

3. Corrosion – Mechanisms, Prevention and Testing

GalvInfoNote

3.6

Galvanic/Bimetallic (including Cut Edge) Corrosion of Galvanized Sheet

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Galvanic Corrosion/Protection

Corrosion reactions require four components: viz., an anode, a cathode, an electrical circuit and an electrolyte. **Galvanic corrosion** is the corrosion that results when two dissimilar metals with different potentials are placed in electrical contact in an electrolyte. The difference in electrical potential that exists between the different metals serves as the driving force for electrical current flow through the electrolyte. This current results in corrosion of one of the metals. The larger the potential difference, the greater the probability of galvanic corrosion. Galvanic corrosion only causes deterioration of one of the metals. The less resistant, active metal becomes the anodic corrosion site. The stronger, more noble metal is cathodic and is protected.

The electrolyte is almost always an aqueous medium that conducts electricity. It can be any moisture that is in contact with both metals, including condensate, dew, rain, bulk water (flood, etc.), damp debris that contacts both metals, moisture in soil, etc.

*When zinc and steel are in contact in the presence of an electrolyte, a current will flow from the steel to the zinc, so that the zinc becomes an anodic electron-producing region while the steel is cathodic and consumes electrons¹, preventing it from combining with oxygen and forming rust. This property of zinc is used in many applications as a **galvanic protector** of steel. The zinc coating also acts as a barrier, further protecting the steel.*

Refer to GalvInfoNote 3.1 for additional information on galvanic and barrier protection of steel by zinc, and why an active metal such as zinc has such a low atmospheric corrosion rate compared to iron and steel.

Bimetallic Corrosion

The fact that zinc is galvanically protective of iron and steel is fortuitous in mankind's unending battle against corrosion. It extends the life of steel components by a factor of 10 to 100. Galvanic couples are also the principle that allows batteries to produce useful electrical current. In many situations, however, galvanic couples cause problems. The term sometimes used to describe this negative outcome is "bimetallic corrosion". Even a small piece of zinc can be consumed rapidly when electrically connected to a large piece of steel in the presence of an electrolyte, due to the high rate of electron flow from the zinc to the steel.

Because copper is much more noble than zinc, the latter can corrode very rapidly in a bimetallic couple of these two metals (see Table 1). In certain situations they do not even have to be in electrical contact. When a noble metal, e.g., copper, corrodes and dissolves slightly in water that subsequently flows over a less noble metal, e.g., zinc, the copper will react with and replace the zinc in a true bimetallic couple. Both these 'contact' and 'flow-over' situations are illustrated in Photo 1. Where the copper tubes pass through the galvanized frame of the A/C unit the corrosion is severe, but less so where the copper-bearing condensate water dripped on parts of the frame removed from the tubes.



• Photo 1 Galvanic (bimetallic) corrosion in A/C unit

Galvanic/Bimetallic Corrosion of Zinc in the Atmosphere

Except for aluminum and magnesium, the corrosion of zinc is increased by electrically connecting it to other common metals. Depending on the connected metal and the type of atmosphere, the galvanic corrosion can be as much as 5 times the normal corrosion of zinc in a rural atmosphere and 3 times that in a marine atmosphere². The corrosion rate of zinc decreases when it is connected to aluminum in urban and marine atmospheres and to magnesium in all atmospheres. **Zinc and aluminum are galvanically compatible materials in atmospheric environments.** That is, when these two metals are in direct contact there will be very little galvanic corrosion of either metal resulting from the coupling³.

Table 1⁴ shows the galvanic corrosion of zinc coupled to different metals. Among the metals, mild steel acts as the most efficient cathodic material, largely owing to the voluminous rust, which can absorb pollutants and retain moisture and thus give rise to an aggressive electrolyte of good conductivity.

