

Background



Cracking of Water Jacket in Service

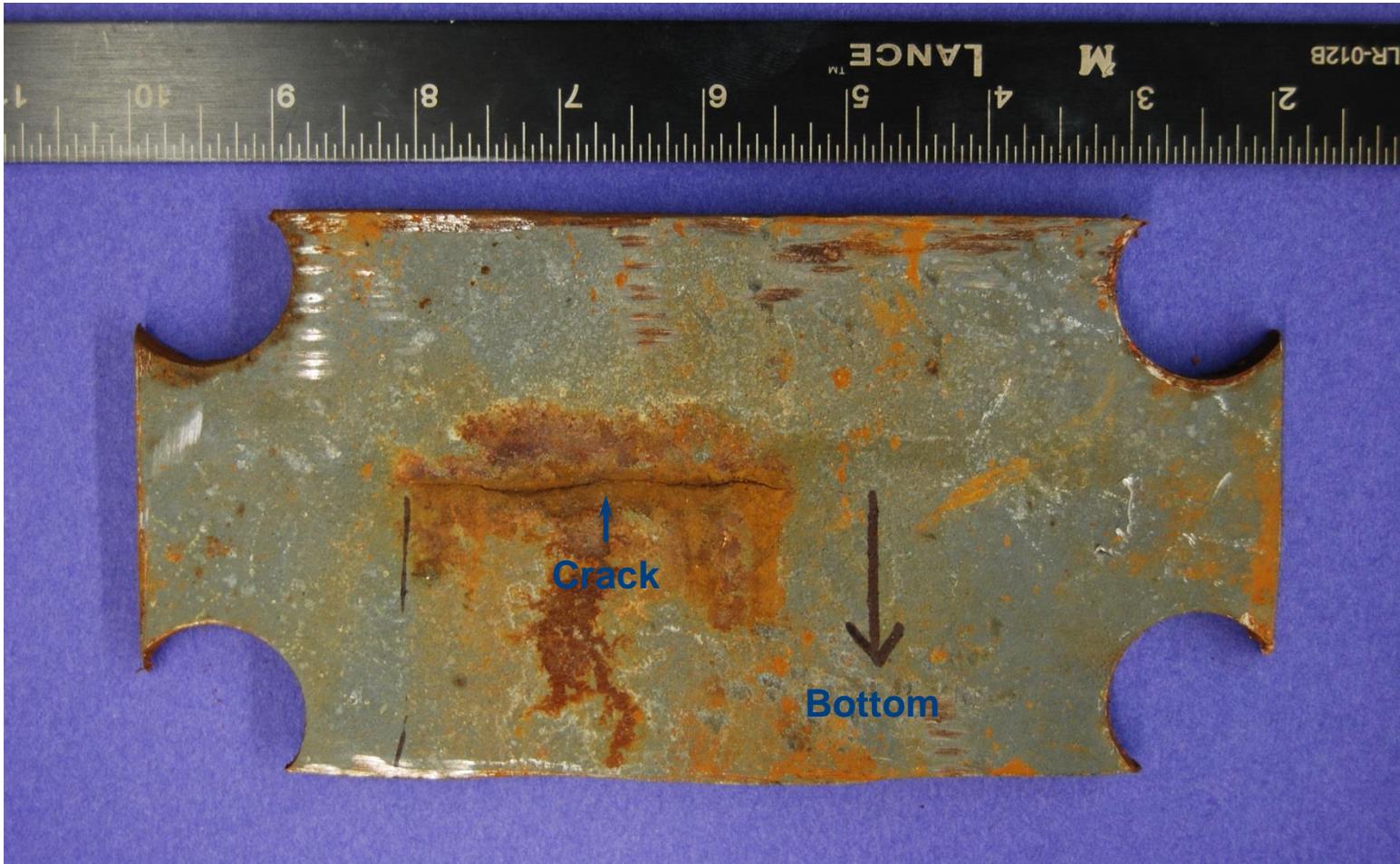


- Material is carbon steel A516 – Grade 70.
- Horizontal cracking 2-3 ft below a stiffener ring almost in line with nozzle L2.
 - Pinhole observed near the corner of the baffle weld.
 - Additional cracks forming.



