# Degradation Propensity of Welded Mild Steel in Coastal Soil of University of Lagos

S. O. Adeosun, O. S. Sanni



***Abstract*****—**Study on corrosion propensity of welded mild steel-bar in soil media around the coastal area of University of Lagos has been carried out using gravimetric method. Six (6) samples each for welded and unwelded mild steels were cut, their initial weights were recorded and buried in two selected soil. The weight losses of these coupons were measured at regular intervals for a period of six months (180 days).

The corrosiveness of the soil media varied widely depending on the potency level of its constituents. The results revealed that soil in the studied area have marked variations in composition and contents. Soil medium with a lower pH and higher chloride ion concentration aggressively attacked the coupons with the welded steel coupon corroding faster than unwelded one. The medium resistivity to the flow of current is another strong factor affecting corrosion rate.

***Keywords*****—**Coastal area, corrosion rate, mild steel, soil media, welds.

## I. Introduction

MOST structural alloys corrode on exposure to moisture in the air, but the process can be strongly influenced by the presence of certain substances. Corrosion can be localized to form pits, or can extend across a wide area to produce general deterioration. Some efforts to reduce corrosion only redirect the damage into less visible and less predictable forms while controlled corrosion treatments such as passivation and chromate-conversion will increase material's corrosion resistance [1].

When metal atoms are exposed to an environment containing water molecules they can give up electrons and become positively charged ions, provided a closed electrical circuit can be established. This phenomenon will lead to localized corrosion in form of a pit and in extreme case can develop to crack and eventual component failure. Localized corrosion that leads to pitting may provide sites for fatigue initiation while corrosive agents like seawater may lead to greatly enhanced growth of the fatigue crack. Pitting corrosion also occurs much faster in areas where microstructural changes have occurred due to welding operations [2].

Mild steel is the most common form of steel as its price is relatively low while it provides material properties that are acceptable for many applications. Mild steel contains approximately 0.05–0.15% carbon and low carbon steel contains 0.16–0.29% carbon. Mild steel is cheap and malleable but has a relatively low tensile strength. Surface hardness can be increased through carburizing, which involves heating the alloys in a carbon rich environment [3].

The risk of corrosion of underground steel pipelines and structures which are expected to have a long working life should be estimated before installation. Several problems related to soil impact on embedded steel structures are due to interaction between water and soil constituents. Corrosion of buried structures is primarily influenced by the presence of soil moisture, rate of oxygen diffusion, redox potential, environment's pH value, soil resistivity to current flow and microbial activity. An increase in soil water content can cause swelling, shrinkage and decline in cohesion. These occurrences result in deterioration of buried pipeline materials and damage of infrastructure in the soil area due to the establishment of general and localized corrosion. Corrosion of mild steel is affected by grain size swelling, shrinkage and clay mineral content. The clay mineral contents serves to control corrosion propensity of mild steel. For example montmorillonite and illite absorbed water more than kaolinite clay minerals and this are effective in metals deterioration [4]. Fine soil particles are considered as corrosive medium for underground pipelines and steel structures owing to the increase in swelling, shrinkage, and plasticity suffered by the material.

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Soil is a complex material that is characterized as porous, heterogeneous and discontinuous environment containing mineral or organic solid phase, water liquid phase, airs and other gas - phase. Corrosiveness of soils varies over a wide range because of the variety in compositions. Tests in one location are generally applicable only to that location. Factors affecting corrosiveness of soils are moisture, alkalinity and acidity, permeability of water and air (compactness and texture), oxygen, salts, stray current and biological organisms. Most of these factors affect electrical resistance, and is a good measure of corrosiveness. High-resistance dry soils are generally not very corrosive [5].

Mild steel is used as a material in oil and gas tubes piping and in piping system welding is needed to join one unit of pipe to another. Weld piece can be divided into base metal, heat affected zone (HAZ) and fusion zone. HAZ is the most susceptible to corrosion attack because of its intergranular structure, and becomes the weak region due to its coarse grain structure, precipitated by the welding process. Generally mild steel is easy to weld compared to the medium and high carbon steels since martensite can easily form in the HAZ which results in poor toughness weldment. In mild steel the strength of the weld region is higher than the base material due to the fine pearlite microstructure that forms during cooling of the HAZ and this renders HAZ, the weakest area in a weld. In plain carbon steels these structures may range from very narrow regions of hard martensite to coarse pearlite.

