WHITE PAPER

How to Design Anticorrosion Equipment for Harsh Industrial Environments

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Abstract

Metal surfaces of industrial equipment are constantly at risk of corrosion, leading to equipment malfunction and irreversible structural damage to the equipment. According to one estimate, corrosion is causing billions of dollars of loss per year in industries around the world. Manufacturers have the responsibility to ensure that their equipment is protected against the effects of corrosion. Modern technology offers many advanced anticorrosion techniques that can help businesses protect their equipment and ensure continuous operation. This white paper discusses the root causes of corrosion and suggests ways to cope with this challenge in harsh industrial environments.

Corrosion Categories and Regulations—ISO 9223 Standard

The ISO 9223 standard for corrosion of metals and alloys specifies two methods for evaluating the atmospheric corrosivity of a site.

Corrosion Categories Based on Atmospheric Wetness and Pollution

Categories C1, C2, C3, C4, C5, and CX, with CX being the harshest, are assigned to a variety of indoor and outdoor locations based on onsite tests conducted to record the deposition rate of corrosive material and by calculating the protection coefficient for the location. The following table lists the corrosion categories that are applicable for various indoor and outdoor applications.

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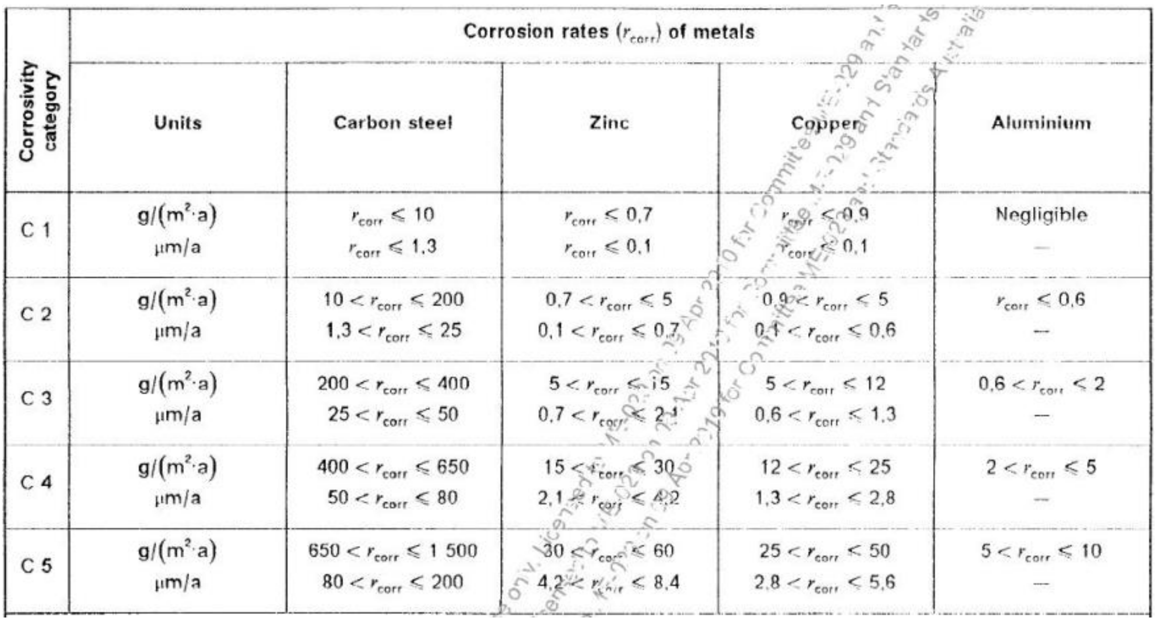
Indoor Applications	Description	Regulation Category
	Dry indoor environments without condensation.	C1, C2
	Indoor environments with temporary condensation.	C1, C2
Outdoor Applications	**Description**	**Regulation Category**
	Outdoor environment with low pollution (>10 km from the sea)	C2, C3
0-1km	Outdoor environment with moderate concentration of pollutions and/or salt from sea water (1-10 km from the sea)	C2, C3, C4
1-10km	Coastal areas (<1 km from the sea)	C3, C4, C5, CX
	Outdoor areas with heaving industrial pollution (<1 km from the sea)	C4, C5, CX

The Corrosion Rate for Standard Metal Specimens

The ISO 9226 standard also defines corrosivity categories C1, C2, C3, C4, and C5 for some standard metal specimens based on their corrosion rate as shown in the following table:



