Nigerian Research Journal of Engineering and Environmental Sciences
Journal homepage: www.rjees.com
RJEES

Review Article

A Review of Corrosion Types, Management Strategies and its Consequences in Oil and Gas as Well as Construction Sectors in Nigeria

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http://doi.org/10.5281/zenodo.12599422

ARTICLE INFORMATION

Article history:
Received 18 Jan. 2024
Revised 26 Apr. 2024
Accepted 10 May 2024
Available online 30 Jun. 2024

Keywords:
Corrosion
Building
Structures
Management consequence
Oil and gas

ABSTRACT

Corrosion which is commonly referred to as rusting of metals and metallic alloys is generally known as the deterioration or breakdown of a substance as a result of its involvement with the surrounding environment. Corrosion has existed for as long as metals and metal alloys have been, it still constitutes a major concern for metallurgical engineers since it is typically understood to be the loss of a metal due to the action of corrosive substances. Though it might not be possible to completely eliminate corrosion being a natural process, it can be controlled in a way that increases the service-life of constructions and other structures by reducing the rate of corrosion. It is of the utmost importance for one to comprehend the various forms of corrosion in order to implement the corrosion control management strategy that is most appropriate for that specific type of corrosion so as to manage and control the corrosion rate in any given material within a specific environment. Hence, various types of corrosion have been reviewed and the management strategies discussed in this work. The construction sector and oil and gas sector were studied as case studies and recommendations were proposed in the conclusion.

1. INTRODUCTION

The word Corrosion originated from the Latin word "corrosus," which can be translated as "gnawed or eaten away" in English. Corrosion which is commonly referred to as rusting of metals and metallic alloys is generally known as the deterioration or breakdown of a substance as a result of its involvement with the surrounding environment (Ogunleye *et al*., 2021). The definition mentioned above applies to virtually every material. Although corrosion is as old as metals and metal alloys, it still constitutes a major concern for metallurgical engineers since it is typically understood to be the loss of a metal due to the action of corrosive substances (Isecke *et al*., 2011). This is particularly when other effects of corrosion in metal are taken into consideration, it can result in building infrastructure collapse and machine breakdown in industrial equipment, which is often costly to repair (costly in terms of losses or contaminated products, potential adverse effects on the environment, and possibly in terms of personnel health and safety). The cost of corrosion repairs is estimated at $2.5 trillion a year worldwide and more understanding on how to tackle it is a good step in the right direction (Hernandez and Arroyave. 2020). To make judgements concerning the long-term integrity of a structure or component, an accurate assessment of the elements driving corrosion and rate of degradation is required (Roberge, 2008). Though it might not be possible to completely eliminate corrosion because it is a natural process, it can be controlled in a way that increases the resilience and usability of constructions and other structures while also reducing the rate of corrosion (Olasunkanmi, 2021). Corrosion management uses a variety of scientific concepts to reduce and regulate the pace at which corrosion spreads across materials. A summary of some of these techniques and concepts, including material selection, engineering design, cathodic and anodic protection, protective coatings, corrosion inhibitors, etc., is given by Olasunkanmi (2021). For a weld joint, welding techniques and welding variables are crucial to the amount of corrosion that occurs within the welded device that is connected (Rambabu *et al.,* 2015). Understanding the different types of corrosion is crucial for putting into practice the corrosion control management strategy that best suits that particular type of corrosion. Many of the structures in construction and oil industries were joined together through welding. Investigating the effect of different types of welding and manipulating welding designs on the corrosion of these structures can serve as a means of mitigating corrosion. This will help to manage and control the corrosion rate in any given material operating any given environment. This work was set to update the knowledge base of corrosion and draw attention to a newly discovered forms of localized corrosion.

2. TYPES/FORMS OF CORROSION

According to Isecke *et al.* (2011), you may classify corrosion based on the type of corrodent or medium it occurs in, as well as the shape it takes. Corrosion is thus divided into two categories: dry corrosion (known as direct chemical corrosion) and wet corrosion (known as electrochemical corrosion). As illustrated in Figure 1, Aslam *et al.* (2022) distinguish between two forms of corrosion: uniform or general corrosion and localised corrosion.

2.1. Uniform or Generalized Corrosion

In interaction with a corrosive environment, a metallic material will experience this type of corrosion across its entire surface. If the attack is evenly distributed, the corrosion is said to be uniformly generalised or uniform corrosion. According to Lahiri (2017), when a metal surface is exposed to a corrosive environment, uniform corrosion is the most typical types of corrosion that ends up fostering all-round loss of thickness. The degree to which a corrosion product is soluble typically determines whether the resulting surface is smooth or rough. This type of corrosion is most commonly seen in atmospheric, acid and general process side corrosion. The impact of homogeneous corrosion on a metal's outermost layer is seen in Figure 2.

According to Bahadori (2014), the management and control of uniform corrosion include:

1. Diminishing or halting the flow of electrons via
   - Coating exposed surfaces with non-conductive materials such as paints, lacquers, or oils
   - In the extreme case, reduce the conductivity of the solution when it comes into touch with the metal by keeping it dry.
   - Regularly remove conductive impurities.
2. Halt or slow the flow of oxygen towards the surface. While fully achieving this is difficult, coatings can help.
3. Prevent the metal from losing electrons by
   - Use metals higher in the electrochemical series that are more resistant to corrosion to prevent the metal from losing electrons.
   - Use a protective layer that is more prepared to give up electrons than the metal it is protecting.
   - Implement cathodic protection and

- Making use of inhibitors.

4. The ideal metal to utilise releases a protective oxide that stops the process.

Regulating and monitoring temperature and environmental factors is also essential.

