Corrosion propagation challenges of mild steel in industrial operations and response to problem definition

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Abstract.
The continuous use of mild steel in major industrial operations is ever uprising due to many engineering factor in materials selection. This mini review gives a cogent corrosion perspective of mild steel, its problem definition and responses for safety and technological progress purposes.

Keywords: Mild steel; degradation; Problem definition; failure

1. Introduction
The severe consequences of corrosion degradation have become a problem of worldwide significance. Corrosion is an electrochemical occurrence; it is the destructive mortification of a metal and alloy by chemical or electrochemical activities by its environment [1]. Corrosion menaces causes plant shutdowns, waste of valuable resources, reduction in efficiency and costly maintenance. It also jeopardizes safety and inhibits technological progress [2].

More so, man demand for fossil fuels has grown speedily which contribute to increasing corrosion challenges with potential disasters that can cause serious issues including negative social impacts, water resource and environmental pollution. Corrosion problems in the oil fields sector also occur at all stages from downhole to surface equipment and processing facilities leading to recurrent partial and eventual total process shutdown, resulting in severe economic losses. The other large problem in operating pipe flow lines is internal corrosion mainly due to stress corrosion cracking [3].

This material destruction results into loss of mechanical properties like strength, ductility, impact strength. This result in loss of mechanical properties and at times ultimate failure. However, where corrosion damage is anticipated, the cost of maintenance and repair cannot be ignored since the costs vary from one industry and nations to the other. This could be either by direct or indirect cost. For instance, corrosion of metals costs in the U.S.A. economy is almost $300 billion per year at current prices. Approximately one-third of these costs could be reduced by broader application of corrosion-resistant materials and the application of best corrosion-related technical practices [4]. The original work, based upon an elaborate model of more than 130 economic sectors, found that metallic corrosion cost in the United States is about 4.9% of its gross national product (GNP) while in South Africa; it was also found that the cost was 4% GNP influence [5].

Corrosion control is achieved by recognizing and understanding corrosion mechanisms, by using corrosion-resistant materials and designs, and by using protective systems, devices, and treatments. The effects of corrosion failures on the performance and maintenance of materials would often be minimized if life monitoring and control of the environmental and human factors supplemented efficient designs. One of the key factors in any corrosion situation is the environment [6]. Variables such as time, humidity and temperature instigate corrosion occurrences in major environments. It is also important to realize that the environment that actually affects a metal corresponds to the micro environmental conditions that this metal really “sees” that is the local environment at the surface of the metal. It is indeed the reactivity of this local environment that determines the real corrosion damage. Most time, corrosion occurs as a result of atmospheric condition [7]. Atmospheric corrosion can be defined as the corrosion of materials exposed to air rather than immersed in a liquid.

Atmospheric corrosion can further be classified into dry, damp, and wet categories. The effect of temperature on atmospheric corrosion rates is also quite complex. An increase in temperature will tend to stimulate corrosive attack by increasing the rate of electrochemical reactions and diffusion processes. For a constant humidity level, an increase in temperature would lead to a higher corrosion rate [3]. The reactivity
of this extreme corrosion propagation in relation to their environmental factors is also linked to the kind of metal or alloy involved [7, 9]. Basically, the impure and heterogeneous nature of some metals contributes immensely to the major cause of their poor corrosion resistance. The existence of anodic and cathodic sites on the metal surface and their reactivity with oxygen and water accelerate change of a metal atom to a metal ion by the loss of electrons which is also known as electrochemical corrosion [10]. To this end, this study aims to give an insight on the mechanism behind mild steel degradation in industrial application, the corrosion challenges and possible curbing mechanism.

2. Mild steel and its phenomenal in service

Mild steel is by far the most widely used and one of the world’s cheapest and useful metals. It is essentially alloys of iron and carbon with small additions of elements such as manganese and silicon added to provide the requisite mechanical properties. The properties of mild steel depend primarily on the amount of carbon it contains [11]. Mild steel contains carbon of up to 0.25% in constituent among other element. This made it useful to be turn into a wide range of products, including structural beams, car bodies, kitchen appliances, and cans treatment [12].