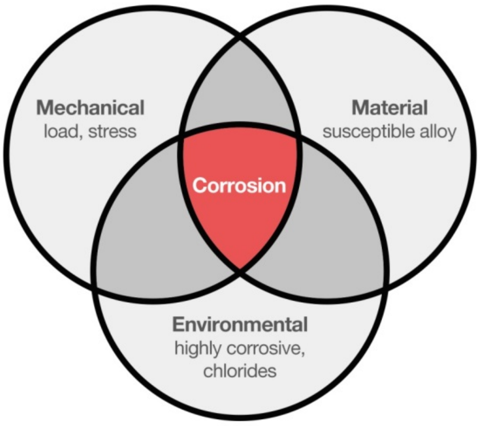
Corrosivity category	Corrosion rates (r_{corr}) of metals				
	Units	Carbon steel	Zinc	Copper	Aluminium
C 1	g/(m²·a) µm/a	$r_{corr} \leq 10$ $r_{corr} \leq 1,3$	$r_{corr} \leq 0,7$ $r_{corr} \leq 0,1$	$r_{corr} \leq 0,9$ $r_{corr} \leq 0,1$	Negligible —
C 2	g/(m²·a) µm/a	$10 < r_{corr} \leq 200$ $1,3 < r_{corr} \leq 25$	$0,7 < r_{corr} \leq 5$ $0,1 < r_{corr} \leq 0,7$	$0,9 < r_{corr} \leq 5$ $0,1 < r_{corr} \leq 0,6$	$r_{corr} \leq 0,6$ —
C 3	g/(m²·a) µm/a	$200 < r_{corr} \leq 400$ $25 < r_{corr} \leq 50$	$5 < r_{corr} \leq 15$ $0,7 < r_{corr} \leq 2,1$	$5 < r_{corr} \leq 12$ $0,6 < r_{corr} \leq 1,3$	$0,6 < r_{corr} \leq 2$ —
C 4	g/(m²·a) µm/a	$400 < r_{corr} \leq 650$ $50 < r_{corr} \leq 80$	$15 < r_{corr} \leq 30$ $2,1 < r_{corr} \leq 4,2$	$12 < r_{corr} \leq 25$ $1,3 < r_{corr} \leq 2,8$	$2 < r_{corr} \leq 5$ —
C 5	g/(m²·a) µm/a	$650 < r_{corr} \leq 1\,500$ $80 < r_{corr} \leq 200$	$30 < r_{corr} \leq 60$ $4,2 < r_{corr} \leq 8,4$	$25 < r_{corr} \leq 50$ $2,8 < r_{corr} \leq 5,6$	$5 < r_{corr} \leq 10$ —

Source: ISO 9223 International Standard—First Edition

Equipment manufacturers can use the corrosivity categories defined by the ISO-9223 standard as a basis for selecting optimal corrosion-resistant material or implementing protective measures for their equipment. The ISO-9223 standard does not take into consideration the design and mode of operation of a product, which can also influence its resistance to corrosion.

The Science of Corrosion

Corrosion is a chemical reaction that occurs when exposed surfaces of metals are chemically attacked by gases or liquids, resulting in oxidization of the metals. Although some metals have an inbuilt capability to resist corrosion, high temperatures and the presence of acids and salts in the environment can accelerate corrosion of metals. In addition, a metal that is highly active tend to corrode easily Corrosion compromises the stability of metals, triggering entropic change in the metal.



In addition to the composition of materials used, mechanical and environmental factors can trigger corrosion in industrial equipment. A continuous load or stress on a machine part or a join can accelerate the degradation of the part causing corrosion to set in. Gases and liquids present in the operating environment can trigger corrosion or accelerate the wearing off of metal surfaces. In a typical industrial environment, there are many corrosive elements like water, oxygen, and carbon dioxide. In addition, chlorine and sulfides are also highly corrosive. The extremely adhesive nature of these elements make them key triggers of corrosion in metals. Another factor that triggers corrosion in industrial environments is high operating temperatures. Industrial products typically have a fanless design that helps maintain system stability. However, an operating environment with continuous high temperatures can accelerate corrosion of metals.