Corrosion studies of a few microalloy steels were conducted in Ganga river water and natural seawater. Microalloy steels were found to exhibit better corrosion resistance than mild steel in river water, while in seawater they were more prone to pitting. Tests were also conducted for welded joints of microalloy steels with various welding parameters [6]. On the basis of damage caused by stress-corrosion cracking on welded components in chemical apparatus construction, comprehensive investigations were conducted on mild and low-alloy steels. Those near-equilibrium structures (ferritic-pearlitic) with slight hardening which existed after the welding process exhibited the lowest sensitivity with regard to stress-corrosion cracking while there was a greater risk of stress-corrosion cracking occurring in the case of non-tempered bainitic and, in particular, martensitic structures [7].

Corrosion of mild steel (both hot and cold rolled) and type 304 stainless steel in welded and unwelded form was studied in the industrial environment of a steel work. The welded mild steel samples corroded faster than the unwelded samples. The gas welded samples show more corrosion propensity than electric arc welded samples. The cold rolled samples corroded faster than the hot rolled samples. Preferential corrosion attack occurred in the weld zone than the parent metal [8].

Steel pipe line, usually made from mild steel, corrodes in soil by complex electrochemical process because of the differing nature of soil electrolytes. It is of importance to examine every study site to explain the mechanism of corrosion models.

Mineral composition is a key to understanding how a soil can influence the corrosion of buried steel. Exposure of this saturated solution to steel surfaces renders it alkaline by electrochemical reactions induced by an effective cathodic protection system which will precipitate hard white carbonate scale on the metal surface. Wet soil with lower oxygen potential usually gives rise to anodic areas, while well-aerated soils form cathodic areas on the metal surface. This heterogeneous environment creates different local aeration zones on the metal surface, and result in serious localized corrosion attack [9].

Mild steel is currently used in fabrication work, piping and structural applications. The increasing use of mild steel in structures requires structural integrity guarantee for all welded joint to avoid pre-mature failure by corrosion. Structures are increasingly been put up along our coastal areas now more than any other time. Pipelines are buried in coastal areas for the transportation of crude and refined petroleum products. Buildings are being erected close to sea-side in areas such as Maroko and Lekki axis of Lagos state, Nigeria, where land reclamation have been done.

Structures in the University of Lagos have also been found to suffer tremendous physical degradation of its steel and concrete members (see Fig. 1). Most alarming are the structures put up in the last ten years which are located close to the lagoon.

This paper presents the results of the corrosion study of unwelded and welded mild steel profiles buried in selected soil environments in the University of Lagos, Nigeria (see Fig. 2).

Fig. 1 Corrosion attacks of steel and concrete structures in the University of Lagos, Nigeria

## II. Experimental Methodology

The welded and unwelded mild steel used for this study was provided by Niger Dock Company, Lagos Nigeria and its chemical composition is shown in Table I.

TABLE I
CHEMICAL COMPOSITION OF WELDED MILD STEEL

| Element | % Composition |
|---|---|
| *C* | 0.2030 |
| *Si* | 0.2530 |
| *Mn* | 0.9400 |
| *P* | 0.0072 |
| *S* | 0.0041 |
| Cr | 0.8000 |
| *Fe* | 97.790 |

The locations of the soil environments used are given below, and are displayed in Fig. 2 while their chemical content is shown in Table II.

Soil A (Sandy) Location – Lagoon Front, University of Lagos

Soil B (Muddy) Location – Distance Learning Institute, University of Lagos

TABLE II
SOIL ENVIRONMENTS PROPERTIES

| Physical Properties | Soil Designation | |
|---|---|---|
| | *A* | *B* |
| $PH_1$ | 7.12 | 7.78 |
| $PH_{2\ (after\ 30\ days)}$ | 6.77 | 7.34 |
| Moisture Content (%) | 18.46 | 17.00 |
| Iron (Fe) Content | 0.216 | 0.368 |
| % oxide of Fe | *0.618* | 1.052 |
| Chloride (Titre Value) | 3.30 | 1.30 |
| $Cl^-$ | 233.97 | 92.17 |
| Electrical Conductivity (µs/cm) | 549.00 | 198.0 |
| Resistivity (cm/µs) | 0.00182 | 0.00505 |

