To Investigate the Effect of Heat Treatment on Low Carbon Steel Corrosion Behavior

Azhar Wahab Abdalrhem[1], Ali Jaber Naeemah[2] and Makki Noori jawad[3]

[1,3] Directorate of vocational education in Babylon Iraq
[2] Ministry of Housing, Construction and Public Municipalities Iraq

Abstract

This work was to investigating the corrosion behavior of low carbon steel in a salt solution of 3.5wt% NaCl after undergoing two different types of heat treatment at 960 ℃ in a furnace. The material of low carbon steel was cut into nine small pieces under three groups A, B and C, without heated annealing and hardening heat treatment respectively. The heat treatment was at temperature 960℃. The hardness of the sample as received will be 203 kg/mm2 while after hardening the hardness was increased. The sample was mounted using hot and cold mounting. The microstructure and surface morphology was observed by using Scanning Electron Microscope (SEM) and Optical Microscope (OM) after grinding, polishing and etching on the sample. In group A cementite can be observed clearly on pearlite on the surface before corrosion test. After four days soaking in 3.5 wt% NaCl solution was observed all cementite and pearlite will be transformed to austenite with the remnants of cementite make the surface unstable hence increases the initial corrosion. After four days soaking when the cementite is oxidized and a thick film of corrosion product covers the material surface. The formation of Martensite due to quenching and rapid cooling in group C sample increases the corrosion rate from 0.072 mpy to 0.302 due to decreased of corrosion potential from -572 mV to -639 mV after four days soaking. The corrosion rate of each sample was measured by using electrochemical polarization measurement and Tafel extrapolation technique. From previous result, it was observed that samples which had undergone annealing mode of heat treatment turned out to be the ones with the best corrosion resistance.

1. Introduction

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. Metallic systems are the predominant materials of construction, and as a class, are generally susceptible to corrosion. Therefore, the bulk of corrosion science focuses upon metals and alloys (Guthrie and Gretchen, 2002). Usually it"s beginning at the surface of the material and occurs because of the natural tendency of the materials to return to their thermodynamic stable state or to one of the forms in which they were originally found. Metals 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 (Ogunleye et al., 2011). The corrosion is happening extensively in carbon steel because the resistance of its relatively limited, despite from this

most widely used engineering material, accounts for approximately 85% of the annual steel production worldwide, carbon steel is used in large tonnages in marine applications, chemical processing, petroleum production and refining, construction and metal processing equipment (Fouda et al., 2011). The corrosion of carbon steel in natural environments is of practical importance, therefore it is considered by many studies. It is widely recognized that the corrosion of carbon

steel 2 may be accounted for by the anodic reaction as in Equation 1.1 and cathodic reaction in the presence of oxygen Equation 1.2, $Fe(s)$ $Fe^{+2} + 2e^-$ Material dissolution (1.1) and ½ O_2 +H_2O + $2e^- \rightarrow 2OH^-$ Oxygen dissolution (1.2). In many corrosion problems, there is strong evidence that the rate of uniform corrosion is controlled by mass transfer rate. This is true whether the corrosion fluid remains static or in fast motion with respect to the metal surface. However, molecular diffusion is not the only factor which influences the rate of corrosion

. In addition, in turbulent fluids, the rate of transport of eddy diffusion appears to participate in the control of the overall transfer rate (Brodkey and Hershey, 1989). Seawater is one of the most corroded and most plentiful naturally happening electrolytes. The corrosively of the seawater is reflected by the fact that most of the common structural metals and alloys are attacked by this liquid or its surrounding environments (Johnsirani et al., 2013)

