Original Research Article

COMPARATIVE ANALYSIS OF EFFECTS OF CORROSION IN MARINE HEAT EXCHANGER PERFORMANCE IN TWO MEDIA USING CAST STEEL C-1020 AND COPPER C-642

ABSRTACT

This research was undertaken to comparatively determine the effects of corrosion in cast steel C-1020 and copper C-642 used as selected materials in marine heat exchanger design. Cast steel C-1020 immersed in freshwater at 0.000004M after twenty one (21) days (0.0567yr) gave corrosion rise from 0.0493mmpy, 0.0555mmpy to 0.0656mmpy while copper C-642 at 0.000004M in freshwater experienced no corrosion rise for the 1st and 2nd week, although a corrosion increase of 0.0006mmpy was revealed at the third week of immersion. Also results at 0.10M of cast steel C-1020 gave corrosion increase from 0.0365mmpy to 0.0617mmpy while copper C-642 gave corrosion rise from 0.0351mmpy to 0.0409mmpy. Results at 0.20M of seawater gave corrosion rise from 0.0369mmpy to 0.0452mmpy and 0.0351mmpy to 0.0363mmpy for cast steel C-1020 and copper C-642. The overall results confirmed higher corrosion rise in cast steel C-1020 compared to copper C-642 sample. The comparative results of both selected materials by weight loss technique and surface analysis by inverted metallurgical microscope at the various concentration of the media revealed the effects of corrosion, as higher corrosion rate was evident in cast steel metal, thus, confirming copper C-642 to be more resistive to corrosion attack than cast steel C-1020.

Keywords: Cast Steel, Corrosion Rate, Sea Water, Fresh Water, Heat Exchanger.

1. INTRODUCTION

In Nigeria, corrosion is seen as a normal process needing limited attention (Akinyemi, Nwaokocha and Adesanya [1]. According to ASM [2], corrosion affects the useful lives of our possession, result in damage of buildings and collapse of electric towers. The methods to control corrosion and its effects present a huge challenge to engineers and despites best effort, the annual costs of corrosion damage and maintenance run into many millions of Great British Pounds (GBP) is estimated at about 4% of the GNP for an industrial country (Gerhardus et al, 2001[3]. According to Peter [4], some accidents in industries, pipeline explosion and collapse of bridges are evidence of corrosion effects. Recent study by Beech [5] on marine microorganism suggested that fungi produced organic acid which contribute to metal deterioration. According to Hamilton [6], metal oxidizing bacteria helps to promote decay of metals. Many researchers Kehr and Roberge [7] have studied the costly terms of production losses in pipelines and the mechanical damage from accelerated corrosion.

In the maritime industry, Carlos et al [8] posited that ship hull failures and oil spill disasters are caused by excessive corrosion. Singh [9], suggested that the consequence of heat exchanger failure are solely due to the site of these industries, structures and metals which are mostly at marine environments and have their atmosphere polluted by corrosion pollutant gases. According to Ailor [10], such failures are known to occur due to chemical or electrochemical reaction with its corrosive environment. Fontana [11] defines corrosion as an electrochemical oxidation of metals in reaction with an oxidant such as oxygen. According to Trethway and Chamberlain [12], Corrosion is defined as the deterioration or decay of metals by direct attack or by reaction with its environment. In the early use of heat exchanger equipment, Shah [13] defines heat exchanger as a device that is used for transfer of thermal energy between two or more fluids at differing temperatures and in thermal contact. According to Ikechukwu and Pauline [14], corrosion takes place in the presence of an electrolyte like water, salt water, or soil. Rajendran et al.[15] stated that the danger in corrosion is that it degrades the metallic properties of the affected metals. The morphology of the corrosion damage can be classified based on the surrounding environment or material. Oliver et al. [16] classify corrosion types as general, pitting, crevice, intergranular, environmental induced fracture, de-alloying, galvanic, and erosion corrosion. Noor et al [17] posited that heat exchangers serviceability depends on the conditions following the initial corrosive attack, stating that protective films can be formed to reduce the corrosion rate to some acceptable level. According to Anyawu and Agberegba [18], other corrosion accelerating factors include; pH values, the amount of oxygen in the fluid, the chemical make-up of the fluid, the velocity of the fluid in the pipe and high temperature which increase virtually all chemical reactions. According to Lowenta [19], corrosion is a natural spectacle and to control its effect, certain tests are carried out by placing the metal in the environment to which its utility is needed to ensure careful study of the metal for a specified time. The main focus of this work is to determine the effects of corrosion on the performance of marine heat exchanger performance at room temperature, with selected materials of cast steel C-1020 and copper C-642, in fresh water and seawater as environmental media.

The consequences of corrosion varies and the effects on the safe, reliable and efficient operation of equipment are often more serious than simple mass loss of a metal [16]. According to Uhlig [20], the costs attributed to corrosion damages of all kinds have been estimated to be of the order of 3 to 5% of industrialized countries' gross national product (GNP).

According to Vander [21], every year 20% of steel produced is used to replace metal lost to corrosion. According to Peter [22], some accidents in industries, pipeline explosion and collapse of bridges are evidence of corrosion effects. According to Akinyemi, Nwaokocha and Adesanya [23] the estimated cost of corrosion in the electricity power industry was $17 billion in 1998, representing about 7.9% of the cost of electricity in the United States. Dennis, et al [24] estimated that the sum of $170 billion per year is spent on corrosion in all the United States industries. According to Oliver et al [16] the petroleum industry spends upward of $2 million per day due to the corrosion of underground installations, e.g., tanks, piping, and other structures. The significance of this study is to determine and provide a comparative analysis on the rate at which cast steel and copper corrodes in two different marine environments and as a result re-awakening the readiness of the material engineering to control this rate of corrosion thereby increasing the service life of cast steel and copper when used in any of the environments.