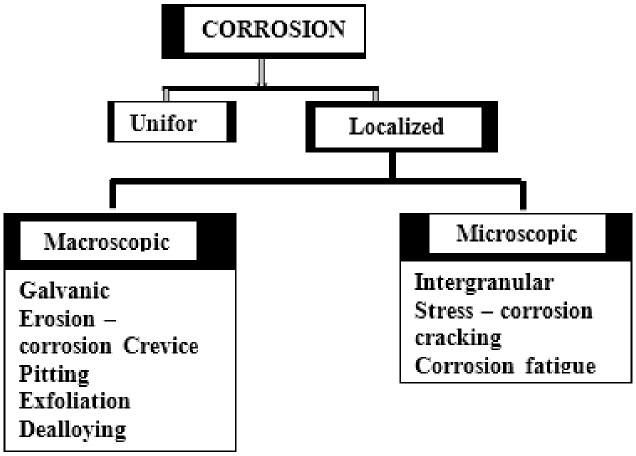


Figure 1: Types of corrosion

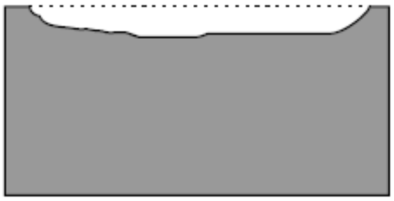


Figure 2: Uniform corrosion

2.2. Localized Corrosion

The type of corrosion known as "localised corrosion" is characterised as one in which specific areas receive severe attacks on the metal surface (Milella, 2013) and this corrosion occurs on specific areas of an exposed surface under two broad circumstances: a heterogeneous state for the substance or surroundings, as well as a specific concentrated influence due to the existence of active biodiversity or reactive system. The consequences of localised corrosion are typically far more severe than those of uniform corrosion because deterioration occurs abruptly with very little use or exposure to the environment. The metal was soon punctured by localised corrosion. These types of corrosion include fretting corrosion, stress corrosion cracking, galvanic corrosion, erosion corrosion, pitting corrosion, and corrosion fatigue.

2.2.1. Wormhole corrosion

According to Yang *et al.* (2023), localized corrosion still needs to be investigated further as the lack of its deep understanding is still a course of concern to engineering systems. They cited an example of a corrosion environment where a form of penetrating corrosion was experienced. They investigated the corrosion that occurred in a Ni-20Cr alloy attacked by molten fluoride salt, both experimentally and mechanistically, and they termed it 1D wormhole corrosion. The corrosion was a localized one dimension, unlike the traditionally known corrosions that are measured in three dimensions or two dimensions. They concluded that this corrosion could function as a mass-flow pathway unlike diffusional pathway that is the tradition leading to a rapid attack.

2.2.2. Pitting corrosion

A prominent kind of localised corrosion is pitting. The term "localised attack" refers to a type of corrosion that only affects a small piece of the metal's exterior, leaving holes or pores in the affected areas where passive coatings or scales are present. Due to its increasing difficulty in identifying, anticipating, and designing against, pitting corrosion is considered a greater danger than uniform corrosion. Pits normally extend vertically, from the surface downward. According to Bhandari *et al.* (2015), the formed pits can take diverse geometries, as illustrated in Figure 3, and are typically hidden by corrosion products. A small, shallow trench could cause a complete engineering system to fail with very little overall metal loss. In addition to the localised loss of thickness, rust pits can also be dangerous because they act as stress risers. According to Kansara *et al.* (2018), pitting corrosion can be aggravated as a result of a breakdown from the protective coating or protective oxide film. The unprotected metal quickly releases its electric charge when this protective layer breaks down, and the reaction begins with tiny pores with constrained chemical processes that permit quick impact. Variations in the composition of metals may exacerbate it even more. Pitting corrosion often occurs in carbon steel when exposed to dirt, freshwater, brackish water, and chloride. Corrosion-resistant materials such as aluminium and stainless steel are also susceptible in chloride environment (Lahiri, 2017). Aslam *et al.* (2022) in their paper "Corrosion inhibition of steel utilising several families of organic compounds: Progress in the past and in the present", discussed at length on pitting on metals. The application of materials with properties that render them impervious to pitting in the specific environment can effectively avoid pitting on metals, they noted. Pitting can be avoided by reducing the concentration of chlorides around the service facility and controlling the interior ambient temperature so that it never rises over the minimum needed for the material to pit. Other precautions that can be performed include establishing anodic/cathodic mechanisms, covering metallic components with a protective layer, and shining the outermost sections that are reachable.

2.2.3. Crevice corrosion

Metal-to-metal and metal-to-non-metal contact between two substances can lead to a constrained deterioration known as corrosion in crevices. Usually, the crevice's gap is big enough to hold liquid in place but too small to let liquid pass through. According to Kansara *et al.* (2018), some of the important elements impacting the corrosion of crevices are (1) crevice form, which is a primary determinant of corrosion in crevices. (2) Shape of crevices. (3) Type of material composition, and (4) Environmental conditions. Consequently, corrosion within crevices or interstitial corrosion, as well as corrosion under deposit, can be brought on by cracking, slits, viewing angles, or materials on the surface of steel (Pedeferri, 2018). It may also occur as a result of a loose washer or gasket that allows liquid to seep between it and the metal surface. It may also occur beneath surface deposits and scale. For this reason, bolted connections are rarely employed in submerged applications, even if cathodic protection can help reduce crevice corrosion. Bolts are also affected by crevice corrosion, as Figure 4 (a) illustrates. While Pedeferri (2018) stated that corrosion within crevices must be addressed primarily during the stages of development and construction, Tait (2018) suggested that crevice corrosion could have been prevented if the gasket had been properly tightened, which would have prevented gaps (or crevices) from forming between the gasket and the flange face. In the event that crevice conditions cannot be avoided, there are two methods to stop them: cathodic protection (iron anodes are commonly used in the case of stainless steel) or selecting a corrosion-resistant material. Figure 4 (b) illustrates the usual shape of crevice corrosion. The majority of industrial plants, including those involved in the chemical-based, petrochemical, pharmaceutical industry, and food manufacturing industries, as well as biomedical, nuclear power, and structural engineering as well as seawater and chloride-containing solutions, suffer from crevice corrosion, which affects stainless steels (Pedeferri, 2018; Tait, 2018).

