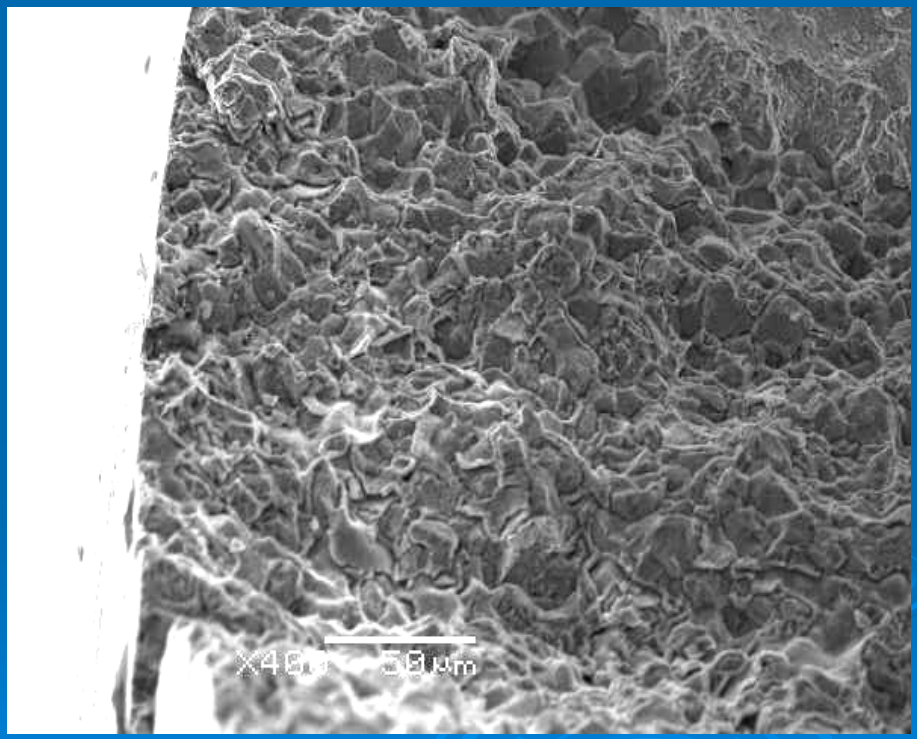
SCC of ASTM A470

in 200ppm Cl- + 50 ppm S= +10%VCl

- E= -1.0 Vsce



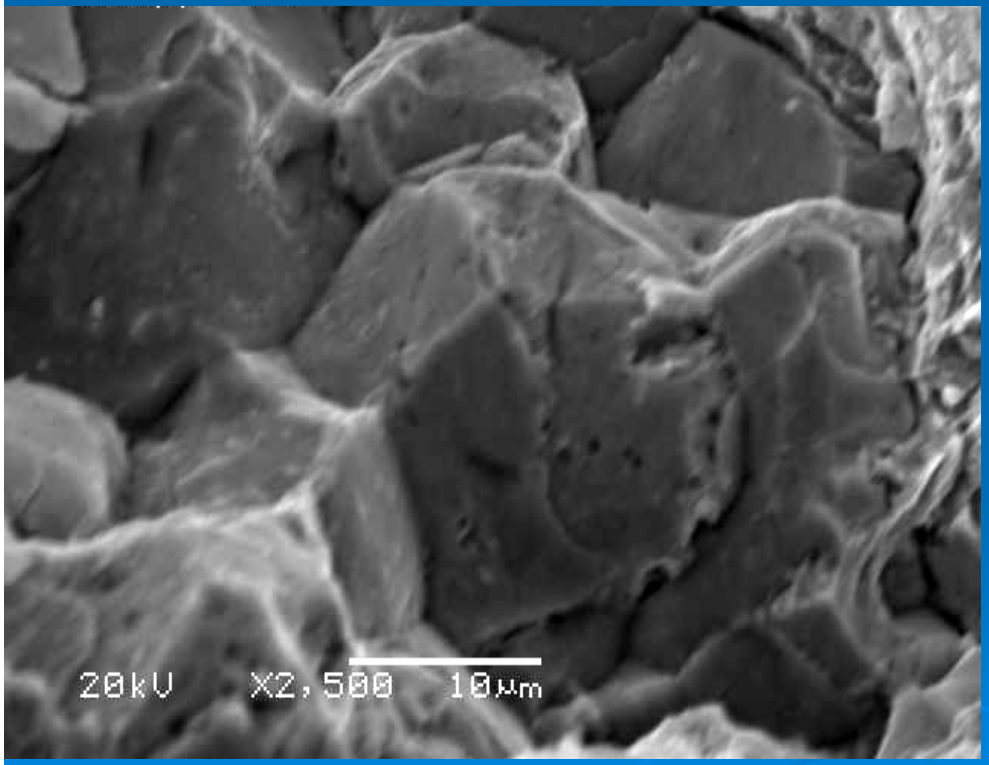
- E= -1.5 Vsce

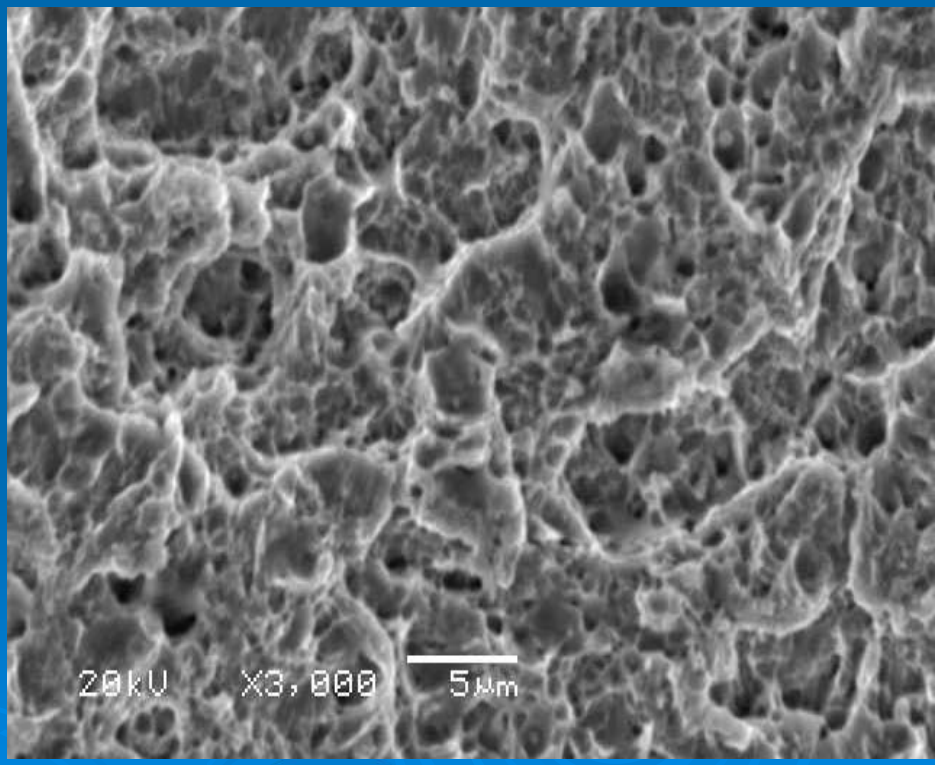


SCC of ASTM A470

E= -1.0 Vsce

- +200ppm Cl- + 50ppm S=
- pH 2.6
- +10.0% VCl





Summary

- HE tests confirmed that none of VCI inhibitors could cause any harmful effect on ASTM A470 up to -1.5 Vsce.
- Presence of both VCI 337 and Ecoline 3690 inhibitors increased critical pitting temperature to 45-50^{o}C, while non-protect ASTM A470 showed a CPT of 8^{o}C in 200ppm Cl^{-} solution.
- In Summary, addition of 10%VpCI337 reduces susceptibility of ASTM A470 steel to SCC and HE in a wide potential range of -1.5 to +1.0Vsce.

- VpCI 337 inhibitor provides an effective corrosion protection for both ASTM A470 steel and 7050 Al-alloys during the shutdown period for the blades and discs in low pressure steam turbines, therefore its addition in the turbo-machinery systems is recommended to preserve and protect metallic components during maintenance and long term shutdown.