2. Materials and Methods

According to Oliver et al [16], the selection of materials to be used in design dictates a basic understanding of the behavior of materials and the principles that govern such behavior. If proper design of suitable materials of construction is incorporated, the equipment should deteriorate at a uniform and anticipated gradual rate, which will allow scheduled maintenance or replacement at regular intervals. Further, the approach of preventive or predictive maintenance is certainly intended to minimize the possibility of unscheduled production shutdowns because of corrosion failures, with their possible financial losses, hazard to personnel and equipment, and resultant environmental pollution.

The study makes use of both primary and secondary sources of information to analyze the issues within the research study. Weight loss technique was used to determine the metal loss in weight and the corrosion rate tabulated and the surface morphology of the metal (cast steel C-1020 and copper C-642) was analyzed respectively by inverted metallurgical microscope to access the grain boundaries of the coupon with the metal hardness taken into account; before and after immersion.

2.1 Corrosion Testing Methods

Metals and alloys do not respond alike to all the influences of the many factors that are involved in corrosion. According to Oliver et al, (2008), it is impractical to establish any universal standard laboratory procedures for corrosion testing except for inspection tests. Corrosion test methods are namely; weight loss analysis, Electrical resistance, linear polarization, Electrochemical Impedance Spectroscopy (EIS) and AC Impedance, X-ray diffraction (XRD), Scanning electron microscope (SEM), Inverted metallurgical microscope (IMM) and transmission electron microscope (TEM). Thus, this study utilized weight loss analysis as experimental method, Positive material identification to obtain the chemical composition of the specimens and inverted metallurgical microscope to show the grain boundaries of the specimen before and after immersion in the corrosion media.

2.2 Positive material identification (PMI)

Positive material identification is a well-established analytical non-destructive material testing and material identification technique, which guarantees material's elemental composition for safety compliance and quality control (Smith Flow Control Ltd, 2010). Method of positive material identification is by x-ray fluorescence and spark emission spectrography. Thus, x-ray fluorescence method of positive material identification was used in this study to determine the chemical compositions of the corroded metal before carrying out weight loss analysis. The uses of Positive material Identification in industries is as follows:

i. Component validation
ii. Installation qualification (IQ)
iii. Plant inspection
iv. In service testing
v. Aerospace castings
vi. In stock materials

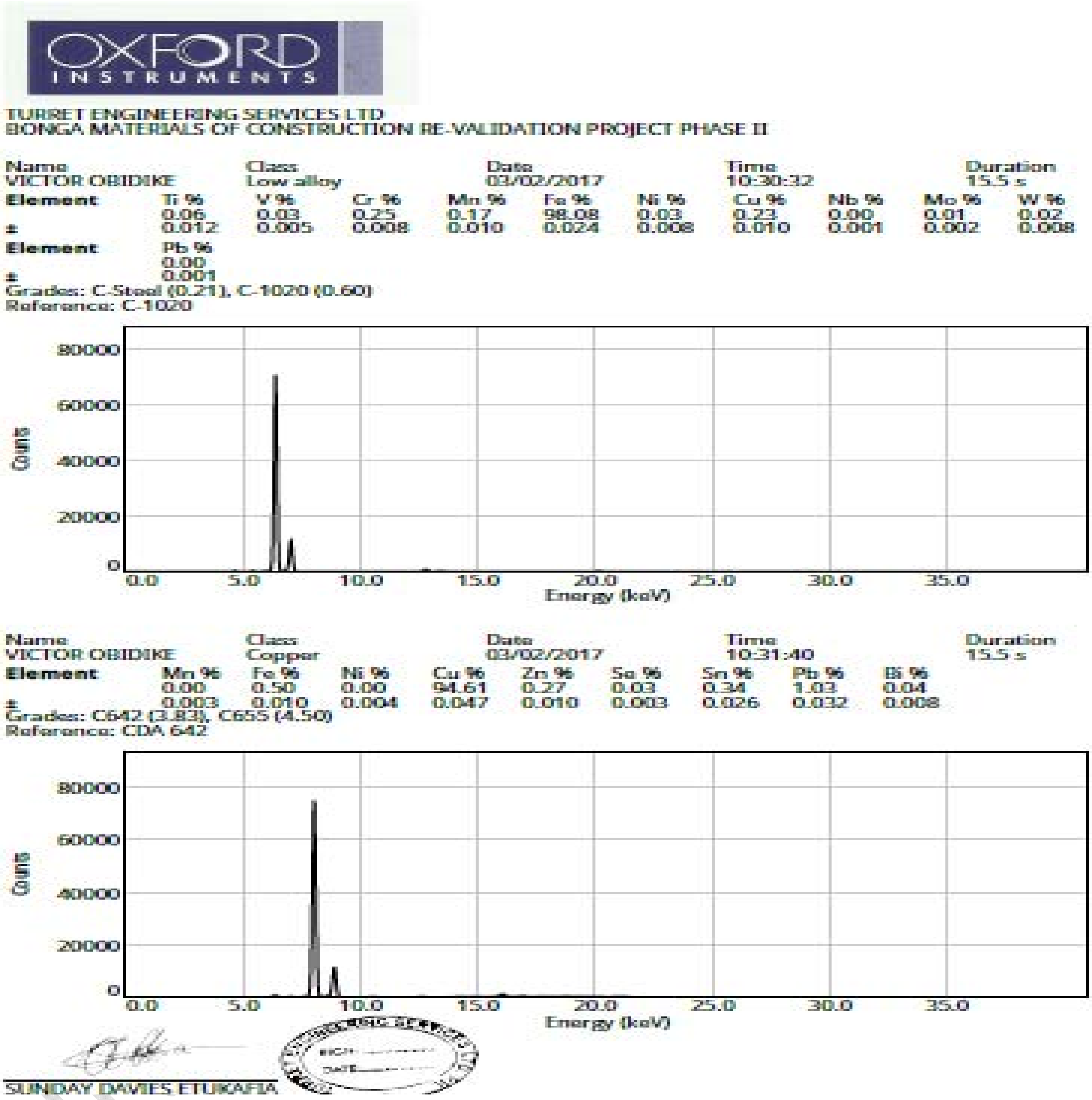
2.3 Sample preparation

The location to be tested is cleaned to remove dirt, rust or adhering grease.

