A mini review on the dependent factor causing corrosion crises: The pictorial perspective

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Abstract
Corrosion has been responsible for failures in different engineering applications and efforts to prevent it has cost thousands of dollars, thereby impacting negatively on the economies of companies, institutions and nations globally. Concerted efforts are ongoing to provide the requisite materials that could help in mitigating the corrosion crises in different applications. This overview explore one of such efforts to understand the iterative factors that results in corrosion crises and how they can be controlled through advanced material technology.

Keywords: Dependent factor, Crises, Corrosion, Prevention

1 Introduction

The devastating effect of corrosion has been established to impact different metallic structures, buildings, and marine applications negatively [1]. The consequent effect of this is a gradual deterioration in the mechanical strength of the parent components of such applications where corrosion is dominant [2]. To effectively mitigate the impact of corrosion, the dependent factors must be identified and scientifically understood. Such fundamental understanding in place, selecting the most appropriate inhibitors, will be easier, and protecting different engineering applications will be efficiently done. In most applications, the environmental factors responsible for corrosion differ, but the iterative combinations of two or more dependent factors will eventually lead to failure [3-5]. This is because certain materials are prone to corrosion than others based on the environment and processes where they are used [6].

The knowledge of such materials and other factors will reduce the cost, time, and effort employed in solving corrosion problems. The prevention of corrosion mechanisms is no doubt strongly related to sections of materials strongly affected by corrosion [7]. However, if not clearly understood based on the various connected factors, the corrosion crisis can lead to expensive and dangerous damage to machinery, equipment, buildings, bridges, electrical systems, and pipelines [8].

The presence of suitable corrosion control, prevention measures, and corrosion processes can, therefore, result in avoiding irreparable damage and serious structural problems that may emerge years to come once the related factors are adequately discovered and eliminated [9-11]. Thus, this review beams attention to the factors responsible for mild steel corrosion.
crises in different applications, thereby providing insights into various means of developing effective inhibitors and promoting design modifications that enhance anti-corrosion coatings durability.

2 Dependent Factors Causing Corrosion and its Classification:

Atmospheric corrosion can be seen as the degradation of materials that are left in the open to air and its pollutants instead of being submerged into liquid. This kind of corrosion has been in existence longer than any other corrosion, it also has affected more materials of construction than any other corrosion. In many literature, different authors have classified atmospheric corrosion into different categories of wet, damp and dry [10]. Depending on the geographic location, the corrosivity of the atmosphere to metals cannot be the same for all geographic location, also depending on certain factors relating to weather, such as precipitation changes in temperature, direction of the wind, type and amount of industrial and urban pollutants, as well as proximity to natural bodies of water [10]. Figure 1 shows the atmospheric corrosion perspective in process industries.

Figure 1: Atmospheric corrosion [14].

Uniform corrosion, also known as general corrosion, happens in solutions with either extremely higher or much lower pH, or at high potentials in electrolytes having very high amount of chloride. In alkaline or acidic solutions, the aluminum oxide is usually not protective as it is not stable [11]. Uniform corrosion can be seen in cases like rusting, tarnishing of silver, fogging of nickel, and oxidation at high-temperature. The preventive measures for uniform corrosion comprises of

i. In the event of providing allowance for corrosion, thicker materials should be used.

ii. For coating, make use of galvanization, anodizing, plating or paints.

iii. Use Corrosion inhibitors or modifying the environment.

iv. Apply anodic and cathodic protection [11].
When aluminium alloys are involved, galvanic corrosion generates the highest amount of corrosion damage. Galvanic corrosion happens when aluminum is connected electrically to a more noble metal, and both of them are connected to same electrolyte [17]. Figure 3 shows the galvanic effect. Galvanic corrosion is referred to as electrolytic corrosion, which is a form of localized corrosion that can occur where two or more alloys are in contact with each other in an environment that supports the exchange of ions [14]. For this reason, importance should be placed on establishing the order of nobility before coupling alloys in a corrosive environment. The preventive measures for galvanic corrosion entail

i. Choose metals/alloys extremely close together in the galvanic series.
ii. Sidestep negative area effect of a minor anode and large cathode.
iii. In any practical cases, non-identical metals should be insulated.
iv. Coatings should be applied carefully.
v. Threaded joints should be avoided for any materials that are far from each other in the galvanic series [15].

