



## CORROSION MECHANISMS, PROCESSES

Understanding the basic elements that cause rust is the first step in preventing rust

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**AS** a metal fabricator, most of your focus is on changing the shape of a metal workpiece, whether you're cutting, bending, end forming, piercing, notching, machining, or some other process. Most of these processes require an oil-, solvent-, or water-based fluid to prevent friction, which in turn prevents overheating or premature wear.

Another consideration, one no less important than fabricating the workpiece, is preventing corrosion. Some fabricators rely on the metalworking fluid to provide both in-process and final corrosion protection; others use a final process to apply a short- to long-term corrosion preventive. Either way, corrosion prevention agents provide a necessary function. Without protection, the iron (Fe) in the steel interacts with oxygen (O) in the atmosphere, causing the steel to corrode.

Whether the corrosion takes the form of red rust (ferric oxide,  $\text{Fe}_2\text{O}_3$ ) or black stain (ferrous oxide,  $\text{Fe}_3\text{O}_4$ ),

the process is similar: Oxidation of the metal is linked to reduction of other constituents in the process, including the metalworking fluids.

### DEFINING CORROSION

Ferrous metal corrosion is the oxidation of iron metal from Fe to  $\text{Fe}^{+2}$ , further to  $\text{Fe}^{+3}$ , caused by electrons flowing from an anode (a point of positive polarity) to a cathode (a point of negative polarity). A common battery uses a similar process to carry electrical current from one terminal to the other. Corrosion control processes stop the flow of electrons or disrupt the chemical reaction at the cathode or anode.

**Rust Requirements.** Three components or constituents are necessary for rust to form:

1. A cell, consisting of a cathode and an anode
2. Moisture, which provides a pathway for current flow

3. Oxygen, which combines with the metal

Six common conditions can turn any piece of steel into a corrosion cell (see Figure 1).

A few key points to keep in mind:

- The requirements for creating a corrosion cell are minimal. For example, steel dust and fines, common byproducts of many metalworking operations, can become the cathode of a corrosion cell. Likewise, merely handling a tube or pipe with bare hands can be enough to begin the corrosion process.
- Some electrolytes in liquid form affect the rate at which corrosion advances.
- Superficial scratches are common and don't necessarily lead to rust; deep scratches that leave shiny steel exposed usually are corrosion sites.
- If the metal is exposed to quite a bit of airflow, the oxygen supply is replenished more or less continuously and the result is red rust. If the parts are

### Corrosion Mechanisms on Steel Surfaces

| Cell  | Anode           | Cathode                          |
|---|-----------------|----------------------------------|
| Steel with existing rust or scale                             | Steel           | Rust or scale                    |
| Steel with dust or fines                                      | Steel           | Dust or fines                    |
| Steel with electrolyte on surface of varying concentration    | Steel           | Acid, salt, or alkali            |
| Steel with fingerprints                                       | Steel           | Residue from oily skin           |
| Unevenly annealed steel                                       | Stained steel   | Annealed steel (coarse crystals) |
| Steel with deep scratch (deep enough to alter surface oxides) | Scratched steel | Unscratched steel                |

Figure 1

*Rust is caused by corrosion cells. Every corrosion cell has an anode and a cathode (positive and negative pole). Moisture provides a pathway for current flow, and oxygen is the agent that causes steel to change form to ferric or ferrous oxide.*

stored or used in an environment that doesn't have much airflow, the metal still can rust, but the process produces black oxide stains.

#### CAVEATS FOR CORROSION PROTECTION

Water-soluble machining and grinding fluids provide temporary corrosion protection. However, fabricators can't rely on these to prevent corrosion because the duration of protection needed varies from fabricator to fabricator; some need just a few hours of protection until parts go to the next process, while others store the parts for weeks. The storage and coolant conditions are critical factors in determining how long the fluids provide corrosion protection.

The factors that affect the duration of corrosion protection include:

1. Upstream manufacturing processes.
2. Surface cleanliness.
3. The corrosion preventive's condition during application.
4. The quality of the application method.
5. The packaging used to enclose the part.
6. The storage environment.

