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Corrosion of Metal

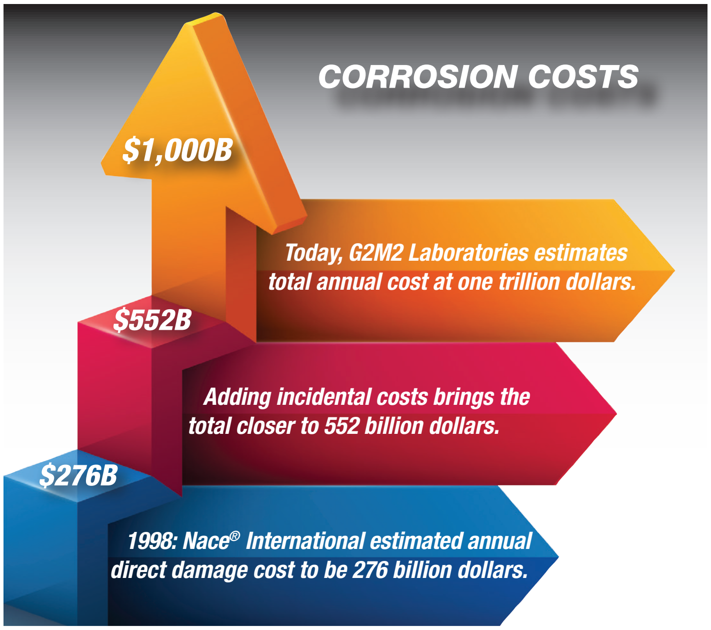
and its Effects on Pressure Instruments

An Old Problem

Since the dawn of the Iron Age, people have struggled with the detrimental effects of corrosion. Caused by natural chemical reactions with substances that contact the surface, this destructive process deteriorates metals and affects their properties. Despite this shortcoming, they have been an integral part of the growth of our civilization, allowing us to build taller buildings, bigger ships and superior machinery. However, since 1200 B.C. when iron was first applied, corrosion is still metal's Achilles heel.

The Cost Continues to Climb

The magnitude of the corrosion problem can best be illustrated by the monetary cost that it inflicts each year. In 1998, NACE® International calculated the annual direct cost to structural owners, operators, manufacturers and suppliers to be approximately 276 billion dollars. Adding in the indirect costs for loss of productivity, failures, litigation, insurance premiums and other factors, the total was closer to 552 billion. Today, G2M2 Laboratories estimates that number to be as high as one trillion dollars annually. Therefore, there are strong economic incentives to understand the causes of corrosion and to formulate methods to mitigate the menace.



The Right Stuff for the Job

Metals are selected based on their unique properties. Depending on the intended use, functional characteristics will dictate which material best serves the purpose. Frequently, combinations of properties may be required. In the case of a car door, the alloy must be malleable enough to stamp, light enough to limit the weight of the car yet must be resistant to corrosives like salt. Thus, there are many factors to consider when choosing which is best for a job:

Composition

An alloy is a mixture of two or more metallic elements intended to form a new metal with a unique set of properties. Often, one of the elements in an alloy can render it unusable when exposed to an unfriendly fluid. For example, concentrated ammonia used in refrigeration and fertilizers will attack alloys containing copper, while the hydrogen sulfide in sour gas and sour crude will attack steel with a high carbon content. For specifying engineers, evaluating each element in an alloy to determine compatibility is not necessary. There are ample data and standards available through organizations that specialize in the compatibility of alloys with specific corrosives.

Temperature

Like in most chemical reactions, temperature can play a part in hastening or slowing it. At some temperatures, there may be no risk of a reaction at all. Relics raised from the depths of the Great Lakes in the northern United States have often suffered minimal corrosion because of the cold water temperature. While cold temperatures are usually favorable to slowing corrosion, they can have an adverse effect on physical properties. Frigid climates will cause many metals to become brittle and much more likely to crack. Conversely, extreme heat will likely speed up reactions that cause corrosion. For example, with similar humidity, iron will rust at a much higher rate in warmer climates. Therefore, an installation in Ecuador may require a different alloy than the same application in Alaska.

Physical State (Properties)

Strength, hardness, density, malleability, and melting point are among the physical properties of a metal that must be considered. These properties are relevant to corrosion because they may limit the use of non-corrosive materials that lack other necessary properties. For example, although Hastelloy® C276 offers outstanding corrosion resistance in many environments, it is a relatively poor conductor of electricity and would not be a good choice for electrical contacts.