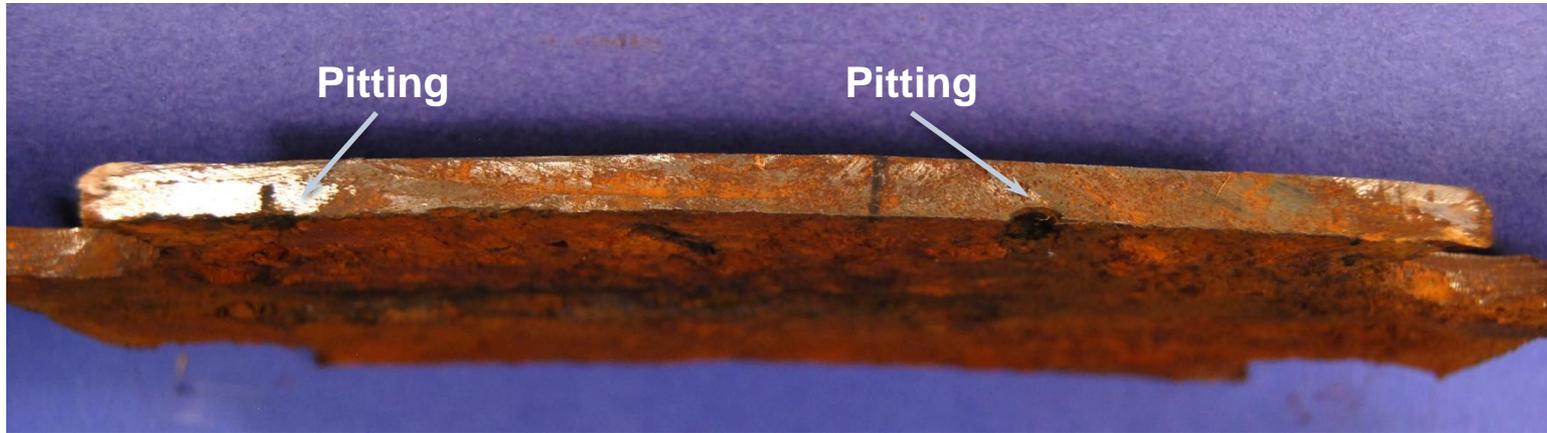
DATE	pH	Cond.	Iron	MOo4	Microbio
11/20/2015	9.4	445	0.59	280	10
10/2/2015	9.1	588	1.1	320	10
7/21/2015	8.4	245	1.1	120	10
6/10/2015	8.2	345	0.75	190	10
4/9/2015	8.5	325	1.1	225	10
3/20/2015	7.8	210	0.99	20	10
3/6/2015	8.9	299	0.7	110	10
2/26/2015	8.9	290	0.7	100	10
2/12/2015	8.8	320	0.79	80	10
1/30/2015	8.6	460	0.6	100	10
1/8/2015	8.6	510	0.8	140	10

As-Received Section of the Water Jacket



As-received jacket wall section showing through wall crack. Arrow indicates the "top" of the vessel.