Knowing about upstream manufacturing processes and fluids used in those processes is a help in understanding how to handle the second factor, surface cleanliness. What sorts of metalworking fluids have been used on the part? Has

the part been stored between manufacturing steps? How has it been handled? If the part has metalworking fluid residues or if it has been stored in an area with fines and dust, surface cleanliness is an issue that must be addressed.

Third, after coating but before packaging, good handling practices are necessary to maintain the protective film's integrity. Gloves are necessary to prevent the oils in workers' skin from coming into contact with the steel.

Fourth, the fluid delivery system must have adequate capacity to wet the parts thoroughly and must be maintained to deliver a consistent quantity of corrosion preventive to the parts. A good filtration system—one that minimizes the sizes and quantities of fines and the levels of tramp oils, chlorides, and sulfates—extends the fluid's ability to prevent corrosion. Also, the fluid's concentration must be maintained at the correct level, which should be measured with an instrument more precise than a refractometer.

Fifth, the packaging to enclose the parts must be of sufficient quality and in good condition, not torn or damaged, to prevent direct access to the coated parts.

Finally, the storage environment must be controlled to prevent gross fluctuations of temperature and humidity (less than 15 degrees F and less than 10 percent change in relative humidity in a 24-hour period).

#### MEASURING A CORROSION PREVENTIVE'S EFFECTIVENESS

A number of short-term and long-term tests can measure corrosion protection. All of these tests are designed to mimic real-life applications under accelerated conditions. Be aware that the interpretation of the test results can be just as important as setting up and controlling the conditions of the tests.

**Metal Removal Fluids.** The chip test is used to assess the interaction of the metal removal lubricant and metal chips that are generated. If the chips are not consistent relative to alloy type, chip size, and cleanliness (for example, no fines on the chips), the results will be inconsistent. Most chip tests involve a fixed amount of chips covered by a measured amount of coolant. The wet chips are then set on filter paper or metal blocks to determine the rust potential. Most chip tests last a few hours.

**Corrosion Prevention Fluids.** Corrosion preventives have more stringent requirements and better-defined test methods than metal processing fluids. Some of the more common tests involve cabinets that control the temperature and humidity. In addition, the handling of coated test panels must be controlled relative to the amount of corrosion preventive that is applied to the surface. Most testing is conducted with duplicate or triplicate panels and the water