2.3.1. Analysis

The X-MET7000 series has factory settings which are applicable to many measurements. X-met is however tested for by measuring the sample specimen.

Chemical composition of the selected materials (cast steel and copper) obtained from Turret Engineering services Ltd is shown in fig. a and table a respectively.



TURRET ENGINEERING SERVICES LTD
BONGA MATERIALS OF CONSTRUCTION RE-VALIDATION PROJECT PHASE II

Name	Class	Date	Time	Duration
VICTOR OBIDIKE	Low alloy	03/02/2017	10:30:32	15.5 s

Element	Ti %	V %	Cr %	Mn %	Fe %	Ni %	Cu %	Nb %	Mo %	W %
	0.06	0.03	0.25	0.17	98.08	0.03	0.23	0.00	0.01	0.02
±	0.012	0.005	0.008	0.010	0.024	0.008	0.010	0.001	0.002	0.008

Element	Pb %
	0.00
±	0.001

Grades: C-Steel (0.21), C-1020 (0.60)
Reference: C-1020

Name	Class	Date	Time	Duration
VICTOR OBIDIKE	Copper	03/02/2017	10:31:40	15.5 s

Element	Mn %	Fe %	Ni %	Cu %	Zn %	Sb %	Sn %	Pb %	Bi %
	0.00	0.50	0.00	94.61	0.27	0.03	0.34	1.03	0.04
±	0.003	0.010	0.004	0.047	0.010	0.003	0.026	0.032	0.008

Grades: C642 (3.83), C655 (4.50)
Reference: CDA 642

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Fig.a: Chemical composition of cast steel and copper sample.

Table a: Chemical composition of cast steel and copper sample

(Source: Turret Engineering Services Limited)

Material	**Composition, wt. (%)**										
	Ti	**V**	**Cr**	**Mn**	**Fe**	**Ni**	**Cu**	**Nb**	**Mo**	**W**	**Pb**
Cast steel **C-1020**	**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**	**0.010**	**0.024**	**0.008**	**0.010**	**0.001**	**0.002**	**0.008**	**0.001**
Copper **C-642**	**Mn**	**Fe**	**Ni**	**Cu**	**Zn**	**Se**	**Sn**	**Pb**	**Bi**		
	0.00	**0.50**	**0.004**	**94.61**	**0.27**	**0.03**	**0.34**	**1.03**	**0.04**		
	0.003	0.010	0.004	0.047	0.010	0.003	0.026	0.032	0.008		

2.4 Weight Loss Analysis

The simplest, and longest established, method of estimating corrosion losses in plant and equipment is weight loss analysis. A weighed sample (coupon) of the metal or alloy under consideration is introduced into the process, and later removed after a reasonable time interval. The coupon is cleaned of all corrosion products and is re-weighed. The weight loss is converted to a corrosion rate (CR) or a metal loss (ML).

$$C.R = \frac{87.6 \times \Delta W\ (grams)}{Density(\frac{g}{m^3})\ \times\ Area\ (mm^2)\ \ \times Time\ \ (yrs)} \qquad (1)$$

2.5 Surface Analysis

Some stages of corrosion are not controlled by the rate of surface, or interface reactions, surface reactions must occur in corrosion and surface analytical methods are the principal tools that exist to study these processes (Thomas, 1981).

2.5.1 Inverted metallurgical microscope.

Inverted metallurgical microscope is a surface analysis tool which allows for inspection of grain size and the state of the metals Prepared metallographic samples of cast steel and copper were inspected using dedicated microscope to assess the grain size and phase of metals.

2.5.2 Preparation for scanning

Before the specimens were inspected with the microscope, the following preparatory steps were taken to ensure the visibility of the microstructure:

- **Sampling:** This involves cutting of the metal specimens to sizes that will fit into the mold for mounting. The metal specimens were cut into smaller dimensions using a hacksaw.
- **Mounting:** The specimens were placed in a mold that has a punch, phenolic powder (Thermosetting material) is been poured into the mold and a heater placed round it. Pressure is applied on the content of the mold with a hydraulic press and the specimen is heated in a heater until the light indicator goes off. The material is ejected out from the heater to form a mounted sample.
- **Grinding:** This is done to ensure smooth finish and uniformity of the surface of the specimen to be scanned. Hence, 5 different abrasive papers were used ranging from P220, 320, 400, 600 and 800. The mounted surface to be scanned was thoroughly scrubbed on the abrasive paper starting from the P800 till the P220 to ensure the surface smoothness as shown in figure b.

Fig. b: Emery cloths used for grinding

- **Polishing:** Using a polishing machine, velvet clothe and a polishing reagents (diamond suspension and lubrication), the sample is inverted while the polishing wheel moves round until a mirror like surface is achieved.
- **Etching:** Different etching reagents were used on the different specimens. The steel is immersed in a solution containing 2% nitride for at least 30seconds and then rinsed with another solution containing 98% alcohol while the copper is immersed in an aqueous solution containing 98% ammonia mixed with few drops of hydrogen peroxide and allowed for at least 5minutes and then rinsed with alcohol. Both specimens are dried with a specimen dryer.
- **Scanning:** The prepared sample is then placed under the microscope for scanning.

2.5.3 Metal Hardness

Macro hardness testing was conducted on both selected materials to determine the hardness of the metal. The equipment used for this test is MH 320.

3. RESULTS AND DISCUSSION

3.1 RESULTS

The corrosion rate of cast steel was calculated at 0.000004M of freshwater and 0.10M and 0.20M of seawater.

3.1.1 Cast steel in 0.000004m of freshwater for 21 days of exposure, at room temperature.

i. Cast steel in 0.000004M in freshwater solution for the first seven days of exposure at room temperature.

ΔW = original weight – change in weight = 14.79g – 14.75g = 0.04g

Area of cast steel = 473mm^2

Density of cast steel = 7.822 $\frac{g}{mm^3}$

T = week = $\frac{7 \times 24}{365 \times 24}$ = $\frac{168}{8760}$ = 0.0192yr

Corrosion rate = $\frac{87.6 \times \Delta W}{D \frac{g}{mm^3} \times A\ mm^2 \times T\ yr}$ = $\frac{87.6 \times 0.04}{7.822 \times 473 \times 0.0192}$ = 0.0493mmpy

ii. Cast steel in 0.000004M of freshwater solution for the second week of exposure at room temperature.