As-Received Section of the Water Jacket

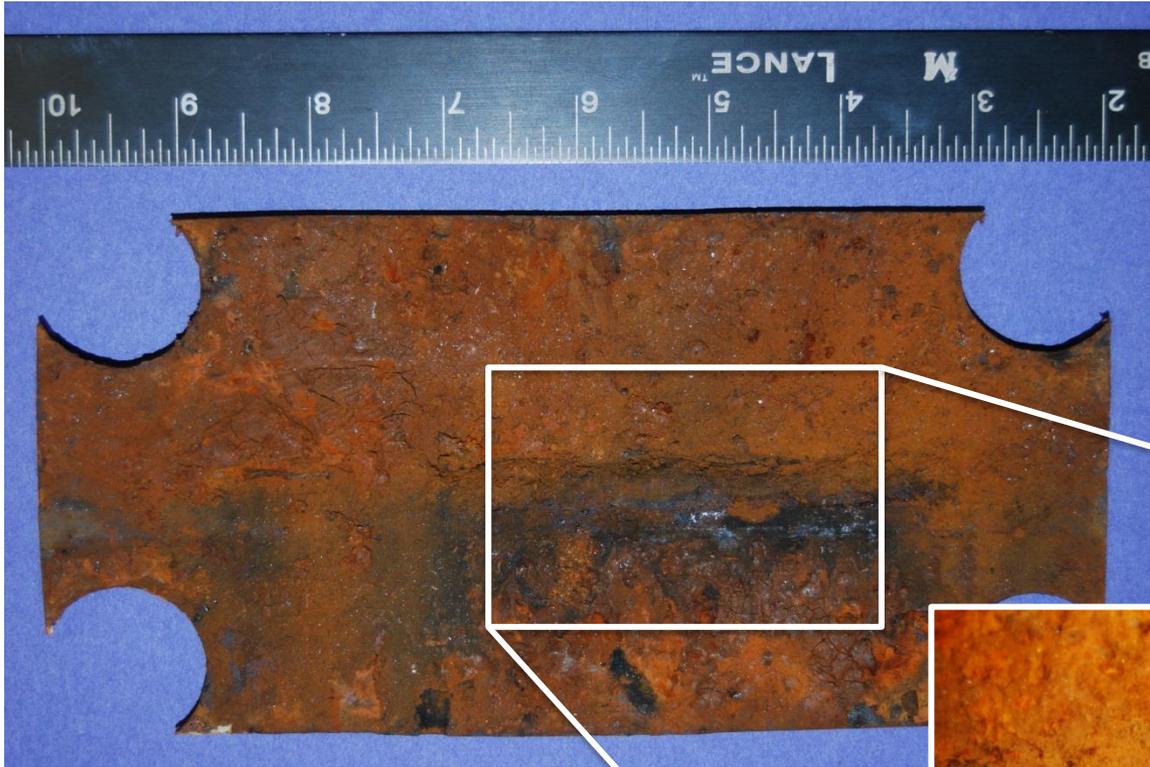


	1	2	3	4	5	6
Thickness (in)	0.25	0.23	0.25	0.26	0.25	0.25
Thickness (mm)	6.35	5.84	6.35	6.60	6.35	6.35

Chemical Composition Analysis

Element (wt%)		ASTM A516-Gr. 70	Base Metal	Weld
Carbon	(C)	0.31	-	-
Iron	(Fe)	98.32	97.68	97.65
Manganese	(Mn)	0.85 - 1.2	1.02	1.01
Phosphorous	(P)	0.035	-	-
Silicon	(Si)	0.15 - 0.40	0.304	-
Sulfur	(S)	0.040	-	-
Zinc	(Zn)		0.139	-
Low Elements Correction	LEC		0.75	1.29

Inside Surface of the Water Jacket Section Post Partial Cleaning



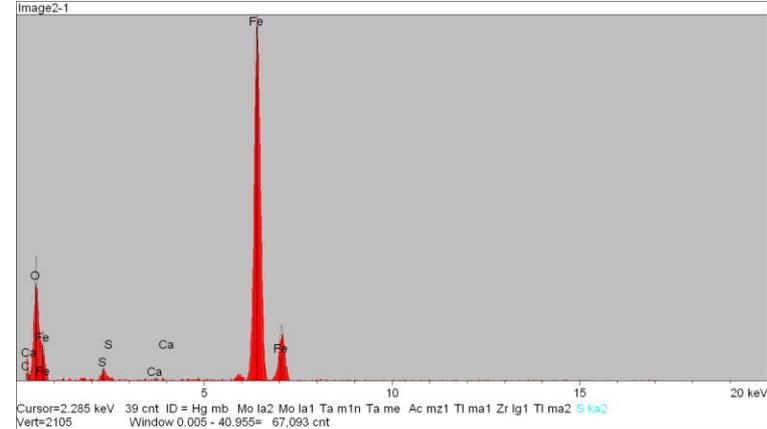
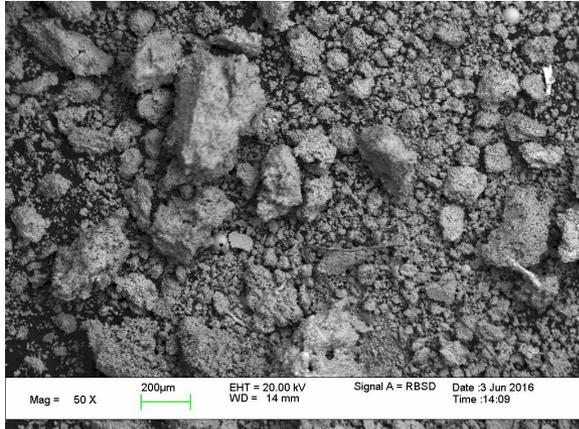
Cracking occurred near stitch weld.

Metal thinning (grooving) observed at cracked location.