TABLE III
DESIGNATION OF SAMPLES

| Test Coupons(TC) Number | | |
|---|---|---|
| *Control Sample* | Welded CP | Unwelded CP |
| *TC1* | W1B | O1B |
| *TC2* | W2B | O2B |
| *TC3* | W3B | O3B |
| TC4 | W4A | 04A |
| TC5 | W5A | 05A |
| *TC6* | W6A | 06A |

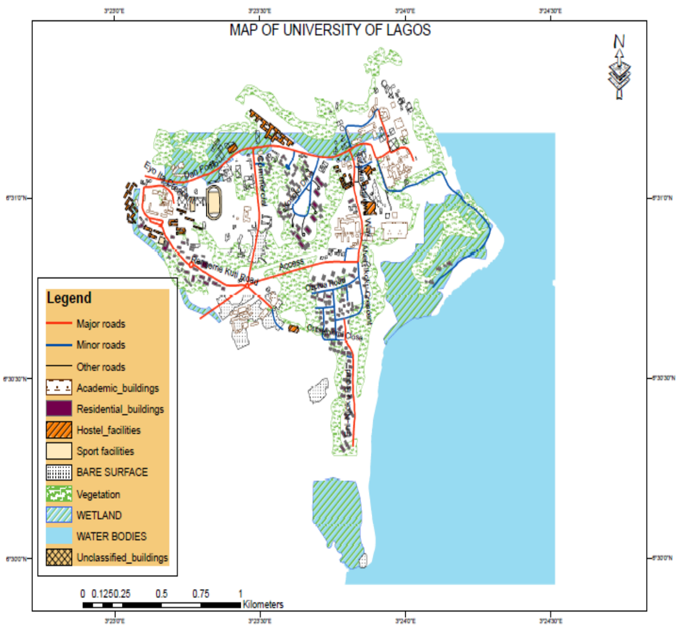
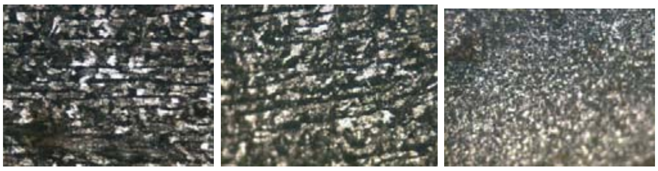



Fig. 2 Map of University of Lagos

The welded and unwelded mild steel samples were cut into seven equal lengths with dimension 75mm x 75mm and their masses measured and recorded, using electronic digital weighing scale model. The test coupons designations are shown in Table III.

Three test coupons (TC) each from both the welded and unwelded steels were buried in soil A and soil B to 20cm depth for an initial period of 110 days before the commencement of measurement. Coupon W4A, W5A, W6A, O4A, O5A and O6A were buried in Soil A while Coupon W1B, W2B, W3B, O1B, O2B and O3B were buried in Soil B. The buried TCs were withdrawn from the soil, cleaned with stream of distilled water while the adherent soil particles on sample surface were removed by light smooth brushing. The weight of each TC was taken using a digital electronic scale model number CT1200B. The test coupons were re-buried for further corrosion tests and measurements.

At the end of 6 months test period, buried samples were cleaned and prepared for microstructural examination. The coupon samples' surfaces were ground with emery paper of grades 40, 32, 10 and 8 in succession. The ground samples' surfaces were further polished with an emery cloth, etched in a solution containing 1 gram of Sodium Hydroxide (Pellets) in 100ml water for 25s and allowed to dry. The morphologies of test coupons obtained using Digital Metallurgical Microscope at magnification of X100, are shown in Fig. 3.



