FAILURE ANALYSIS

MIC Failure of Type 316L Seawater Pipeline

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Type 316L stainless steel (SS) (UNS S31600) pipeline carrying seawater suffered pitting and leakage within a few years of installation. Visual examination revealed penetrations and shallow pits. Electron probe microanalysis results indicated a decrease in chromium concentration within the pit and in the iron concentration at the pit periphery. Microbial investigation confirmed the presence of sulfate-reducing bacteria and chromium-, manganese-, and iron-oxidizing bacteria.

Austenitic stainless steels (SS) have considerably good corrosion resistance and have been extensively used as material for piping systems. The Type 316L SS (UNS S31600) variety is preferred for various services because of its good pitting corrosion resistance. In a seawater environment, the potential problem for this material usage is the presence of microorganisms such as iron-, sulfur-, and manganese-oxidizing bacteria and sulfate-reducing bacteria (SRB). These bacteria greatly accelerate the corrosion process of SS.[1]

A Type 316L SS pipeline system, carrying seawater in a process plant near the east coast of India, failed from excessive pitting within a few years of its installation. This article presents the microscopic and electron probe microanalysis (EPMA) results used to diagnose the cause of failure.

Experimental Procedures

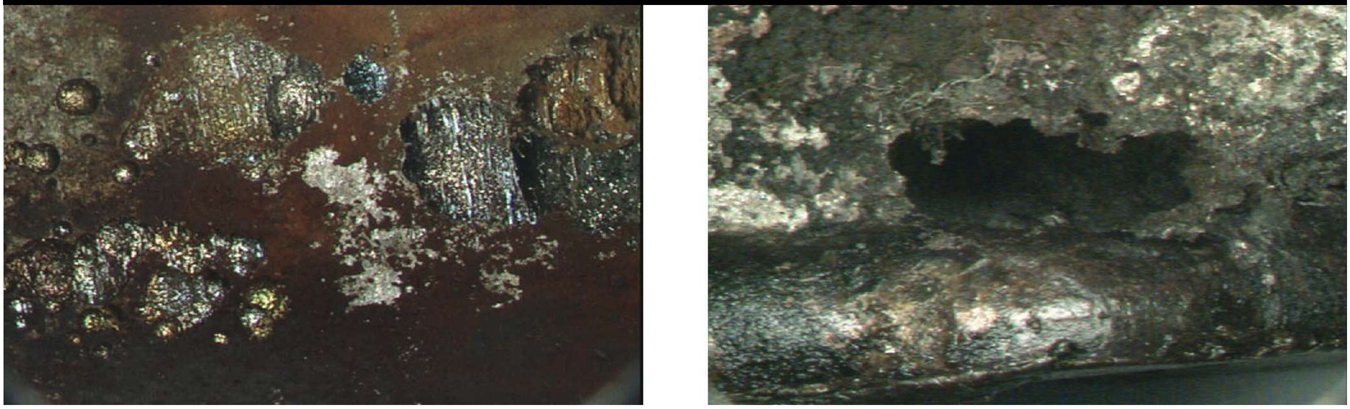
The failed Type 316L SS pipes were subjected to a series of metallurgical examinations. Visual examination and macroscopic examinations were made using a stereo video microscope. Microstructural examination of the failed piece and EPMA of the pitted region were also carried out.

Results

Visual Examination

The visual examination revealed penetrations and shallow pits on the inside diameter (ID) of the pipe at the weldment, heat-affected zone (HAZ), and base material. Leaky regions were confined to the bottom section from the five to seven o'clock position. The regions on the inner tube side where pitting was observed showed reddish deposits (Figure 1). The transverse section of the pipe also showed pits (Figure 2).