$\Delta W = 14.79g - 14.70g$ = 0.09g

T = week = $\frac{14\ x\ 24}{365\ x\ 24}$ = $\frac{336}{8750}$ $=$ 0.0384yr.

Corrosion rate = $\frac{87.6 \times 0.09}{7.822 \times 473 \times 0.0386}$ = 0.0555mmpy

iii. Cast steel in 0.000004M of freshwater for the third week of exposure at room temperature.

ΔW = 14.79g – 14.63g = 0.16g

T= week = $\frac{21\ x\ 24}{365\ x\ 24}$ = 0.0576yr.

Corrosion rate = $\frac{87.6 \times 0.16}{7.822 \times 473 \times 0.0576}$ = 0.0658mmpy

3.1.2 Cast steel in 0.10m of seawater for 21 day of exposure at room temperature

i. Cast steel in 0.10M of seawater for the first seven days of exposure at room temperature.

ΔW = 13.40g – 13.37g = 0.03g

Area of cast steel = 473mm^2

Corrosion rate = $\frac{87.6 \times 0.03}{7.822 \times 473 \times 0.0192}$ = $\frac{2.628}{71.036}$ = 0.0369mmpy

ii. Cast steel in 0.10M of seawater for the second week of exposure at room temperature.

ΔW = 13.40g – 13.31g = 0.09g

Corrosion rate = $\frac{87.6 \times 0.09}{7.822 \times 473 \times 0.0384}$ = $\frac{7.884}{142.073}$ = 0.0555mmpy

iii. Cast steel in 0.10M of seawater solution for the third week of exposure at room temperature.

ΔW = 13.40g – 13.25g = 0.15g

Corrosion rate = $\frac{87.6 \times 0.15}{7.822 \times 473 \times 0.0576}$ = $\frac{13.14}{213.109}$ = 0.0617mmpy

3.1.3 Cast steel in 0.20m of seawater for 21 day of exposure at room temperature.

i. Cast steel in 0.20M of seawater solution for the first week of exposure at room temperature.

$$\Delta W = 15.61g - 15.58g = 0.03g$$

Corrosion rate = $\frac{87.6 \times 0.03}{7.822 \times 473 \times 0.0192}$ = $\frac{2.628}{71.036}$ = 0.0369mmpy

ii. Cast steel in 0.20M of seawater solution for the second week of exposure at room temperature.

ΔW = 15.61g – 15.54g = 0.07g

Corrosion rate = $\frac{87.6 \times 0.07}{7.822 \times 473 \times 0.0384}$ = $\frac{6.132}{142.073}$ = 0.0432mmpy

iii. Cast steel in 0.20M of seawater solution for the third week of exposure at room temperature.

$$\Delta W = 15.61g - 15.50g = 0.11g$$

Corrosion rate = $\frac{87.6 \times 0.11}{7.822 \times 473 \times 0.0576}$ = $\frac{9.636}{213.109}$ = 0.0452mmpy

3.2 Calculation of corrosion rate for copper at room temperature.

The corrosion rate of copper was calculated at 0.000004M of freshwater and 0.10M and 0.20M of seawater.

3.2.1 Copper in 0.000004m of freshwater for 21 days of exposure at room temperature.

i. Copper in 0.000004M of freshwater for the first week of exposure at room temperature.
ΔW = original weight – change in weight = 1.960g – 1.960g = 0.000g
Area of copper = $550mm^2$
Density of copper = 4.727 $\frac{g}{mm^3}$
T = week = $\frac{7\times 24}{365\times 24}$ = $\frac{168}{8760}$ = 0.0192yr
Corrosion rate = $\frac{87.6\times \Delta W}{D\frac{g}{mm^3}\times A\ mm^2\times T\ hr}$ = $\frac{87.6\times 0}{4.727\times 550\times 0.0192}$ = 0.0000mmpy.

ii. Copper in 0.000004M of freshwater for the second week of exposure at room temperature of 25°C.
ΔW = 1.960g – 1.960g = 0.000g
Corrosion rate = $\frac{87.6\times 0}{4.727\times 550\times 0.0384}$ = $\frac{0}{99.834}$ = 0.0000mmpy.

iii. Copper in 0.000004M of freshwater for the third week of exposure at room temperature
ΔW = 1.960g – 1.950g = 0.01g
Corrosion rate = $\frac{87.6\times 0.01}{4.727\times 550\times 0.0576}$ = $\frac{0.876}{149.751}$ = 0.0006mmpy.

3.2.2 Copper in 0.10m of seawater solution exposed for 21 days at room temperature.

i. Copper in 0.10M of seawater solution for the first week of exposure at room temperature.
ΔW = 1.920g – 1.900 = 0.02g
Corrosion rate = $\frac{87.6\times 0.02}{4.727\times 550\times 0.0192}$ = $\frac{1.752}{49.917}$ = 0.0351mmpy.

ii. Copper in 0.10M of seawater solution for the second week of exposure at room temperature.
ΔW = 1.920g – 1.88g = 0.04g
Corrosion rate = $\frac{87.6\times 0.04}{4.727\times 550\times 0.0384}$ = $\frac{3.504}{99.834}$ = 0.0351mmpy.

iii. Copper in 0.10M of seawater solution for the third week of exposure at room temperature.
ΔW = 1.920g – 1.850g = 0.07g
Corrosion rate = $\frac{87.6\times 0.07}{4.727\times 550\times 0.0576}$ = $\frac{6.132}{149.751}$ = 0.0409mmpy.