(a) (b) (c)

Fig. 3 Structural morphology of mild steel before soil immersion (a) plain (b) HAZ (c) Fusion zone

## III. RESULTS AND DISCUSSION

The results of soil media analysis in Table II show that soil A has a slightly lower pH (7.12) than Soil B (7.78). The corrosiveness of soils towards mild steel, in general, has been found to be 65% moisture content of their water holding capacity at peak, which may be termed as "Critical Soil Moisture Content." Corrosion of mild steel in a soil becomes appreciable, only when the soil moisture content 50 % of its water holding capacity [10]. Soil A has higher moisture content (18.46%) than Soil B (17.00%), though below critical value this is sufficient to transport oxygen and other liquid constituents and this condition could accelerate corrosion of buried coupons. Generally, as soil resistivity decreases, corrosiveness increases. On the other hand, as soil moisture content increases, resistivity decreases [11]. The higher electrical conductivity of soil A (549µs/cm) also favors the rapid corrosion rates of the steel samples in soil A. The soil media contain chloride ion and the presence of highly aggressive chloride ions in high concentration causes severe corrosion. Chloride ions have the ability to destroy oxide films which may protect metals such as steel, stainless steel and copper and its alloy [12]. The soil's chloride ion effect and electrical conductivity appear to be the major contributing factors to its higher corrosion deterioration capability than soil B [13].

Figs. 4 and 5 show that samples buried in soil A corroded faster than those in soil B for both the unwelded and welded mild steel samples.

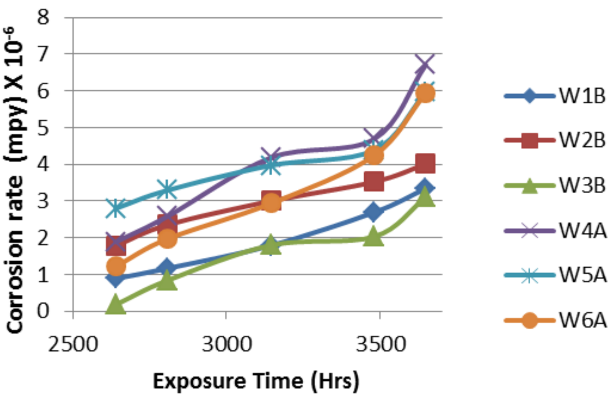



Fig. 4 Corrosion responses of welded Mild Steel coupons in soil environments A and B

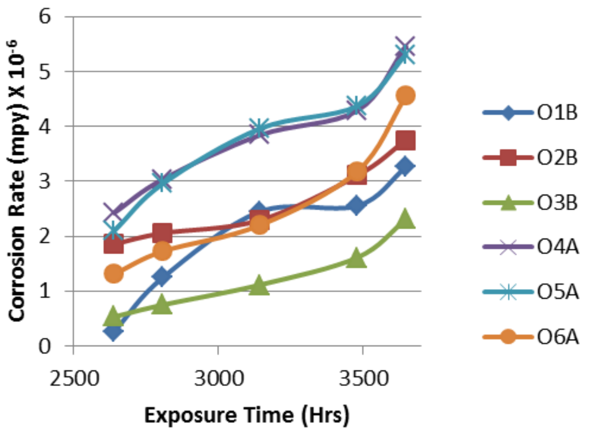



Fig. 5 Corrosion responses of unwelded Mild Steel coupons in soil environments A and B

Figs. 6 and 7 show that the welded mild steel corrodes faster than the unwelded mild steel within the same soil environment. The cause of this is hinged on the stresses induced during welding and the effect of retained austenite along ferrite grain boundaries which limits recrystallization and helps to retain fine grain size, which contributes to the strength of the welded region of mild steel.

The metallurgical factor can cause corrosion of the weld zone to occur. The cycle of heating and cooling that occurs during welding affects the surface composition of the microstructure of welds and that of adjacent base metal.