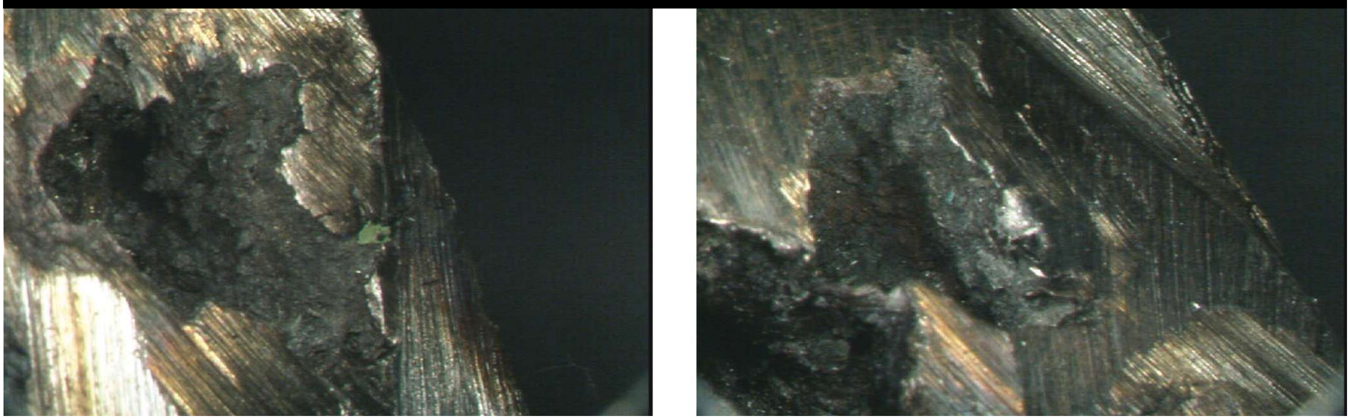
FIGURE 1



(a) (b)

Pits near (a) and away (b) from the weld on the internal diameter surface of Type 316L SS tube (original magnification 175X).

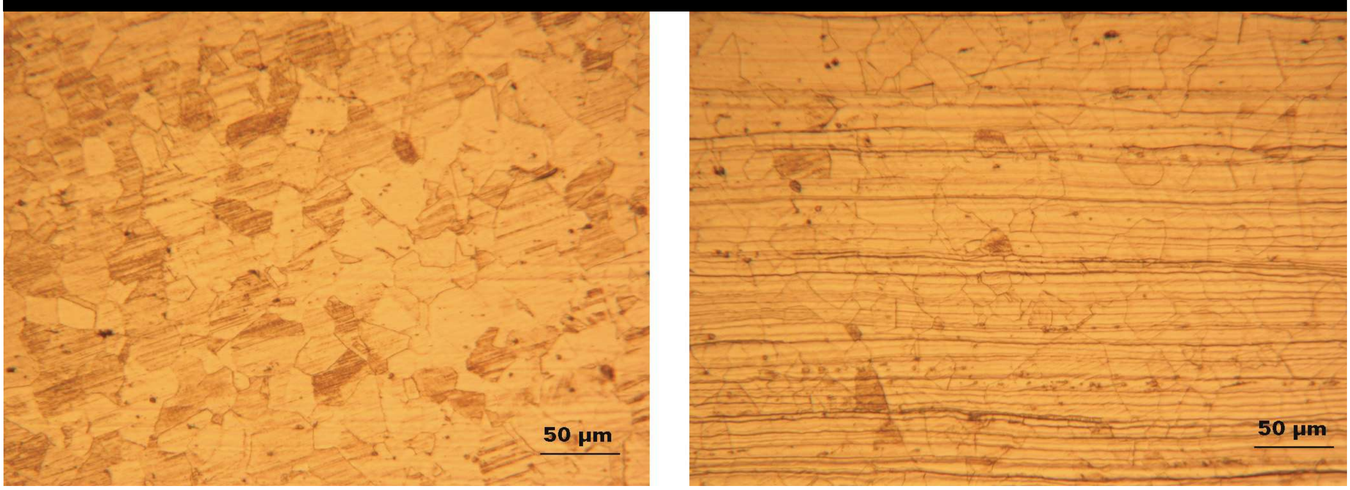
FIGURE 2



(a) (b)

Pits (a) and (b) along the cross section of the pipe (original magnification 175X).