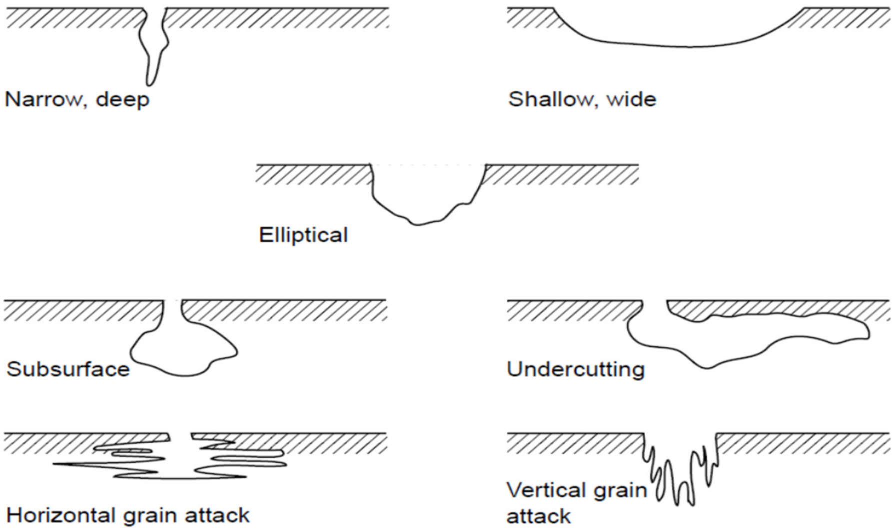


Figure 3: Various forms or shapes of pitting corrosion (Bhandari *et al.,* 2015)

2.2.4. Galvanic corrosion

Galvanic corrosion, also known as bimetallic corrosion, is the term used to describe the deterioration that results from the interaction of two distinct metals in a corrosive media. Two metals are connected when one is the cathode (higher noble metal) and the other (lower noble metal) is the anode, where corrosion occurs more quickly than in an uncoupled state. Figure 5 (a) and (b) illustrate this as they are shown. Heidershack (2018) found that galvanic corrosion could also be caused by any situation that alters electrochemical potential, including temperature changes and chemical reactions in the surrounding environment. Galvanic corrosion cannot occur unless the anode and cathode are electrically connected and continuously exposed to an electrolytic environment. The two most common electrolytic environments are water and damp soil.

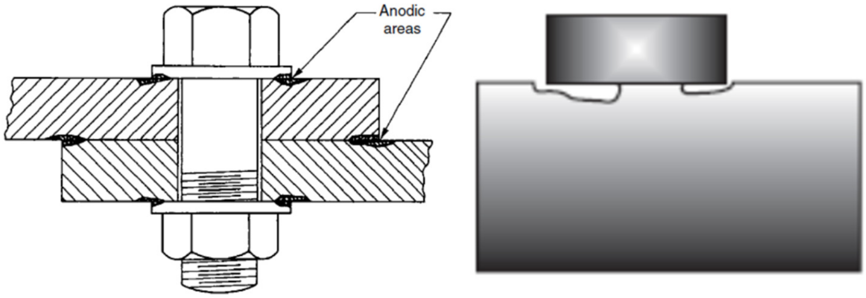


Figure 4: (a) Crevice corrosion locations on a bolted connection (b) Illustration of Crevice form of Corrosion (Pedeferri, 2018; Tait, 2018).

(a) (b)

Figure 5: (a) Galvanic corrosion of galvanized piping in connection with bronze valve (Heidersbach, 2018), (b) galvanic corrosion

For example, brass corrodes in a marine environment when it comes into contact with steel screws. Moreover, the steel corrodes in domestic water heaters where copper tubing and steel are connected. Bahadori (2014) noted that this type of corrosion cannot occur unless three special features of this process are active:

- Electrical contact is required between the metals.
- A second path for the flow of ions and electrons is required and
- One metal has to be far more efficient at giving electrons than the other.

Bahadori (2014), stated that the three aforementioned characteristics cannot coexist simultaneously in any environment to manage and regulate galvanic corrosion. Taking any of the following actions can help achieve this:

- Use coatings or plastic insulators between the metals to break the electrical contact.
- Select adjacent metals that belong to the same electrochemical series.
- Make sure the area is dry and that liquids cannot become trapped, or coat the connection with an impermeable substance to prevent ions from passing through it.

2.2.5. Erosion corrosion

When solid surfaces come into contact with harder materials, they erode away mechanically. The underlying metal becomes susceptible to corrosion as surface coatings, usually mineral scale or passive films are removed. Similar to cavitation corrosion, erosion corrosion arises when a fluid's motion eliminates rust from a metal's surface, leaving new metal particularly prone to deterioration. Erosion-corrosion is accelerated by fluid flow across eroded metal surfaces as opposed to highly fast fluid contacting the metal surface, which is the distinction between erosion-corrosion and cavitation-corrosion (Tait, 2018). This issue typically affects pipeline networks or pipework, particularly at T-joints, bends, and abrupt changes in flow. Corrosion can occur to parts such as nozzles, pumps, impellers, heat exchanger tubes, valves, and orifices that transfer corrosive slurries. Damaged metal surfaces often exhibit curved or wave-like appearance patterns that point to a well-established pattern of targeted attack. Erosion corrosion is frequently particularly prone to soft metals, such as aluminium and copper alloys, as well as metals like stainless steel, which rely on thin layers of oxides for protective purposes against corrosion (Bahadori, 2014). When machinery or parts come into direct contact with reactive sludge, the erosion-corrosion phenomenon can cause severe damage. This exacerbates problems such as reduced efficiency, increased maintenance costs, and the possibility of catastrophic failure leading to total breakdown (Andrews *et al.*, 2014). For the control of erosion corrosion, Kuruvila *et al.* (2018) identified key areas that should be given consideration to be flow geometry, surface finish, material selection, pH value and particle size. Wang *et al.* (2014) asserted that some flow system design elements that can lessen the effects of erosion-corrosion include using flanges, increasing elbow radius, gradually changing the fluid movement, substituting Tee joints for elbow joints, and using helically made pipes. Surface roughness-induced localised pitting corrosion will eventually give way to erosion-corrosion. Reduced flow velocity will lead to a reduced rate of erosion and corrosion. Sliding abrasion, as opposed to erosion-corrosion, happens when the flow rate is decreased below the allowable velocity limit. If it is more severe, maximising the flow rate should reduce pitting corrosion. By using the proper materials and techniques, erosion-corrosion's negative consequences can be reduced. New composite materials like nickel-aluminium bronze alloy are an instance of how material preferences have evolved. Erosion-corrosion impacts can be lessened by increasing thickness at vulnerable locations and reducing particle size. Controlling the sludge's pH levels and particle count will also help prevent erosion and corrosion. Figure 6 shows erosion corrosion.

