

Analysis of Coating Blister Failures and Associated Coating and Substrate Risks

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By Michael Kibler and Patrick Cassidy, Elzly Technology Corp.; and Jay Ong, Naval Surface Warfare Center, Carderock

Blistering is a common coating failure, and for many years, the causes and mechanisms of blistering have been studied to characterize and determine the effects on coating performance and underlying substrates. These studies have led to a better, but still incomplete, understanding of blistering and its effects on a substrate, such as corrosion. Several different blistering mechanisms have been identified, including osmotic, electrostatic and solvent- or gas-induced blistering, as well as blisters from anodic and cathodic reactions. Typically, more than one of these mechanisms will contribute simultaneously.

These studies have also found that the risk that blisters pose to the underlying substrate varies greatly, often with the predominant blister mechanism, which can be related to coating type and exposure. In areas where aesthetics are not important, the general view has been that blisters are not ideal, but as long as they are intact, they still provide some protection to the substrate and are not necessary to repair right away. In a recent study, it was determined that this is not always the case¹ and that the substrate below a blister may be more prone to pitting in certain exposures.² This suggests a need for a better understanding of how to evaluate blistered coatings when considering repairs.

PREVENTING COATING BLISTERING

While blistering may be a common coating failure, in most cases, it can be mitigated by following well-known surface preparation and coating application guidelines. The mechanisms for blister formation suggest the appropriate prevention methods.

The first step of prevention is to ensure that the substrate is clean of contaminants that could lead to osmotic blistering (Fig. 1). The typical contaminants that lead to osmotic blistering are salts, especially in marine environments, which remain on the surface through incomplete surface preparation and cleaning or redeposit on the surface between cleaning and painting. Surface preparation includes processes such as abrasive blast-cleaning, waterjetting, power-tool cleaning or a combination of these to remove all coating and corrosion products in an area to be painted. This should then be followed by a solvent wash to clean off any residual salts or other contaminants. Finally, before coating application, QA tests should be performed to ensure that the surface is free of contaminants.

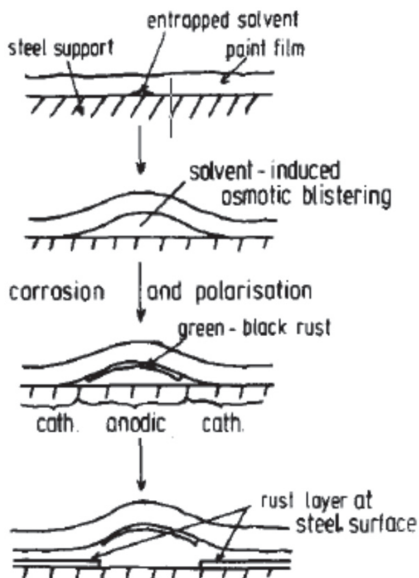


Fig. 1: Schematic illustration of rust formation in solvent-induced blistering.

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For salts, the common QA method is the patch cell (Bresle) test, in which a known quantity of deionized water is added to a patch to cover a known area of the surface. After a set amount of time, the water is removed from the patch and put into a conductivity meter to determine the conductivity. The higher the conductivity, the more ionic species there are on the substrate. These could be salts or other ions, but either could support osmotic blistering.

Several studies have determined $3 \mu\text{g}/\text{cm}^2$ (30 micro-siemens/cm) as an acceptable level of salt contamination to significantly lower the chance of coating failure, including blistering, in immersion services.⁶ For atmospheric service, this limit is $5 \mu\text{g}/\text{cm}^2$ (70 micro-siemens/cm).⁶ These values have been widely accepted in the industry, including by the U.S. Navy and within the SSPC Good Painting Practices manual. A single test only gives the contamination level of a small area, so sufficient testing should be performed to give confidence that the entire area is clean.

Once an area has been properly cleaned, it should be coated as soon as possible. If an extended period of time is expected between preparation and coating, the area should be isolated as well as possible through containment. When time comes to paint, the area should be solvent-washed again and surface salt testing repeated. If contamination levels are found to be too high, the area may need to be

completely re-prepared before coating application.