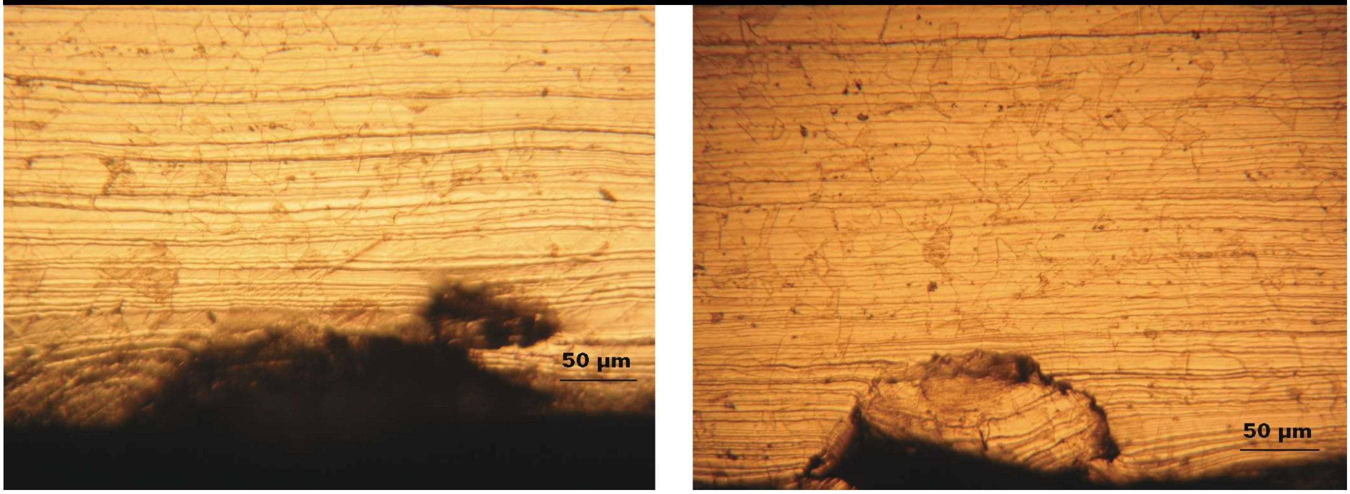
FIGURE 3



(a) (b)

Annealed microstructure of Type 316L SS tube: (a) no manganese sulfide (MnS) stringers, (b) presence of MnS stringers.

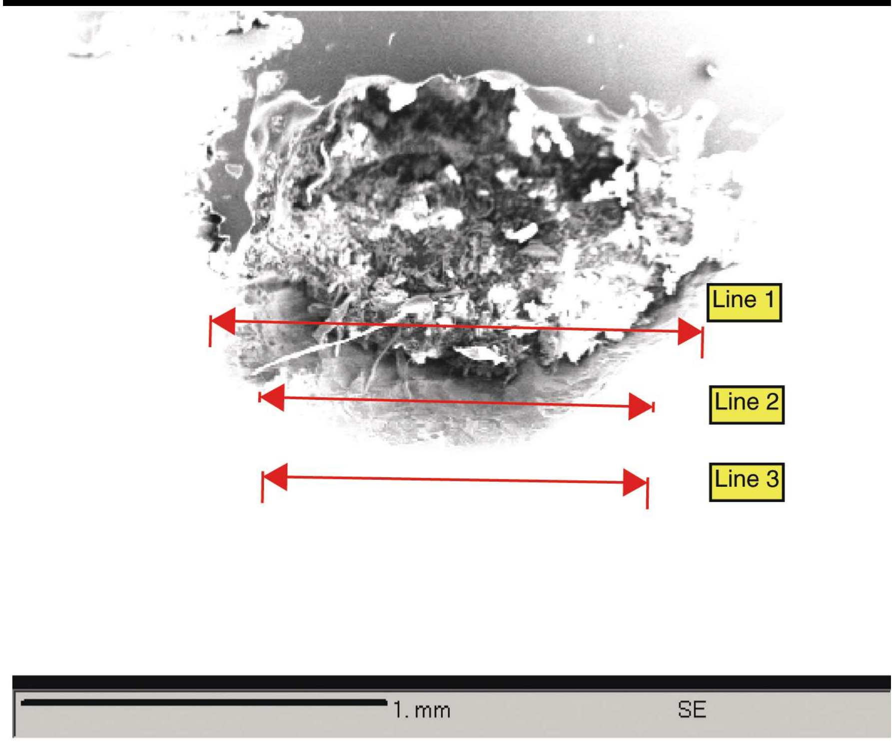
FIGURE 4



(a) (b)