Preventing Corrosion in Industrial Environments

Corrosion poses a serious threat to industrial equipment, causing functional and structural damage. As more and more industrial activity is taking place in harsh and severe environments, the need for products that are designed to withstand the corrosive effects of natural elements such as dust, wind, rain, salt, and snow, is increasing. Modern technology has made considerable progress in reducing the effects of corrosion and in many cases delaying corrosion, bringing various benefits to industrial operators. Besides, the anticorrosion techniques cost only a fraction of the cost of replacing damaged equipment.

The two main benefits of corrosion-proof industrial equipment are:

Better Performance: The more stable a product, the more accurate and precise the application results. Many industrial products require continuous operation of equipment, sometimes in the harsh environments. Corrosion-free equipment can guarantee stable operation and better performance, which in turn leads to higher productivity.

Less Maintenance Cost and Longer Lifetime: Before the advent of IoT, many industries relied on human efforts to check and maintain onsite devices and equipment. Although this costly business model is no longer necessary as devices and equipment located even in the most distant and remote areas can be easily controlled and maintained using remote monitoring solutions, designing corrosion-resistant equipment and using anticorrosion protection can extend their lifetime and considerably reduce maintenance costs.

The critical aspects to preventing corrosion in industrial equipment include selecting suitable materials to fit the application environment, designing products to minimize corrosion, using manufacturing techniques that prevent corrosion, and utilizing external mechanisms to protect industrial equipment.

Material Selection

Selecting the right materials is a key factor to preventing corrosion in equipment. The ISO 9223 standard defines corrosivity categories that can be used as guidance when selecting material and combining materials. Although it is hard to find materials that are 100% resistant to the effects of corrosive elements, careful selection of materials, especially when combining them in a product, can reduce corrosion. A good understanding of the corrosion process in metals and knowledge of their mechanical properties and the metal strength required to withstand the effects of corrosion goes a long way in building corrosion-resistant equipment.

When two heterogeneous materials are combined in a product, free electrons move between them causing corrosion in the long run. If the two materials combined have a high electric potential difference, the chances of corrosion are much higher. Therefore, equipment builders need to carefully choose the materials used in building industrial equipment. They should select materials that can withstand corrosive environments that are characterized with high temperature, humidity, and high pH values. Manufacturers should select materials with lower electric potential differences when combining them.

Product Design

Design elements that are not given proper consideration may prove to be the weak link in corrosion control. When designing products, mechanical engineers should work closely with corrosion engineers to avoid crevices and overloaded structures that could cause *pitting corrosion*. A localized intrusive pitting corrosion could expand to cover a larger surface area, thereby accelerating product damage. For example, a pitting corrosion can accelerate to cause structural damage to equipment when they come in contact with chlorides in the air.

Other design techniques that can help prevent corrosion include:

- Increasing the thickness of equipment parts to make allowance for the effects of corrosion and thereby increasing the lifetime of the equipment
- Using similar material throughout an equipment to avoid galvanic corrosion
- Minimizing surface temperature differences in equipment exposed to extremely high/low temperatures
- Avoiding the concentration of stress on certain parts of the equipment
- Avoiding contact with other corrosive parts or equipment

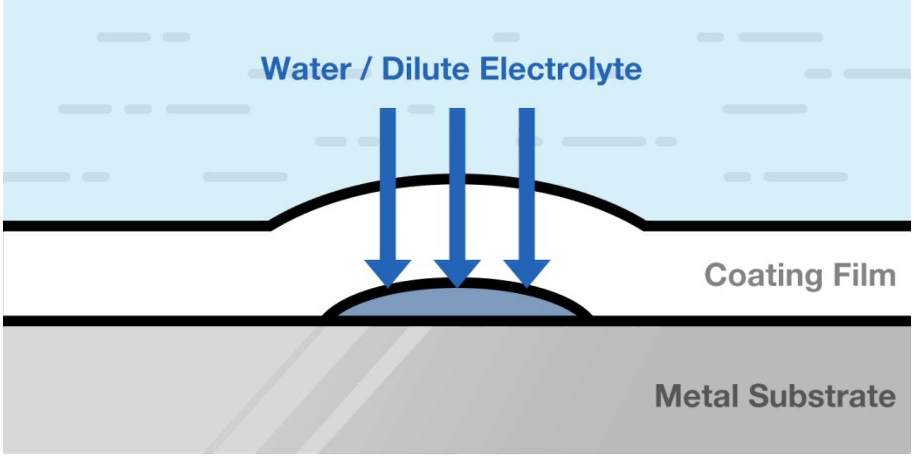
The location and the direction in which a product is deployed and used also play a role in arresting the effects of corrosive elements. Industrial product designers should carefully consider these factors when designing and deploying equipment.