• Table 1 Galvanic corrosion rate of zinc coupled to other common commercial metals in different atmospheres (µm/y)

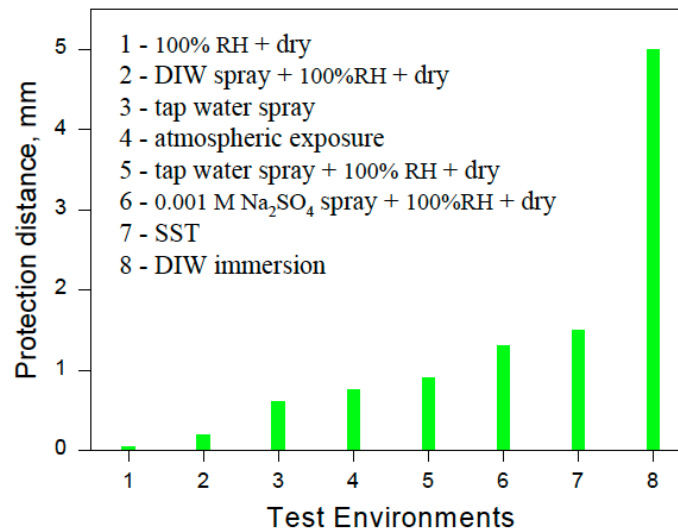
Coupled alloy	Rural	Urban	Marine
Zinc freely exp.	0.5	2.4	1.3
Mild steel	3.0	3.3	3.9
Stainless steel	1.1	1.8	2.0
Copper	2.2	2.0	3.2
Lead	1.6	2.4	3.4
Nickel	1.5	1.9	2.8
Aluminum	0.4	1.1	1.1
Anode aluminum	0.9	1.9	1.0
Tin	1.0	2.6	2.4
Chromium	0.7	1.4	1.9
Magnesium	0.02	0.04	1.1

Cut Edge Corrosion

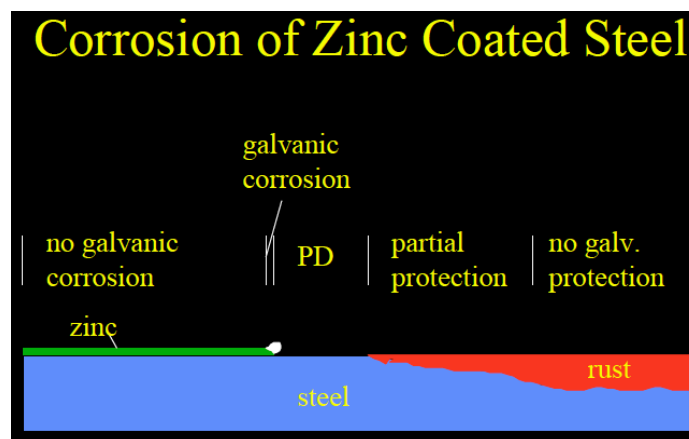
Galvanic corrosion of galvanized steel occurs at areas where the steel underneath the zinc is exposed, such as at cut edges, gouges or scratches. At these areas, the exposed steel is cathodically protected while the surrounding zinc coating is galvanically corroded. In most cases, however, the amount of coating loss due to galvanic corrosion, compared to normal corrosion, is small because the exposed areas of bare steel are usually too small to cause significant corrosion of the relatively much larger zinc surface area. As a result, the atmospheric corrosion rate, including galvanic and normal corrosion, of a zinc coating is usually very similar to that of uncoupled zinc. The larger the anode (zinc) to cathode (steel) ratio, the better the protection offered, as there is a sufficient supply of electrons to prevent oxidation of the cathode.

How much exposed steel will the adjacent zinc protect, i.e., what is the **protection distance** offered by zinc? Protection distance (PD) is essentially determined by the potential drop in the lateral direction in the electrolyte arising from the current flow from zinc to steel⁵. The exact protection distance for a given geometric setting depends on the specific environment as shown in Figure 1, while Figure 2 is a schematic of the protection distance phenomenon. PD increases with increasing conductivity and thickness of the electrolyte. Note that galvanic action between zinc and steel under atmospheric exposure extends only a very short distance.