Considering the microstructure of mild steel for instance with 0.2% carbon. Such steel consists of about 75% of proeutectoid ferrite that forms above the eutectoid temperature and about 25% of pearlite (pearlite and ferrite being microstructure components of steel). When the carbon content in the steel is increased, the amount of pearlite increases until we get the fully pearlitic structure of a composition of 0.8% carbon [13]. However, in slowly cooled mild steels, the overall hardness and ductility of the steel are determined by the relative proportions of the soft, ductile ferrite and the hard, brittle cementite. Hence, so as to be able to respond to such a great demand and to suit the requirements to different applications, mild steel needs to offer several desired properties and these properties is achieved by alloying it [14].

A study of the constitution and structure of all steels and irons must first start with the iron-carbon equilibrium diagram as presented in Figure 1. The iron-carbon diagram provides a valuable foundation on which to build knowledge of steel transformation. Many of the basic features of this system influence the behavior of even the most complex alloy steels. For example, the phases found in the simple binary Fe-C system of mild steel persist in complex steels, but it is necessary to examine the effects alloying elements have on the formation and properties of these phases [15].

It should first be pointed out that the normal equilibrium diagram really represents the metastable equilibrium between iron and iron carbide (cementite). Cementite is metastable, and the true equilibrium should be between iron and graphite. Although graphite occurs extensively in cast irons (2-4 wt % C), it is usually difficult to obtain this equilibrium phase in mild steel (0.03-1.5 wt %C) due to its in homogeneity [7]. The much larger phase field of γ-iron (austenite) compared with that of α-iron (ferrite) reflects the much greater solubility of carbon in γ-iron, with a maximum value of just over 2 wt % at 1147°C. This high solubility of carbon in γ-iron is of extreme importance in heat treatment, when solution treatment in the γ-region followed by rapid quenching to room temperature allows a supersaturated solid solution of carbon in iron to be formed [16].
Figure 1: Iron-Carbon Equilibrium Diagram (Jiang et al. 2012:256)

The α-iron phase field is severely restricted, with a maximum carbon solubility of 0.02 wt% at 723°C (P), so over the carbon range encountered in steels from 0.05 to 1.5 wt%, α-iron is normally associated with iron carbide in one form or another [17]. Similarly, the δ-phase field is very restricted between 1390 and 1534°C and disappears completely when the carbon content reaches 0.5 wt% (B). There are several temperatures or critical points in the diagram, which are important, both from the basic and from the practical point of view [18].

Furthermore, as it has been seen that hardness, brittleness and ductility are very important properties as they determine mainly the way these different metal steels are used. During processing and forging mild steel surface is oxidized by air, and the scale produced is usually termed millscale. In air, the presence of millscale on the mild steel may reduce the corrosion rate over comparatively short periods, but over longer periods the rate tends to rise. In water, severe pitting of the steel may occur if large amounts of millscale are present on the surface. For example, in the open air a mild steel containing 0.2% Si rusts about 10% less rapidly than an otherwise similar steel containing 0.02% Si [19].

In reality mild steel are selected not for their corrosion resistance but for such properties as strength, ease of fabrication, and cost. Primarily mild steel has quite good resistance to alkalis, many organics, and strong oxidizing acids. As a general rule, acids should be avoided. Mild steel can be susceptible to SCC in media that contain nitrates, hydroxides, ammonia, and hydrogen sulfide. Any evolved hydrogen may cause embrittlement and blistering in the steel [9]. Like other metals that form passive oxide films, iron benefits in situations in which there are essentially no oxygen to depolarize the cathodic reaction or sufficient oxidizing power to form a stable oxide film. The corrosion rates of mild steel when immersed in seawater or buried in soil are not the same with other metal. Mild steel has number of phases and inhomogeneities at the surface, which can cause local cells. The corrosion resistance of iron is low, because cathodic reduction can easily take place on its surface, and moreover, its corrosion product is porous and non-adherent. Mild steel finds extensive application primarily because of its low cost, reasonably good mechanical properties, and ease of fabrication. Ambient conditions in an industrial environment are relatively more corrosive because of the presence of moisture and chemical pollutants in the air. Chlorides...
in coastal areas and sulfur dioxide are highly aggressive, and they lower the critical humidity level for the onset of corrosion [20].