Manufacturing Process

The manufacturing process can introduce implicit corrosion points in products. For examples, the design may cause stress to be concentrated on certain parts, especially the joins, which are susceptible to corrosion when they are exposed to corrosive elements. These equipment parts require additional isolation protection. In addition, metals tend to absorb hydrogen during the smelting and electroplating process, which then penetrates the plating layer rendering it ineffective. External corrosive factors can augment the damage to equipment parts that have internal damage. A dehydrogenation step needs to be introduced in the manufacturing process to eliminate the effects of hydrogen absorption by metals.

Coating equipment parts with different chemicals can make the components heavier and costly, thereby reducing the competiveness of products. Therefore a different type of protection mechanism, such as a protective paint, is required to lower the cost of the product and enhance the protection against corrosive environments. Such paints should be low in hydrogen, should protect against water osmosis, and should be highly resistant to ionization. Coating machine parts with a layer or two of paint that is specifically created for this purpose helps avoid material surface blistering and reduces damage caused by the density difference between the material used and its external environment.

Water-osmotic paint offers less resistance to corrosion than powder-based paint. Osmatic activity causes blisters in the coating layer. Osmotic blisters may develop between the paint and base substrate, between coats of paint, or within the matrix of a single layer of a composite paint film. An example of a blister caused by water osmosis in a metal substrate coated with water-soluble salt-based coating film is shown in the following diagram. When the film comes in contact with water/low concentration of electricity, water will start to seep in. When the concentration of water is the same on both sides of the coating film, the film will pop out to form a blister.



The adhesive capability of paint is another key factor in preventing corrosion; more adhesive the paint, the stronger the protection it provides, because of its resistance to the effect of surface impurities or oxides.

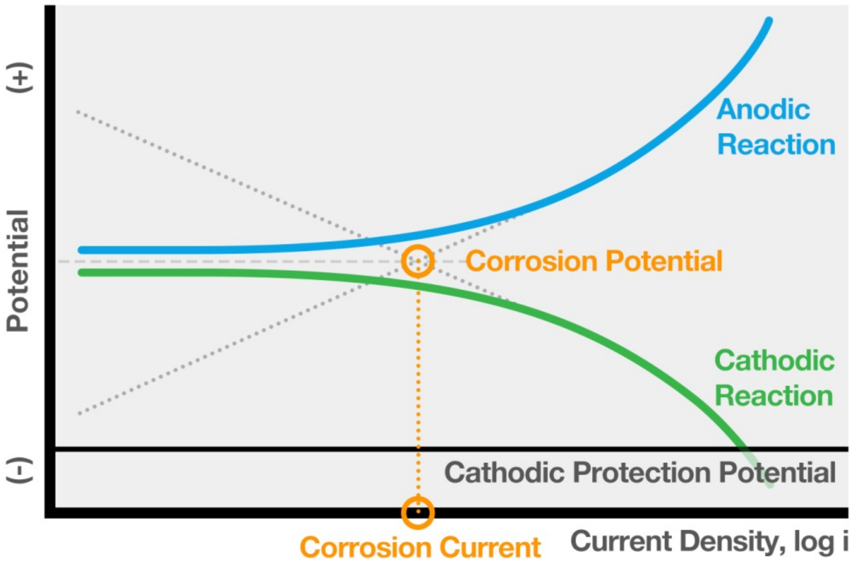
External Protection Mechanisms

A cheaper way to protect metals against corrosion is to apply protective coating. The anticorrosion effect of a protective coating can vary based on its material composition. Zinc is usually used as one of the components in the protection layer. Aluminum is also added in the platting layer to protect metals from corrosion because of its ability to effectively block external corrosive factors. Aluminum provides better performance in withstanding oxidation and has a more suitable internal structure to block external corrosive factors. It is also known for its high durability against heat and can withstand the effects of high external heat. Products coated with aluminum are known to get two times more protection against surface corrosion as compared to the ones coated with zinc. Materials that have a high concentration of chromium or molybdenum can also be effective as a protective coating. For example, machine builders can use stainless steel or aluminum materials in their machines to resist the effect of corrosive environments.

