White Paper

Mission Critical Facilities - Is the Use of Galvanized Pipe an Effective Corrosion Control Strategy in Double Interlock Preaction Fire Protection Systems?

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By Jeffrey T. Kochelek

Engineered Corrosion Solutions™

Complete Corrosion Control.

Engineered Corrosion Solutions, LLC
11336 Lackland Road
St. Louis, MO 63146
314-432-1377
ecscorrosion.com

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ecscorrosion.com

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There is now a significant body of evidence that suggests that the use of galvanized steel pipe in dry and preaction fire sprinkler systems may expose mission critical facility owners to the risk of premature system failure due to internal corrosion. Conditions that typically exist within dry and preaction fire sprinkler system piping create an environment in which zinc coated mild steel will corrode, sometimes quite aggressively. In the case of mission critical facilities, the risks of premature failure are more pronounced than they might otherwise be because of the sensitivity and costs of the systems that are being protected. A water leak simply cannot be tolerated.

The evidence indicates that galvanized fire sprinkler systems designed for a service life of 25+ years may require pipe replacement and/or complete system replacement after less than 10 years. Moreover, galvanized steel piping is often installed with a premium price over less costly mild steel piping. The price premium, which can be as high as 30% over mild steel, is ostensibly paying for superior corrosion performance but the evidence from the field does not support the claim.

Make no mistake; mild steel piping will also corrode in the environment that is found in dry and preaction fire sprinkler systems. However, in the case of galvanized steel the corrosion mechanism creates highly localized attack of the base metal once the galvanized layer is breached. As a result, although mild steel initially corrodes more quickly than galvanized steel in the persistently moist oxygenated environment that exists within the piping, the corrosion is more uniform and the oxygen attack is distributed over the entire wetted metal surface. In the case of galvanized steel, voids in the zinc coating tend to concentrate the corrosion of the underlying base metal in those portions of the piping where the zinc coating has been dissolved. These areas are subject to aggressive pitting attack and the resultant through the wall pipe penetrations.

The sources of evidence include:

- Reference material from:
    - National Association of Corrosion Engineers (NACE)
    - Midwest Metal Fabrication
    - Association of Water Technologies (AWT)
- Water and deposit samples captured from dry and preaction fire sprinkler systems that are in service
- Pipe samples from dry and preaction fire sprinkler systems that have failed due to internal corrosion
- Corrosion chamber testing of galvanized coupon samples
- Field maintenance and replacement histories on actual dry and preaction fire sprinkler system installations

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Trapped Water and Oxygen

Trapped water is the primary cause for the corrosive conditions that exist within dry and preaction fire sprinkler systems. Although there is an awareness that pitching the pipes and draining water is important, it is virtually impossible to remove all of the moisture. Even a small amount of moisture combined with the oxygen that is introduced with the pressure maintenance air creates a very corrosive environment. There are typically three sources for the trapped water:

1. Water that cannot be drained after hydrostatic testing of the piping after installation
2. Water that condenses from the moist air that is injected with the pressure maintenance air
3. Water that is introduced during periodic fire sprinkler system testing

Once the water is trapped inside the piping, it is very difficult to remove. The bottom line is that the internal environment of the piping can be considered *persistently moist and oxygenated*. In the corrosion that occurs the amount of wetted metal is the rate limiting component, i.e. the corrosion reactions speed up and slow down based on the amount of wet metal that is available. Oxygen exists in abundance to drive the corrosion reaction inside the pipe. The corrosion reaction is the same, whether the metal is iron or zinc:

Anodic Reactions: $Fe^{o} \rightarrow Fe^{+2} + 2e^{-}$ iron becomes a water soluble ion
$Zn^{o} \rightarrow Zn^{+2} + 2e^{-}$ zinc becomes a water soluble ion

Cathodic Reaction: $\frac{1}{2}O_2 + H_2O + 2e^{-} \rightarrow 2OH^{-}$ oxygen creates demand for e-

Electrochemical Reaction: $Fe^{o} + \frac{1}{2}O_2 + H_2O \rightarrow Fe(OH)_2\downarrow$ iron hydroxide precipitate

$Zn^{o} + \frac{1}{2}O_2 + H_2O \rightarrow Zn(OH)_2\downarrow$ zinc hydroxide precipitate

It should be noted that if dry and preaction fire sprinkler systems could be constructed to <u>**completely**</u> eliminate the trapped water, then galvanized pipe would provide very effective corrosion protection. However, if the water is completely eliminated, then corrosion will stop and the less costly mild steel would be just as effective.

