

Technical Brief: Chemical and Corrosive Properties of Solid Zinc Strip

General Properties

Zinc has an atomic number of 30 and an atomic weight of 65.38. Its crystalline structure is hexagonal close-packed which determines physical and chemical properties. Zinc is an electro-positive element giving up two electrons for an oxidation state of +2. It is more reactive than brass, steel, nickel or copper but less so than aluminum or magnesium. The term reactive is relative and relates more to zinc's position on the electrochemical series at 0.76 volts to the standard hydrogen electrode.

In a normal atmosphere, zinc forms a basic zinc carbonate film that greatly retards its corrosion rate, which is similar to the aluminum oxide film that forms on aluminum which accounts for its low corrosion rate. Zinc -- when connected with metals below it in the electrochemical series -- will sacrificially protect that metal, which accounts for its wide usage in the galvanized steel industry.

Zinc Protects Steel In Two Ways:

1. It is a barrier coating, and with its low corrosion rate (0.1 mil/year in a rural environment) offers extended life service.
2. It is sacrificial and protects the steel when exposed to the atmosphere. The sacrificial situation needs to be considered when coupling zinc to dissimilar metals.

Zinc is amphoteric and will form positive zinc ions in low pH solutions or negative zincate ions in high pH conditions and remain relatively insoluble in the neutral range. The lowest corrosion rates are encountered in the pH range of 6 to 10.5.

Zinc corrosion is controlled by four factors:

1. Zinc is attacked by acids at rates which decrease as pH increases.
2. Zinc is capable of forming insoluble basic salts when appropriate pH levels are reached (approximately 8).
3. Zinc has a high hydrogen overvoltage.
4. Zinc is anodic to its metal impurities, to hydrogen and to most surface contaminants.

The mechanism for zinc corrosion is largely determined by the formation and stability of the basic carbonate film. Zinc reacts with oxygen to form zinc oxide (hydroxide) with subsequent reaction with carbon dioxide and water to form the basic carbonate ($ZnO/CO_2/3Zn(OH)_2$). Once this film is formed, the surface becomes passivated to further attack.

The atmosphere and location in which the material is used as well as weathering, rates of oxygen diffusion, wet/dry conditions, etc. will all have a bearing on corrosion rate. The composition of zinc seldom has a significant effect on its rate of corrosion in atmospheric exposure. It is probable that all commercial forms of zinc have within plus or minus 10% of the same corrosion rate in any given outdoor environment.

Galvanic Corrosion

When two dissimilar metals are in electrical contact in the presence of an electrolyte, galvanic corrosion of one takes place while the other is protected. Any metal that is above another in the galvanic series will corrode (oxidize) at the expense of the other metal. In the case of zinc and iron or galvanized steel, this protection is sometimes called sacrificial or cathodic protection.

The farther two metals are separated in the galvanic series, the greater the potential difference between them and, correspondingly, the greater should be the resultant electric current when coupled. The greater the potential difference between two metals, the greater the driving force for the corrosion process. Zinc is high enough in the galvanic series to act as an anode in couples with most of the common metals.

Cathodic Protection

When a metal surface is in contact with an electrolyte, differences in electrical potential develop between local areas of the surface corresponding to this respective electrochemical reactivities; a more reactive (less noble) area is referred to as being anodic to a less reactive (more noble) cathodic area.

The difference in potential between two areas causes current to flow from the cathode to the anode through the metal, and from the anode to the cathode through the electrolyte to complete the circuit. When the current enters the electrolyte, metal ions go into solution, causing corrosion of the anode.

This corrosion can be prevented if it is connected electrically by a wire or rod to zinc, also in contact with the electrolyte. Cathodic protection is effective in such diverse mediums as salt water, fresh water, and most soils. The structures most frequently protected are underground pipelines and ship hulls.

Table 3
Galvanic Series of Some Commercial Metals and Alloys in Seawater

| | |
|---|--|
| Active or Anodic (-) | Magnesium |
| | Magnesium Alloys |
| | Zinc |
| | Galvanized Steel |
| | Aluminum 1100 |
| | Aluminum 2024 (4.5 Cu, 1.5 Mg, 0.6 Mn) |
| | Mild Steel |
| | Wrought Iron |
| | Cast Iron |
| | 13% Chromium Stainless Steel Type 410 (Active) |
| | 18-8 Stainless Steel Type 304 (Active) |
| | Lead-Tin Solders |
| | Lead |
| | Tin |
| | Muntz Metal |
| | Manganese |
| | Bronze |
| Naval Brass | |
| Nickel (Active) | |
| 76 Ni-16 Cr-7 Fe alloy (Active) | |
| 60 Ni-30 Mo-6 Fe-1 Mn | |
| Yellow Brass | |
| Admiralty Brass | |
| Red Brass | |
| Copper | |
| Silicon Bronze | |
| 70:30 Cupro Nickel | |
| G-Bronze | |
| Silver Solder | |
| Nickel (Passive) | |
| 76 Ni-16 Cr-7Fe Alloy (Passive) | |
| 13% Chromium Stainless Steel Type 410 (Passive) | |
| Titanium | |
| 18-8 Stainless Steel Type 304 (Passive) | |
| Silver | |
| Graphite | |
| Gold | |
| Platinum | |
| Noble or Cathodic (+) | |

Figure 4
Effect of temperature on corrosion of zinc in distilled water. As the temperature increases, the corrosion of zinc increases up to that temperature at which the solubility of oxygen decreases with a corresponding decrease in the corrosion rate of zinc.

