Original Research Article

EVALUATION OF THE EFFECT OF TEMPERING ON THE CORROSION SUSCEPTIBILITY OF LOW CARBON STEEL IN SEA WATER

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ARTICLE INFORMATION

ABSTRACT

Corrosion remains one of the most severe limitations to the use of low carbon steel in the manufacturing, construction, chemical, petrochemical industries. In this research work, the effect of tempering on the corrosion susceptibility of low carbon steel in seawater was evaluated. Low carbon steel purchased from a local market in Benin City, Nigeria was properly machined and divided into four samples. Sample A was the low carbon steel as received, sample B was water-tempered low carbon steel, sample C was oil-tempered low carbon steel, and sample D was brine-tempered low carbon steel. A tempering temperature of 700ºC was used in this work. The samples were exposed to 1000 ml of seawater collected from sea in Warri, Delta State, Nigeria for a period of 100 days. The results obtained reveal that brine-tempered low carbon steel had better corrosion resistance and minimal weight loss when compared to other samples investigated. The study therefore recommends brine-tempered low carbon steel for equipment used in seawater.

1. INTRODUCTION

Materials often have a natural tendency to combine with other chemical elements to return to their lowest energy state. In order to return to lower energy states, materials frequently combine with oxygen and water, both of which are present in most natural environments, to form hydrated oxides and in the case of iron, the iron oxide is refers to as rust. Corrosion is one of the major causes of failure of materials in the long term (Revie, and Uhlig, 2008). Corrosion is the gradual deterioration of materials, usually metals, by chemical reaction with its environment (Roberge, 2008; Kamachi, 2009; Cwiek, 2010). 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. The applications of low-carbon steel range from chemical, oil gas storage tanks and transportation pipelines and this is due to its moderate strength, good weldability and formability (Afolabi, 2007; Abdulkhaleq, 2013). Low carbon steels (0.002-0.25% C) account for a large proportion of the total output of steel (Onyekpe, 2002). However, low carbon steel is susceptible to corrosion when used in chemical environments such as sea water (Deyab, 2014).

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 0.04 mΩ 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 of metals. Previous research work has shown that corrosion rate is faster in seawater, and this is due to the presence of numerous minerals in sea water (Hoseinpoor et al., 2014). The corrosion properties of low 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).

Heat treatment is the heating and cooling operation applied to metals and alloys in solid state so as to obtain the desired properties. Heat treatment improves the microstructure of the metal and gives the metal desired properties for different service conditions. Heat treatment is of various forms which include annealing, normalizing, tempering, hardening and isothermal operations (Daramola et al., 2011). Tempering is usually the process of eliminating martensite from steel. It is done by heating the steel to a temperature below the lower critical temperature, and this is followed by cooling in air. It is normally done at a temperature between 200°C and 700°C. Tempering process also allows the formation of martensite by diffusional process and removes internal stresses set up during quenching (Callister 2007). By tempering, the properties of quenched steel could be modified to decrease hardness and increase ductility and impact strength gradually. The resulting microstructures are bainite or carbide precipitate in a matrix of ferrite depending on the tempering temperature.

Considering the general usage of low carbon steel, hazardous effect of corrosion on it, and the need to heat work on it mainly to improve its mechanical properties, this study thus sought to evaluate the effect of tempering on the corrosion susceptibility of low carbon steel in sea water.

2. MATERIALS AND METHODS

2.1. Material

Low carbon steel was purchased from a local market in Benin City, Nigeria. A low carbon steel of 0.19% weight of carbon was used. The sea water used was obtained from Warri, Delta State, Nigeria. The equipment used includes; a power saw for cutting the low carbon steel into required sizes. A weighing balance was used to determine the weight loss. A muffle heat treatment furnace was used for the heat treatment.

2.2. Methods

The low carbon steel was properly machined with a lathe machine to remove all trace of corrosion. The chemical composition of the low carbon steel in percentage was determined in the laboratory. The samples were divided into four with dimension of diameter 18 mm and length 45 mm as:

Sample A = As received
Sample B = Water tempered
Sample C = Oil tempered
Sample D = Brine tempered

A portion of the collected sea water was taken to laboratory where the composition was thoroughly analysed. The various samples of low carbon steel used in this research work were weighed before and after exposure to seawater. Equation (1) was used to determine the weight loss.

$$W_L = W_i - W_f \tag{1}$$

Where: W_L = Weight loss; W_I = Initial weight; W_F = Final weight

Equation (2) was used to determine corrosion rate of the low carbon steel (Revie and Uhlig, 2008).

$$C_R = \frac{87.6W_L}{DAT} \tag{2}$$

Where:

C_R = Corrosion Rate (mm/y); W_L = Weight loss (mg); D = Density of Low Carbon Steel = 7.85g/cm^3; A = Area of low carbon steel samples used (cm^2); T = Exposure time to sea water (days)

The area of low carbon steel is given by Equation (3).

$$A = \pi r^2 h \tag{3}$$

The prepared samples of low carbon steel as received and tempering at 700ºC (i.e., heat treatment) were used to set up the corrosion experiment using seawater. Four different 1000 ml beakers were filled with the seawater. The samples (A-D) were weighed and recorded as initial weight. The samples were exposed to seawater and weight loss monitored and recorded after ten (10) consecutive days and this ran for a period of one hundred (100) day.