From the National Association of Corrosion Engineers (NACE) - Resource Library on Materials Selection [1]

Zinc owes its high degree of resistance to atmospheric corrosion to the formation of insoluble basic carbonate films.

Zn^{o} (zinc metal) → ZnO (zinc oxide) → $Zn(OH)_2$ (zinc hydroxide)
→ $ZnCO_3$ (zinc carbonate)

Environmental conditions that interfere with the formation of such films may ***attack zinc quite rapidly****. The important factors that control the rate at which zinc corrodes in atmospheric exposure are:*

- *the duration and frequency of moisture*
- *the rate at which the surface dries*
- *the extent of industrial pollution of the atmosphere*

The rate of drying is also an important factor because a thin moisture film with higher oxygen concentration promotes corrosion.

It cannot be stated any more clearly. Galvanized steel piping will corrode quickly under the persistently moist oxygenated environment that typically exists in dry and preaction fire sprinkler systems.

From Midwest Metal Fabrication Website (Galvanized Steel Fabricators)[2]

This presents more evidence against the use of galvanized steel in the persistently moist oxygenated environment that exists in dry and preaction fires sprinkler system piping.

The surface of galvanized coatings is almost 100% zinc. It is the durability of the zinc that provides the outstanding anti-corrosion performance for steel, yet zinc is a relatively 'reactive' metal. It is the stable oxides that form on the zinc's surface that determine its durability, and these oxides are formed progressively as the zinc is exposed to the atmosphere, air. Carbon dioxide in particular is a contributor to the formation of these stable oxides.

White rust is simply the chemical compound, zinc hydroxide, which forms when zinc is in contact with moisture. It does not convert to a zinc carbonate passive film because the tightly packed sheets are not freely exposed to carbon dioxide-containing air. The protective zinc carbonate film never gets a chance to form. Since the corrosion reaction continues to proceed as long as the surfaces are wet and starved for carbon dioxide, a large accumulation of zinc hydroxide can form. Zinc is a very reactive metal in the presence of moisture when conditions do not allow the passive film to form.

There are times, albeit seldom, when the sheets have been wet for a long time; long enough that the amount of corrosion of the zinc coating can be *severe. In these cases, the product may no longer provide the corrosion resistance desired for the application. In these cases the white rust may take on a dark grey or black appearance. When the stain on galvanize turns black it usually means that iron has become part of the corrosion product, i.e. enough zinc has been consumed to expose the steel substrate.*

When white rust does occur, there is an actual loss of zinc coating, and some of the zinc that is intended to protect the coated steel product while in service is lost. The extent of the damage is primarily dependent on:

- *the exposure time to moisture,*
- *the temperature that is experienced during storage, and*
- *the presence of accelerating corrosive agents, such as chloride-containing salts.*

From the Association of Water Technologies

The most damning case against the use of galvanized steel in this persistently moist environment comes from a white paper prepared by the Association of Water Technologies **"WHITE RUST: An Industry Update and Guide Paper 2002."**[3]

Post-construction white rust is a problem where the fresh galvanized surface is not able to form a protective basic zinc oxide and typically the surface is partially wetted or completely submerged in water. In both cases, the deterioration begins when a localized corrosion cell is formed. The activity of such a corrosion cell/pit, results in rapid penetration through the zinc coating to the steel. Under these corrosive conditions, the surrounding zinc coating may be unable to protect the base steel and consequently the ***corrosion will continue to penetrate through the base steel****.*