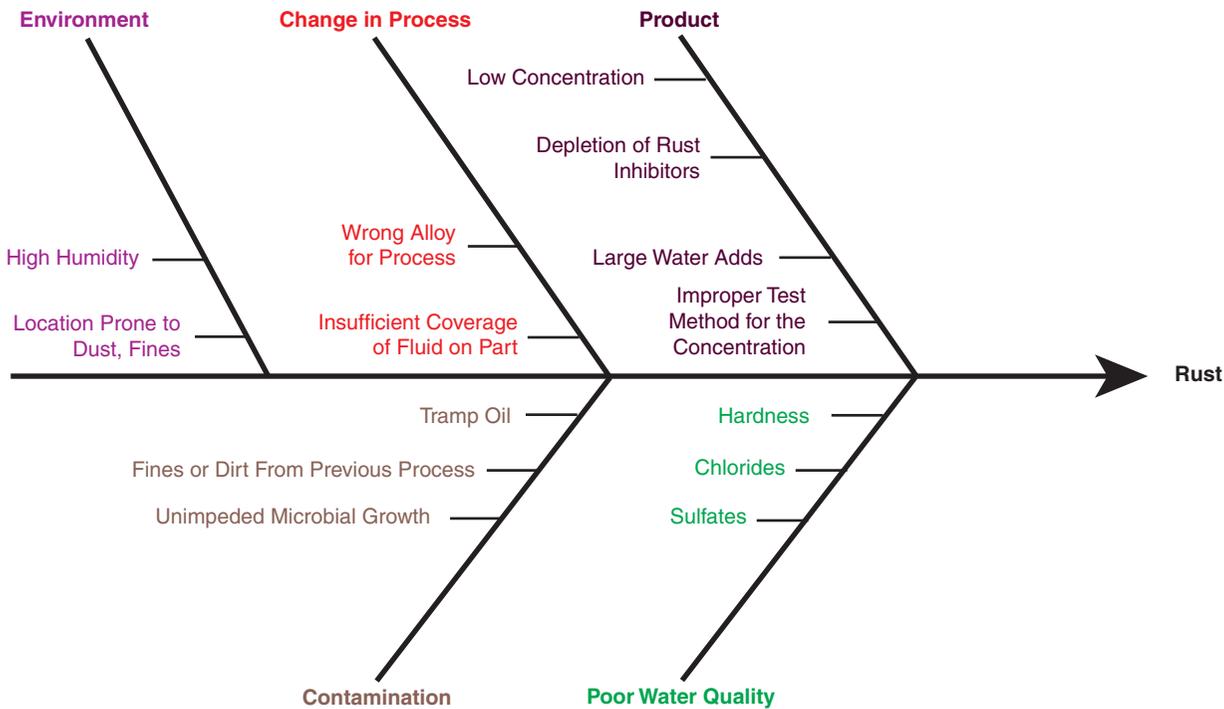


Figure 2

Finding the cause of corrosion doesn't need to be a daunting task. Breaking the causes down into five broad categories gives you a starting point.

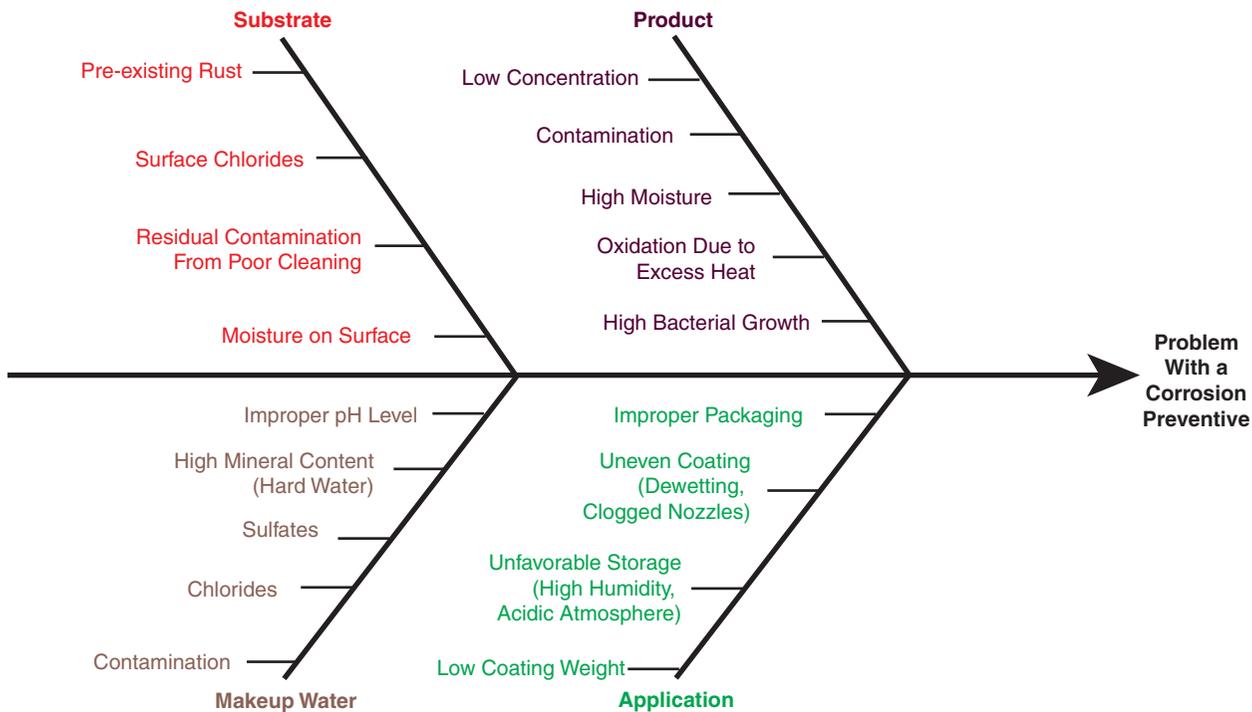


Figure 3

More troubleshooting details can help you home in on the problem area.

source must be pure to eliminate any contaminants (chlorides or sulfates) that could affect the results.