Cleaning is not the only necessary step to give the best chance of avoiding blistering. The coating application itself is also important. Coating formulations, cure characteristics and protection mechanisms all vary greatly from paint to paint. For this reason, it is necessary to follow the manufacturers' directions when applying paints. This includes everything from mixing to time allowed for curing before service.

Improper mixing and application methods can lead to blisters through gas entrapment. Improper mixing ratios may affect the coating's ability to release solvent during the cure process, leading to blistering as well. This can also result from applying coatings at thicknesses beyond the intended film build or top-coating before the solvent has had a proper amount of time to release. If a coated area is put into service, especially immersion service, before the solvent has completely diffused from the coating, there is an increased chance solvent-induced blistering will occur.

EFFECT OF BLISTERS ON THE SUBSTRATE

There are several ways in which blistering can affect the corrosion of the substrate. While blisters formed by cathodic polarization can weaken adhesion of a coating, they will typically have little effect on the underlying substrate. The cathodic reactions produce hydroxide at the substrate, which can contribute to the delamination and growth of the blister.^{3,7} Yet, the pH of water found in these blisters is usually alkaline at values around 10–11.⁴ At this pH, steel is normally passive and does not corrode. Typically, if a cathodic blister is opened, bright, uncorroded steel will be found underneath. Therefore, these blisters are not considered a risk to the substrate.

On the other hand, anodic blistering will certainly have corrosion products forming below the coating. Anodic blistering usually begins below a pore or microdefect in the coating or next to a macrodefect like a scribe or crack in the coating.^{3,4} In the case of blistering at small defects or pores, corrosion will begin where oxygen and ionic species, often salts like NaCl, are able to pass through the coating to the substrate and initiate corrosion. As corrosion product builds up, the pore or defect will become blocked, once again making the coating film semipermeable to the surroundings.^{3,4,8} The corrosion products then react with incoming oxygen, making the area under the pore oxygen-deficient. The whole area below the pore becomes anodic, and cathodic reactions at the surrounding perimeter begin to disbond the coating. This process supports continued osmosis and electroosmosis to bring water and ionic species into the blister, and the blister growth continues. If an anodic blister is opened, a ring of black-red rust will be found on the underside of the dome and surrounding the central anodic area. Figure 2 illustrates the formation of anodic blisters at microdefects.

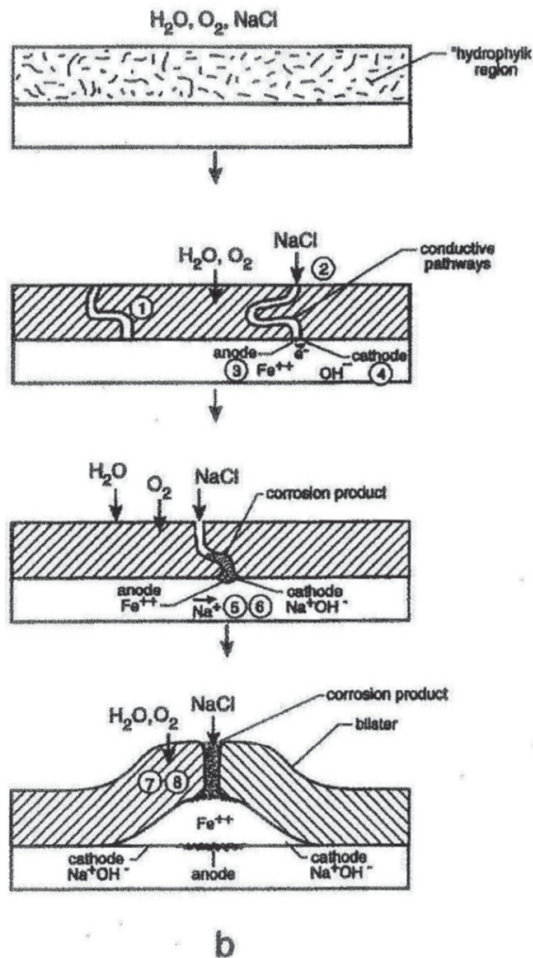


Fig. 2: Anodic blistering at a pore or microdefect

Anodic blistering along a scribe happens similarly, but through a different initiation. In this case, oxygen, water and ionic species can pass under the coating through weak and damaged points in the coating along the scribe. This allows micro-corrosion cells that naturally form below the coating to change into anodic sites and form blisters through the anodic blister mechanism above.^{3,8} A Naval Research Lab

study found that corrosion under blisters next to scribes showed deeper pitting than boldly exposed steel.² This is likely due to the area under the blister working as the anode to a larger cathodic area spread throughout the surface. Values of pH in anodic blisters are slightly acidic or neutral.

