



FAILURE ANALYSIS OF PIPELINE COATINGS

INVESTIGATING THE ROOT CAUSES TO IMPROVE
PERFORMANCE AND BUILD A SAFER ENVIRONMENT

C O N T E N T S

Background	3
Case study.....	4
Laboratory analysis.....	5
Observations and discussion.....	6
Conclusion of analysis and recommendations.....	6
Conclusion.....	7

BACKGROUND

Pipelines that transport and distribute oil, gas, chemicals, water, petroleum products and other substances are of critical significance for the economy, and the health of these assets is paramount to avoid catastrophic damage.

This makes pipeline coating an extremely important issue for the oil and gas industry.

Pipeline coating is defined as a protective lining that creates a barrier against deterioration of the pipe surface when exposed to its operating environment. This lining improves durability and eliminates some of the life-threatening failures and costs related to repair and premature replacement.

In order to provide these functions, the protective coating must remain intact and adherent to the surface to which it has been applied. Additionally, given that pipelines can run above ground, be buried underground, or immersed in fresh or salt water, coatings designed for external pipeline applications must be engineered to withstand these widely different exposures.

Although the vast majority of coatings perform admirably until old age, they can fail rather quickly under such adverse environmental conditions, preventing their functions to be realized. Pipeline leaks, ruptures, and ultimately a pipeline's service life can all be directly attributed to coating failure.

A thorough and objective analysis of the fundamental causes behind a coating failure is beneficial to understand what caused it to fail. By closely inspecting the pipeline, its fracture surfaces, and its environment, it is possible to collect the evidence and observations needed to determine proper remedial actions and prevent similar failures in the future.



CASE STUDY

Failure analysis of a transmission and distribution pipeline coating.

This case study involves a 12-inch diameter Fusion Bonded Epoxy (FBE) coated steel pipe that carried natural gas for residential service and was under cathodic protection while in service. The pipe showed blistering of the FBE coating and corrosion in the pipe (Figure 1-2-3). Standard failure analysis techniques were applied to determine the primary causes of the blistering. A determination of detrimental effects to the pipe wall was conducted as well.

ANALYSIS TECHNIQUES

The laboratory analysis for this investigation included:

- cross-section microscopy of the FBE coating in a blistered and non blistered area of the abandoned pipe
- coating thickness measurements
- chemical analysis of liquid extracted from the inside of two blisters
- chemical analysis of soil taken from near the submitted pipe
- SEM/EDS analysis of the underside of the coating from a blister and cross-sections of two blisters.



Figure 1: blistering of FBE coating on steel pipe



Figure 2: blistering of FBE coating on steel pipe



Figure 3: evidence of corrosion on the FBE coated steel pipe

LABORATORY ANALYSIS

The first work performed was the mapping and photography of five specified coated areas on pipe sample cut from site 1. Each area was outlined with a dashed line and marked at 15 different spots with a single black dot. The coating thickness was then measured at each of these 15 dots using a coating thickness gage. Each dotted spot was also visually examined and categorized based on the condition of the surrounding coating.

Three coating samples were selected for analysis by energy dispersive x-ray spectrometer (EDS). The three samples were cleanly removed from the blistered areas of the coating during the on-site investigation. The presence of chlorine and sodium in all samples was a strong indication of surface contamination.

The backsides of three de-laminated coating samples were selected for contamination analysis. The samples were evaluated at 30x magnification. Generally, the percent contamination was somewhat higher at the blistered areas (49-55%) than next to the blistered areas (30-35%). The estimate was recorded at percentage of total area.

Cathodic disbondment testing was performed at -1.5 volts versus a Cu/CuSO₄ (copper/copper sulfate) electrode for 48 hours on a coated sample cut from the pipe from site 1. Sodium hydroxide 0.01 Molar was used as the electrolyte. At the end of the test, using a utility knife, the coating was chipped off until coating adhesion resisted the levering action. The radius of the disbonded area from the holiday edge to the coating was measured to be 5.3 millimeters (mm). This determination indicates a high FBE de-lamination rate on areas next to the blisters. The de-lamination rate was estimated at 5.3 mm / 48 hours.

Samples from three blistered and two non-blistered areas of the abandoned pipe were prepared for cross-sectional optical light microscopic (OLM) examination. Cross-section samples in blistered and non-blistered (good) areas were prepared by sectioning transversely, mounting in epoxy resin and polishing. Both blistered and non-blistered areas displayed an irregular blast profile, surface high temperature iron oxide, and bubbles/voids in the coating.

Average coating thickness values of the cross-sectioned blistered samples ranged from 9.25 to 10.04 mils (where 1 mil = 0.001 inch); and 11.00 to 11.38 mils for the cross-sectioned non-blistered samples. The average values in the blistered areas were not much smaller than those in the non-blistered areas suggesting the coating had not degraded in the blistered area.

Macroscopic thickness measurements were also conducted on the submitted section of pipe in blistered and non-blistered areas. The thicknesses in the blistered areas were somewhat lower than those in the non-blistered areas, averaging between 9.99 and 11.91 mils for the blistered sample and 11.48 to 12.55 for the non-blistered samples. Thickness below 12 mils is considered very low for underground applications and corrosive moist soil. A minimum of 14-20 mils is commonly specified.



Figure 4: liquid extracted from the blisters.

As shown in Figure 4, a hypodermic syringe was used to extract liquid from inside two blisters during the on-site investigation for subsequent laboratory analysis. The liquid samples were analyzed to reveal their chemical analysis and determine if they were harmful to the carbon steel pipe.