Despite these shortcomings, mild steels, with or without minor alloying elements, are widely used as the most economic materials of construction under ambient, aggressive conditions, and with various combinations of protective coatings and other corrosion prevention or control methods [3]. Corrosion of mild steel in the presence of moisture is particularly severe when acidic gases or vapors are involved, such as oxides of nitrogen and sulfur or chlorine. At high temperature, water vapor does not contribute to corrosion, but once the dew point is reached, condensation takes place, and the corrosion rate rises drastically [8].

Steel is nowadays a wide-ranging term covering an extensive area of iron alloys. Mild steel is one of the world’s inexpensive and beneficial metals. Mild steel is simply a class of steel with very low hardness invariably with low ultimate tensile strength and ductility [11]. Its great demand as to suit the requirements of different applications is incomparable to other metals. Certainly, mild steel bring into being diverse use in several fields, beginning from building construction to kitchen utensils, aerospace and automobile [13].

Mild steel is iron of crystalline alloy, carbon and some additional elements, which hardens above its dire temperature to give a desired property. The manufacturing process of mild steel is relatively extensive as it comprises of several stages of metallurgical decontamination [15].

The properties of mild steel hinge primarily on the extent of carbon it contains. Mild steel is a type of steel having maximum carbon content up to 0.25% along with small percentages of silica, sulphur, phosphorus and manganese. Mild steel is very strong due to the low amount of carbon it contains. Mild steel has a high resistance to breakage. Mild steel, as opposed to higher carbon steels, is quite malleable, even when cold. This means it has high tensile and impact strength [12]. Mild steel is especially desirable for construction due to its good weldability and machinability. Mild steel is made into a wide range of products, including structural beams, car bodies, kitchen appliances, and cans.

Mild steel will corrode in many media, especially most atmospheres. Generally, they are often selected not for their corrosion resistance performance but for economical and mechanical resilient behavior such as strength, ease of fabrication and cost. Mild steel can be susceptible to stress corrosion cracking in media that contain nitrates, hydroxides, ammonia, and hydrogen sulfide. Any evolved hydrogen may cause embrittlement and blistering in the steel [10].

Often, reactions in corrosion process occur if there is an appropriate electron acceptor to associate with the electron discharge by the iron atom. In reality, the process of corrosion, and the rate at which corrosion occurs is dependent on factors which include but not limited to, concentration of oxygen, acidity/alkalinity of pH level, water temperature and dissolved salts like chloride, sulphate, and sulphites. However, there are types of corrosion which range from pitting to bacterial corrosion; they pose huge threat particularly for the marine, petrochemical and automobile industry [21], [22].

Zhu et al., [23] stated that from a purely technical standpoint, an obvious answer to corrosion problems would be to use more-resistant materials. In many cases, this approach is an economical alternative to other corrosion control methods. Corrosion resistance is not the only property to be considered in making material selections, but it is of major importance in the chemical process industries. The choice of a material is the result of several compromises (Do. For example, the technical appraisal of an alloy will generally be a compromise between corrosion resistance and some other properties such as strength and hardness. Therefore, there is need for corrosion scientists to study corrosion mechanisms to improve the understanding of the causes of corrosion and the ways to prevent or at least minimize damages caused by corrosion [24]. Different ways that have been proposed to reduce corrosion by engineers include but not limited to cathodic protection on a large scale for buried pipelines, new and better paints, prescribes proper dosage of corrosion inhibitors, and correct fabricated coatings [25]. The corrosion scientist and engineer, in turn, develops better criteria of cathodic protection, outlines the molecular structure of chemical compounds that behave best as inhibitors, synthesizes corrosion resistant alloys, and recommends heat treatment and compositional variations of alloys that will improve their performance. Both the scientific and engineering viewpoints supplement each other in the diagnosis of corrosion damage and in the prescription of remedies.

