



Investigation of different Annealing Temperature on Corrosion Rate of Medium Carbon Steel in Sea Water

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Abstract: In A medium carbon steel of 0.3 percentage weight carbon obtained from a local market in Nigeria was investigated for corrosion under the influence of sea water corrosion environment. An annealing process was carried out using a muffle furnace. The medium carbon steel samples were annealed at varying temperatures of 900°C, 950°C and 980°C and soaked for duration of one hour. The various steel samples were weighed with an analytical weighing balance and recorded as (W_i) before being immersed into their respective labeled plastic bowls. After twenty (20) days intervals, each of the steel samples were retrieved, properly cleaned and allowed to dry for about ten (10) minute. They were then placed on a weighing balance to record their weights (W_f) and returned into their respective plastic bowls. This procedure was repeated at twenty (20) day intervals for a period of eighty (80) days. The results obtained revealed that corrosion rate of all the samples increases steadily for the forty (40) days with the peak on day forty (40). This was followed by continuous decrease in the corrosion rate of all the samples. However, the corrosion rate of the samples become partially uniform after the (60) days and the pattern remain the same for the remaining twenty (20) days. It was observed that the samples loss in weight and corrosion rate was increasing with exposure time with increased in annealing temperature.

Keywords: Medium Carbon Steel, Sea Water, Corrosion Environment, Annealing, Corrosion Rate, Weight Loss

INTRODUCTION

Heat treatment is a heating and cooling operation applied to metals and alloys in solid state to impart desirable properties to the metal or alloy. Heat treatment of metals is an important operation in the final fabrication process of many engineering components. Heat treatment is of various forms which include annealing, normalizing, tempering, hardening and isothermal operations (Daramola *et al.*, 2011). Heat treatment improves the microstructure of the metal, and this is what gives the metal desired properties for different service conditions. Annealing is the heating to and holding at a suitable temperature above re-crystallization, followed by cooling at a suitable rate in a switched off furnace for such purposes as inducing softness and enhancing cold work (Onyekpe, 2002). Annealing is the type of heat treatment most frequently applied in order to soften iron or steel materials and refines its grains due to ferrite-pearlite microstructure; it is used where elongations and appreciable level of tensile strength are

required in engineering materials (Motagi and Bhosle, 2012). Is a heat treatment process in which a metal is exposed to an elevated temperature for an extended period of time and then allow to slowly cooled in the furnace.

Medium carbon steel is classified on the basis of their carbon content as their major alloying element is carbon. According to Rajan *et al.* (1988), steels with carbon content varying from 0.25% to 0.65% are classified as medium carbon, while those with carbon content less than 0.25% are termed low carbon. The carbon content of high carbon steels usually ranges within 0.65-1.5%. Medium carbon steels are extensively used for many industrial applications and manufacturing on account of their low cost and easy fabrication (Onyekpe, 2002; Smith and Hashemi 2006; Oyejide *et al.*, 2017; Orhororo *et al.*, 2022). The wide application of medium carbon steel ranges from chemical, oil gas storage tanks and transportation pipelines are due to its moderate strength, good weld-ability and formability (Afolabi, 2007). Nonetheless, this material is susceptible to corrosion when used in chemical and sour crude oil environments such as sea water (Deyab, 2014). Deterioration of materials produced from low carbon steel as a result of corrosion has come to be accepted worldwide as an unavoidable fact of life. For instance, 2241 major pipeline accidents were reported in the United Kingdom (UK) in the last 10 years and in the US alone the lost number on corrosion is approaching 350 million dollars per year (Tretthewey, and Roberge, 1995). In Nigeria, petroleum pipeline explosions occur regularly resulting in loss of lives and environmental pollution. There was a report of pipeline explosion in Idjerhe (Jesse) where hundreds of lives were lost (Trevor, 2005). A related incident in Adeje village near Warri, Delta State, where more than 250 Nigerians were fared died (Bodude, 2006).