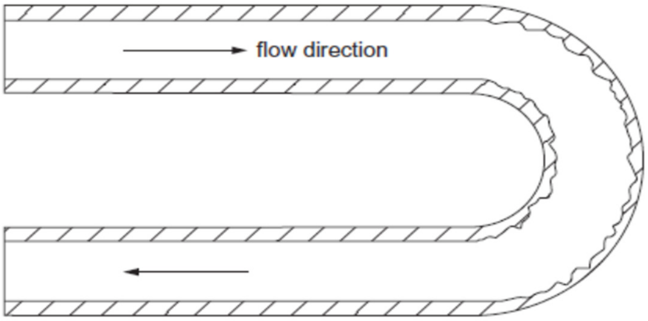


Figure 6: Erosion corrosion (Khoshnaw and Gubner, 2019)

2.2.6. Cavitation

A common form of erosion-corrosion is cavitation wreckage (Faes *et al*., 2019). When liquid comes into contact with a metal surface, Pedeferri (2018) states that this is when vapour bubbles form and explode. Cavitation destroys protective surface scales by causing the collapse of gas bubbles within a fluid (Zhang *et al*., 2015; Qin *et al*., 2018; Pendar *et al*., 2020). Figure 7 illustrates this. Dular and Petkovšek (2015) stated that cavitation is a common problem that occurs when running turbines, pumps, ship propellers, and valves. Usually occurring around high-elevation areas of large machinery, on the pump impellers, or in the presence of vibrations, such as inside cooling sheaths of diesel engine cylinders, this attack takes the form of loosely spaced pits that provide a roughened surface area (Bahadori (2014) By preventing air intrusion, reducing fluid pressure gradients, and avoiding significant pressure dips within the liquid's vapour pressure range, cavitation can be avoided throughout the design phase. Furthermore, coatings could help slow down the rate of material loss (Shree, 2021).

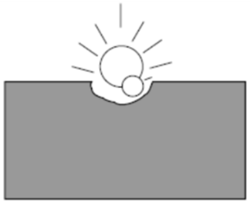


Figure 7: Illustration of cavitation corrosion

2.2.7. Selective leaching or dealloying

The selective or preferential removal of at least one element from an alloy by electrochemical corrosion, or the dissolution of the matrix material that a type of component in the alloy's composition is selectively dissolved into the highly corrosive liquid, leading to the deterioration of its fundamental features, is known as de-alloying corrosion. This is known as selective leaching, selective attack, parting, or demetalification, according to Kunduraci (2016) and Cerrato *et al.* (2017). The majority of an alloy's active components will enter solution preferentially during this process, leaving the remaining portion as a porous and mechanically

extremely weakened mass. In many cases, this corrosion is not visible to the unaided eye, but perforation or fracture may occur due to the diminished strength. Brass dezincification is the most prominent example, but other copper alloys also show aluminium, manganese, nickel, and cobalt selective etching.
In gold-silver and lead-tin alloys, copper is specifically targeted, but in copper-silver alloys, silver and tin are selectively attacked. Generally, the nobler or passive element does not corrode; the more reactive element does (Pedeferri, 2018). Figure 8 illustrates this kind of corrosion. Alloys prone to dealloying are those made up of elements having widely disparate oxidation potentials. To synthesise porous compounds with enhanced catalytic capabilities, scientists have taken use of the fact that dealloying yields porous metals (Kunduraci, 2016). Thus, by carefully eliminating the more reactive metal component of the alloy combination, it has developed into a useful commercial technology for creating metal nano-porous structures (Zhang *et al.*, 2013). Dealloying can be done chemically in a corrosion-free environment or electrochemically by providing a voltage to the electrode. Higher precision in controlling the corrosion or leaching current is one of the benefits of electrochemical dealloying over chemical dealloying. The process involves.

1) The alloy's surface is etched to eliminate the reactive atoms.
2) Clusters of the inert atoms that are still present at the alloy/electrolyte contact rearrange and form, revealing the reactive atoms.
3) The freshly exposed reactive atoms are etched
4) Keep performing steps 2 and 3 until the dealloying front has penetrated the entire alloy.

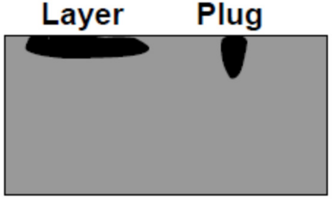


Figure 8: Selective leaching or dealloying corrosion

Grey cast irons become graphitized in saline conditions, aqueous solutions, and some kinds of water. The technique requires selective etching of iron to enhance the quantity of graphite on the surface (Pedeferri, 2018). While the chemical reaction goes on, graphite maintains its size and shape, but the mechanical qualities deteriorate. Their failures in plate heat exchangers are rare since selective leaching may be avoided by using the appropriate material for each application (Faes *et al.,* 2019). This implies that choosing the right kind of material is one method of controlling dealloying corrosion. Environmental management can help minimise selective leaching and sacrificial anode cathodic protection or impressed current cathodic protection are two efficient ways to reduce dealloying corrosion. To reduce dezincification, for example, cathodic protection or oxygen elimination can be used, albeit they are usually not cost-effective. When the surrounding environment is less hostile, dezincification decreases. As a far less sensitive metal alloy, it is often utilised. For example, 15% Zn concentration makes reddish brass nearly impermeable. Superior brass is manufactured by adding 1% tin to 70-30 brass (admiralty metal) (Bahadori, 2014).