Pitted region of the Type 316L SS tube (a) main pit with satellite, (b) scooping of material.

FIGURE 5



Pitted region across which EPMA scanning (Lines 1, 2, and 3) was done.

Metallographic Examination

The sample for metallography was cut from the pipe, polished to a mirror finish, and electrolytically etched to reveal the microstructure. Figure 3(a) shows annealed, step-type microstructure with negligible stringers present, while in Figure 3(b) there is presence of stringers aligned along the deformation band. Figure 4(a) shows the pit morphology, and Figure 4(b) shows where the secondary pit has initiated from the bottom surface of the primary pit.

Electron Probe Microanalysis Results

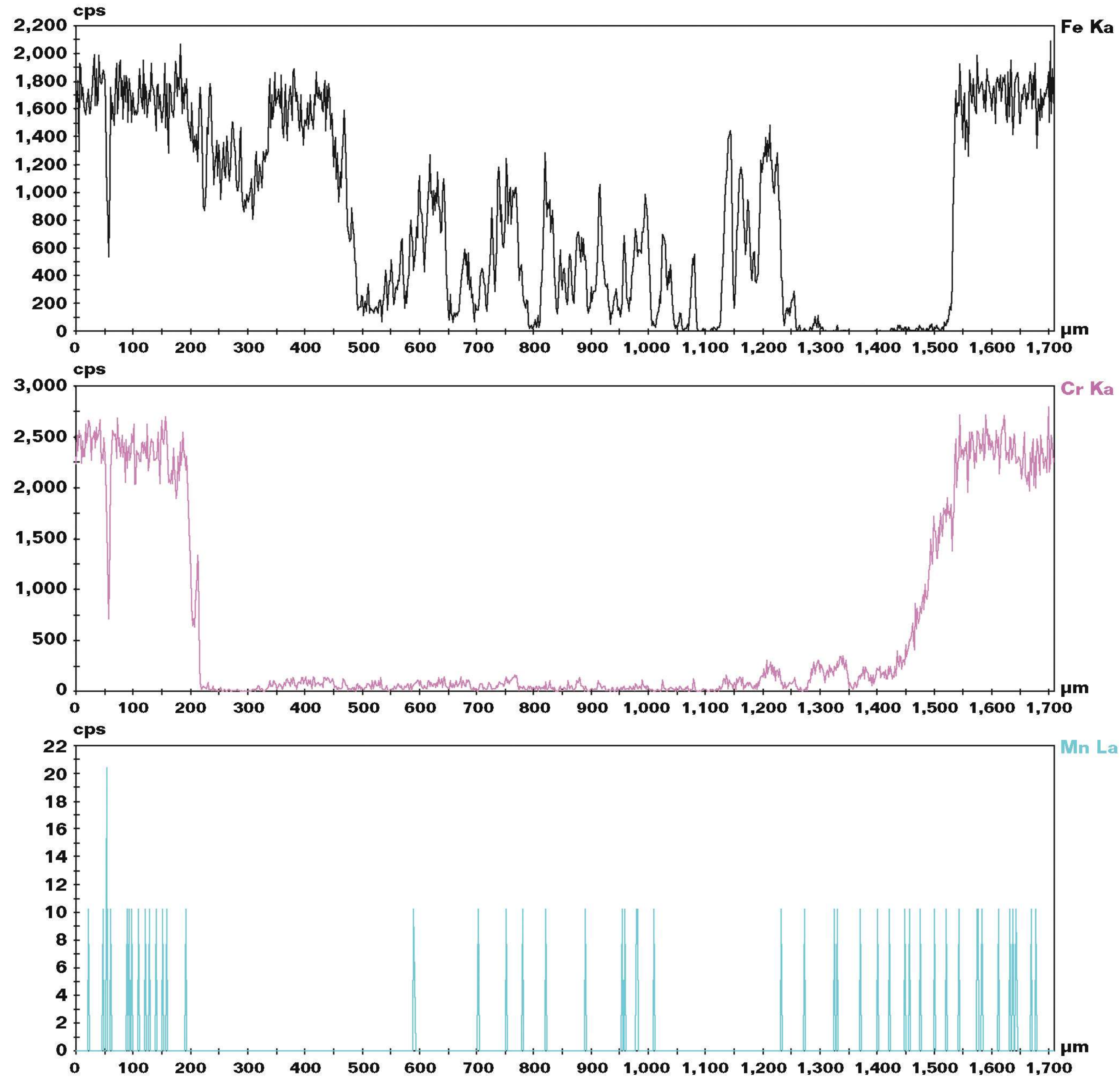
EPMA was completed on the cross section of the pitted tube region and scanning was done at three different regions near the pit, designated as Line 1, Line 2, and Line 3 (Figure 5).