The present degradation of infrastructures in corrosion environment particularly in sea water has continued to generate a lot of worries to researchers across the world in view to procure lasting solution to the problem. Seawater is an extremely complex ionic aqueous solution containing at least 70 elements in widely-varying concentrations (Osman, 2007). It has a very good electrical conductivity of 0.04mΩ cm⁻¹, which is at least 4,000 times better than most freshwater (Caceras *et al.*, 2009). Salinity, pH, oxygen level, and temperature are parameters that have a strong influence on corrosion reactions. These factors vary in vertical distribution from the seabed to the surface. The salinity and pH of seawater are relatively stable measurements whereas temperature and dissolved oxygen may vary. The salinity increased as the depth increased and thus, decreased pH to more acidic. Research work had proven that corrosion rate is faster in sea water, and this is due to the presence of numerous minerals in sea water composition (Hoseinpoor *et al.*, 2014). Seawater is an extremely complex ionic aqueous solution containing at least 70 elements in widely-varying concentrations (Krkwood, 1982). It has a very good electrical conductivity approximately 0.04 mΩ cm⁻¹, which is at least 4,000 times better than most freshwater (Malik *et al.*, 1999). Salinity, pH, oxygen level, and temperature are parameters that have a strong influence on corrosion reactions. These factors vary in vertical distribution from the seabed to the surface. The salinity and pH of seawater are relatively stable measurements whereas temperature and dissolved oxygen may vary. The salinity increased as the depth increased and thus decreased pH to more acidic. Temperature may vary with the amount of sun and oxygen content depends on life forms in the seawater. Theoretically, salinity is the mass of dissolved salt ions present in 1 Kg of seawater. Normal salinity is 35 grams/kg of water (3.5%). Fig. 1 provides a simple illustration of the constituents comprising the 3.5% salt content of seawater. Salinity is also used to express the salt content of seawater. Almost 99% of all seawaters have a salinity ranging between 33ppt and 37 ppt. The pH of seawater is usually 7.7-8.3 at the surface, but will decrease and become more acidic (3-4) in deep water as the density increases. The pH is also affected by bacterial action. Organic compounds produce carbon dioxide, which can lower the pH to ≈ 5-6 (Malik *et al.*, 1999).

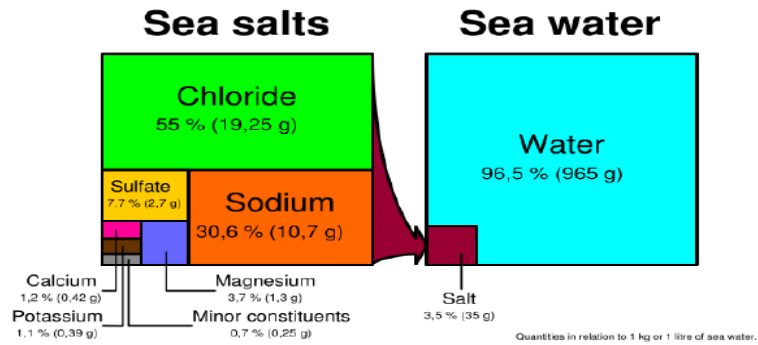


Fig.1 Composition of Seawater (Grobe and Majewsky, 2009)

The mainly accepted definition for corrosion is the damage of material due to chemical reaction of the material with its environment. Generally, this destruction takes place on its surface in the form of material dissolution or redeposit ion in some other forms. Medium carbon steel just like every other metals and alloys are generally prone to corrosion because most of them occur naturally as ores, which is the most stable state of low energy and there is a net decrease in free energy, (ΔG) from metallic to oxidized state. The corrosion of medium carbon steel in natural environments such as sea water is of practical importance. Generally, the chemistry of corrosion processes is shown in equation (1), and equation (2).



The corrosion characteristic of medium carbon steel in natural seawater is the formation and growth of compact and thick layers composed of oxides, insoluble salts and organic materials (Aramide *et al.*, 2010). The result of surrounding environmental conditions such as water oxygen supply, ionic species, bacteria and organic matter are the formed layer. The exchange of various species (ions, molecules, gas) between seawater and the rust layers or the metal depends both on the kinetics of the Faradaic reactions of the entities with either the oxides or the metal, as well as on their transport properties through the different strata of the rust layers (Adedayo *et al.*, 2010). Salts dissolved in water have a marked influence on the corrosivity of water. At extremely low concentrations of dissolved salts, different anions and cations show various degrees of influence on the corrosivity of the water. Generally, the corrosivity of waters containing dissolved salts increases with increasing salt concentration until a maximum is reached, and then the corrosivity decreases. This may be attributed to increased electro-conductivity because of the increased salt content, until the salt concentration is great enough to cause an appreciable decrease in the oxygen solubility, resulting in a decreased rate of depolarization (Senthilkumar and Ajiboye, 2012).