2.2.8. Microbiologically influenced corrosion (MIC)

Microbial corrosion, commonly referred to as microbiologically influenced corrosion (MIC), is corrosion caused by the existence and activity of microorganisms. Microscopic organisms are living things that are invisible to the unaided eye. They can be found in virtually every natural aquatic environment as well as a wide range of industrial fluids (Bahadori, 2014; Saji and Umoren, 2020). As sulphate is abundant in many systems, including saltwater, brackishwater, and agricultural runoff water, sulphate-reducing bacteria (SRB) and sulphate-reducing archaea (SRA) have been extensively studied as the main causative microorganisms in MIC for decades (Jia *et al.,* 2017a; Jia *et al.*, 2017b). Although microbes require water to survive, MIC cannot exist without it. MIC is currently known by several names including microbiological corrosion, biocorrosion, biodeterioration, and microbially induced corrosion. Biocorrosion is a term that is becoming more popular in Europe and South America as a result of recent developments in the United States, the expression "biocorrosion" is now used to describe corrosion inside human beings, such as implants, caused by both biotic and abiotic processes, which is especially confusing (Little and Lee, 2014). In many industries where organisms adhere to surfaces, microbiofilm formation (MIC) is a problem because it affects corrosion. Water systems (Rhoads *et al.,* 2017), power generation facilities, petroleum refineries, petrochemical manufacturing equipment, steel plants, paper factories, as well as maritime infrastructure, are all vulnerable to MIC because of high microbial populations, insufficient control, as well as stasis or low flow conditions and temperatures that allow microbial survival (Little *et al*., 2020). This is a major factor in the deterioration of various metals and alloys, which leads to corrosion wrecks, collapses of infrastructure, and financial losses; it is a worry for many industries, including the aviation, natural gas, and crude oil sectors (Blackwood, 2018). Marciales *et al.* (2018) reported that MIC is believed to be accountable for 20 to 40% of corrosion-related localised issues, while Li *et al.* (2018) recognised that MIC is a difficult problem in the oil and gas sector and is accountable for over 20% of pipeline degradation. The majority of MIC appears as pits that form beneath biodeposits, biologically active minerals, and clusters of living things. This biofilm growth creates a shielded environment where corrosion accelerates and conditions can get quite severe. Microbiologically induced localised corrosion may also result in dealloying, enhanced erosion-corrosion, increased galvanic corrosion, stress-driven corrosion cracking, and hydrogen-induced embrittlement. It is believed that deterioration that has an undetermined cause could be permanently related to MIC. Given this scenario, it is necessary to look into different preventative measures because of the limited comprehension and relatively considerable destruction (Saji and Umoren, 2020). Khan *et al.* (2021) proposed an overview of MIC prevention and control techniques. He claimed that MIC characterization, monitoring, and inspection are crucial for preventing, controlling, or even minimising these occurrences. Effective characterization, monitoring, and inspection systems help prevent costly maintenance and equipment failure. Characterization can be carried out using bacteria culture, molecular biology procedures, microscopic examination, electrochemical methods (Kashkovskiy *et al.,* 2019) and rapid check tests. Only the equipment most susceptible to MIC requires inspection and monitoring. Processing and transportation facilities, particularly pipeline systems, can be prioritised since they have an increased chance of corrosive substances and are more susceptible to MIC. Corrosion effects can be significantly reduced by using the appropriate materials. The material's outstanding resistance to localised corrosion, including pitting and crevice corrosion is the main material section criteria for MIC activities where the attack is typically localised. Videla (2018) mentioned coatings as an additional MIC preventive and control method. Using biocides to prevent and control MIC issues is the most widely used method. Biocides are chemicals (or mixtures of substances) that can eliminate microorganisms and prevent microbial growth. The location of the MIC within the equipment or facility will determine which cleaning method—mechanical or chemical—is used. In a corrosive environment, Figure 9 depicts the mechanism of microbiologically induced corrosion (MIC) (Tripathi *et al*., 2021).

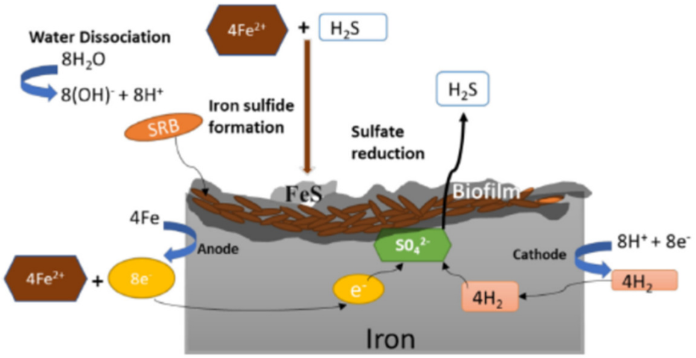


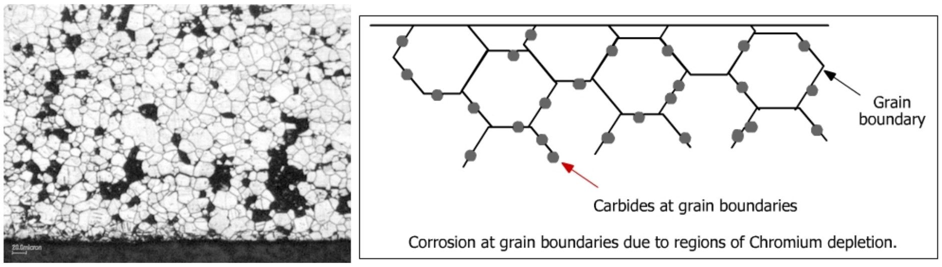
Figure 9: Mechanism of microbiologically influenced corrosion (Tripathi *et al.,* 2021)

2.2.9. Inter-granular corrosion (IGC)

Inter-granular corrosion (IGC), a form of localised or confined corrosion, is distinguished by an inclination for corrosion at the grain boundaries or surrounding regions, with little or no attack on the grains. Like other types of localised corrosion, it primarily targets inactive alloys exposed to specific corrodents (Cragnolino, 2021). The restricted attack causes the grain to become out of alignment, which results in a decrease in ductility and strength. When operating within grain boundaries, it weakens strength more than the same quantity of total metallic breakdown spread equally throughout the entire region. Gupta *et al.* (2015) reported that inter-granular corrosion accounts for a significant portion of industrial failures involving stainless steel components. When a small area of grain-border material acts as an anode and large portions of grain operate as a cathode, energy is created that causes a quick attack that deeply penetrates the metal and occasionally causes catastrophic breakdowns. In nuclear fuel reprocessing, waste management corporations, and many chemical manufacturing companies that use nitric acid (HNO_3) as the process fluid, IGC is the main corrosion concern (Fauvet, 2012). Intergranular corrosion is affected by numerous manufacturing, compositional, and environmental conditions. Several factors have been identified as influencing the heightened sensitivity in grain bordering areas (Gupta *et al.*, 2015; Lim *et al.,* 2015; Xin *et al.*, 2018):

a) Specific elements or alloys being separated, as in the case of aluminium or nickel-chromium alloys.
b) A grain boundary that has been enriched with one of the alloying elements, like brass.
c) The erosion of the element that resists corrosion along the grain boundary, which can be detected in stainless steel.