White rust corrosion is often identified by the white, gelatinous or waxy deposit that can be observed. This deposit is a zinc-rich oxide, reportedly $3Zn(OH)_2 \bullet ZnCO_3 \bullet H_2O$ *and can be quite similar chemically to the protective zinc oxide typically identified as a dull-gray passive oxide. One critical difference between the two oxides is that the white rust oxide is porous and generally non-protective of the substrate, while the passive oxide is dense and non-porous effectively protecting the substrate from exposure to the environment. Corrosion control of galvanized steel, as with any metal, depends on forming and maintaining a stable and passive oxide layer. If the oxide is disrupted, repair is crucial. If the oxide layer is constantly disrupted or removed, general corrosion potential will increase or in the case of galvanized steel, depletion of the zinc coating will eventually occur. And if pitting corrosion occurs and is not mitigated, the* ***life expectancy of the component will be greatly reduced****.*

The conclusion drawn from all of these different sources is that galvanized steel produced by Hot-Dip Galvanizing (HDG), Heavy Mill Galvanizing

(HMG) or Electrogalvanizing will experience significant and irreversible deterioration and will fail very prematurely under the persistently moist oxygenated environments that exist inside dry and preaction fire sprinkler system piping.

Water and Deposit Samples from Galvanized Dry or Preaction Fire Sprinkler Systems

One of the clearest indicators that the galvanized (zinc) layer is degrading within a fire sprinkler system is the presence of zinc in water and deposit samples extracted from the piping. Zinc is rarely found in the supply waters that are connected to the fire sprinkler system and as such, any zinc found in water from the system is almost certainly from the degradation of the galvanized coating. Water samples should be collected from the following locations:

- Main drain
- Auxiliary drains
- Test connection
- Low points or dips in the system piping

Zinc levels of up to 2000 parts per million have been found in water samples collected from actual fire sprinkler systems. Zinc is also present in deposits extracted from those systems. Once the zinc coating is breached, the level of iron in the water begins to rise indicating that oxygen is beginning to attack the base metal substrate in the piping where the zinc coating has been breached. As such, the progression of corrosion will demonstrate several stages:

Stage One: No zinc present with low iron (after initial installation); water chemistry is essentially the same as the potable water supply – corrosion start up

Stage Two: Zinc levels in the water up to 200 ppm with less than 50 ppm iron; oxygen corrosion of the zinc layer with no breaches of the galvanized layer to the mild steel base metal substrate

Stage Three: Zinc levels in the water exceed 500 ppm with iron levels up to 200 ppm; galvanized layer continuing to corrode, some exposed mild steel base metal substrate

Stage Four: Zinc levels in the water exceed 1000 ppm with iron levels in excess of 500 ppm; excessive deterioration of the galvanized layer with significant pitting of the exposed mild steel base metal substrate

Failed Pipe Samples from Galvanized Dry or Preaction Fire Sprinkler Systems

Most of the galvanized pipe samples that fpsCMI has analyzed to determine the root cause for through the wall failures reveal the following characteristics:

- Visible evidence of a water stain lines in all of the pipe samples indicating that water was trapped in the pipe and was pooling in the low spots
- White crystalline deposits on the pipe walls and accumulated at low points in the pipe (zinc hydroxide corrosion by-product)
- Orange crystalline deposits on the pipe walls and accumulated at the low points in the pipe (iron oxide corrosion by-product)
- Pitting in the mild steel base metal substrate that is characteristic of "oxygen" attack, i.e. smooth, rounded pits with significant metal loss

Failure analysis reveals the following:

1. Oxygen corrosion (dissolution) of the zinc coating produces a void in the zinc layer and exposes the mild steel base metal – this correlates to the increase in zinc levels in water samples pulled from the system
2. Oxygen corrosion of the iron in the exposed, underlying mild steel substrate produces a pit in the base metal of the pipe – this correlates to the increase in iron levels in water samples pulled from the system
3. Build up of corrosion by-product solids, both zinc hydroxide and iron oxide, accelerates the corrosion via under-deposit mechanisms

Two other phenomena have been observed in the fire sprinkler system samples that have been collected by fpsCMI:

1. There is a lack of microbial contamination in the water and deposit samples from the corroding galvanized systems which seems to indicate that microbiologically influenced corrosion (MIC) is not a viable explanation for the corrosion that is taking place. There is some evidence in the literature[4] that suggests that soluble zinc can be biocidal when levels in the water exceed 800 ppm. All of the evidence suggests that oxygen corrosion is the predominant mechanism.
2. Failed pipe from several systems have demonstrated "knife cut" corrosion of the welded metal seam in the galvanized pipe. The ASTM specification (A795-796) for fire sprinkler tubing does not require heat annealing of the mild steel tubing to normalize it

before it is galvanized. As such, once the galvanized layer is dissolved, the anodic character of the seam may fail first as the oxygen attacks the weld metal or the heat affected zone.