- The Joint Army-Navy (JAN) cabinet test, in use since the 1940s, uses a temperature maintained at 120 degrees F with 100 percent relative humidity. It is a condensing environment, meaning that water collects on the surface of the test panel and runs down the panel and the coating.

- The salt spray cabinet test (ASTM B117) exposes specimens to a 5 percent salt spray in the form of a fog; the temperature is maintained at 100 degrees F.

- The GM 10-cycle test, developed by General Motors to evaluate corrosion preventives, has been adopted by many suppliers aligned with GM. This method is similar to the JAN but it runs at 100 degrees F in a noncondensing environment. In addition, it runs 10 cycles, each cycle consisting of 18 hours in the cabinet and 6 hours out of the cabinet.

## TROUBLESHOOTING

When you first investigate a rust issue, it is important to learn the metal surface's exposure history; you need to trace back through all of the processes to determine where the corrosion began. The investigation should involve every process and fluid that contacts the parts. Only by tracing the entire process do you have a chance at determining the application that has the greatest impact on the corrosion problem. In addition, the fluids involved in the process should be evaluated for fitness for use relative to fresh fluid.

Cause-and-effect diagrams can help you find the root cause (see **Figure 2** and **Figure 3**).

## FLUID ANALYSIS

Analyzing the fluid provides an indication of the corrosion preventive's effectiveness. Seven tests measure the fluid's inherent characteristics—acidity, moisture, dirt,

percent solids, calcium, viscosity, and specific gravity. An eighth evaluation, the copper corrosion test, is a subjective measure of how the fluid stains copper.

1. **Acidity.** Excessive acid content, which may be caused by overheating the product, contamination, or excessive solvent evaporation, promotes and accelerates corrosion. Low acidity can be attributed to overdilution with solvent or contamination.

2. **Moisture.** Water in an oil- or solvent-based corrosion preventive will promote rusting or staining. An elevated level usually is associated with residual film present on incoming parts.

3. **Dirt.** Solid particles—iron fines, sand, or airborne particles—on the surface of the part act as corrosion sites. As the corrosion preventive is applied, drained, and reapplied, the dirt level continues to rise.

4. **Percent Solids.** The solids content can be used to determine concentration. Low concentration can occur from contamination or overdilution with solvent. High solids can be caused by contamination or solvent evaporation. Low solids content means low concentration, which translates into less corrosion protection.

5. **Calcium.** This is the direct measure of the key raw material used to provide the corrosion protection. Low calcium levels typically indicate low concentration, the result of excessive contamination or overdilution. High calcium levels may indicate solvent evaporation, excessive contamination, or the presence of water.

6. **Viscosity.** Viscosity, the measure of the product's ability to flow over, or *wet out*, the part is critical for forming a continuous, uniform barrier film over the entire part. The oil film thickness that remains on the part is related directly to the level of corrosion protection. In general, thinner films provide less corrosion protection whereas thicker films provide more.

Low viscosities can result from low concentration, excessive contamination, or overdilution. High viscosities usually indicate high concentration from solvent evaporation or excessive contamination.

7. **Specific Gravity.** Sometimes referred to as *density*, this measurement provides a fair indication of contamination. Low specific gravity values typically indicate low concentration, excessive contamination, or overdilution. High specific gravity usually indicates high concentration from solvent evaporation or excessive contamination.

8. **Copper Corrosion Test.** Described by ASTM D130, this test assesses a petroleum product's corrosiveness caused by active sulfur compounds. Results are rated by comparing the stains on a copper strip to a color scale from 1 to 4. A typical source of sulfur is honing oil.

## CORROSION — AT WHAT COST?

According to the "Corrosion Costs and Preventive Strategies in the United States," a 2002 study commissioned by the Federal Highway Administration, undertaken by CC Technologies Laboratories Inc. and sponsored by NACE International, the direct costs of metal corrosion in the U.S. total \$276 billion annually. To put this into perspective, it amounted to more than 3 percent of U.S. gross domestic product.

Corrosion comes with another cost. A manufactured component or assembly that fails or requires a remedial corrosion prevention treatment results in customer dissatisfaction. Using comprehensive corrosion control methods is critical in minimizing both types of costs. **TP**

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