Heat exposure of the metal during welding operations, stress relief, and other heat-related activities is the cause of all the elements influencing intergranular corrosion. After many hours of sensitization at 600°C, Figure 10 (a) shows the intergranular corrosion of AISI 304 austenitic stainless steel with 0.06%C (Pedeferri, 2018), whereas Figure 10 (b) shows a schematic diagram of intergranular corrosion.



(a) (b)

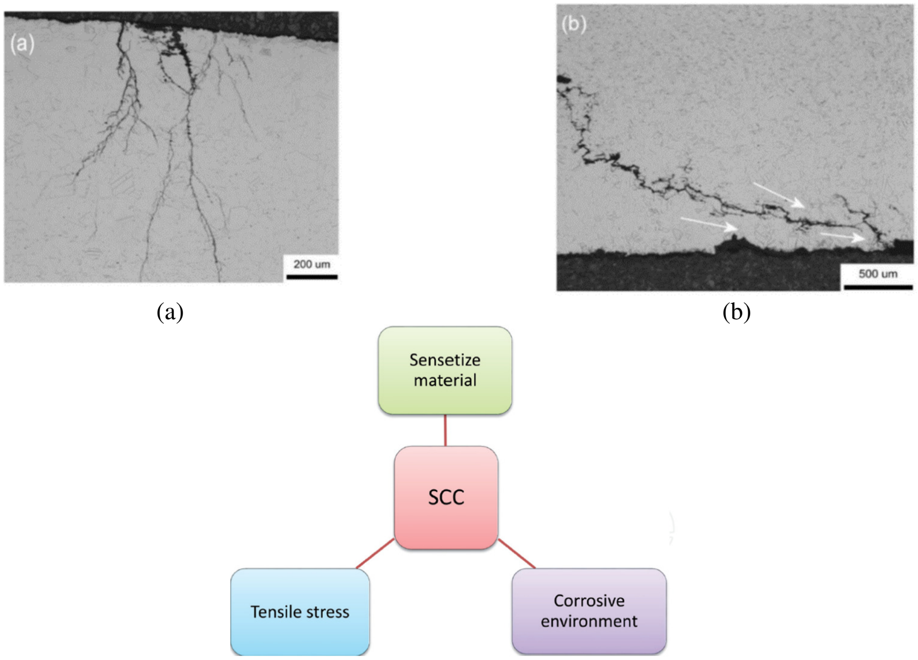
Figure 10 (a): Intergranular corrosion of an austenitic stainless steel AISI 304 with 0.06% of C, sensitized at 600 °C for several hours (Pedeferri, 2018); (b) A schematic illustration of inter-granular corrosion

Jayaraman and Arun (2017) pointed out that prevention of inter-granular corrosion should take the following in to consideration.

(i) Use low-carbon stainless steels whenever possible.
(ii) Choose stabilised and niobium-or titanium-alloyed grades.
(iii) Both niobium and titanium react with carbon to form the necessary carbides, which helps to reduce the removal of chromium.
(iv) After welding, apply heat treatment.

2.2.10. Stress corrosion cracking (SCC)

According to Zhang et al. (2016), stress-induced corrosion cracking (SCC) is a type of material deterioration that is associated with environmental concerns and is brought on by the interaction between strain from tensile stress and corrosive conditions. This combination of static tensile stress, the environment, and, in some cases, the metallurgical state results in an extreme aspect ratio fracture that begins and spreads, eventually breaks down components. Khalifeh (2020) reported that while a significant portion of the material is devoid of the SCC phenomena, little sprout cracks grow within it as shown Figure 11 (a) and 11 (b). Figure 11 (c) shows the three crucial elements required for the early formation and propagation of stress-induced corrosion cracking: a sensitised substance, particular environmental conditions, and sufficient tensile stress. SCC can take on several morphologies, such as inter-granular SCC (I-SCC) and trans-granular SCC (T-SCC), and can take place in both fragile and ductile substances, as well as metallic and non-metallic substances. This cracking mechanism may be producing catastrophic fractures in the structural materials and equipment because it can occur at stress values that are much lower than those predicted by the producer. Crack bifurcation is common in SCC-damaged components, and in some situations, the amount of tensile stress required to initiate this process may seem to be no more than 5% of the yield stress (De-Meo et al., 2016).



(a) (b)

(c)

Figure 11: Stress corrosion cracking (a) internal surface; (b) external surface (Mohtadi-Bonab, 2019) and (c) requirements for SCC to occur (Khalifeh, 2020)

Many types of SCC have been identified. When oxygen, the chloride ion, and a high-temperature combination are present, chloride SCC forms in austenitic stainless steels under tensile stress from mechanical factors (Khalifeh *et al.,* 2017). The fracturing of stainless steel within corrosive conditions and when there is an abundance of hydrogen is known as caustic embrittlement (Parnian, 2012). Oil and gas companies often deal with sessional cracking, another type of SCC that initially appears when brass is exposed to ammonia. This occurs when hydrogen sulphide conditions are applied to steels. Khalifeh (2020) stated that if any one of the three SCC components is absent, this type of breakdown will not occur and cracking from stress corrosion will be avoided. Therefore, implementing one or more of the following measures will aid in reducing the prevalence of SCC:

- Reduce Stress level
- Removing hostile species from the natural surroundings
- Altering the component's composition or its elements is one potential solution
- Applying cathodic protection
- Regularly applying a layer of paint

- Shot-peening to induce residual compressive stress

2.2.11. Corrosion fatigue

An alloy or metallic material experiences corrosion fatigue when corrosive environmental conditions and repeated, varying stress combine to cause breaking down a phenomenon that is more damaging than either corrosion or overloading when done individually (Deng *et al*, 2019; Anye and Soboyejo, 2022). Under operational conditions, metals and alloys may be exposed to corrosive environments. In a corrosive medium, breakdown occurs at any tension when the total number of cycles is sufficient. The rate of breakdown decreases with increasing pressure or load applied during each cycle. Understanding that numerous mechanical, environmental, and metallurgical factors influence the corrosion fatigue process makes the complexity of the phenomenon clear (Ahmad, 2006; Youssef *et al.,* 2016). As seen in Figure 12. Components that are susceptible to this type of failure include boilers, aircraft wheels, rotors, heat exchanger tubes, pump shafts, and steel equipment. Pitting corrosion fatigue has been shown to have detrimental effects on a wide range of industries, including crude oil and natural gas, the nuclear industry and wind energy Larrosa *et al.* (2017). Youssef *et al.* (2016) and Larrosa *et al.* (2017) have identified many major areas where corrosion fatigue is most commonly found. These include: offshore platforms, drilling rigs, naval constructions, oil and gas pipelines, communication equipment, maritime vessels, the chemical sector, and the aerospace and power generation industries.