The use of medium carbon steel of no doubt is crucial to virtually all facets of human endeavor. Our human civilization cannot exist without metals and yet corrosion is their Achilles heel (Orhorhoro *et al.*, 2018). Corrosion remains one of the most severe limitations to the use of carbon steel in the manufacturing, construction, chemical, petrochemical industries, etc. Millions of naira is lost each year because of corrosion. Much of this loss is due to the corrosion of iron and steel, although many other metals may corrode as well (Orhorhoro *et al.*, 2018). The problem with carbon steel as well as many other metals, and alloys is that the oxide formed by oxidation does not firmly adhere to the surface of the metal and flakes off easily causing pitting. Failure of equipment, parts and components of engineering origin in different industries by corrosion is one of the major problems. Corrosion is responsible for so many mishaps that have occurred in the engineering history of man.

The two particular reasons for the extraordinary versatility of steel are heat treatment and alloying. Medium carbon steel is one of the most common types of steel used for general purposes, in part because it is often less expensive than other types of steel. Sea water offers numerous corrosion problems due to its process conditions, including factors such as temperature and pH. Medium carbon steel usage is versatile, and large percentage of machines, vessels, tank barge, ships, etc., that are used in sea environment are produced from low carbon steel. Corrosion, like taxes and death is inevitable especially in the manufacturing, chemical, and petroleum industries. Hence, if one considers the mammoth amount of money spent in fighting corrosion and the attendant severe consequences of corrosion disasters, then, this research work is a right step in the right direction. Therefore, there is the need to investigate corrosion rate of medium carbon steel in sea water under different annealing temperature, thus this research work.

MATERIALS AND METHODS

A medium carbon steel of 0.3 percentage weight carbon obtained from a local market in Nigeria was used in this research work. The seawater used was obtained from Escravos River in Delta state. The medium carbon steel samples were machined using lathe machine into cylindrical pieces of diameter of 20 mm and length of 60 mm. The cylindrical pieces of machined medium carbon steel samples were divided into the following groups:

- i. Sample A: As received
- ii. Sample B: Annealed at 900°C
- iii. Sample C: Annealed at 950°C
- iv. Sample D: Annealed at 980°C

The annealing process was carried out using a muffle furnace. The medium carbon steel samples were annealed at varying temperatures of 900°C, 950°C and 980°C and soaked for duration of one hour (60 minutes) as recommended by [Orhorhoro et al., \(2022\)](#). A portion of the sea water sample was analyzed to determine the chemical composition. The prepared medium carbon steel samples and the seawater were used for the experiment to determine the corrosion rate of the medium carbon steel in seawater environment, which was performed at room temperature. Four (4) plastic bowls were filled with seawater and labeled A to D. The various steel samples were weighed with an analytical weighing balance and recorded as (W_i) before being immersed into their respective labeled plastic bowls. After twenty (20) days intervals, each of the steel samples were retrieved, properly cleaned and allowed to dry for about ten (10) minute. They were then placed on a weighing balance to record their weights (W_f) and returned into their respective plastic bowls. This procedure was repeated at twenty (20) day intervals for a period of eighty (80) days. Equation (3) was used to calculate the weight loss. Equation (4) was used to calculate the corrosion rate of medium carbon steel

$$W_L = W_i - W_f \tag{3}$$

$$C_R = \frac{87.6W_L}{DAT} \tag{4}$$

where,

W_L = Weight loss

W_i = Initial weight

W_f = Final weight

C_R = Corrosion Rate (mm/y)

W = Weight loss (mg)

D = Density of Low Carbon Steel = 7.85g/cm³

A = Area of medium carbon steel samples used (cm²)

T = Exposure time to sea water (days)

RESULTS AND DISCUSSION

Table-1 shows the chemical composition of seawater. From the results analysis, the pH of the sea water was gotten as 7.43 (m), conductivity of 894 ($\mu\text{s}/\text{cm}$), TDS of 447 (mg/l), total alkalinity of 1.66 (mg/l), chloride of 2677.5 (mg/l), sulphate of 293 (mg/l), nitrate of <0.01 (mg/l), phosphate of 0.001, and salinity of 2988 (mg/l).