Additional corrosion and metal thinning observed.



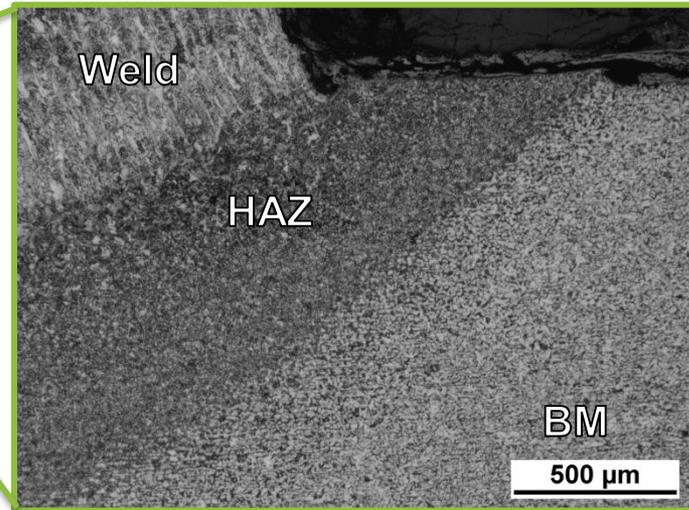
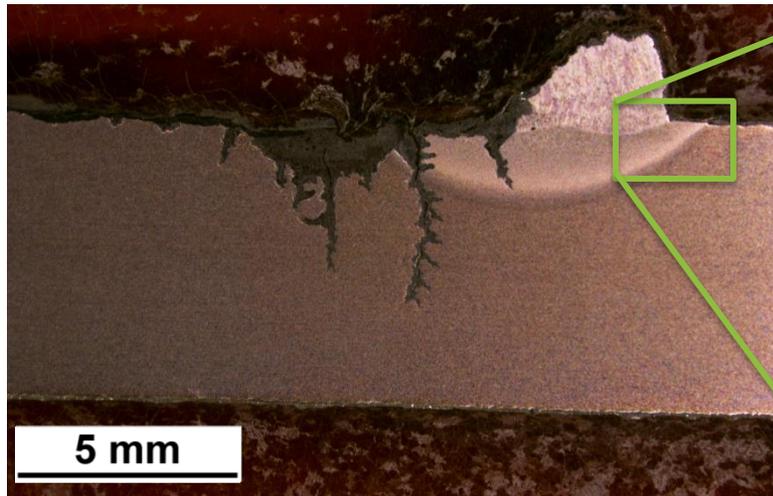
EDS Characterization of Scale



Element (wt%)	Intensity (c/s)	Error 2-sig	Concentration (wt%)
Oxygen (O)	160.58	4.504	13.693
Molybdenum (Mo)	21.44	2.790	0.843
Calcium (Ca)	3.97	2.355	0.149
Iron (Fe)	961.06	10.335	85.315

Analysis of scale product removed from the interior surface of the water jacket showed that the scale was mostly iron oxide (Fe_2O_3) with minor concentration of molybdenum (Mo)—should be noted that sulfur (S) and Mo peaks overlap in the EDS spectrum and if S is present is difficult to differentiate the species.