For crevice corrosion to take place, a crevice, oxygen and a salt water environment should be present. The initial phase of crevice corrosion in aluminium happens when salt water wets the aluminum and water enters the crevice (see Fig. 4). With time, oxygen is used up inside the crevice as a result of the precipitation and dissolution of aluminum [11]. Crevice corrosion can be seen as an intense localized corrosion that occurs within crevices or under shielded areas [12]. The preventive effect includes
i. When dealing with new equipment, welded butt joints should be applied and not bolted or riveted joints.
ii. Continuously weld or solder lap joints to prevent crevices.
iii. Completely drain vessels and make sure there are no stagnant conditions.
iv. Make use of solid, non-absorbent gaskets such as Teflon.
v. To enhance crevice corrosion resistance, make use of higher alloys [11].

![Figure 4: Crevice corrosion][17]

Pitting corrosion is closely related to crevice corrosion. Aluminum alloy pitting happens when the electrolyte contains a low level of chloride anions, and in a case where the alloy exist at a higher potential than the "pitting potential [10]. Pitting corrosion is a localized occurrence and is one of the most destructive forms of corrosion. Figure 5 shows the pitting effect begins by creating a hole on the metal at an increasing rate; it is self-stimulating and self-perpetuating and attacks the steel underneath the passive layer. Pitting corrosion are not easily detectable at their early stage due to their small sizes. Therefore, it is hard to predict this type of decay as it can take months or years to initiate, but then failures occur with extreme rapidity. Pitting corrosion can be prevented by adding the elements (molybdenum, nitrogen, chromium) known to improve corrosion resistance in stainless steel [12]. The appropriate control over pitting evolution comes with materials whose resistance to the service environment is known should be used.

i. Control pH, temperature and chloride concentration.
ii. Anodic and cathodic protection.
iii. To enable higher pitting corrosion resistance, higher alloys should be used [11].
Intergranular corrosion can be seen as the selective attack of grain boundaries without attacking the grains. This type of corrosion happens due to the potential differences between the adjacent grain bodies and the grain-boundary region [12]. From a microscopic point of view, metals are made up grains arranged into a microstructure. Surfaces of those grains join to form grain boundaries. Corrosion can take place along those boundaries that separate the grains. The existence of impurities along the grain structure therefore leads to intergranular corrosion as described in Figure 6. The flow of ions (which is enhanced by the difference in electrolytic potential between the grain and the boundary) can lead to the deterioration of the bonds between the grains. Grains dissolve or fall out, resulting in a loss of strength in the metal [12]. Intergranular corrosion can be influenced by welding, improper heat treating, and high temperature operations. The preventive measures for intergranular corrosion can be achieved by
i. the stainless steels of low carbon grade.
ii. use post-weld heat treatment [11]

Exfoliation corrosion is a unique type of intergranular corrosion that takes place when the grains are leveled by massive deformation during cold or hot rolling, and in cases where there have been no crystallization [10]. The surface view of exfoliation corrosion is presented in Figure 7.
In erosion-corrosion mechanism, the corrosion takes place in high flowing water as is closely related to jet-impingement corrosion as shown in Fig. 8. In pure water, this kind of corrosion is very slow, it is not accelerated by pure water but at pH greater than 9, it is accelerated, mostly with high silica and high carbonate content of the water. Unlike in alkaline or acidic water where aluminium will easily corrode, is very much stable in neutral water. Either changing the water chemistry or lowering the water velocity or applying both approaches can mitigate erosion-corrosion. When dealing with the water chemistry, the pH must be less than nine, also the level of silica and carbonate must be lowered [10].