Table-1 Chemical Composition

S/N	Parameters	Result
1	pH	7.43
2	Conductivity, $\mu\text{s}/\text{cm}$	894
3	TDS, mg/l	447
4	Total alkalinity, mg/l	1.66
5	Chloride, mg/l	2677.5
6	Sulphate, mg/l	293
7	Nitrate, mg/l	< 0.01
8	Phosphate, mg/l	0.07
9	Salinity, mg/l	2988

The samples were exposed to sea water for a period of eighty (80) days. Corrosion action and rate on the test samples were evaluated by visual observation and corrosion rate measurement using weight loss. Formation of corrosion products on the surfaces of the samples and the edges of the steel samples were observed. Weight loss was monitored after each twenty (20) days. The results obtained were used to evaluate the corrosion rate of the medium carbon steel. The process of corrosion started with colour transformation to yellow deposits in the five (5) days and this was a confirmation of presence of ions concentration in the sample of sea water. As the exposure continues, the yellow deposits turned dark brown colouration that surrounded the surface of the samples of medium carbon steel. On withdrawal of the used samples, the dark brown deposits of were noticed on them which is a confirmation of corrosion on the samples. Fig. 2 shows the plot of corrosion rate of medium carbon steel in exposed sea water environment for as received (control) and annealed medium carbon steel samples. It was observed from the plot that corrosion rate of all the samples increases steadily for the forty (40) days with the peak on day forty (40). This was followed by continuous decrease in the corrosion rate of all the samples. However, the corrosion rate of the samples become partially uniform after the (60) days and the pattern remain the same for the remaining twenty (20) days.

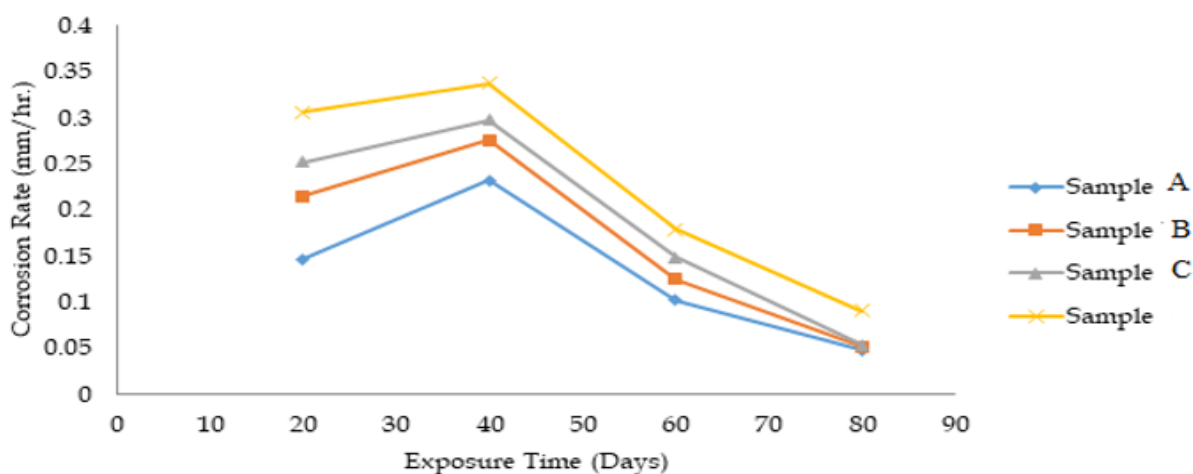


Fig. 2 Evaluation of corrosion rate of medium carbon steel in exposed sea water environment

The decreased in the corrosion rate of all the samples between the period of 40th day and 60th day can be attributed to the aggressiveness of the chemical reactivity, transport properties of the corrosion medium, pH of the corrosion medium which is within neutral, concentration of the corrosion species in the used sea water, and most importantly the metallurgy of the alloy sample and temperature of the sea water which served as the corrosion medium (Orhorhoro *et al.*, 2018; Orhorhoro *et al.*, 2022). The continuous decline in corrosion rate for annealed samples confirm that the brown colouration formed on the samples surfaces has some inhibitive property on the medium carbon steel and sea water interface which partially passivate the metal. Besides, the corrosion rate of low carbon steel generally decreased with exposure time as protective barrier films are formed on the steel surface (Callister, 2007).

Fig. 3 shows the plot of weight loss of medium carbon steel against time of exposure in sea water corrosion medium. It was observed that the samples loss in weight was increasing with exposure time with increased in annealing temperature. Also, for sample A (as received without annealing) that served as control, the situation was the same but with minimal weight loss in comparison to the annealed samples. For the all samples, rapid weight loss was observed for the first forty (40) days. This was followed by gradual dropped in weight loss and become stable after the sixty (60) day. This stability was obtained for the remaining exposure time of twenty (20) days. However, weight loss was highest with samples annealed at temperature of 980°C (sample D), followed by samples annealed at temperature of 950°C (sample C), and this was followed by samples annealed at temperature of 900°C (sample B). However, for as received samples without annealing, weight loss recorded was the lowest. This simply shows that, increasing the annealing temperature of medium carbon steel will lead to increase in weight loss when exposed to sea water corrosion environment.