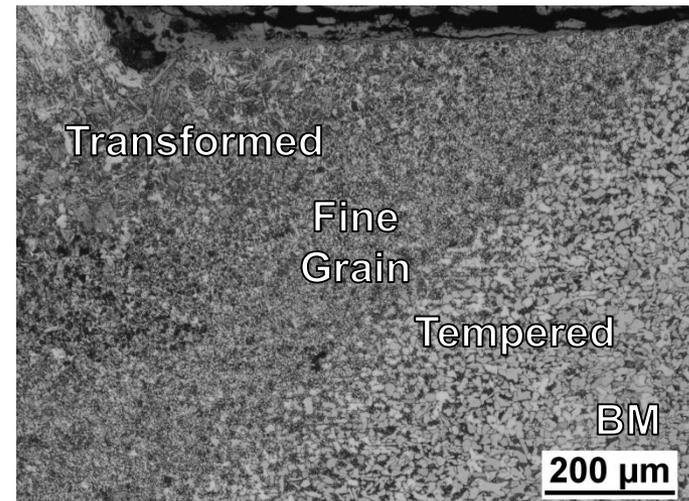
Metallography



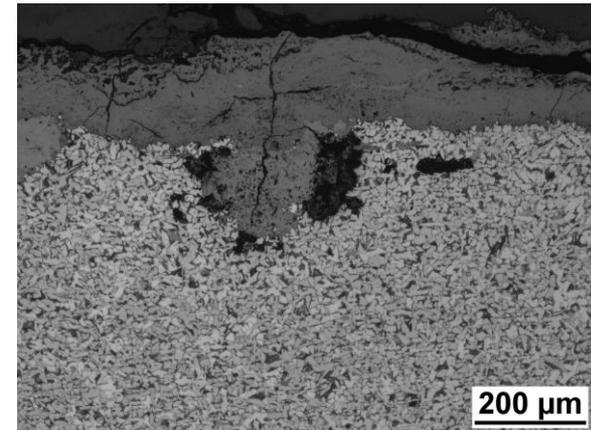
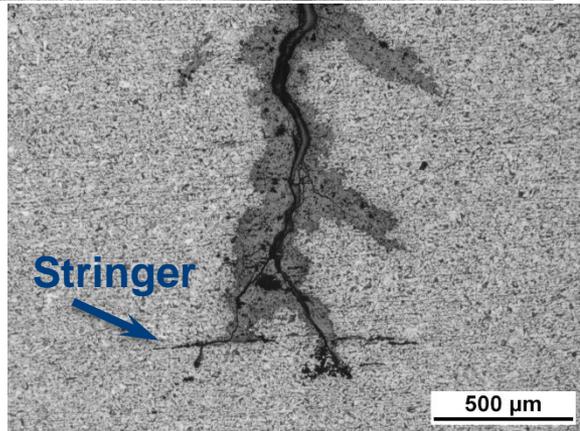
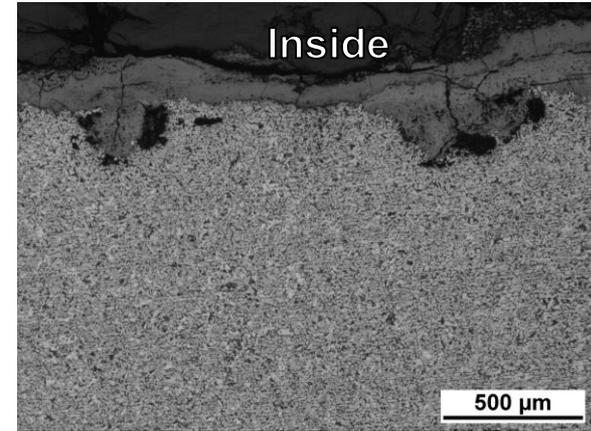
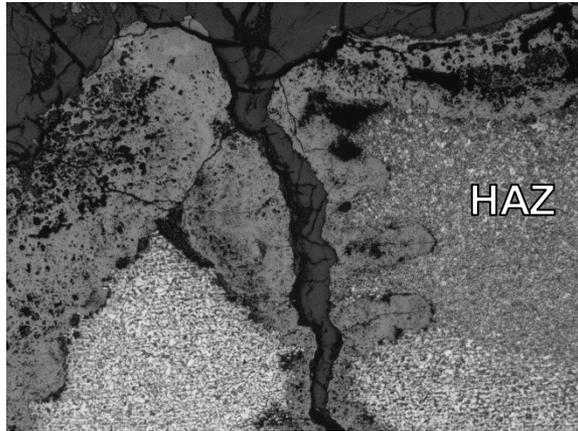
Etched cross-section taken at the location where cracking was present, near the baffle welds.

Microstructure of the base metal (BM) plate is ferrite and pearlite. The weld heat affected zone (HAZ) showed microstructure typical of as-welded material.

Cracking was not localized within the HAZ of the weld.