In the case of solvent entrapment, the substrate is not affected by blistering. However, a blistered coating is a weakened coating and more susceptible of sustaining ionic permeability and other electrochemical factors leading to more aggressive corrosion conditions. Eventually, corrosion can form under these blisters, but it is typically through usual corrosion mechanisms not due to the blistering.⁴

RISK CONSIDERATIONS: INSPECTION AND MAINTENANCE OF BLISTERED COATING

The U.S. Navy and other industries use ASTM D714 to rate blisters based on size and density.⁹ In the Navy, judgement based on this rating determine which blisters are acceptable, and which are unacceptable. Larger and more dense blisters are more unacceptable; there is no consideration of mechanisms. Unacceptable blistering is considered coating failure—just the same as damaged and openly corroding areas.

A major risk of blistering is whether the blisters will break during continued service, resulting in open corrosion and potential damage to the substrate. A recent study of the blistering of in-service, high-solids tank and void coatings was performed to determine blister characteristics that could correlate to coating failure through blister breakage.¹ This program was a follow up to a short-term lab study, which found that once blisters form, they stabilize and do not tend to grow or break over time.¹⁰ The recent study tested these findings by inspecting four ship tanks for blistering after six-to-nine years of service. Each tank had five, 8-inch by 10-inch areas marked off for blister inspection. Each area was then covered with a sheet of transparent grid paper, and the inspector marked blisters (broken or intact) and corroded areas. One to three years later, depending on the ship, the tanks and areas were reinspected to determine changes in the blistering.^{1, 11} Table 1 breaks down the inspection timelines of each of the tanks. Figure 3 shows examples of initial blister conditions found in the tanks, as well as an example of the transparencies used to record blister locations.¹¹

Table 1: Age of Tanks at Initial and Final Blistering Inspections

Tank No.	Coating Age at First Inspection (Years)	Coating Age at Final Inspection (Years)
1	6	7
2	8	9
3	9	12
4	9	12

A primary finding was that during service, many initially intact blisters broke, exposing the substrate to the environment and allowing open corrosion.^{1, 11} Also, the blister propensity for failure (“breaking”) showed variance from tank to tank, but within a given tank, blister failure was similar from area to area.



Fig. 3: Examples of blistering areas at first inspection

The relatively large amount of blister breakage—up to 45% of the areas inspected in the worse tank^{1, 11}—directly opposes the findings of the short-term lab testing that saw no blister breakage.¹⁰ This significant amount of blister breakage in the tanks could be the result of a few factors. Coating age could play a role in the likelihood of blisters breaking. It may be that as the coatings age and fatigue, they become more brittle. At a certain point, they may no longer be elastic enough to grow with changes in pressure related to the flow of water into and out of the blister, and the blistered coating cracks as a result. As a coating ages, the risk of blisters breaking may increase. If it is a

contributing factor, the lab exposure may not have been long enough to show results representative of coatings in a real immersion setting. Additionally, the test conditions may not have accurately represented the environment of in-service coatings. The tanks' service conditions may have been more severe in terms of humidity, time of wetness or physical stress, leading to more broken blisters.

Service environment may explain the difference in blister failure between tanks, as well. Each tank may have been exposed to a unique environment for different amounts of time. The tanks with more blister failure may have had higher times of wetness, more frequent wet/dry cycles, had more aggressive fluid in them, or may have been exposed to significant periods of high humidity. Blisters in the most corrosion-prone areas should be prioritized for repair over those in less corrosive areas. Similarly, differing physical stresses like fluid flow, foot traffic and debris movement may vary the degree of blister breakage between tanks. A lower quality of surface preparation and poor coating application may have been performed in one tank compared to another, resulting in more surface contamination and undercoating corrosion. This could lead to more blisters breaking as well. Blister characteristics such as size did not indicate a higher likelihood of blister breakage.

