Corrosion Effects on Low Carbon Steel Marine Heat Exchanger

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ABSTRACT

While heat exchangers are of extreme relevance in industrial applications, the effect of corrosion encountered have rarely been studied. Corrosion is a naturally occurring phenomenon that cannot be totally eradicated. However, its effect can be studied as well as controlled to a degree. In the maritime industry, machineries and other structures which comes in contact with saltwater constitute a major concern as to its corrosive response to its operating environment. This paper therefore reviews the corrosive behaviour of low carbon steel by an examination of its structural integrity and performance when exposed to different corrosive environments placed at room temperature and varying concentrations. From the conducted experiment, he observed loss in weight proved that low carbon steel corrodes with greater weight loss in all the test media with a rate of 0.0450mm/yr. - 0.0660mm/yr. Furthermore, mechanical test to determine hardness and tensile strength revealed the tensile strength and hardness.

Keywords:Corrosion rate, Heat exchanger, Hardness test, Surface analysis.

1. INTRODUCTION

Steel is a common material which is usually employed in industrial equipment and metallic structures because of its economic benefits as well as its desirable mechanical properties such as strength, hardness, corrosion resistance etc especially when they are exposed to certain atmospheric conditions as brutal as that of the maritime environment[1]. Although several studies sought to address the issues of coastal corrosion on structures, details are still shortcoming.Recent events such as critical incidents in structures designed from steel especially those used in marine applications have all been traced back to corrosion as its origin [2]. This destructive phenomenon is influenced by reaction of metallic material with environmental elements as this consequently results in the degradation of structures coupled with the reduction in mechanical properties like the ductile strength, toughness, hardness [3][4] as well as eventual failure in extreme situations[5], [6]. Furthermore, corrosion has a huge economic significance in industries as seen in the World Corrosion Organization (WCO) estimations which showed that theimpact of corrosion on a global scale cost a whopping approximate of $US2.4 trillion[7]. Similarly, the environmental impact of corrosion could be devastatingly high in terms of incidents and failures resulting from this elusive phenomenon[1].

Corrosion is an ancient adverse occurrence which destroys the diminished the structural integrity of materials in practical applications as well ascontributing to the obstructions of technological progress and material quality[8]. It majorly contributes to the loss of useful properties of metals such as plasticity, ductility, electrical conductivity and optical reflectivity by metal due to attack of the environment [9].Corrosion is also related with pollution, and this is evident because many contaminants produced by burning fossil fuels, increases the rate of corrosion while some products of corrosion like oxides, salts, etc tends to contaminatebodies of water[10]which weaken the quality of the environment as well as disturb the durability of marine structures[11][12]. This is further intensified when pollutants from industrial, municipal processes find their way into water bodies thereby damaging structures. The characteristics of effluents (chemical, biological and thermal)releases an undesirable effect on the entire marine environment as it affects corrosion processesand mechanisms.

In heat exchangers, the presence of chlorine and fluorine compounds in surrounding regions, increased level of humidity and the presence of condensed fluid could potentially lead to corrosion in the long run [13].

Various researchers have gained keen interests in studies related to the corrosion kinetics which have been linked to the increasing problem of structural breakdown due to corrosion[14].Corrosion kinetics can be studied in various ways but mostly carried out using the weight loss method [12]. Tan [15], also investigated the impact of temperature and salt solutions as it relates to the rate of corrosion of mild steel and aluminium products using the gravimetric method. His analysis showed that therate at which corrosion propagates was proportional tointensification in temperature and salinity. Some of the main factors influencing marine corrosion includes salinity which is the concentration of salt in the water. This property affects the material conductivity and amount of oxygen dissolved in the water. Additionally, pH level of sea water inhibits corrosion to a degree. Other physical factors include flow rate, temperature etc.Aminu et al. [16]research was based on the analysis of the corrosion kinetics of mild steel in several biodiesel types. His analysis was based on the weight loss measurements evaluated some days to establish the corrosion rate which showed that thepeakfluid was the Premium Motor Spirit (PMS) from the petroleum refined products.Similarly, Ismail et al [17]studied the corrosive behaviour of metals in varying strength of acidic solutionsfor aluminium, mild steel and copper

The nearness of carbon dioxide (CO_2), hydrogen sulphide (H_2S) in marine environments can cause serious corrosion issues in metals plates of heat exchangers. Interior corrosion is affected by temperature, CO_2 and H_2S content, fluid chemistry, stream velocity, and surface state of the metal (usually steel). A little change in one of these parameters can change the consumption rate significantly, because of changes in the properties of the thin layer of corrosion items that aggregates on the steel surface[18]. Confined corrosion can be prevented by the action of adsorptive inhibitors which avert the adsorption of the bellicoseredicals(anions)on the metal plates [19].