Protection Distance









• Figure 1 Protection distance of zinc on steel for various environments



• Figure 2 Schematic of protection distance of zinc on steel

The ability of a zinc coating to protect exposed steel at a cut edge is shown in Figure 3⁶. The edge of a 1 mm thick sheet remains essentially free of red rust after 6 months atmospheric exposure, while that of a 2.3 mm thick sample exhibits rust after 2 weeks, shows more severe rust in the center of the thickness after 3 months, and actually has less rust after 6 months. This apparent “self healing” is likely the result of zinc corrosion products, e.g., zinc carbonate complexes, that wash off the zinc layer and adhere to the exposed steel, and in the process provide additional protection.

	Thickness	After 2 weeks	After 3 months	After 6 months
Galvanized steel	1.0mm			
	2.3mm			

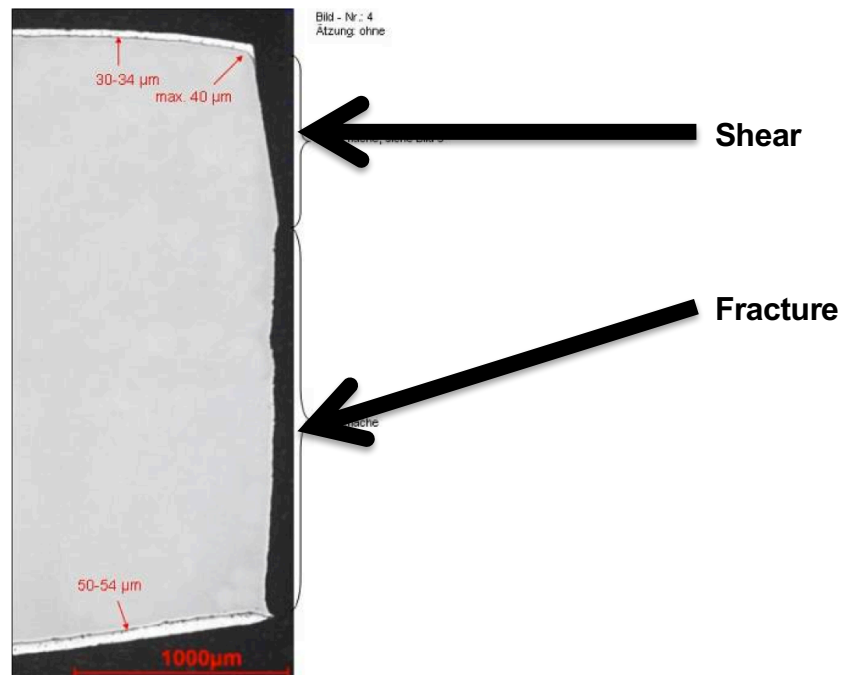
Appearances of cut end sections after atmospheric exposure test

- Figure 3 Exposed edge steel corrosion of 90/90 g/m² coated sheet after field exposure

Types of cut edges on galvanized sheet

If continuously galvanized sheet is used in its parent, full width form, a cut edge is produced only where lengths of sheet are cut from a coil. In the manufacture of smaller parts, the sheet is cut into much smaller pieces that create many more exposed steel edges.

The most common method of cutting is by shearing. It is accomplished by the use of straight blades, rotary shears or blanking/punching dies. Shearing of steel sheet, when properly done, produces a cut face that is almost perpendicular to the sheet surface. This cut face is one-third shear cut and two-thirds fracture with no or very little burr. Photo 2 shows the configuration of a good rotary shear cut edge.



- Photo 2 Rotary sheared edge of ~ 3mm coated sheet showing the shear and fracture regions⁷

Studies have shown⁸ that the shearing of galvanized sheet can “smear” some surface zinc over the 1/3 shear portion of the cut face, although zinc smearing is not evident in Photo 2. While the thickness of the zinc that may be pulled down is very much less than that on the surface, if present it does provide some added protection that can keep the shear portion of the cut free of rust for a longer period than if it was not present. Even if there is some zinc smear, with its small mass, the degree of extra protection it

provides is small and cosmetic. The bulk of galvanic edge protection comes from the larger mass of zinc nearby on the surface of the sheet.