3. RESULTS AND DISCUSSION

Table 1 shows the chemical composition of low carbon steel sample (wt. %). It was observed that apart from carbon with percentage weight percent of 0.1912, other alloying element constituents such as silicon (0.6702%), chromium (0.0802%), Molybdenum (0.0053%), etc., were present. The percentage weight carbon obtained falls within the range of low carbon steel as reported by Onyekpe, (2002).

Table 2 shows the results of chemical composition of seawater used in this research work. As reported by Osman (2007), seawater contains complex ionic aqueous solution. The present of chloride, sulphate, nitrate, phospahate, justified Osman, (2007) claim. Besides, the presence of these salts formed from chemical reaction of acid and base will enhance corrosion rate of low carbon steel. Also present in the chemical composition of used seawater in this research work includes; pH (7.43), salinity, mg/l (2988), conductivity, µs/cm (894), TDS, mg/l (447), and total alkalinity mg/l (1.66). As reported by Hoseinpoor et al. (2014), salinity, and pH are parameters that have a strong influence on corrosion of metals. Above and beyond, corrosion rate is faster in seawater, and this is due to the presence of numerous minerals in sea water.

Table 1: Chemical composition of the low carbon steel sample

Element Present	Percentage Weight (%)
Carbon (C)	0.1912
Silicon (%)	0.1503
Manganese (Mn)	0.6702
Phosphorous (P)	0.0271
Sulphur (S)	0.0280
Titanium (Ti)	0.0000
Copper (Cu)	0.3414
Nickel (Ni)	0.0504
Chromium (Cr)	0.0802
Molybdenum (Mo)	0.0053
Vanadium (V)	0.0003
Aluminium (Al)	0.0241
Tungsten (W)	0.0062
Niobium (Nb)	0.0000
Nitrogen (N)	0.0061

Table 2: Chemical composition of seawater used

Parameters	Value
pH	7.43
Conductivity, µs/cm	894
TDS, mg/l	447
Total alkalinity, mg/l	1.66
Chloride, mg/l	2677.5
Sulphate, mg/l	293
Nitrate, mg/l	< 0.01
Phosphate, mg/l	0.07
Salinity, mg/l	2988

Figures 1 to 4 show the plot of corrosion rate and weight loss against exposure time for the period of one hundred days. Figure 1 and 2 shows the corrosion rate of Samples A to D. It was observed that the corrosion rate was comparatively high in the first ten days, and then decreased gradually with subsequent increase in exposure time. However, corrosion rate was slow and stable starting from day sixty to day one hundred. The reason for this may

have been as a result of the stagnant corrosion medium (seawater) used in this research work (Oyejide et al., 2017). Also, Oxygen is an important factor that enhances corrosion rate (Adedayo et al., 2010), the rate of intake of oxygen would have been reduced, thus the decrease in corrosion rate. The corrosion rate of steel material is affected by the concentration of oxygen in the seawater.

Furthermore, the corrosion rate of material is determined by other factors which include variation in marine fouling, contamination of the seawater near the shoreline, variation in seawater velocity and differences in the seawater temperature. The decreased in corrosion rate could also due to the formation of passive film that was formed on the low carbon steel surfaces. The formation of reddish brown colour established an inhibition property on the low carbon steel and its environment interface which partially passivate the alloy (Callister, 2007; Ikpeseni, 2012). However, in a real ocean scenario, continuous removal of the passive film under the influence of flowing water could increase the corrosion rate of the low carbon steel.

Moreover, it was observed that corrosion rate was faster in water‐tempered low carbon steel (i.e., Sample B), this was closely followed by oil‐tempered low carbon steel (i.e., Sample C), as received low carbon steel (i.e., Sample A), and brine‐tempered low carbon steel (i.e., Sample D). The reason for low corrosion rate of brine‐tempered low carbon steel was as a result of improved properties due the transformation of the retained austenite in the material which resulted to optimum combination of mechanical properties. Nevertheless, water‐tempered sample had the highest cumulative corrosion rate (Figure 2). Thus, brine‐tempered low carbon steel has better performance among the three samples tested.