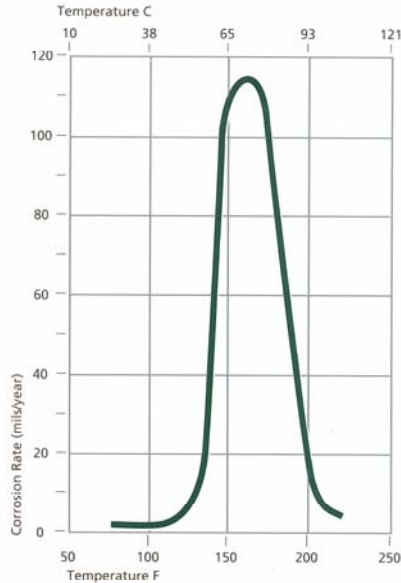


Figure 5
Effect of pH value on the corrosion of zinc in water. Zinc is an amphoteric metal and is useful in aqueous solution only in the pH range from 7 to 12.

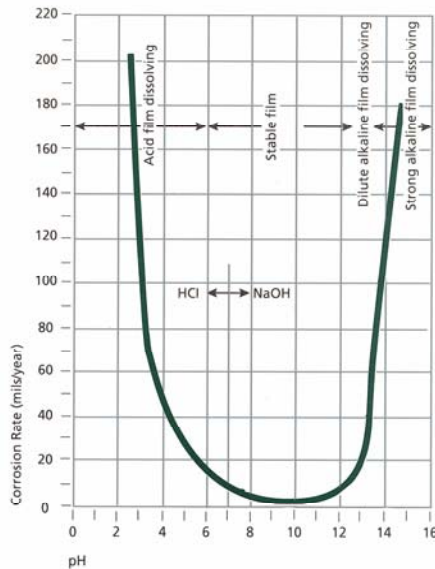


Figure 6
Corrosion of zinc as a function of oxygen concentration in solution.

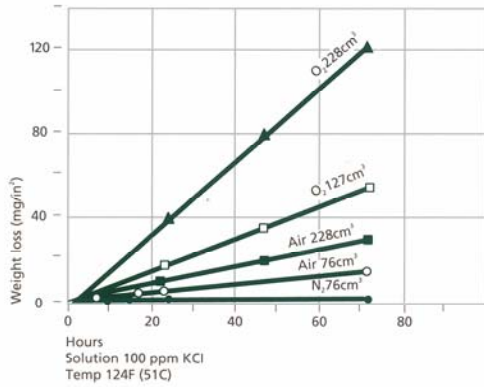


Figure 8
Effect of initial corrosion rate on the final steady corrosion rate of zinc exposed to the atmosphere at Middleton, Ohio.

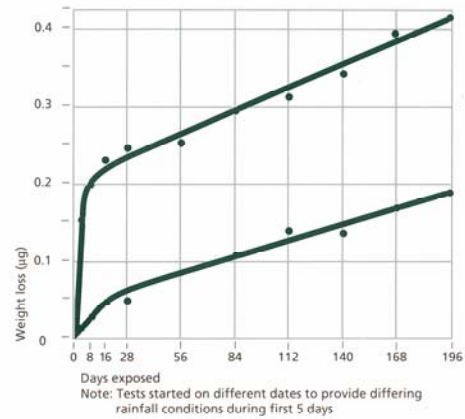


Figure 7
Dissolution of corrosion layer

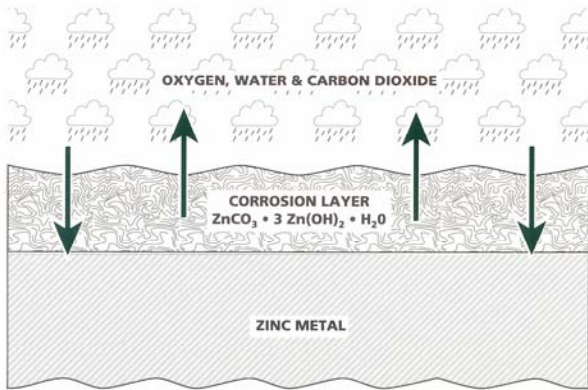


Figure 9
The Average 20-Year Corrosion Penetration Based On Location

| Type of Atmosphere | Average Penetration mils per year | Ratio of Penetration Rate To That At Arid |
|--------------------|-----------------------------------|---|
| Industrial | 0.252 | 36 |
| Seacoast | 0.058 | 8 |
| Rural | 0.042 | 6 |
| Arid (Phoenix) | 0.007 | 1 |

1. Most severe condition is the industrial environment due to presence of corrosive agency.
2. Difference between the rural and arid rate of corrosion is due to the relative humidity differences.
3. Seacoast environment is slightly higher than rural and is due to presence of more moisture and some salt content.