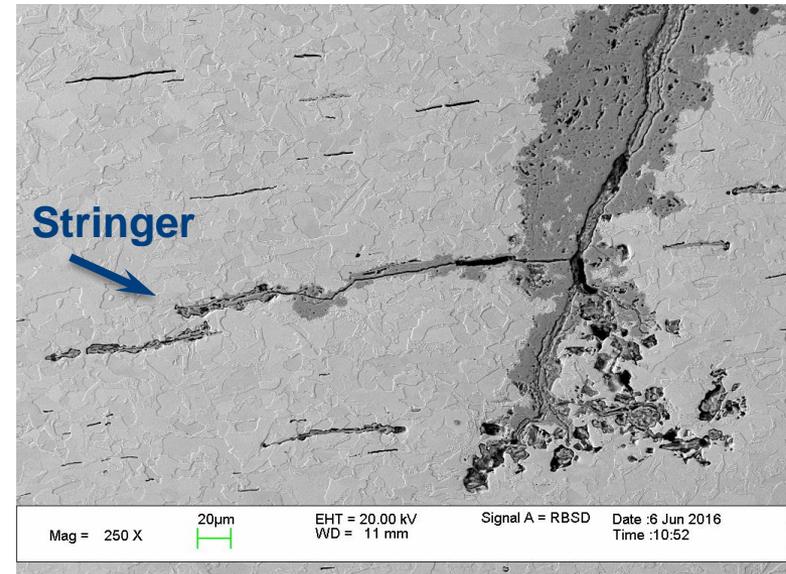
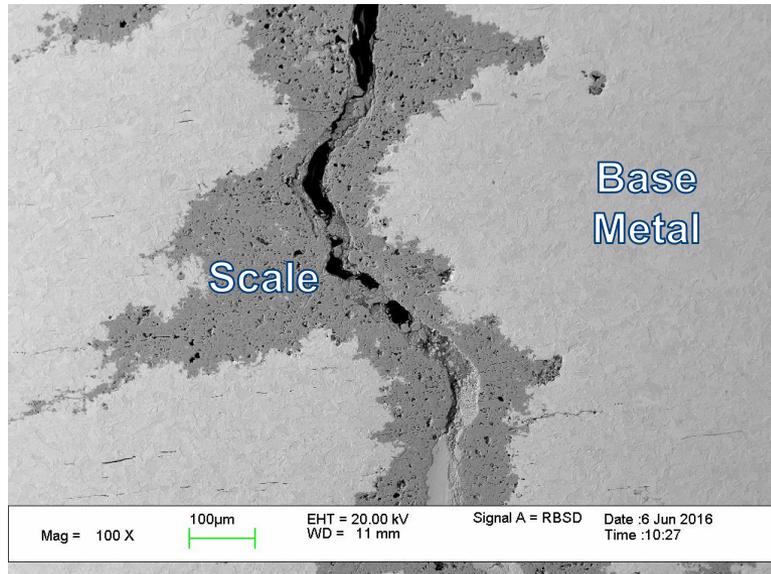


Metallography



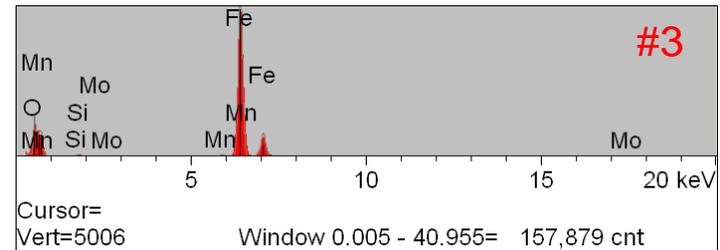
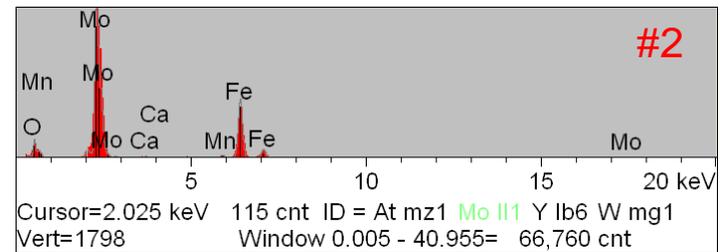
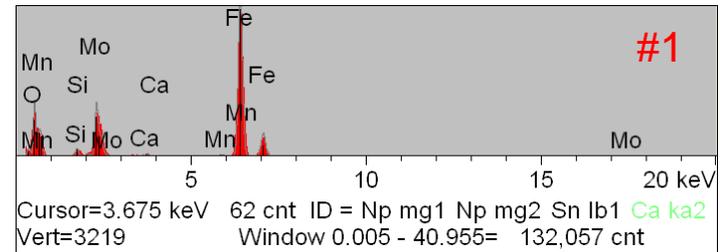
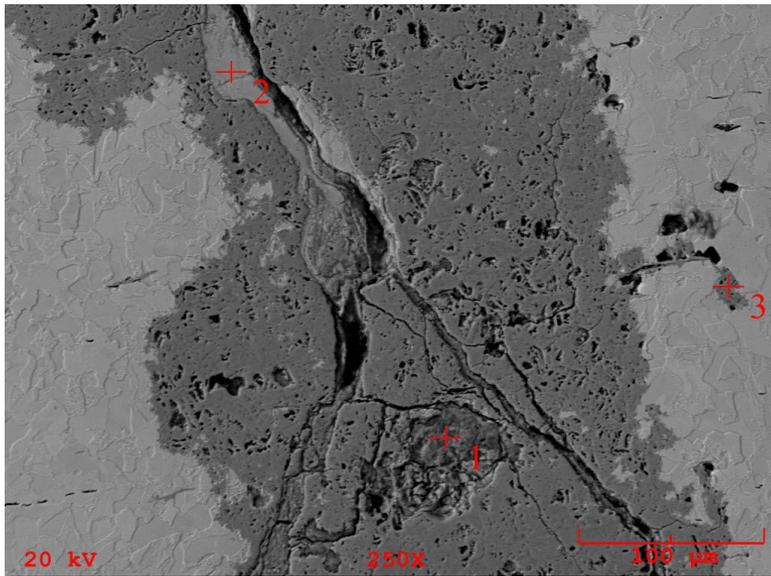
Cracks were branched and transgranular with initiation at corrosion pits on the surface of the plate. Crack extension is preceded by corrosion of exposed metal and formation of a thick corrosion scale.