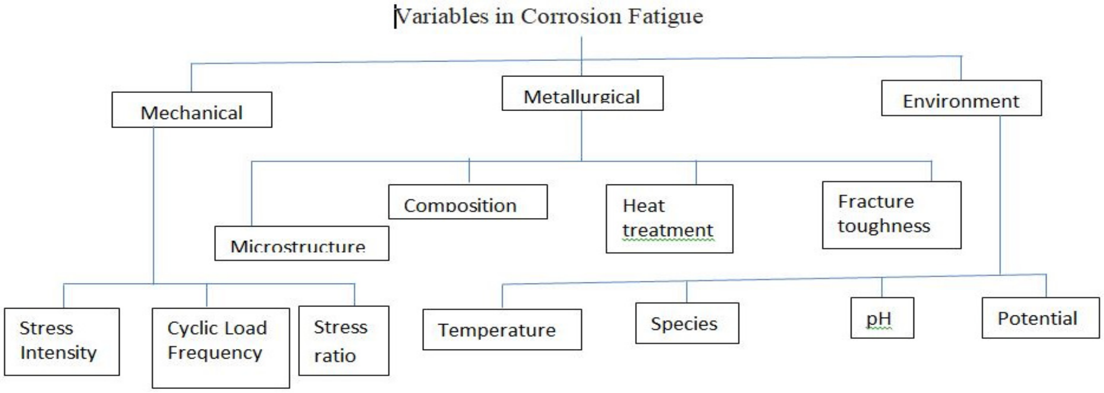


Figure 12: Variables that contribute to the corrosion fatigue process (Ahmad, 2006)

The two primary mechanisms of corrosion fatigue, according to Sun *et al.* (2015), are fracture initiation and propagation. Anaee and Abdulmajeed (2016) however, noted that this type of corrosion necessitates four steps, which are;

a) Initiation
b) Stage I of fracture propagation, having a crack direction that is approximately 45° from the direction of the tensile stress.
c) Stage II of crack development
d) the last breakdown

According to Anaee and Abdulmajeed (2016), Figure 13 depicts the various stages of corrosion fatigue.

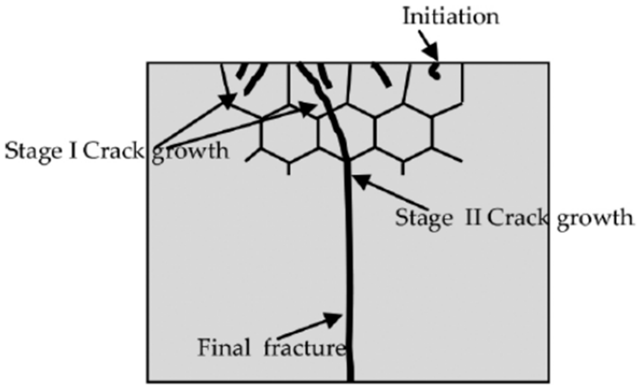


Figure 13: The stages of development of a fatigue fracture

Evaluating the factors that contribute to corrosion fatigue is crucial for effective control and minimization. When evaluating the metallurgical aspects of the variable, proper material selection and consideration of the various manufacturing processes are crucial to ensure the material can withstand the stress it is subjected to. For the mechanical aspect of the variable, the intensity and frequency of the stress applied should be reduced. Critical consideration should be given to surface treatments including hardening and appropriate heat treatment. The third variable, the environment, can be changed by using corrosion inhibitors, adjusting the pH level in the working environment to lessen the corrosive action on the materials, and applying the appropriate coating on the component surfaces. These treatments can prevent the initiation of the micro-cracks and also reduce the rate of propagation.

2.2.12. Fretting corrosion

Friction or nibbling between two surfaces can cause progressive wear known as fretting. Fretting corrosion, according to Diomidis *et al.* (2011), is a hybrid of corrosion-related and fretting processes that include deterioration at the points where two metal surfaces interact. It manifests as swirls or holes in the metallic substance covered in corrosion by-products. Friction oxidation, wear oxidation, and chafing are some other terms for fretting. It can be found in mechanical components such as the roots of tube blades in engines, automotive parts such as the separation of a railway car wheel from the axle as a result of vibrations, fastened elements such as riveted and bolted joints and structures, pumps and other equipment (Lahiri, 2017). Fundamentally, fretting is a type of erosion corrosion that occurs in the absence of atmospheric moisture. According to the fretting corrosion mechanism, bonding agent breakdown first releases metallic particles from the substance's top layer. The generated particles subsequently oxidise, creating substances that leave the region between the two surfaces connecting the two components. Repeating this practice leads to its rapid decline. Figure 14 shows corrosion with fretting. The following actions can be performed to reduce or prevent fretting corrosion:

a) Reducing the relative movement of materials
b) Using materials resistant to fretting corrosion
c) Enhancing one or both materials' capacity to withstand stress
d) Applying contact lubricants and
e) Vibration absorption using seals

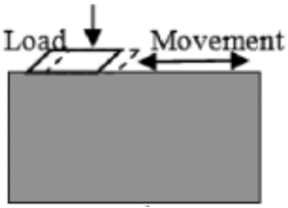


Figure 14: Fretting corrosion

2.2.13. Thermogalvanic corrosion

The phrase "thermogalvanic corrosion" describes the possibility of developing a temperature variation involving the extremes of temperature domains when a corrosive substance is exposed to temperature change while functioning in a corrosive environment (Fernández-Domene *et al.*, 2011). Temperature changes affect the cathode during the degradation process, as the heated portion of the surface functions as the anode and the cool portion as the cathode because of the temperature-sensitive anodic characteristics (Anaee and Abdulmajeed, 2016). Elevated temperatures have been linked to increased rates of thermogalvanic corrosion on the anode. Figure 15 illustrates this.