Corrosion Chamber Testing of Galvanized Coupons

Corrosion chamber tests have been performed by fpsCMI under various conditions to evaluate corrosion control strategies (chemical corrosion inhibitors and nitrogen) and to observe the characteristics of galvanized steel metal attack under persistently moist oxygenated conditions. Standardized galvanized weight loss coupons and potable water were used in the tests. The results indicate the following:

- The zinc layer on the galvanized coupons is dissolved first at the air/water interface where oxygen solubility in the water is highest
- The zinc hydroxide precipitate is a white, fluffy, non-adherent by-product
- Attack of the zinc coating under the water line appears to be random and may be tied to irregularities in the galvanized layer
- The oxygen depleted areas where the galvanized coupons touch the chamber wall (non-metallic) exhibit zinc dissolution next
- Once the zinc coating is breached, the underlying mild steel begins to exhibit oxygen attack with the resultant iron oxide (hematite) formation

Field Maintenance and Pipe Replacement History

Evidence gathered from the field suggests that the average life of a dry or preaction fire sprinkler systems constructed using Schedule 10 galvanized pipe is less than 15 years. Failures have occurred in as few as 18 months although the average for first leaks is in the range of 3 – 5 years. There have been several systems that have required complete replacement in as little as 8 – 10 years.

Factors that affect the service life include:

- Quality of the piping installation – pitched to drain with no/few air leaks
- Amount of water trapped within the fire sprinkler system
- Frequency of air compressor operation – indirect indication of leaks within the system piping
- Location and number of auxiliary drains for removal of trapped water

Using galvanized pipe as a corrosion control strategy for dry and preaction fire sprinkler systems may not be a sound investment insofar as the service life of the system is concerned. However, in the case of mission critical facilities, the far greater risk is borne in assuming that a leak caused by internal corrosion is less likely because of the up-front investment in the more costly galvanized pipe. A single discharge of the trapped water from the fire sprinkler system onto a multi-million dollar computer array might have liability costs that dwarf the entire cost of the fire sprinkler system. Better to invest the funds that would have been spent on galvanized pipe to deploy a comprehensive corrosion control strategy that provides measureable performance against oxygen corrosion and can provide the assurance of an extended service life.

Mission critical facility designers develop very stringent metrics and redundancy into all of the “systems” that are deployed as part of these complex buildings. It is time to reconsider the fire sprinkler systems that service these facilities and demand the same scrutiny for measured performance in corrosion control that is required with all of the other building systems. A corrosion control strategy that integrates nitrogen generators, in-situ gas analyzers and supervised corrosion monitoring devices can provide the required level of reliability to meet these standards.

References

[1] NACE Resource Library on Materials Selection – Zinc

[2] Midwest Metal Fabricators Website http://www.midwestmetalfabrication.com/galvanizedsteel-whiterust.html

[3] *"White Rust: An Industry Update and Guide Paper 2002"* Association of Water Technologies – technical committee of Association of Water Technologies

[4] *"Toxicity of Zinc to Heterotrophic Bacteria from a Tropical River Sediment"* – C.O. Nweke, C.S. Alisi, J.C. Okolo and C.E. Nwanyanwu - Applied Ecology and Environmental Research 2007

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Engineered Corrosion Solutions, LLC is a corrosion management consulting firm that offers fire sprinkler system assessment and analysis coupled with design services and a full suite of corrosion management strategies that include equipment and integrated devices for controlling corrosion in water-based wet, dry, and preaction fire sprinkler systems. We understand the science of corrosion in fire sprinkler systems in a complete variety of different settings from parking structures to warehouses to clean rooms to data centers.

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