CASE STUDY

Premature Failure of Repainted Epoxy on the Internal Bottom Plate of a Fuel Oil Tank

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This article describes the premature failure of repainted epoxy coating applied over the inner side of the bottom plate of a fuel oil tank, leading to perforation of the bottom. Some cavities and minute pits were already present on the inner surface of the plate when the coating was reapplied, but the painters overlooked them. After ~2 months of service following repainting, penetration of the bottom plate of the tank occurred. The coating failure is attributed to chloride contamination of the steel surface prior to the coating application.

Extensive coating failures have occurred when the coatings were applied over surfaces contaminated with soluble salt. In general, the failures occur in the form of blisters, rust, tubercles, or loss of adhesion. The cause of failure is generally attributed to the retention of a minute amount of contaminant or corrosion product along grain boundaries of steel surfaces, even though they are blasted to white metal. The chloride contamination, which is most prevalent in marine environments, is the most damaging anion because of its characteristic migration under a coating film. The chloride-containing solutions have a high osmotic pressure that contributes to moisture penetration, loss of adhesion, and blistering of the coating.

A number of studies on the level of chloride contamination on clean steel surfaces and the premature failure of coatings applied over such surfaces have been reported in the literature.[1-5] Various correlations between the level of chloride and the premature failure of coatings were also deduced. Unfortunately, chloride contamination on steel structures is not only a surface contaminant, but it is also found in rust and micropits. Significant amounts of the contaminants remain even after blast cleaning.

Neal and Whitehurst[6] studied the effect of chloride contamination of line pipe on the performance of a fusion-bonded epoxy (FBE) coating by contaminating pipes with various levels of chloride. The chloride remained in the micropits after sandblasting of the steel surface. It was found that chloride contamination could cause serious loss of performance in an FBE coating in hot cathodic disbonding and hot water tests. For underground coatings and other immersion coatings in critical applications, a maximum level of 2 µg/cm^2 of chloride contamination was suggested. The chloride contamination that remains in micropits after blast cleaning can be satisfactorily removed by phosphoric acid (H_3PO_4) treatment.

The Failure

Table 1 describes the details of the tank. The original epoxy coating on the bottom failed after ~14 years of service. The tank was emptied and the bottom was sandblasted. Cavities and minute pits were present on the bottom plates, but were overlooked when the replacement epoxy coating was applied and no chloride decontamination was done. About 2 months after the repainting, the new coating failed, and two penetrations in the tank bottom occurred.

The cause of the coating failure has been investigated through a physical examination of the bottom plate. Material and corrosion products were analyzed using inductively coupled plasma (ICP), carbon-sulfur (C and S) analyzer, and energy dispersive x-ray (EDX) techniques. The cause of the failure is attributed to chloride contamination in the cavities and pits on the steel surface that existed prior to applying the new coating.

This article describes the investigation and provides recommendations to prevent such failures in the future.

TABLE 1

INFORMATION DATA ABOUT THE MAIN FUEL OIL TANK (MFOT)

Plant Equipment No.	**MFOT #3 12 PA 52B 103**
Type	Floating roof
Capacity	15,000 m^3
Diameter	46.5 m
Height	12.45 m
Fluid stored	Crude oil
Bottom and shell plate material	ASTM A36
Bottom plate thickness	7.5 mm
Annular plate thickness	12.0 mm
Fluid temperature	35 to 40°C
Internal paint dry film thickness	240 µm
Type of CP	Impressed current (external)
pH of stored fluid	~5

FIGURE 1

Interior surface of bottom plate sample in the as-received condition.

Visual Examination

Figures 1 and 2 show the bottom plate sample in the as-received condition. A visual examination of the plate showed two holes with cavities (the average depth and diameter of the cavities were ~5.1 and 15.0 mm, respectively), in addition to some pits on the inner surface (working side) of the plate. Figure 3 provides a closer view of the plate and shows the large perforations.

Analysis of Plate Material and Corrosion Products

Table 2 lists the chemical composition of the plate material as analyzed by the ICP technique and C and S analyzer. The chemical composition matches the specified composition of the plate material ASTM A36, a carbon steel. The EDX studies of the corrosion products on the surface of the pit, beneath the epoxy lining, show strong peaks of Cl, Si, Fe, O, Al, Mg, S, P, K, Ca, and Ti (Figure 4). This result suggests the presence of chloride contamination and other impurities, which remained on the pitted surface in significant amounts prior to the application of the coating.

Discussion

Although crude oil itself may not be particularly corrosive, the contact of crude oil with seawater or a marine atmosphere can make it extremely corrosive. The cavities and minute pits already present on the inner surface of the plate were caused by local corrosion from a long exposure of the original epoxy coating to the crude oil. The seawater's contact with crude oil slowly penetrated through the epoxy lining, initiating localized corrosion attack at the coating/metal interface, and led to the breakdown of the coating. The breakdown of the epoxy coating was followed by the formation of an electrolytic cell. The anode of this cell consisted of the minute exposed area of the metal, and the cathode was the large coated area. The large potential difference of this passive-active cell accounted for the considerable flow of current with rapid corrosion at the small anode. This caused the formation of small pits. The epoxy lining surrounding the anode and the activating property of corrosion products within the pits accounted for the tendency of corrosion to penetrate the metal rather than spread along the surface. Since the pH of the

FIGURE 2

External surface of bottom plate sample in the as-received condition.