The large amounts of nitrates (614 parts per million to 0.16%) and sodium (1.16 to 1.62%) were significant because they usually do not permeate through the coating readily, which means they were present prior to the application of the coating. Water and oxygen will permeate through the coating and combine with the sodium to create sodium hydroxide.

A sample of soil was collected from an area near the submitted pipe for laboratory analysis. The soil was analyzed to determine its chemical make-up. The resistivity of the soil around the pipe was measured on-site from areas at the bottom of the pipe, top of the pipe and near a blister. Soil resistivity ranged from 2000 ohm-centimeters near the blister to 7400 ohm-centimeters near the pipe top.

OBSERVATIONS AND DISCUSSION

In order to prevent corrosion of underground structures, moisture must be prevented from reaching the steel surface. The penetration of moisture through the coating to the substrate is a controlling factor in the corrosion process.

Propelling forces are osmotic and electroendosmotic pressures aided by thermally induced molecular movements and vibrations within the coating. But, all coatings will also possess varied imperfections that will allow the environment to easily reach the metal surface. For this reason, cathodic protection is used in conjunction with coatings to protect those exposed areas.

FBE blisters are local defects that form because of the pressure exerted by an accumulation of water or aqueous solution at the coating-substrate interface in conjunction with loss of adhesion and distention of the coating. In general, the mechanism of blistering is attributed to osmotic attack and/or the presence of contamination in the coating interfacial region, in combination with the influence of moisture and cathodic protection.

One of the main factors in the blistering of the FBE coating was the chemical analysis of the liquid inside the blisters and back contamination observed on de-laminated coatings. As oxygen reduction takes place at the contaminant site under the film, hydroxyl ions build up in the blister solution. The alkaline environment at the cathodic sites weakens or destroys the adhesion of the film while producing osmotically active substances at the coating/metal interface.

Sodium was not detected in the coating cross section so it must have been present on the surface of the pipe before the coating was applied. EDS analysis of the backside of the de-laminated FBE coating samples indicated the presence of sodium and chlorine. SEM/EDS analysis of the coating showed no sodium in the coating, which confirmed it was not permeating through the coating but rather already present on the pipe surface as a contaminant.

The alkaline environment inside the blisters, the presence of negatively charged ions (nitrates) in the blister liquid, and the presence of contaminants (such as sodium and chlorides) are all indications of osmotic (or endosmotic) passage of water from the coating surface to the interface. This resulted in pressures that exceeded the interfacial strength of the film. Eventually the fracture strength of the film would be affected, causing further de-lamination of the coating.

CONCLUSION OF ANALYSIS AND RECOMMENDATIONS

Based on testing and analysis, it was determined that the blistering of the Fusion Bonded Epoxy (FBE) coated steel pipe was due to surface contamination of the pipe prior to or during the coating application.

This determination is based on the following items:

- The presence of chlorine in sample, nitrate ions in the blister solution and sodium in all three samples are strong indications of surface contamination;
- The presence of nitrates, sodium and chlorine (on the backside of the de-laminated coating) in the blisters confirms the proposed failure mechanism;
- Cathodic disbondment testing indicates a high FBE de-lamination rate on areas next to the blisters;
- Sodium was not detected in the cross section analysis. Therefore, it must have been present on the surface of the pipe;
- SEM/EDS analysis of the coating shows there is no sodium in the coating, which confirms it was not permeating through the coating but rather already present on the pipe surface as a contaminant;
- The blister liquid analysis indicates the contamination was present prior to the application of the coating.

To ensure public safety and avoid liability claims, it is very important that the blister growth, FBE de-lamination, adhesion loss and cathodic protection effectiveness on this pipe is monitored.

The pipe should be recoated in areas where general de-lamination of the coating is observed. This is to avoid localized corrosion of the pipe in the event there is lack of protection, inadequate cathodic protection, or shielding effects due to areas where the epoxy coating has a much higher thickness than 12 mils.

Blister formation and FBE de-lamination can be controlled through appropriate application of the FBE coating by being extremely careful in cleaning the substrate of all contaminants, and implementing a quality control program to ensure there are no contaminants present on the substrate prior to the coating application.

CONCLUSION

A considerable amount of financial loss is incurred every year as a result of early failures of pipeline coatings. The cost to repair such failures far outweighs the initial cost of painting, since repair, clean-up, and in some cases replacement of the pipeline may be needed.

Additional liability may also be expected if a facility must stop operation for the necessary repairs to be made. The costs, environmental impact and negative publicity associated with failures are something that every major oil and gas company seeks to avoid.

Knowing the root causes why protective coating fails prematurely is vital to identify effective measures that can be taken to reduce the likelihood of such incidents. Failure analysis investigation assists in preventing future coating failures of a similar nature, and aids in placing liability.

Element is an international provider of testing, advisory and certification services. We are trusted by many of the world's best organizations to test and advise on the safety, quality and performance of their products and operations. Our laboratories provides testing and consultancy services in metallurgy, polymers and coatings, including corrosion risk assessment and mitigation to the oil and gas and industrials sectors. We also offer advisory services in areas including failure analysis and corrosion investigation.

REFERENCE

“Failure analysis of paints and coatings for transmission & distribution (T&D) pipeline and utility structures case studies. Mehrooz Zamanzadeh and George T. Bayer. Matco Services, Inc., Pittsburgh, PA, United States. 2005





Contact.us@element.com Europe: **+44 (0) 808 234 1667** Germany: **+49 800 000 5137** Americas: **+1 888 786 7555** - **www.element.com**