It can be expected that, for the most part, a tank will have a similar surface preparation, coating application and environment throughout. This would explain why there was a similar amount of blister breakage from area to area within a given tank. Some exceptions could be if a tank is only filled halfway, blisters above the waterline would be less likely to break than those below, or an area that is hard to reach for surface preparation may show more blister breakage than those in easy-to-clean areas.

Perhaps the clearest sign of blisters at a greater risk of breaking or causing damaging corrosion is the extent of coating damage in the vicinity of the blistering. Blistering near open corrosion is a sign of activity under the coating, and these blisters are often anodic. Not repairing these blisters may lead to damaging pitting corrosion. Additionally, if the open coating is repaired and the blistered coating is left as found, even more current may come from the anodic area, increasing the corrosion rate. Blisters near active corrosion on open surfaces should not be ignored and should always be repaired.

These factors are important as coating maintenance funds are limited. Often, decisions must be made on which blistered areas should be repaired and which can be left with the least risk. The biggest economic factor in determining when to repair problematic blistering is the incremental cost to repair blistered areas. If the area is easily accessible, can be inspected regularly, and can be repaired without difficulty, then it is not as important to repair a blistered coating right away. This decision can be reinforced by opening a few blisters to attempt to determine what mechanism is causing the blistering and if there is major damage to the substrate below the blister. If the substrate seems to be mostly undamaged, then these areas can be touched up and the rest of the blisters left intact until the condition of the entire area worsens or the blisters begin to break.

If there are many years of service before the next maintenance availability, more significant consideration should be given to blistering. Blisters form for a reason; they are a product of some underlying issue or weakness in the coating. Therefore, they show the coating is at a higher risk of failing in the future and causing damage to the structure, if corrosion is not already occurring. In cases where there is extensive blistering with many existing broken blisters, experience suggests that blisters will continue to break, and active corrosion will continue in these areas. Such blistering should be repaired as soon as funds allow.

If minimal blistering is found adjacent to planned rework areas, it may be prudent to additionally repair the blistered areas, as the funds have already been invested to mobilize and prepare to paint in the area. It should be noted that touch-up repairs typically do not last as long as a full repair and repaint, so reinspections should take place at the next availability where touch-up is performed.

CONCLUSION

Each blistering mechanism has different effects on the substrate underneath—but all blisters are a sign of poor performing coating. Blistered coating can lead to increased pitting damage below an intact blister and is at a higher risk of breaking and causing open corrosion to a substrate. The findings of this ship tank blister inspection project suggest that further investigation into additional factors—beyond blister size and density—may be beneficial for evaluating blistered coating. Service environment and coating age may be important factors to investigate. For the most part, proper surface preparation, good painting procedures and timely repair of damaged coating should significantly reduce the risk for blistering.

ABOUT THE AUTHORS



Michael Kibler is a Staff Engineer at Elzly Technology Corporation and has worked in the corrosion and protective coatings industry for two years. He graduated from Virginia Tech in 2017 with a bachelor's degree in chemical engineering. He is an SSPC-certified NAVSEA Basic Paint Inspector (NBPI) and a NACE-certified Shipboard Corrosion Inspector.

Patrick Cassidy is a Senior Engineer with Elzly Technology Corporation who has been working in the corrosion and coatings industry for over 10 years. He has been involved in a diverse number of programs including coatings research, field investigation and application of corrosion control products. Cassidy is an SSPC-certified NBPI and Thermal Spray Inspector, a NACE-certified Shipboard Corrosion Inspector, and has completed additional training in NAVSEA Cathodic Protection Design.



Jay Ong is the Corrosion and Coatings Engineering Branch Head with the Naval Surface Warfare Center, Carderock Division, where he has been employed for almost 10 years. He holds a B.S. and M.S. in chemical engineering from Villanova University and an M.S. in engineering and industrial management from Drexel University. He is an SSPC-certified NBPI and a NACE-certified Coating Inspector (Level III).



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