There was a gradual weight loss for the four samples used in this research work. Weight loss increased gradually from day one to day forty which was the peak (Figure 3), and there was a gradual drop in weight loss from day forty to sixty. From day sixty to the last day of exposure (i.e., day one hundred), weight losses across the four samples were uniform. The brine‐tempered low carbon steel sample was observed to have least value of cumulative weight loss, thus more resistance to corrosion (Figure 4). In the order of increasing weight loss water‐tempered low carbon steel (i.e., Sample B) was the highest, followed by oil‐tempered low carbon steel (Sample C). This was closely followed by as received low carbon steel (i.e., Sample A), and finally brine‐tempered low carbon steel (i.e., Sample D) coming least.
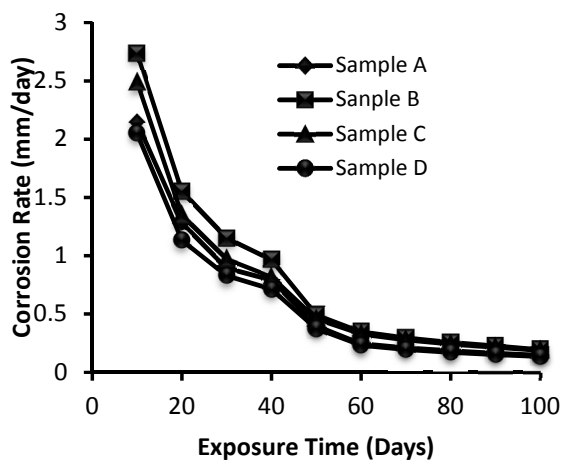

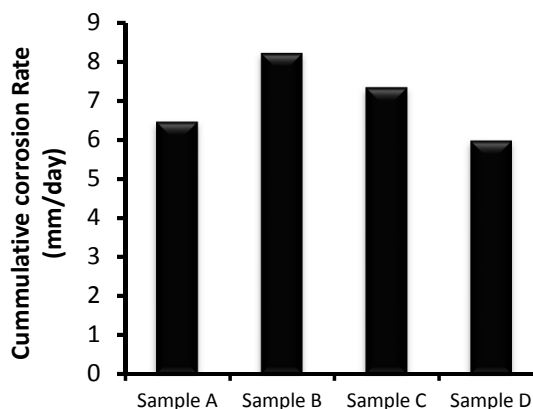Figure 1: Plot of corrosion rate against exposure time
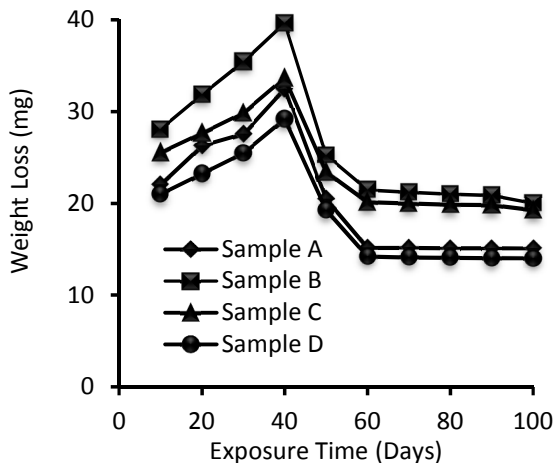
Figure 2: Plot of cumulative corrosion rate

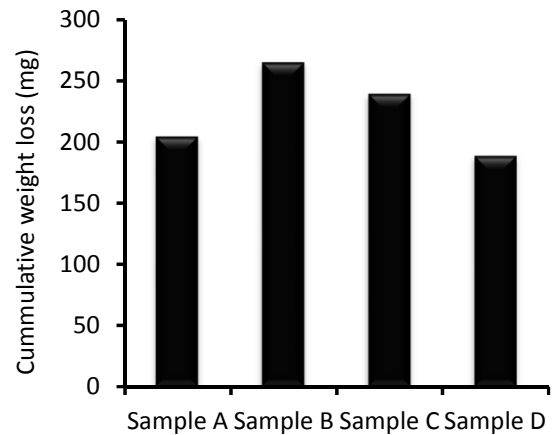Figure 3: Plot of weight loss against exposure time

Figure 4: Plot of cumulative weight loss

Figure 5 shows the picture of samples of low carbon steel after exposure to seawater for a period of one hundred days.

Figure 5: Samples of low carbon steel after exposure to seawater

4. CONCLUSION

In this research work, the effect of heat treatment (i.e., tempering) on the corrosion of low carbon steel was evaluated. From the results obtained, the following conclusions were made:

i.   The corrosion behaviour of water-tempered low carbon steel (i.e., Sample B), oil-tempered low carbon steel (i.e., Sample C), brine-tempered low carbon steel (i.e., Sample D), and as received low carbon steel (i.e., Sample A) were comparatively alike throughout the duration of exposure of the specimen to seawater for a period of one hundred days.

ii. Corrosion rate was comparatively high in the first ten days but as the exposure time continues, a drop in corrosion rate was observed.

iii. The brine-tempered low carbon steel shows better corrosion resistances in comparison to other samples tested.

iv. Least weight loss was experienced with brine-tempered low carbon steel, while water-tempered low carbon steel experienced the highest weight loss.

v.   Therefore, if tempering must be carried out on low carbon steel, brine-tempering is recommended.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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