If shearing is done poorly, and the edge has a pronounced burr, this protrusion is usually further away from the coating zinc and therefore can rust very quickly, resulting in a poor and perhaps unacceptable appearance.

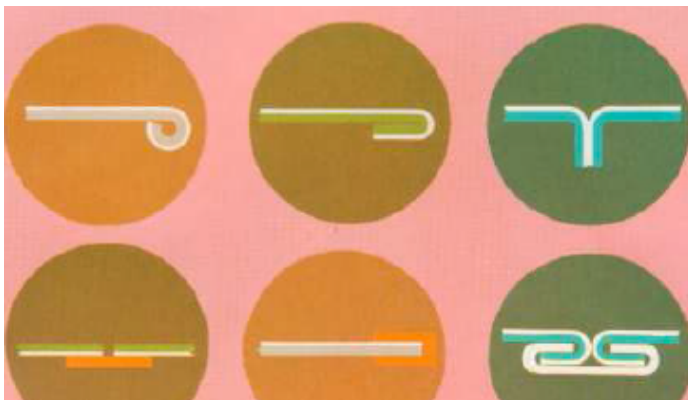
Other methods of cutting steel sheet include: blade sawing, abrasive sawing and laser cutting. These methods can produce clean-cut edges. However, to the extent that “smeared” zinc on the edge provides extra protection, these methods do not have this advantage, as they will absolutely not transfer any zinc to the edge. Saw and abrasive cuts also have the disadvantage that they can sometimes produce ragged burrs and small protruding pieces of steel that can rust even more quickly than a shear burr.

Utility of cut edges

While the degree of cut edge rust that occurs on even the most well cut galvanized sheet can be aesthetically unacceptable, such corrosion does not detract from the structural integrity of the component. Also, until the zinc on the surface near the cut edge has been consumed, the degree of rust will change very little. For thin sheet (< 1 mm), a cut edge can remain free of edge rust for the life of the component in most environments. Photo 3 illustrates a relatively thick galvanized part with visible cut edge corrosion that in all likelihood will never worsen over its useful life. While this edge may not be attractive, it is still functional.



Photo 3 Edge rust on a galvanized part



• Figure 4 Designs for concealing edges

For applications where aesthetics are important, and rust staining from superficial corrosion would be an issue, strategic design can be employed⁹. This is illustrated in Figure 4 where trims, adhesive tapes or rolled flanges can be used to conceal the edges.

Summary

That an electrochemically active metal like zinc can offer long-term corrosion protection to steel is a great benefit to modern society. It does this through galvanic protection and by acting as a barrier coating. While zinc's galvanic properties can protect exposed steel areas, e.g., cut edges, on galvanized steel, they can also result in rapid bimetallic corrosion of zinc if it comes into contact with a more noble metal, such as copper, in the presence of an electrolyte.

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¹ Porter, Frank C., Corrosion Resistance of Zinc and Zinc Alloys, Marcel Dekker, Inc., New York, 1994, p. 84

² Zhang, X. Gregory, Corrosion and Electrochemistry of Zinc, Plenum Press, New York, 1996, p. 209

³ Galvanic Compatibility of Galvanized Steel and Aluminum, Zhang, X.G., CSSBI, Technical Bulletin, Volume 2, Number 2, March 1999

⁴ Zhang, 1996, Op. Cit., p. 210

⁵ Zhang, 1996, Op. Cit., p. 213

⁶ Nisshin Steel Quality Products, publication R-15 '10.07

⁷ Zermout, Z., Richter, A., de Bruycker, e., Cut edge corrosion of metallic coated steel, Dusseldorf, 30-31 May 2006, Arcelor

⁸ Andrew, T. O., Edge Protection by Zinc, Product Development Technical Digest, BSC, March, 1986

⁹ Ibid