A Closer Look

So we know that corrosion happens, but do we know why? Understanding the causes will help specifiers make informed decisions:

Uniform General Corrosion – Corrosion that is evenly distributed over a metallic surface. On iron or steel, this would commonly be referred to as “surface rust”.

Pitting Corrosion – Deterioration that is localized and forms depressions or holes through the surface. It is sometimes difficult to visually detect because it can be covered by apparent surface rust and can compromise the strength of the metal.

Galvanic Corrosion – When two dissimilar metals are in direct contact and are in the presence of an electrolyte, an electrical path is formed that facilitates ion migration. This will cause the less noble metal to suffer the majority of the corrosion while leaving the other predominantly free from damage. Used to the advantage of shipbuilders, sacrificial anodes fastened to the ship bottoms help to keep their hulls free from corrosion damage.

Crevice Corrosion – Often the result of careless design or flawed manufacturing processes, crevices allow corrosives to accumulate and stagnate, providing prolonged exposure for the reagent to corrode the metal. This is commonly experienced around welds that are porous or have not completely adhered.

Dealloying - In alloys, two or more elements are mixed together to form a new metal with a unique set of properties. Although combined within the new material, elements can separate out as a result of a chemical reaction with surrounding substances. Also known as “selective leaching”, this phenomenon may cause cracks that can lead to failure of the metal. This is especially common in brass alloys containing higher ratios of zinc. Exposed to unfavorable environmental chemistry, zinc will leach out and leave behind an ineffectual metallic structure that is highly susceptible to failure.

Stress Corrosion Cracking – When both tensile stress and a corrosive environment are impacting a metal, small cracks can form that may not be visible to the naked eye. Although the material may appear unharmed, even shiny, catastrophic failure due to stress corrosion cracks may occur unexpectedly. This is a particular problem at gas and oil wellheads, where the raw petroleum released from the ground can contain significant concentrations of hydrogen sulfide.

Intergranular Corrosion - Metals have a microscopic grain or “crystallite structure”. The borders where the crystallites meet are called “grain boundaries”. Exposure to excessive temperatures, usually from welding or heat treatment can damage the boundaries, leaving them vulnerable to corrosion. Although the resistant metal between the boundaries can remain unaffected, the boundaries will weaken and allow the segments to separate, creating “hairline” fractures that can deepen over time.

Erosion Corrosion – Deterioration of metals due to dynamic, mechanical contact. Particulates carried by slurry flowing through a pipe can scratch and wear the interior.

Keeping it in Check

Most would agree that practical measures taken to mitigate this problem will be cost effective over the long term. So what can be done?

Corrosion resistant alloys are the best solution, but often the most expensive. In the most severe applications, they may be the only viable solution.

Plastics and polymers are becoming more sophisticated and can replace metal in many applications. Often, they may not provide as much strength and can be damaged by long-term exposure to sunlight.

Corrosion inhibitors can be combined with the fluid that is contained by the metal. Inhibitors usually serve to control pH levels, preventing acid from attacking the metal. A good example is an additive to an automobile’s engine coolant to prevent corrosion inside the radiator core and engine block. This is only practical in closed systems.

Protective coatings like paint, epoxies and plating can form a barrier between metals and corrosives. However, coatings can deteriorate and require ongoing maintenance.

Cathodic protection counters galvanic corrosion. By adding a second, less noble metal in electrical contact with the primary metal, it will serve as a sacrificial anode to attract corrosion away from the less reactive metal. This is considered the best solution for underwater metal structures and ship’s hulls. In pipeline applications, anodic protection is often established by adding electricity from a power source to create an “impressed current”.

Design considerations will eliminate crevices where corrosives can accumulate and linger. This will help to eliminate extreme corrosion effects at these points, but will still require measures to ensure that the rest of the system or device is protected as well.

Use of thicker materials than needed for immediate structural requirements will allow it to last longer than the time it will take for the corrosion to erode enough metal to cause failure. Called “corrosion allowance”, this method will require the use of heavier, more costly materials and introduces a higher risk of failure over time.

Effect on Pressure Instruments

Corrodents can exist in the environment surrounding the instrument as well as the pressure medium that is in contact with the elastic element inside. While a pressure gauge aboard a ship may be measuring the pressure of harmless compressed air, the exterior of the gauge may be exposed to salt spray, establishing the need for a stainless steel housing.