2. MATERIALS ANDEXPERIMENTAL PROCEDURES

The estimation of corrosion rateinvolved the implementation of gravimetric analysis. The specimen (Low Carbon Steel) was weighed before being exposed to the solvent(seawater)whose salinity was estimated as 4.23mg/litre while that of freshwater was 0.24mg/litre, for a period of 504 hours.

Samples of the specimen exposed was prepared by sectioning to obtain a pre-set dimension. After which, the sample was grounded, polished and degreased using a solution of detergent before being wiped clean and placed in solutions of seawater and freshwater with conscious effort made to ensure that a large surface area of the as exposed to the corrodents.

The surfaces of the cut specimen where filed, brushed and made smooth by means of an emery cloth, cleaned with water and acetone before drying. The samples were further cut into rectangular shapes of predetermined area.

In the experimental setup, the samples were gently suspended in beakers full of corrosion media of varying solvents sea water and fresh water of 0.1M, 0.2M and 0.000004M by the aid of elastic bands, while the beakers were properly labelled and isolated to give room for uninterrupted and uniform conditions for accuracy of results. Finally, the samples observation was for a total period of 504 hours at room temperature while periodic weight measurement to estimate the weight difference before and after exposure was determined by utilising Vernier calliper and ultra-sensitive weighing machine.

Figure 1: Experimental setup of samples and solvent

Given that corrosion rate depends on weight loss, it is imperative that an accurate weight of the sample is measured to derive suitableoutcome. This was achieved through the use of an ultra-sensitive scaleas shown in figure 2. The obtained samples chemical configuration was determined using Positive Material Identification after which the grain boundaries of the metal was determine by inverted metallurgical microscope before and after exposure to the corrosion media.

Figure 2: Digitalweighing balance

Original weight of the coupon obtained from the weigh balance is as shown below,

Table 1: Samples original weight in grams

Samples No.	1	2	3	4
Weight	12.40	15.61	14.79	13.40

Table 2: Low carbon steel composition wt.%

Alloying element	Composition, wt. (%)										
	Ti	V	Cr	Mn	Fe	Ni	Cu	Nb	Mo	W	Pb
Low Carbon Steel	0.06	0.03	0.25	0.17	98.08	0.03	0.23	0.00	0.01	0.02	0.00
	0.012	0.05	0.008	0.01	0.024	0.008	0.01	0.001	0.002	0.008	0.001

During the experimental procedure, the samples of metal in the solution was periodically extracted after every one hundred and sixty-eight hours for the total duration of the procedure. This was for physical examination as well as for cleaning of corroded particles. The cleaning process involvedscrubbing of the sample's surfaces using soft emery cloth and brittle brush (wire brush) to remove the corrosion product. Finally, the tensile and hardness test was carried out.

2.1. Surface Preparation

In preparing the sample surface for testing and scanning, the samples were initially grinded in order to achieve a smooth and uniform surface. This was achieved using varying sizes of abrasive papers ranging from the coarsest grits P220, P320, to the finest gritsP800.

Subsequently, the samples were polished to achieve a mirror like reflective surface just before etching treatment of samples by immersion in a solution containing 2% nitride for about 30 seconds and rinsed with solution containing 98% alcohol before drying. After these procedures, the samples were then ready for scanning.

2.2. Hardness and Tensile Test

The values of both hardness and tensile strength for both specimens was recordedprior to and after immersion. Thisallowed for easy comparison of the corrosive effect. The test was performed using the MH 320 Mitechtesting equipment.

Before testing for hardness and tensile strength, the sample surface was measures, smoothened and polished then, each measured area of samples was tested thriceafter which the average values of the obtained results were calculated.