Characterization of Scale



- Scanning electron micrographs of a crack near the baffle weld showing corrosion of the crack surface as the crack propagated into the base metal.
- Crack branching is observed at location of manganese sulfide inclusion, which are typically susceptible to corrosion due to lower corrosion potential.

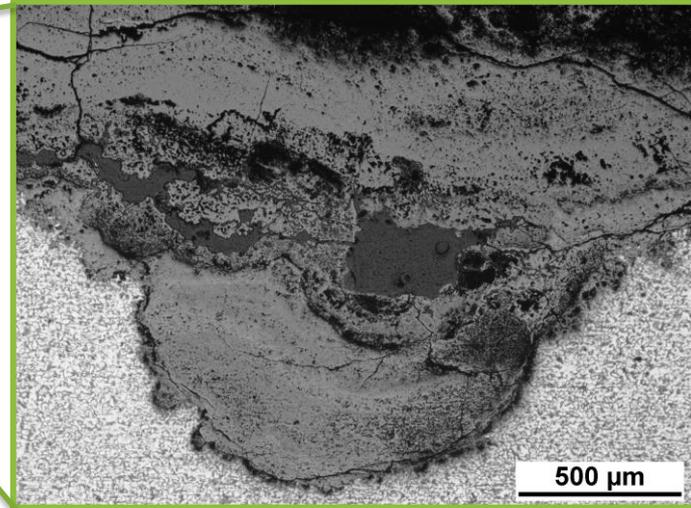
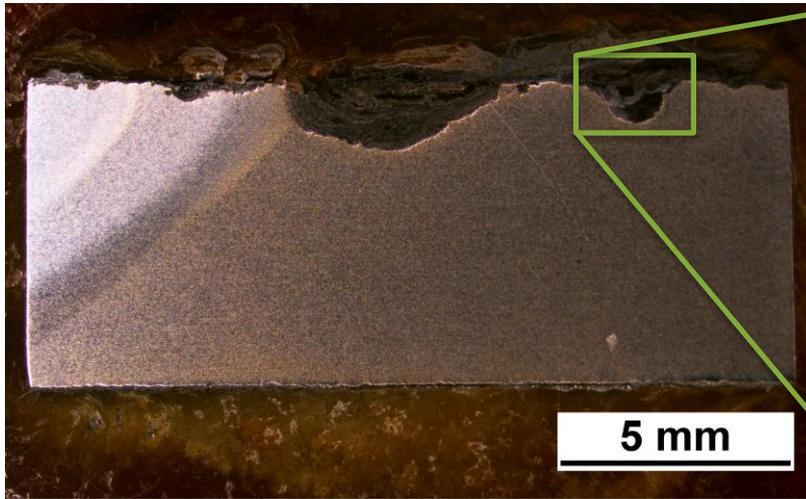
EDS Characterization of Scale