FIGURE 3

Close-up view of the hole in the existing cavity.

crude oil is ~5, the pit growth is expected to be controlled by the amount and availability of dissolved oxygen. The propagation of a pit involves the dissolution of metal and the maintenance of a high degree of acidity at the bottom of the pit by the hydrolysis of dissolved metal ions.

The increased concentration of Fe^{++} within the pits led to the migration of chloride ions (already present as a contaminant in the crude oil) to maintain neutrality. The iron chloride ($FeCl_2$) formed is hydrolyzed by water to give iron hydroxide [$Fe(OH)_2$] and free acid, as shown in Equation (1)

$$FeCl_2 + 2H_2O \rightarrow Fe(OH)_2 + 2H^+ + 2Cl^- \quad (1)$$

The generation of acid lowers the pH at the bottom of the pit and accelerates the dissolution of metal at that point, whereas the pH of the bulk solution remains neutral.

The EDX profile of the corrosion products at the surface of the pit beneath the epoxy lining shows strong peaks of Cl, Si, Fe, O, Al, Mg, S, P, K, Ca, and Ti, suggesting the presence of a significant amount of chloride contamination and other impurities in the corrosion product that remained in the pits prior to the application of the coating. The chloride in contact with steel forms ferrous chloride ($FeCl_2{\cdot}4H_2O$), which in the presence of air further oxidized to $FeCl_3$. $FeCl_3$, being a hygroscopic salt, drew in moisture, creating a concentrated $FeCl_3$ solution on the steel surface. The repainted epoxy coating failed prematurely as iron salt drew water through the coating by osmosis and created an area of poor adhesion and blistering. The epoxy coating applied over the existing cavities further contributed to the premature failure of that coating. After failure of the epoxy coating at the existing cavities, an ideal site for pitting corrosion was created. The corrosion proceeded at an accelerated rate and ultimately led to the perforation of the remaining plate thickness in ~2 months.

Conclusions

1) The cavities and minute pits already present on the inner side of the bottom plate of the tank were caused by local corrosion that stemmed from the failure of the original epoxy coating from its long exposure to crude oil.

2) The failure of the repainted coating and subsequent perforation of the plate were caused by:

a) The presence of chloride contamination and other impurities, which remained in the existing cavities and pits in a significant amount prior to the application of the new coating. The chances of retention of chloride in the cavities are high in the absence of a chemical cleaning operation after sand blasting.

b) The presence of a coating applied over the existing cavities.

Recommendations

The following preventive measures are recommended to overcome this type of failure.

1) To avoid premature failure of such coatings, chloride decontamination should be considered as an essential step after sandblasting. The chloride decontamination may be achieved by phosphoric acid treatment through which insoluble iron phosphate ($FePO_4 \cdot 2H_2O$) is formed rather than $FeCl_3$.

2) The surface pits should be repaired before applying the coating.

References

1. B.R. Appleman, JPCL 10 (1987): p. 68.

2. V.E. Helvig, Metal Finishing 7 (1980): p. 41.

3. D.G. Weldon, A. Bochan, M. Schlieden, JPCL 6 (1987): p. 46.

4. S. Flores, T.L. Starr, JPCL 4 (1994): p. 76.

5. B.P. Alblas, A.M. Van Londen, Protective Coating Europe 2 (1997): pp. 16-25.

6. D. Neal, T. Whitehurst, "Chloride Contamination of Line Pipe—Its Effect on Fusion-Bonded Epoxy Coating Performance," MP 34, 2 (1995): p. 47.

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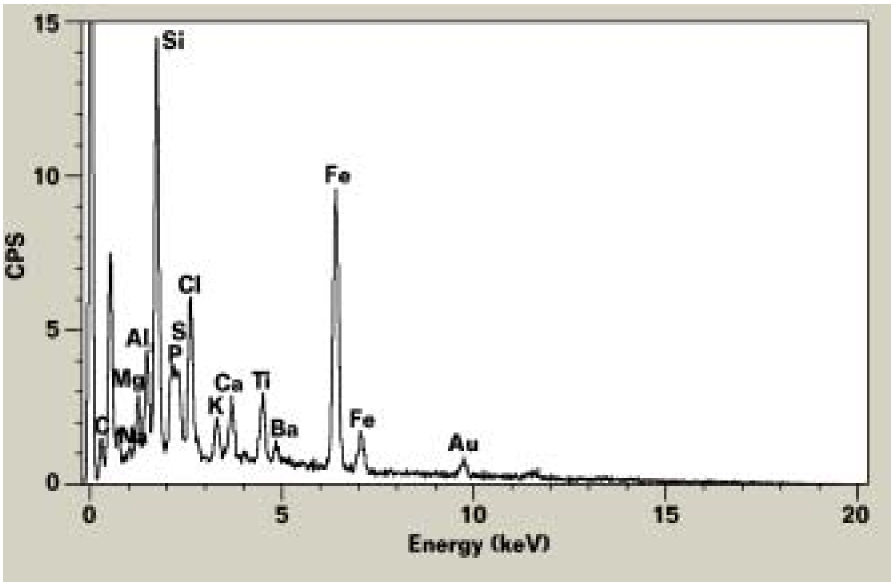
FIGURE 4



EDX profile of corrosion products collected from the surface of the pits beneath the epoxy lining on the plate.

TABLE 2

CHEMICAL COMPOSITION OF SAMPLE PLATE AS ANALYZED BY ICP TECHNIQUE AND C AND S ANALYZER

Element	wt%
C	0.17
Mn	0.47
S	0.007
Cu	0.12
Cr	0.05
Ni	0.03
Silica (SiO_2) (soluble)	<0.03
Fe	98