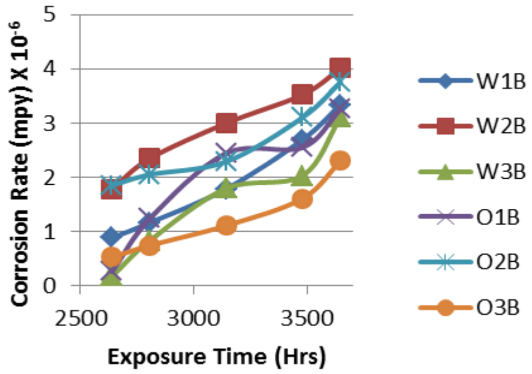



Fig. 6 Corrosion responses of welded and unwelded Mild Steel coupons in soil B

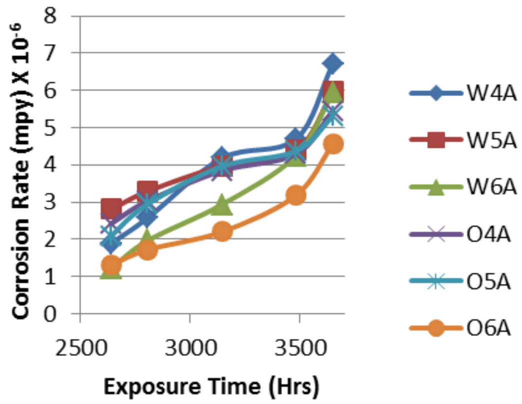



Fig. 7 Corrosion responses of welded and unwelded Mild Steel coupons in soil A

In Fig. 3, the unwelded mild steel morphology contains coarse crystals having roughly uniform volume fractions of ferrite and pearlite phases with visible and well defined grain boundaries (Fig. 3 (a)). In the HAZ area, there is a slight reduction in crystal size of the phases when compared to the unwelded steel (Fig. 3 (b)) and there is no significant difference in the arrangement of the phases. The HAZ area is made of crystals that are both fine and coarse (Fig. 3 (b)). Its morphology is a mixture of those in Figs. 3 (a) and (c). It is highly inhomogeneous and will respond to corrosion faster than the unwelded coupon. These features are however, different from what is observed in the fusion zone (Fig. 3 (c)).

However, during welding, precipitation of fine and uniformly distributed crystals occurred which induces high strength and generates high internal stresses in welded coupons during cooling (Fig. 3 (c)). This phenomenon promotes increase corrosion propensity. The pearlite crystals occupied grain boundaries and with the lock up stresses increase the corrosion rate.

In natural seawater, pitting is essentially the only form of attack. The contribution to corrosion in the investigated environment by bacteria cannot be overlooked. In the metabolism of living organism, there is energy intake and energy release. In some bacteria, these energy changes result in a measurable electric current. When corrosion – causing organisms reproduce on the surface of an iron, electrochemical removal of iron takes place. Microorganisms can participate in iron and steel corrosion by creating favorable conditions for electrochemical reaction to take place. One mechanism is the changing of a surface film resistance with metabolic products such as sulfuric or organic acids. In other instances, slime deposits can form in selected areas so that they become anaerobic. If oxygen is present in solution, the anaerobic sites will become anodic to the aerobic areas [14].

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In summary, the following deductions can be made from the study:

1) Coupons in soil with lower pH degraded faster than samples in soil with higher pH. As pH increases, the soil become increasingly passive and inhibits further corrosion by retardation of the process kinetics.
2) The presence of high chloride ions concentration lowers the resistivity of the soil as water acts as a cathode depolarizer. Increasing concentrations of chloride ions and moisture content in the soil will increase the corrosion rate of its buried steel.
3) Coupons in the soils with lower conductivity have a lower corrosion rate compared to those with higher conductivity.
4) In the two environments considered, the unwelded mild steel corrodes at a lower rate than the welded mild steel and this can be explained in terms of the existing morphology of each test coupon before immersion. The weld has a fine microstructure than the HAZ and unwelded mild steel coupons and this accelerates its corrosion. It should be noted that HAZ degraded faster than unwelded Mild Steel.

## IV. Conclusion

Corrosiveness of soils varies over a long range because of a variety of compositions. Tests in one location are generally applicable only to that location. The study shows that corrosion rate is high at the Lagoon front area than at Distance Learning Institute area for both the welded and unwelded mild steel samples.

Welded components of steel especially at the heat affected zone (HAZ) are subjected to a complex thermal cycle (sudden heating followed by rapid cooling). The HAZ usually contains a variety of microstructures and this condition generates internal stresses which serve as corrosion catalyst near the weld. Thus corrosion rate of unwelded mild steel is lower to that of welded steel in the coastal environment studied.

Structures in the coastal area of Lagos lagoon are constantly being subjected to degradation which may not have been taken into consideration at design and construction stages. The chemical composition of the environment is constantly changing due to unwholesome practices of dumping or discharging hazardous industrial and domestic wastes into it.

Structures along coastal areas should be protected against collapse which may be occasioned by corrosion precipitated by the soil nature.

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