3.2.3 Copper in 0.20m of seawater exposed for 21 days at room temperature.

i. Copper in 0.20M of seawater solution for the first week of exposure at room temperature.
ΔW = 1.970g – 1.950g = 0.02g
Corrosion rate = $\frac{87.6\times 0.02}{4.727\times 550\times 0.0192}$ = $\frac{1.752}{49.917}$ = 0.0351mmpy.

ii. Copper in 0.20M of seawater solution for the second week of exposure at room temperature.
ΔW = 1.970g – 1.930g = 0.04g
Corrosion rate = $\frac{87.6\times 0.04}{4.727\times 550\times 0.0384}$ = $\frac{3.504}{99.834}$ = 0.0351mm/y.

iii. Copper in 0.20M of seawater solution for the third week of exposure at room temperature.
ΔW = 1.970g – 1.908g = 0.062g
Corrosion rate = $\frac{87.6\times 0.062}{4.727\times 550\times 0.0576}$ = $\frac{5.4312}{149.751}$ = 0.0363mm/y.

3.3 Presentation of results for weight loss and corrosion rate

The corrosion rate data for specimen 2, 3 and 4 of cast steel and copper in various solvents at room temperature is shown in table 1 to 5 and in figure 1 to 6.

Table 1: Experimental data for cast steel coupons weight at room temperature for 21 days of immersion

Concentration (M)	Original weight (g)	Week 1 (0.0192yr)	Week 2 weight (0.0384yr)	Week 3 weight (0.0576yr)
0.000004	14.79	14.75	14.70	14.63
0.10	13.40	13.37	13.31	13.25
0.20	15.61	15.58	15.54	15.51

Table 2: Experimental data for copper coupons weight obtained at room temperature for 21 days (0.0576yr) of immersion.

Concentration (M)	Original weight (g)	Week 1 weight (0.0192yr)	Week 2 weight (0.0384yr)	Week 3 weight (0.0576yr)
0.000004M	1.960	1.960	1.960	1.950
0.10M	1.920	1.900	1.880	1.850
0.20M	1.970	1.950	1.930	1.910

Table 3: Weight loss of cast steel coupons for 21 days (0.0576yr) of exposure

Concentration (M)	Weight loss (0.0192yr)	Weight loss (0.0384yr)	Weight loss (0.0576yr)
0.000004	0.04g	0.09g	0.16g
0.10	0.03g	0.09g	0.15g
0.20	0.03g	0.07g	0.11g

Table 4: Weight loss of copper coupons for 21 days of exposure

Concentration (M)	Weight loss (0.0192yr)	Weight loss (0.0384yr)	Weight loss (0.0576yr)
0.000004	0.00g	0.00g	0.01g
0.10	0.02g	0.04g	0.07g
0.20	0.02g	0.04g	0.06g

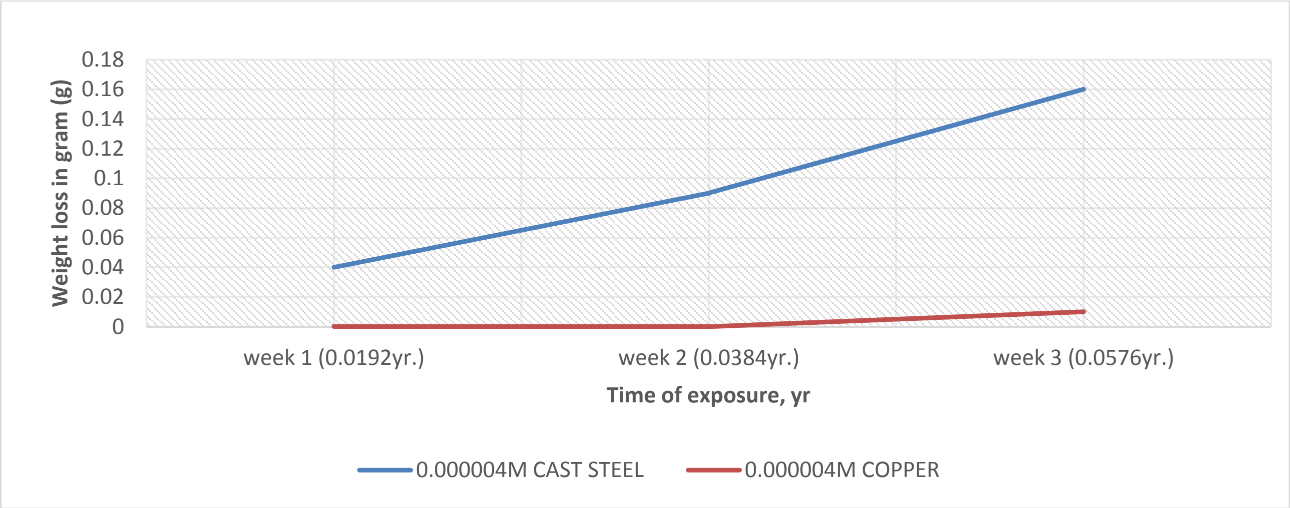

Fig. 1: Effect of time on the weight loss of cast steel and copper in 21 days (0.0576yr) of exposure to 0.000004M of freshwater solution.

The effect of immersion time and weight loss of both specimens was studied. A gradual increase in weight loss from 0.04g, 0.09g to 0.16g was observed in cast steel for exposure time of 0.0576yr, while copper showed no increased in weight loss for the first and second week but a slight increase in weight of 0.01g was determined at the third week (0.0576yr) of exposure.