Stress Corrosion Cracking can occur under specific surroundings like seawater when metal cracks under constant stress [12]. For stress corrosion cracking to take place, three conditions must occur simultaneously, (1) a susceptible alloy, (2) a humid surrounding, (3) a tensile stress that will cause an opening in the crack and promote the propagation of crack (see Fig.9). There are 2 different ways in which this type of corrosion can occur, such as transgranular stress corrosion cracking or intergranular stress corrosion cracking [10].
Corrosion fatigue can take place in a situation where aluminium structure is allowed to go through continuous stress level in an environment with high corrosion possibility [12]. Corrosion Fatigue occurs when there is alternating or cyclic stress as demonstrated in Figure 10. In seas water or any other related environment, the aluminium alloy’s fatigue strengths are lower as compared to air. Water is very much required in this type of corrosion just like in stress corrosion cracking of aluminum alloys [10].

Filiform corrosion is a cosmetic issue for painted aluminum. In a case where the corrosion starts with salt water pitting, the corrosion usually begins with pinholes created from scratches as presented in Figure 11. Chloride is required for filiform corrosion to take place [12] . In order to prevent this type of corrosion, holes or defects should be sealed, also the relative humidity should be kept low [10]. The preventive measures for filiform corrosion involves, (1) the relative humidity should be controlled and kept low, (2) Coatings should be brittle [11].
Microbial corrosion is a type of corrosion that is caused by the biological organisms. An example of microbial corrosion is the case of fungus growth at the fuel-water interface in the fuel tanks of aircraft (see Figure 12). Since this type of corrosion is mostly influenced in a water environment, to prevent it water has to be blocked from remaining or finding its way into the fuel tanks, also the fuel quality should be monitored and maintained. Fungicides are used in the aircraft fuel in situations where the quality control of the fuel is not obtainable [10]. The preventive measures for microbial corrosion entail

i. Mechanical cleaning should be constantly carried out.

ii. Biocides should be used for chemical treatment in order to control the population of bacteria.

iii. Tanks, vessels or any other device should be drained totally also storage should be dry [11]

3 CORROSION MITIGATION TECHNIQUES
Several methods have been employed in the fight against corrosion over the years, some of those methods include the following [13].
3.1 Choice of Metal
Using corrosion resistant metals such as aluminium or stainless steel is a very easy method of resisting corrosion. These metals are useful in reducing the need for extra protection against corrosion, depending on the application [14].

3.2 Protective Coatings
The use of paint coating is an economically viable approach to prevent corrosion. Paint coatings function as a shield to oppose the transfer of electro-chemical charge to the metal under from the corrosive solution. Powder coating is another way of preventing corrosion. Several different powders including epoxy, acrylic, nylon, urethane and polyester, are usable [15].

3.3 Environmental Measures
Corrosion can be effectively minimized by taking several measures to control the environment. This can be as simple as limiting rain exposure or seawater, or much difficult measures like controlling the amounts of oxygen, chlorine or sulfur in the environment.

3.4 Sacrificial Coatings
Sacrificial coating is a process of adding another metal that can easily oxidize to the surface of the metal that is to be protected. Sacrificial coating include two different methods such as cathodic and anodic protection. Cathodic protection is applied is places such as ship hulls, steel pipelines conveying fuel or water, offshore oil platforms and water heater tanks. Whereas anodic protection is usually used on carbon steel storage tanks that stores 50% caustic soda and sulfuric acid.

3.5 Corrosion Inhibitors
These are certain chemicals that are capable of undergoing reaction with the metal surface or the gases in the surrounding to subdue the electro-chemical reactions resulting in corrosion. They form a protection in form of film on the metal surface when they are applied on the metal surface, and by so doing provides protection to the metal against corrosion. Certain factors such as environmental pH, temperature, and surrounding chemical composition influences the formation of the layer. Corrosion inhibitors are widely applicable in several areas of human endeavors ranging from chemical production, petroleum refining, water treatment works, home appliances, etc.

3.6 Design Modification
In order to enhance the durability as well as lower the corrosion of any protective anti-corrosive coatings, it is best to modify the design. Ideally, designs should not have open crevices, promote air movement and also avoid trapping water and dust. Proper and regular maintenance is very vital to ensure that the material last long and is constantly free from corrosion attack.

4. Conclusion
This study has provided insights into various measures that can be put in place to mitigate the undesirable effects of corrosion in different environment by considering the contributing factors and how they can be eliminated through developing advanced materials, design concept, sacrificial coating, and suitable inhibitors against corrosion for different engineering applications.
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