Figure 15: Thermogalvanic corrosion process (Anaee and Abdulmajeed, 2016)

In many industrial areas, especially in production facilities with heat exchangers, thermogalvanic corrosion may be blamed for corrosion damage. In addition, supply systems and pipes—especially those composed of copper and subjected to continuous temperature changes—may experience premature failure due to thermogalvanic corrosion. According to Anaee and Abdulmajeed (2016), the following actions can reduce this type of corrosion:

a. The selection of an appropriate design
b. Refraining from variations in heating and cooling
c. Maintaining constant insulation for pipes that require heat conservation to reduce heat loss;
d. Cathodic protection or coatings are applied

3. CONSEQUENCE OF CORROSION DAMAGES IN NIGERIA

Nigerians' lives are negatively impacted by corrosion damage, either directly or indirectly, in terms of their economic and safety activities. Environmental deterioration is a major problem in addition to safety and economic issues. This study takes into account the oil and gas sector as well as the construction sector.

3.1. Consequences for the Oil and Gas Sector

n acidic environment accelerates and facilitates the corrosion of engineered materials. Undoubtedly, deterioration, also referred to as corrosion, is present in every facet of life, encompassing the building and construction sector, nuclear power industry, food processing and agriculture industries, transportation, petrochemical and petroleum industries, and naturally, our homes (Unueroh *et al.*, 2016). According to a study by Mohammed *et al.* (2016), 28% of oil spills in Nigeria are the result of sabotage, 50% are the result of corrosion in oil pipes, and 21% are the result of oil-producing operations. According to Obike *et al.* (2020), the primary causes of pipeline breakdowns have been shown to include mechanical problems, corrosion, and third-party activities/sabotage, in addition to operational errors and natural disasters. However, corrosion is increasingly acknowledged as one of the main causes of pipeline failures worldwide. Oyewole (2011) classifies the repercussions of corrosion failures into three primary groups: safety impacts, environmental consequences, and commercial or economic effects The problem of property damage, injuries, and fatalities resulting from thermal radiation from a fire fed by high-pressure venting fluid from the location of a ruptured pipeline or leak can have disastrous consequences for safety. Pollution of the groundwater table and water channels, both close to the damage and in the vicinity where drain-down can occur is the main cause of the negative effects on the ecosystem. The Niger Delta oil leak in Nigeria has had a catastrophic impact on people's socioeconomic conditions, agricultural work and water-related industries like fishing. Product loss can be used to identify pipeline corrosion issues from a commercial and economic perspective. It invariably causes revenue loss, jeopardises the company's reputation, and negatively impacts the business's economic condition. In addition, Akpan *et al.* (2023) emphasised that corrosion has led to a considerable increase in operating expenses for the pipeline business since it necessitates frequent equipment replacement, aside from the deaths brought on by leaks and flaring. There were numerous fatalities, according to Nwilo and Badejo (2005). A second pipeline failure-related fire disaster in the Nigerian community of Adeje, Delta State, claimed over 1,000 lives, according to Johnson *et al.* (2022).

3.2. Implications for the Construction Sector

There's been a rise in reinforced concrete structure collapses in Nigeria (Alo *et al.*, 2017; Bamigboye *et al.,* 2017). Many issues can lead to construction failure, including the use of inferior materials and the substitution of amateurs or non-professionals for experts by builders to save money. More specifically, structural quality of the used steel reinforcing bars did not match the real design specifications, which is one of the most often cited causes (Ede *et al.*, 2015). Rebar's size and strength are essential prerequisites for safe, trustworthy, and long-lasting buildings and other structures. However, employing inferior or inappropriate materials or workmanship might lead to a structure's structural integrity deteriorating, which will make it incapable of withstanding trouble areas with maximal and operational loading processes. Corrosion of inferior made reinforcing bar is one of the main causes of building and structural failures in Nigeria, according to multiple research (Bamigboye *et al.,* 2017; Igibah *et al.*, 2019). The necessity of closely monitoring the production standards of the widely accessible, high-yield-grade reinforcement steel manufactured and used in Nigeria's building sector was stressed. This is due to the increasing prevalence of locally produced reinforcing steel bars made from scrap metal in Nigeria and throughout Africa (Bamigboye *et al.,* 2017; Igibah *et al.*, 2019). For the imported reinforcement bar, it was asserted that most private companies import materials, and because these goods are generally brought in from numerous countries without going through a rigorous standardisation procedure regarding their structural characteristics, the quality of imported products cannot be guaranteed most of the time (Igibah *et al.*, 2019). Buildings and other structures in a maritime environment deteriorate significantly as a result of corrosion-related issues, according to Uchenna *et al.* (2021).

4. CONCLUSION

Man is constantly faced with different types of corrosion, which can be seen in practically every area of human endeavour as long as the material being used is necessary. Efficient measures can be taken to mitigate the incidence of corrosion and its detrimental effects on human well-being, societal economic endeavours, and the ecosystem. This can be achieved through adequate understanding of the different types of corrosion and management techniques. This review covered the different types of corrosion and their respective strategies for managing them. The review addressed the oil and gas and well construction industries, where corrosion has had some detrimental effects. Corrosion continues to be a major issue in the review, even though there may be other elements that contribute to the failure of buildings, structures, and even oil spills. In order to prevent the consequences that are covered in the review, it is therefore necessary to continuously monitor and assess corrosion in each location where it may be suspected. In particular, when producing the various steels used in the construction and oil and gas industries, the organisations that oversee the quality of domestically produced goods, such as the Standard Organisation of Nigeria (SON), the Council for the Regulation of Engineering in Nigeria (COREN), and others, must make sure that quality standards are upheld. A prohibition on the entry of inferior materials into the nation must also be pursued. More quality control labs that can test any substance to determine its quality would help achieve this. Anybody engaged in the importing of inferior materials into the nation should likewise face disciplinary actions. This will help control and minimise the threat posed by corrosion.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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