“Wetted” materials refer to the parts of a device that come in direct contact with the pressure medium. In the case of pressure instrumentation, these parts are usually limited to the process connection, sensing element and perhaps a cap or plug. A gauge measuring the pressure of an acid in a laboratory environment will require appropriately resistant wetted parts, but the housing material may be unimportant.

Bourdon Tubes and Sensors

To translate pressure input into mechanical pointer motion, a curved, “C” shape or coiled “Bourdon” tube is used as the elastic element. Linked to the gauge’s gearing or “movement”, pressure will deflect the closed tube tip, which will activate the gears to rotate the pointer. To ensure adequate repeatability, linearity and hysteresis, only metals that possess conforming elastic properties may be used.

Hardness and thickness of a metal must be carefully controlled during Bourdon tube design and manufacture. This is necessary to regulate the distance that the tip will deflect at specific pressures. Some metals will perform better than others in this role, yielding a more precise and predictable deflection. However, those materials may or may not be ideal for a specific corrosive medium. While 316 stainless steel or Monel® wetted parts may resist the corrosive effects of a wider range of potentially harmful media, they may still be vulnerable to others.

Pressure sensors, transducers and transmitters are also available with materials resistant to the corrosive propensities of specific media. However, beware of universal claims that instruments are equipped with “corrosion resistance”. Inquire about the wetted materials to make sure their devices are sufficient for your application.

Diaphragm Seals

If an instrument’s wetted materials do not offer adequate resistance to the corrosive medium, then a media isolation device like a diaphragm seal will be required to prevent harmful contact. Installed in between the process and the instrument, this device consists of four major components; a lower housing, the diaphragm, an upper housing and a liquid fill. When the seal and instrument are fastened together, the upper housing of the seal and the pressure sensing element (we’ll use the Bourdon tube in a dial gauge as an example) are solid filled with a fluid so that nearly all of the air has been removed. This creates a simple hydraulic connection between the diaphragm seal and the Bourdon tube. With no air to compress, any displacement of the diaphragm will cause an equivalent displacement of the Bourdon tube; much like pressing the brake pedal in a car pushes fluid through tubing to actuate the brakes. While some accuracy may be lost in the translation, the use of a diaphragm seal protects the pressure instrument and ensures that the pressure medium is safely contained.

Due to its simplicity, the components comprising the diaphragm seal can be made from a greater variety of materials. This will allow the specifier to save money by selecting the least expensive material required for each component. For example, a Hastelloy® C276 lower housing and diaphragm may be chosen, while 316 stainless steel is used for the upper housing since it does not come in contact with the corrosive. In another example, a particular corrosive may inflict just enough damage on a thin, flexible 316L stainless steel diaphragm to change its displacement properties or cause a breach. While a Hastelloy® C276 diaphragm would be chosen instead, a 316 stainless steel lower housing may still be a viable, less costly material since light corrosion will have no functional effect on the thicker metal.

Who Knows?

There has been much written about corrosion, material compatibility and mitigation. Companies, educational institutions and organizations originating in various countries all contribute to the pool of available information. Among the best sources are international organizations dedicated to conducting research and producing standards and publications to educate decision makers. The most well-known are:

NACE® International: http://www.nace.org/
“NACE International, the Worldwide Corrosion Authority… is recognized globally as the premier authority for corrosion solutions.”

ASM International: http://www.asminternational.org/
“ASM is the world’s largest association of metals-centric

materials scientists and engineers…ASM is dedicated to informing, educating and connecting the materials community to solve problems and stimulate innovation around the world."

World Corrosion Organization (WCO): http://corrosion.org/
Mission: "To facilitate global implementation of best practices in corrosion protection for public welfare."

ASTM: http://www.astm.org/Standards/corrosion-and-wear-standards.html
Provides standards for many different fields, including corrosion and wear on metal. Good source for test standards.

At the End of the Day

Understanding how to control corrosion is an ongoing concern to metallurgists. It can ravage anything from large metal structures to the smallest screw, with worldwide damage estimates measured in billions of dollars per year. The enormity of the problem and the far-reaching economic implications have spawned a number of organizations dedicated to providing standards and guidelines to help manage or prevent it. Regardless, corrosion continues to pose a direct threat to infrastructure and public safety. Informed specification decisions are the first step in mitigating the harmful effects of this natural and unavoidable phenomenon.

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