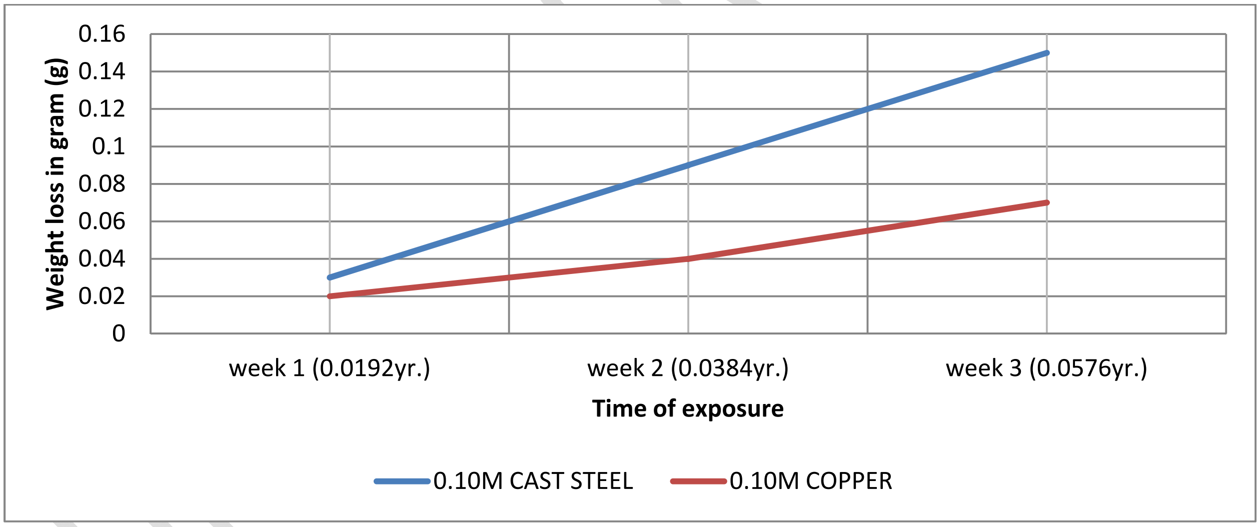

Fig. 2: Effect of time on the weight loss of cast steel and copper in 21 days (0.0576yr) of exposure to 0.10M of seawater solution.

Figure 2 is a repeat of the exposure time versus the weight loss method. However, this was done for 21 days (0.0576yr). This, once again, confirms the interdependence of exposure time and weight loss. It was demonstrated to further affirm the effect of the exposure time on both specimens in 0.10M of seawater solution. A gradual increase in loss in weight from 0.03g, 0.09g to 0.15g was determine in casts steel and 0.02g, 0.04g to 0.07g was determined in copper.

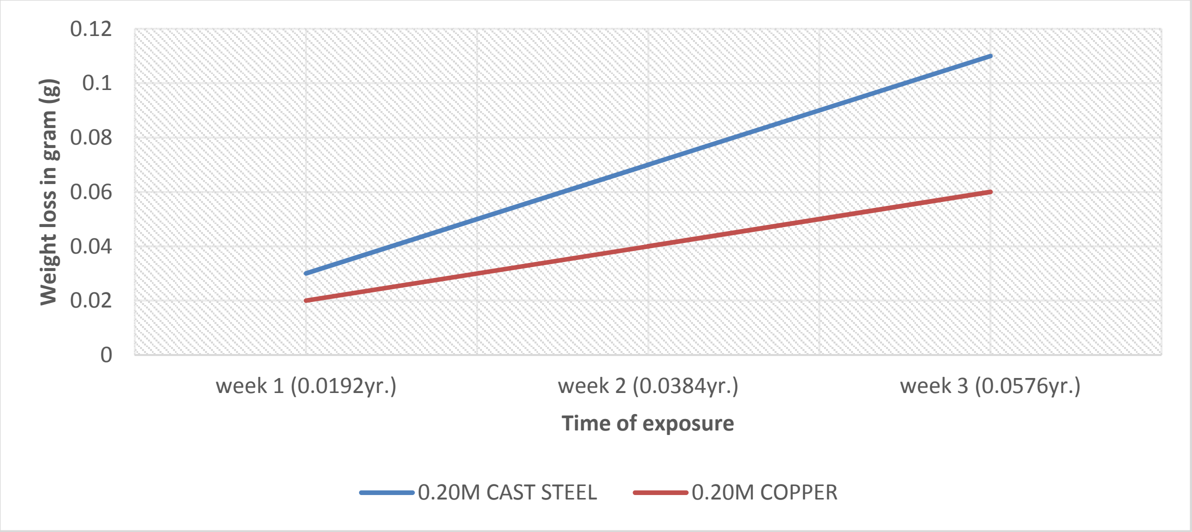

Fig. 3: Effect of time on the weight loss of cast steel and copper in 21 days (0.0576yr) of exposure to 0.20M of seawater solution.

Figure 3 is a demonstration of the interdependence of exposure time and weight loss in 0.20M of seawater. The increase in loss in weight of cast steel is from 0.03g, 0.07g to 0.11g while copper is from 0.02g, 0.04g to 0.06g for the 21 days (0.0576yr) of exposure in 0.20M of seawater solution. This result determines high corrosion impact in cast steel C-1020, revealing that copper C-642 is more resistive to corrosion than cast steel metal.

Table 5: Corrosion rate obtained at various media of concentration of cast steel coupons at room temperature in 21 days of exposure.

Concentration (M)	Corrosion rate (mmpy) (0.0192yr)	Corrosion rate (mmpy) (0.0384yr)	Corrosion rate (mmpy) (0.0576yr)
0.000004	0.0493	0.0555	0.0656
0.10	0.0369	0.0555	0.0617
0.20	0.0369	0.0431	0.0452

Table 6: Corrosion rate obtained at various media of concentration for copper coupons at room temperature for 21 days of exposure.

Concentration (M)	Corrosion rate (mmpy) (0.0192yr)	Corrosion rate (mmpy) (0.0384yr)	Corrosion rate (mmpy) (0.0576yr)
0.000004	0.0000	0.0000	0.0006
0.10	0.0351	0.0351	0.0409
0.20	0.0351	0.0351	0.0363

Table 5 and 6 gives the corrosion rate for both specimens at various concentrations exposed for 21 days (0.0576yr), at room temperature. The graphical illustration is shown in figure 4.