3. The fallout of mild steel in service a critical problem definition and way-out.
Corrosion, thermal instability and wear failures are the most frequently encountered failure in major mechanical and chemical components. According to Nahle et al., [26], when these catastrophes exist concurrently together their existence often leads to a more severe humiliation of metals. Mild steels are widely used as structural components in automobile, petrochemical and marine industries due to their good mechanical properties [22]. However, the author’s submissions are restricted owing to poor mechanical and chemical characteristics.

According to Tiwari et al., [6], “mild steel possess reasonable good strength but exhibit poor resistance to corrosion”. When mild steel come in contact with alkalis and acidified media such as HCl and NaCl they are susceptibility to corrosion degradation which imposes a major limitation of its usage in severe atmospheric environment. The authors indicated that increasing the corrosion resistance of mild steel requires formulation of a suitable conversion coating to provide adherent and protective layer on mild steel substrate. An adaptation coating was formulated and applied on mild steel prior to sol–gel Al2O3 by using silica sol and aluminium oxyhydroxide followed by heat treatment at 500°C. The transformation coating formed a composite oxide containing Al2O3, SiO2, α-Fe2O3 and Fe3O4 on the surface of the substrate. From examined study, the results showed barrier type protection of the substrate with improved corrosion resistance of mild steel. The sol–gel coating reduced the corrosion current density of the substrate by 5 orders of magnitude with improved protection over the substrate.

According to Montemonr et al., [27] “Poor tribological and plastic deformation of mild steel is a huge concern of its usage in advance manufacturing application”. The authors attested that abrasive wear component such as metal tend to deform mild steel surface severely during abrasive operation. These deformation challenges attested by numerous authors on mild steels inflict its disadvantages. The authors affirmed that the efficient approach to improve the tribological and plastic deformation is to fabricate a hard coating alloy on mild steel. A developed composite multilayered coating which consisted of an electrodeposited Zn–Fe alloy layer, a zinc phosphate conversion layer, and one, two, or three organic layers were deposited on a mild steel substrate. The adhesion between these multilayered coating and the mild steel substrate was studied with the aid of a scratch testing technique. Observation of the worn surface of different multilayered coatings was performed with the aid of metallurgical microscopy. The same multilayered coatings were examined with FTIR spectroscopy and X-ray diffraction techniques. From the studies, experimental deductions indicated that multilayered coatings appeared to be continuous, uniform in thickness and without cracks or flaws. The multilayered coating with organic layers had the highest cohesion and adhesion strength compared to the steel substrate. All multilayered coatings increased the tribological resistance of mild steel substrate.

According to Panagopoulos et al., [28] “cost incur due to the failure and repeated damage of mild steel in service condition is a huge detriment to the integrity of steel usage in harsh conditions. The possibility of increasing the corrosion resistance and cost of mild steel has been on increasing paths since it is relative cheap and posse’s good weldability. The authors resolve that electrodepositing becomes a preferred method depending on the admixed alloy particle and the process variables. With proper electrodeposition parameter such as current density, electrolyte flow rate, and pH, deposited steel will provide high chemical and mechanical resistance to deformation and hence provide reduce cost wastage. The authors elucidate this fact with cobalt contents varying from 0.2 to 7 wt% in zinc electrolyte. The influence of these process parameters on the characteristics of the coating morphology could be related to the hydroxide suppression mechanism for anomalous codeposition. The application tests showed that zinc-cobalt alloy coatings have a good adhesion level when compared to pure zinc coatings and base mild steel. On the other hand, the corrosion resistance of a homogeneous film-forming zinc-cobalt alloy coating is significantly better than that of the substrate which will apparently reduce cost.