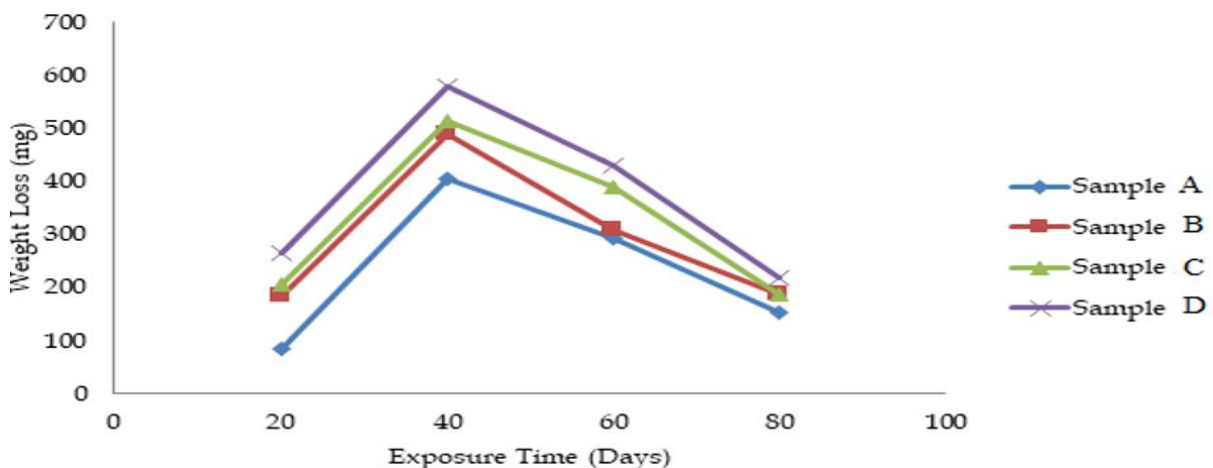


Fig. 3 Evaluation of weight loss of medium carbon steel against time of exposure in sea water corrosion medium

CONTRIBUTION TO KNOWLEDGE

This study has shown that increasing the annealing temperature of medium carbon steel will lead to increase in weight loss and corrosion rate when exposed to sea water corrosion environment.

CONCLUSION

This study that involves the investigation of different annealing temperature on corrosion rate of medium carbon steel in sea water was successfully carried out. From the results analysis, the pH of the sea water was gotten as 7.43 (m), conductivity of 894 ($\mu\text{s}/\text{cm}$), TDS of 447 (mg/l), total alkalinity of 1.66 (mg/l), chloride of 2677.5 (mg/l), sulphate of 293 (mg/l), nitrate of <0.01 (mg/l), phosphate of 0.001, and salinity of 2988 (mg/l).

The process of corrosion started with colour transformation to yellow deposits in the five (5) days and this was a confirmation of presence of ions concentration in the sample of sea water. As the exposure continues, the yellow deposits turned dark brown colouration that surrounded the surface of the samples of medium carbon steel. On withdrawal of the used samples, the dark brown deposits of were noticed on them which is a confirmation of corrosion on the samples. The results of corrosion rate evaluation showed that corrosion rate of all the samples increases steadily for the forty (40) days with the peak on day forty (40). This was followed by continuous decrease in the corrosion rate of all the samples. However, the corrosion rate of the samples become partially uniform after the (60) days and the pattern remain the same for the remaining twenty (20) days. It was observed that the samples loss in weight was increasing with exposure time with increased in annealing temperature. Also, for sample A (as received without annealing) that served as control, the situation was the same but with minimal weight loss in comparison to the annealed samples. For the all samples, rapid weight loss was observed for the first forty (40) days. This was followed by gradual dropped in weight loss and become stable after the sixty (60) day. However, weight loss was highest with samples annealed at temperature of 980°C (sample D), followed by samples annealed at temperature of 950°C (sample C), and this was followed by samples annealed at temperature of 900°C (sample B). However, for as received samples without annealing, weight loss recorded was the lowest.

CONFLICT OF INTEREST

There is conflict of interest associated with this research work.

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