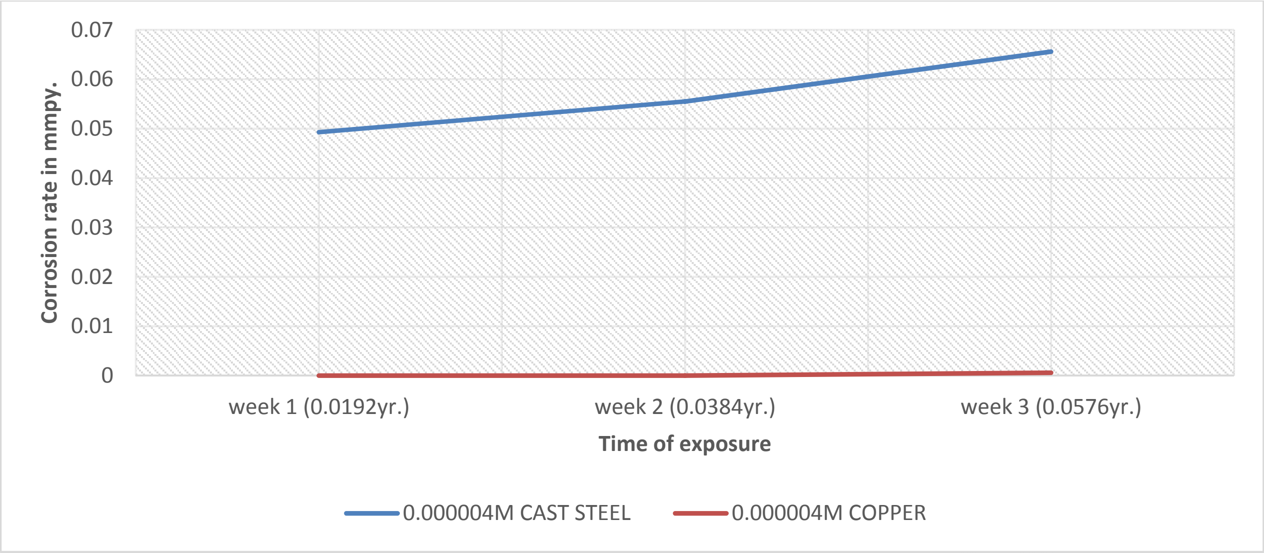

Fig. 4: Graphical illustration of corrosion rate against the time of exposure, (0.0576yr.) of cast steel and copper in 0.000004M of freshwater.

Fig. 4 gives the corrosion rate of cast steel and copper in 0.000004M of freshwater in 21 days (0.0576yr) of exposure. A gradual increase in the rate of corrosion from 0.0493mmpy, 0.0555mmpy to 0.0656mmpy was determined in cast steel coupon while copper showed no corrosion rate for the first two weeks, although a slight increase of 0.0006mmpy was determined at the third week of exposure.

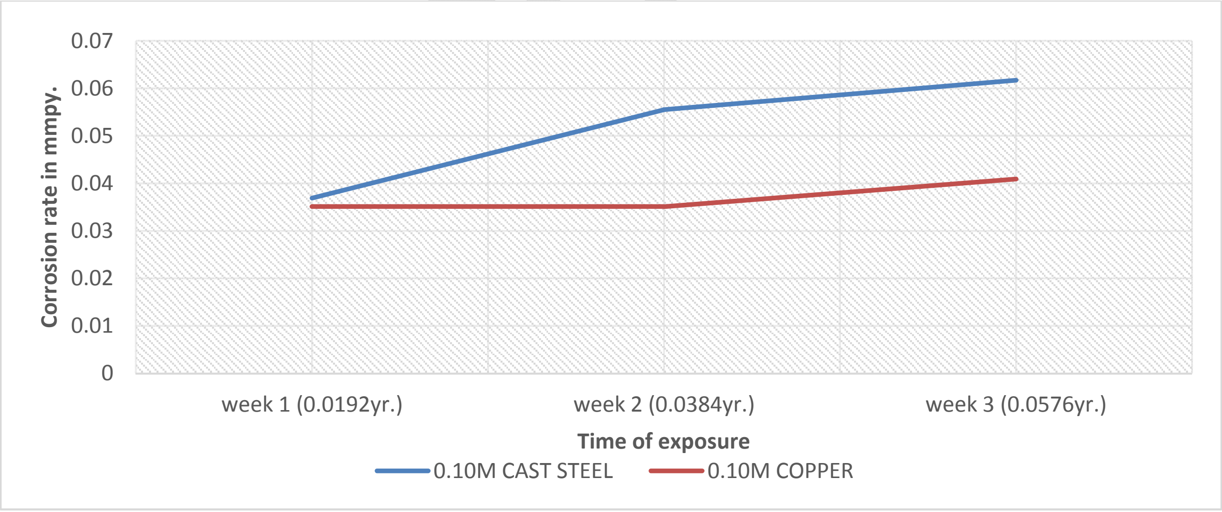

Fig. 5: Graphical illustration of corrosion rate against Time of exposure.

Fig. 5 illustrates the corrosion rate of cast steel and copper in 0.10M of seawater solution exposed for 21 days (0.0576yr.). The results show the effect of salinity on both specimens. Corrosion rate in cast steel coupon increased gradually from 0.0369mmpy, 0.0555mmpy to 0.0617mmpy. Copper experienced a constant corrosion rate of 0.0351mmpy for the first and second week with a slight increase of 0.0363mmpy for the third week of exposure.