Dong et al. [24] stated that the anticipated performance of mild steel under service condition that require thermal stability and improved microstructural properties has fallen out because of low thermal resistance in high temperature environment. In view of the demands and application of mild steel in harsh industrial usage, several techniques have been employed with attractive mechanical behaviour for high temperature condition but with poor oxidation instability. With the intention of improving the desire thermal stability, the author studies the thermal properties of dispersible SiO2 nanocomposite in Ni-P electrolyte on steel substrate in the absence of surfactant. The resulting Ni/P- SiO2 composite coating were heat-treated for 1 h at 200 °C, 400 °C, and 600 °C, respectively. More so, the structural changes of the composite coatings before and after heat treatment were measured and investigated. Results show that co-deposited SiO2
particle contributed to improved thermal stability and the composite coating heat-treated at about 400 °C had the maximum mechanical performance. The authors ascertain that there is a good relationship between the microstructural change and the thermal characteristics of the developed coatings as microstructural buildup improved the thermal strengthening properties was maintained.

According to Mahieu et al.,[29] “In order to strengthen industrial application of mild steel for maximum usage, composite particulate are known as functional materials to enhance mild steel structural characteristics and relieve stress evolution. Crack and stress evolve often seen on mild steel due to in homogeneity and contamination. The proffers solution to this challenge deposited zinc-nickel alloys embedded on mild steel under various deposition conditions was used to enhance their structural properties. The effect of surface treatment and plating variables (bath composition, pH, current density) on the coating composition, morphology, corrosion property and microhardness were investigated. The result shows a modified morphology with perfect crystal growth, uniform arrangement of crystals, refinement in crystal size and hence bright deposit was obtained from sulfate Bath-3 containing 30 g/l H3BO3 at a current density of 75 mA/cm². Corrosion resistance as well as microhardness of Zn-Ni alloy coatings increased with %Ni increase in the deposit for all the sulphate baths studied. It was found that the characteristics of the deposited coating depend on the initial surface preparation, bath composition, additives and temperature. The authors concluded that phases and microstructure of the surface of the deposited Zn-Ni alloys is another important characteristic which controls the corrosion resistance and other mechanical properties. One serious drawback during the electrodeposition process was the generation of internal stresses resulting in the formation of micro cracks. However, the internal stress levels were reduced by buildup structure and heat treatment.

According to Rusu et al.,[31] “one of the unique ways to enhance the microhardness behavior and spread out the engineering application of mild steel is to develop a harder resistance coating. The authors study vividly the microstructural impact of the microhardness by varying the deposition parameters to induced changes in the structure and properties of the deposits. It was found that microstructure of deposits changed with the current density and deposition time. The authors prepared and characterized thin Ni layers by electrodeposition through galvanic statically technique from a Watts bath at different current densities in the range from 1 to 10 A dm² and for deposition times between 900 and 7200 s. The structure and the morphology of the nickel coatings were investigated by SEM and XRD techniques. The authors mentioned that the systematic experimental study was made to determine the role of the working parameters (current density and deposition time) on the structure and hardness properties. At a current density of 1 or 2 A dm⁻² the nickel crystals were larger and better separated than at higher current densities. The uniform deposits obtained at 5 A dm⁻² showed fine grains and better protection against corrosion. Microhardness was lowest for the layers electrodeposited at 10 A dm⁻². The deposit hardness for the nickel Watts bath was highest for the layers electrodeposited at 1 A dm⁻² and diminished when the current density was increased. In all, the author asserted that the excellent microstructural properties produced on the steel through the reinforced composite gave improved hardness properties observed.

Conclusion
The appearances of material degradations are often traced to the varying conditions and changes in fluid compositions, changes in operating conditions of the pressures and temperatures, the underlying or contact materials with working metals and other atmospheric conditions. The degree of corrosion reactivity would depend upon the sensitivity of a particular metal or alloy to a specific medium or environment and mild fall within this space. This study has attempted to critically observed the challenge of mild steel in industrial operation vis and viz the problem definition.

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