Location	Element (wt%)					
	O	Si	Ca	Mn	Fe	Mo
#1	15.981	1.043	0.385	0.474	63.879	18.239
#2	11.188		0.227	0.827	24.368	63.390
#3	10.062	0.291		0.661	88.767	0.219

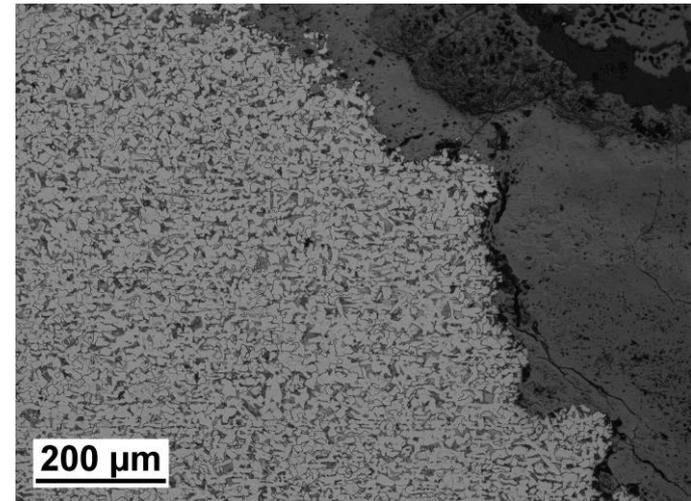
Corrosion scale on crack surface showed characteristic energy peaks for Mo, Fe, Mn, and O. Additional peaks for Ca and Si observed. Location #1 showed peaks for Mo, Fe, and O likely due to the formation of FeMoO_4 . Location #2 showed high concentration of Mo coated on the surface due to absorption into the corrosion product.

Metallography

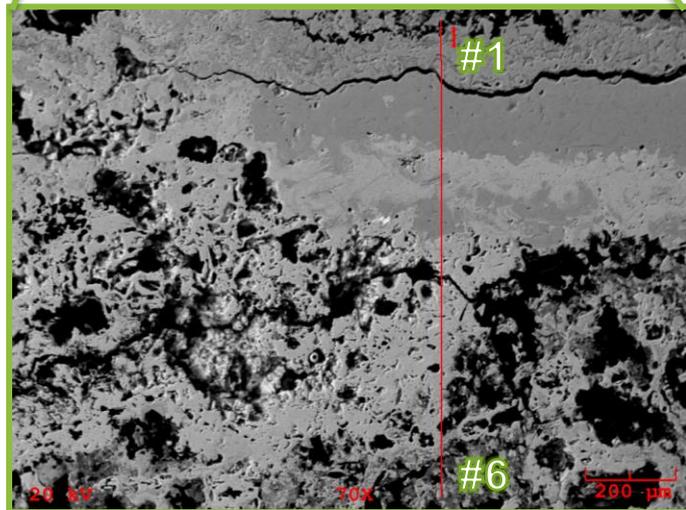
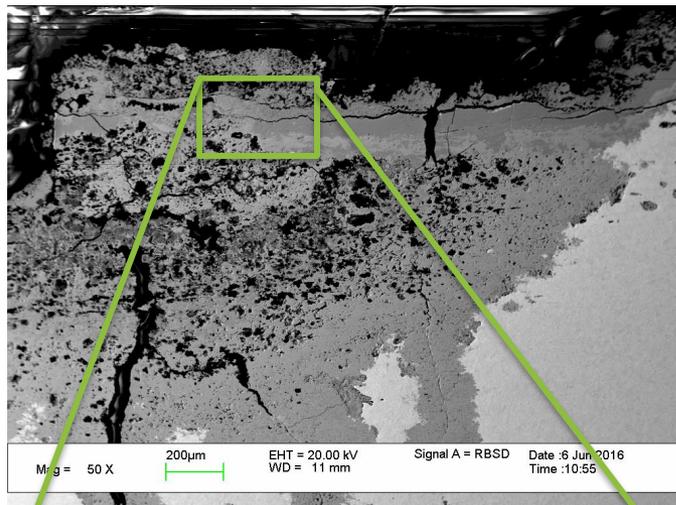


Etched cross-section taken away from the location where cracking was present but showing corrosion pits.

Thick porous scale filled the cavity of the pit.



EDS Characterization of Scale



- Increased Mo content observed in the porous regions of the scale (Locations #1 & #6).
- Mo content increased towards the base metal, where protective molybdenum oxide formation is promoted.
- Element concentration measure by EDS.