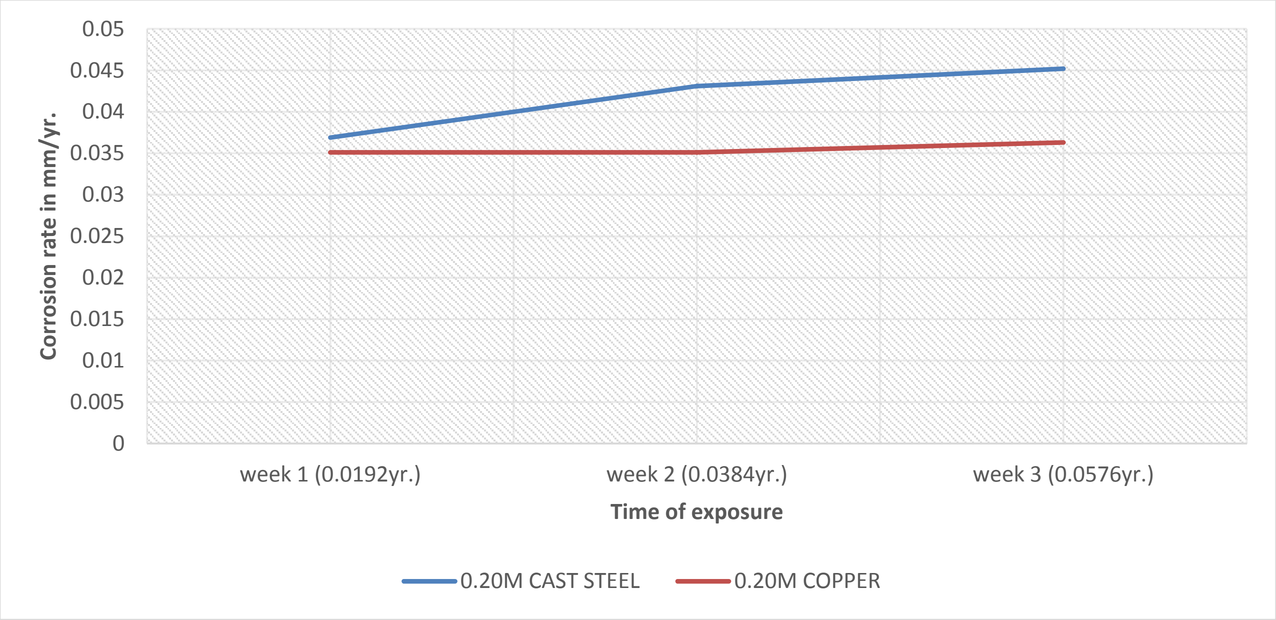

Fig. 6: Graphical illustration of corrosion rate against time of exposure.

Fig. 6 illustrates the corrosion rate of cast steel and copper in 0.20M of seawater solution exposed for 21 days (0.0576yr.) at room temperature. The result obtained shows the rate of corrosion for both specimens. From figures 4 to 6, cast steel metal gave higher corrosion rate than copper metal in the three media of consideration.

3.4 Discussion of Results

3.4.1 Weight Loss and Corrosion Rate results

The original weights and the losses in weights as well as the corrosion rates data of cast steel and copper in freshwater (0.000004M) and seawater solutions at different salinity concentrations of 0.10M and 0.20M were presented in tables 2 to 4 respectively as shown above. Tables 3 and 4 clearly showed the increase in loss in weight for both specimens. Comparative analysis for increase in loss in weight at room temperature for both specimen at various concentration of 0.000004M, 0.10M and 0.20M demonstrated in fig. 1 to 3 illustrated high corrosion rise in cast steel C-1020. Thus, underlying that corrosion prevailed more in cast steel sample than copper metal after the 21 days (0.0576yr.) of immersion.

Furthermore, tables 5 and 6 illustrated corrosion rise with increase in salinity concentration. A thorough examination and comparison of both specimens in fig. 4 to 6 also confirmed the fact that salt content (salinity) enhances the rate of corrosion as higher corrosion rate was prominent in cast steel C-1020.

The result obtained in this research gives a comparative analysis of the effects of corrosion in the intended performance of marine heat exchanger performance in freshwater and seawater media.

From the micrograph result of cast steel C-1020 before and after immersion, it is evident that steel cast C-1020 sample after the 21 day (0.0576yr) of immersion in 0.10M of seawater experienced uniform (general) corrosion as the surface was rough and bumpy. The grain boundaries of the surface morphology revealed general corrosion effects on the metal after the 21 days of immersion as the film present on the surface was cracked.

Copper C-642 sample before and after immersion showed no or merely general corrosion influence of the surface morphology from the micrograph viewed.

From the comparative analysis of the micrograph results for cast steel C-1020 and copper sample C-642, it was evident that cast steel C-1020 immersed for 21 days undergoes corrosion as revealed by the micrograph as it gave a clear picture of the metal surface morphology, while copper coupon demonstrated no or little general corrosion attack before and after immersion. This result once again confirms the data obtained in the weight loss analysis of cast steel C-1020 and copper C-642, as higher corrosion effects was evident in cast steel C-1020 compared to copper. Proving that cast steel C-1020 was more susceptible to corrosion and that copper C-642 was a better resistive material to corrosion. The results before immersion revealed that cast steel possess lower Brinell hardness and tensile strength compared to copper C-642.

The result after immersion to the corrosion media revealed that copper tensile strength and Brinell hardness reduces after twenty one (21) days of exposure while cast steel C-1020 sample increases in Brinell hardness and tensile strength. The overall result of the research work indicated higher corrosion effects in cast steel C-1020 compared to copper C-642; which was more resistive to corrosion as it proves to be a better material selection in marine heat exchanger design for better performance in a corrosive environment. The study comparatively analyzed the behavior of cast steel C-1020 and copper C-642 material in a corrosive environment. The effects of corrosion on materials vary; hence proper material selections and maintenance tragedy should be provided to enhance heat exchanger intending performance.

4. CONCLUSION

The research work on the comparative analysis of effects of corrosion in marine heat exchanger performance and the calculated corrosion rate from the weight loss obtained from both selected materials (cast steel and copper), at dissimilar weight in room temperature revealed corrosion effects on both selected materials. Also, the surface morphology of the selected samples and metal hardness testing using MITECH 320 predicted damages incur in marine heat exchangers equipment in a corrosive environment (freshwater and seawater media).

The research work, thus, shows the comparative analysis of the effects of corrosion in the both selected materials used in the research. Corrosion by the influence of salt concentration (salinity), on the selected materials used in the design process was also determined by weight loss technique and inverted metallurgical microscope to demonstrate the surface morphology and metal hardness. The research was centered on the comparative response of the selected materials (cast steel and copper) to corrosion in a corrosive media. The results briefly revealed higher corrosion rate in cast steel sample than copper as demonstrated by the research methods.

This hence demonstrated that proper material selection and best engineering design are the best means of combating corrosion and reducing its failures and effects in marine heat exchanger performance.

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