Figure 6 shows the iron, chromium, and manganese intensity profile along Line 1, which scans across the pit. The profiles indicate a decrease in chromium concentration within the pit and in the iron concentration near the pit periphery. Line 2 exhibited a similar decrease of chromium concentration within the pit and a decrease in iron near the edge of the pit. Line 3 is in the bulk material, and no such depletion of chromium or iron is seen (Figure 7). The manganese intensity profile taken for all of the three scans shows only background peaks as the concentration of manganese is below the detectable limit.

Microbial Investigation

The corrosion products collected from one of the pits were analyzed for microbial activity. The bacterial culture results indicate the presence of SRB and chromium-, manganese-, and iron-oxidizing bacteria.

FIGURE 6



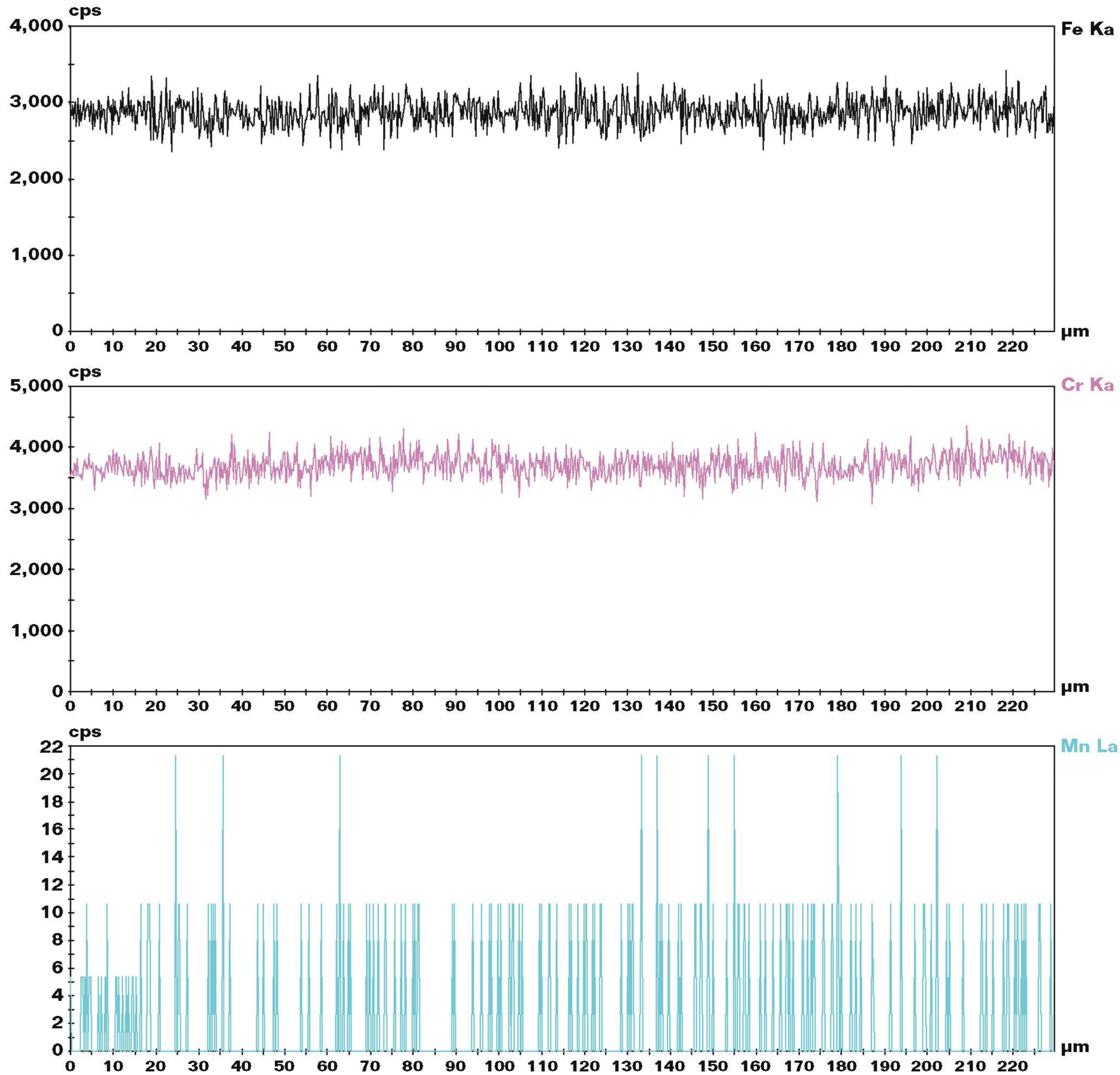
Intensity profile for iron, chromium, and manganese along Line 1 shows the depletion of chromium and iron.