3. RESULTS AND DISCUSSIONS
3.1 Corrosion Rate Data:

Result obtained from the experiment indicated significant reduction in the thickness of the samples. The corrosion resistance andrecorded weight losses was analysed and used to estimate the rate of corrosion as an index of penetration per year (mm/yr) which is shown below;

$$\text{Corrosion rate (C.R)} = \frac{Weight\ Loss\ (W) \times K}{D\ (\frac{g}{mm^3}) \times A\ (mm^2) \times T\ (yr)} \tag{1}$$

Where, K =rate constant (87.6), ΔW =weight loss in grams, $A =$ surface area of metal (mm^2), $T =$ time of exposure in years, and

$$D = \text{density of metal in } \frac{mass\ (g)}{volume\ (mm^3)} \tag{2}$$

$$\text{Corrosion rate} = \frac{87.6 \times \Delta W}{D \times A \times T} = \frac{g}{\frac{g}{mm^3} \times mm^2 \times yr} = mm/yr \tag{3}$$

The density of the samples was obtained by estimating the dimensions of the rectangular sampleusing the equation 4 below

$$\text{Density} = \frac{Mass\ (g)}{Volume\ (mm^3)} = \frac{Mass\ (g)}{L \times W \times H} = 7.822\ (g/mm^3) \tag{4}$$

Where, $L =$ length, $W =$ width and $H =$height of the specimen

The original weights and the loss in weights was used to estimate the corrosion rates data for the sample of low carbon steel in fresh water and sea water at different concentrations and at room temperature. The table below shows the data obtained from the experiment in their various environmental media.

Furthermore, the results from the various tests carried out on the specimens have been analysed and presented below

Table 3: Weight loss data for both specimens

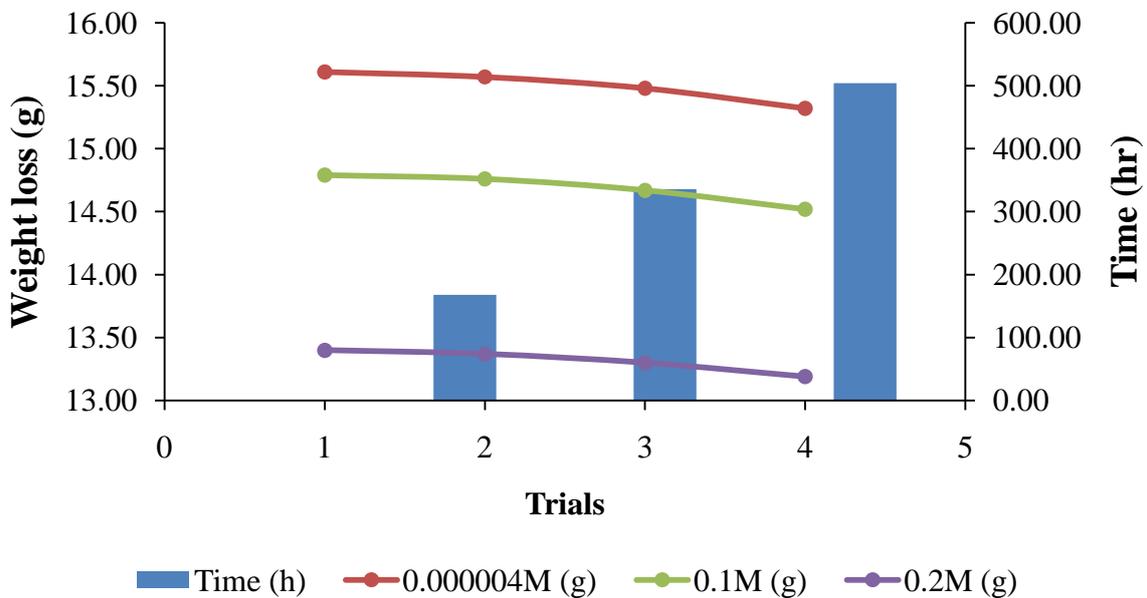|	Concentration		
	Fresh water	Sea water	
Time (h)	0.000004M (g)	0.1M (g)	0.2M (g)
0.00	15.61	14.79	13.40
168.00	15.57	14.76	13.37
336.00	15.48	14.67	13.30
504.00	15.32	14.52	13.19
Time (h)	0.000004M (mm/yr.)	0.1M (mm/yr.)	0.2M (mm/yr.)
168.00	0.0493	0.0369	0.0369
336.00	0.0555	0.0555	0.0431
504.00	0.0656	0.0617	0.0452