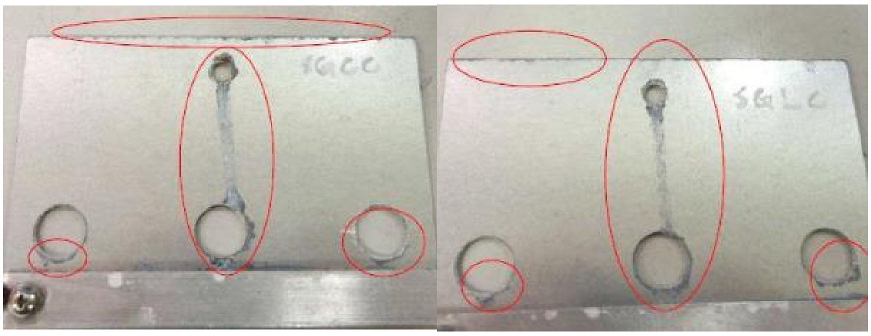
Anticorrosion technology also includes methods for active protection and passive protection. Active protection relies on the use of external mechanism to reduce or resist corrosion, while passive protection relies on protection derived from the anticorrosion capability of the material used in the products. Active corrosion protection can be further categorized into cathodic protection and anodic protection.

Cathodic Protection: This method consists of applying a stable direct current through a protective metal to achieve the compensation of the delocalized electron and pushing the corrosive electronic potential to the negative polarity where the oxidizing rate is slower.

Anodic Protection: This method uses the environmental corrosive factor control for the metals with more reactivity, so that the corrosion will only occur at the positive polarity and protect the component at the negative counterpart.



Both these methods have their advantages and disadvantages. The most ideal way is to combine both these methods to lower the negative electric potential and to boosting the positive potential, thereby maximizing the potential difference. This can absorb more external delocalized electrons and corrosive factors, achieving maximum anticorrosion protection. These active protective methods increase the protection against surface corrosion in metals to 30% as measured using the area-method measurement. However, these protection methods provide limited protection to equipment with joins and edges.



In a highly corrosive scenario, judging the application environment and identifying existing corrosive factors are the first steps to designing a product. Using materials suitable to the application environment and tweaking the production process can help provide intrinsic protection against corrosive environments. If the operating environment is too harsh and beyond what the majority of metals can endure, then the only way is to use external protection methods. An integrated protection mechanism such as the combination of cathodic with anodic protection methods could be an ideal solution to enhance the structural strength of industrial equipment and increase product stability.

Moxa’s Certifications for Anticorrosion Standards

Moxa’s products can be used in various industrial applications, such as oil & gas, power, maritime and railway—all of which take place in harsh environments where natural corrosive factors are found in abundance. Moxa’s tests it products for reliable operation in these harsh environments. The tests include a continuous salt-fog test based on the EN 50155/NMEA 4X/ASTM B117/IEC 60068-2-11 standards. The salt-fog circuit is based on the IEC 60068-2-52 and DNV 2.4 standards. Moxa uses the acetic acid salt spray test (AASS) and the copper accelerated acetic acid salt spray (CASS) tests based on the ASTM (B117) method, which consists of increasing the temperature and lowering the PH value of salt-fog liquid to shorten the test period and reduce cost.

Test method Item	**Neutral salt spray (NSS)**	**Acetic acid salt spray (AASS)**	**Copper-accelerated acetic acid salt spray (CASS)**
Temperature	35 °C ± 2 °C	35 °C ± 2 °C	50 °C ± 2 °C
Average collection rate for a horizontal collecting area of 80 cm^2	1,5 ml/h ± 0,5 ml/h		
Concentration of sodium chloride (collected solution)	50 g/l ± 5 g/l		
pH (collected solution)	6,5 to 7,2	3,1 to 3,3	3,1 to 3,3

The natural day/coast day index given below for each international category is used to convert the results from hours to days.

NSS	• 1 hour=5 days for coastal environment=15 days for natural environment
ASS	• 1 hour=15 days for coastal environment=45 days for natural environment
CASS	• 1 hour=40 days for coastal environment=120 days for natural environment

Moxa’s industrial panel computers and displays are also designed in strict accordance with globally accepted standards for explosion protection in hazardous locations. Approved certifications include UL/cUL Class I Division 2, ATEX Zone 2, IECEx Zone 2, and marine standards such as DNV GL, ABS, LR, NK, and CCS.

For additional details visit: https://www.moxa.com/RuggedHMI.

Additional Reading

ISO 9223 International Standard

Corrosion of metals and alloys: Corrosivity of atmospheres—Classification, First edition