Discussion

The failure of this Type 316L SS is a classic case of microbiologically influenced corrosion (MIC). The visual examination of the pipe revealed pits that have an aspect ratio <1. The pits are shallow and have propagated in the transverse direction. The pit morphology gives a clear indication of MIC attack. M. Geiser, et al.[2] have reported that pits have aspect ratios and shapes closely resembling the shape and aspect ratio of the bacteria.

The presence of sulfide stringers would be the favorable sites for the initiation of pitting attack. Ryan, et al.[3] have demonstrated that pitting was likely to be initiated around the sulfide stringers in SS. Microbial analysis indicated the presence of SRB and manganese-, iron-, and chromium-oxidizing bacteria. The presence of manganese-oxidizing bacteria could have led to the ennoblement of the Type 316L SS, as reported in literature.[4-5] Once a pit (primary) has been formed, the bacterial activity would become localized within the pit and soon would cover itself

FIGURE 7



Intensity profile for iron, chromium, and manganese along Line 3 (scanning across bulk material) shows no depletion of chromium and iron.

with biofilm. The SRB would be active when an anaerobic condition sets in during pit propagation. The bacteria are likely to thrive within the pit cavity and produce an acidic chloride environment. Once this process has initiated, kinetics of pitting attack would accelerate auto catalytically and lead to very fast propagation. EPMA results indicate the depletion of chromium in the pitted region and depletion of iron along the periphery of the pit. X. Shi, et al.[6] have studied the chemistry of pits generated electrochemically as well as by microbes. The results obtained are very similar to our EPMA results for the microbial induced pits in the failed Type 316L SS pipes. Decrease of chromium content on the surface led to the loss of passivity. This phenomenon would increase the rate of corrosion significantly, leading to perforation. The presence of microorganisms not only modifies the near-surface environmental chemistry by microbial metabolism, but also interferes with the electrochemical processes occurring at the metal-environment interface.

Conclusions

The leakage in the Type 316L SS pipeline system occurred because of pitting in the seawater environment caused by MIC. EPMA results showed a chemical profile of the pit that has the signature of MIC.

Acknowledgment

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