Figure 3: Sample weight loss in freshwater and seawater with respect to time

The graph shown above clearly indicates a proportional increase in weight loss of the sample with increasing time spent in the solution. The impact of submersion time and the weight reduction in fresh water and ocean water at room temperature and various solution concentration have been considered. The variety in corrosion rate with consideration of time for thesamples at room temperature is shown in the figure 4below:
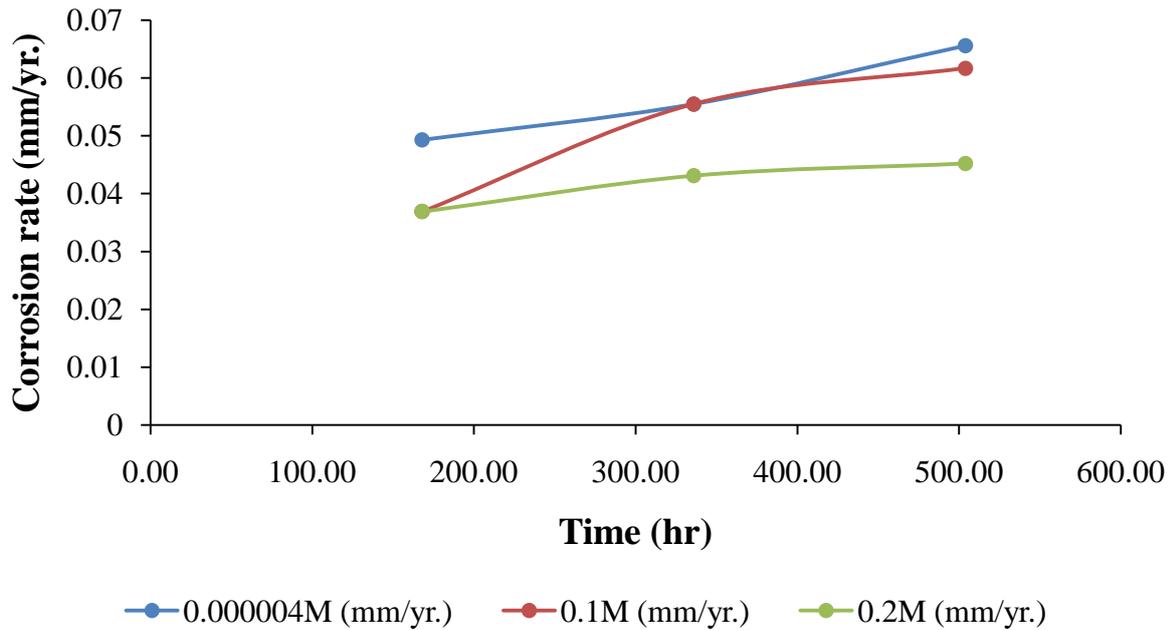
Figure 4: Corrosion rate vs. time in various solutions

The obtained result of the experiment of samples in different conditions, it is clear that the corrosion rate of the samplesis an indication of low carbon steel performance with respect to corrosion under different operating conditions. A thorough examination showed thatthe cast iron samples corrodes faster with increasing solution concentration with more weight reduction. Additionally, after three hundred hours of samples in the solution, the effect of salinity begins to have effect on the corrosion rate of the samples.

Therefore, the continuous increment in weight reductionof the cast samplefor the various concentrations individually affirmed the association of material exposure time and weight reduction.

3.2 Hardness and Tensile Data:

Hardness and tensile tests were performed on the samples after immersion. The results showed an increase in hardness and tensile strength of the samples after completion of the test. Table 4 below showed an average increase in hardness and tensile strength of the sample.

Table 4:Hardness and tensile strength data

No.	Low carbon steel	Brinell hardness			Tensile strength (MPa)		
		0.000004M	0.1M	0.2M	0.000004M	0.1M	0.2M
1	Prior test	118	129	95	433	418	391
2	After test	143	116	96	451	475	395

4. CONCLUSION

This study was conducted with the aim of analysing corrosion effect on marine heat exchanger made of low carbon steel. This was accomplished by placingsamples in a mixture of different concentrations of both fresh water and sea water which are the practical medias to be encountered in operating conditions. The setup was observed for 504hrs while the effects of corrosion was investigated using gravimetric analysiswhich was used to determine the corrosion rate of the samples in different solutions. The result showed that the corrosion rate lies between 0.0452mm/yr., - 0.0656mm/yr., for all concentrations.

Further analysis for hardness and tensile strength of the samples prior to the test as well as after the test showed an upward change. This therefore suggests that careful consideration should be employed in selecting of suitable material for long term corrosion control although coating the samples with anti-corrosion resins could possibly reduce the rate of corrosion.

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