2. Related Work

The corrosion characteristic 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. The result of surrounding environmental conditions water oxygen supply; ionic species; bacteria and organic matter, these layers are formed. 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 (Memet et al., 2002). 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. So there are many investigations for corrosion of 3 carbon steel in neutral aerated salt solutions, especially sodium chloride (NaCl) solution. Some investigation has been found for corrosion of carbon steel in Na2SO4 salt solution. For example corrosion of turbine caused by a thin film deposit of fused salt (sodium sulphate) on alloy surface (carbon steel) is an example of corrosion in sodium sulphate (Bornstein and Decrescente, 1971; Goebel et. al., 1973). During combustion in the gas turbine, sulfur from the fuel reacts with sodium chloride from the ingested air at elevated temperatures to form sodium sulphate. The sodium sulphate then deposits in the hotsection components, such as nozzle guide vanes and rotor blades, resulting in an accelerated oxidation attack. This is commonly referred to as "hot corrosion" (Stringer, 2007). 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 (Revie and Uhlig, 2008). It is accepted that the corrosion of mild steel in aerated water is controlled by the rate of cathodic reduction of oxygen and hence by the oxygen transport from the mainstream solution to the reacting surface, generally if a metal is corroding under cathodic control it is apparent that the velocity of the solution will be more significant when diffusion of the cathode reactant is rate controlling, although the temperature may still have an effect. On the other hand if the cathodic process requires high activation energy, temperature will have the most significant effect. The effects of concentration, velocity and temperature are complex and it will become evident that these factors can frequently outweigh the thermodynamic and kinetic considerations (Shreir et al., 2000). Also the temperature representing one of the critical environmental parameters in corrosion studies because of its severe effects on physicochemical and electrochemical reaction rates. 4 Accordingly, passive film stability and solubility, pitting and crevice corrosion behavior is known to be closely related to temperature (Samuel et al., 2011).

3. Methodology

In this work will be carried out to determine the corrosion rate of carbon steel specimens under static concentration, and different type of heat treatment of media using electrochemical polarization methods then all the above tests were carried out in aerated multimedia. Heat treatment was chosen because of its practical importance. The experimental work will be dived into main parts as shown in Figure 1.1:

    i.   Heat treatment of metals hardening and annealing

    ii.   Microstructure test of the metal by using scanning electron microscope (SEM)

    iii.   Optical microscope (OM) observation of the metal

    iv.   Electrochemical polarization measurements of the potential corrosion

3.1 Raw Materials

The selection of metal be according to special criteria, for example, is based on the corrosion effect on the metal in

chloride, a saline environment. In addition to consideration to the economic factor which is considered the backbone of industry as in low carbon steel that is one of the most commonly used metals and cheapest price and at the same time the most susceptible to corrosion. Which is leads to a large loss as we pointed out in earlier. In this research low carbon steel samples were brought from the General Company for Mechanical Industries in Alexandria, one of the Ministry Formations of Industry and Minerals in Iraq. Where is used of this type of metal and are widely used in the manufacture of some parts of pumps and sprinkler irrigation systems as well as manufacturing heat boilers and oil pipeline. These industries face the risk of corrosion and here we will see the effect two types heat of treatment on the corrosion rate. The samples shown in Figure 3.1a of low-carbon steel were used in this study.
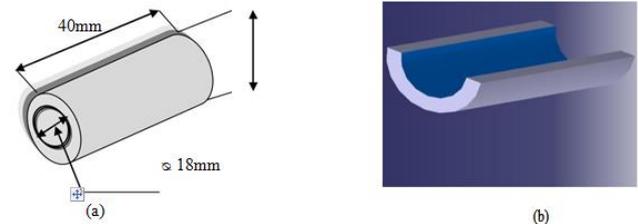

Figure 3.1 Samples shape and dimension (a) before cutting (b) after cutting

The type of material identifying by optical emission spectrometer (OES) material analysis first step doing the grinding of the surface that will be focused the optical, put the sample inside the device, using argon as a gas Assistant as shown in Figure3.2

Figure 3.2 sample analysis by (OES) material analysis

The second method was used the (XRD) materials analysis. Put the sample in the (XRD) devise. In X-Ray Diffraction (XRD), an x-ray beam is incident onto the sample and the diffracted beam is detected. The intensity of the diffracted radiation is dependent on the interaction of the beam with the sample Figure 3.3 shown XRD device.

Figure 3.3 X-Ray Diffraction (XRD)

3.2 Sample Preparation

The steel sample selected for the work was a diameter 18 mm and 40 mm length, nine samples of 15 mm long pieces of the pipe were cut using a hacksaw and the samples as shown in Figure 3.1b grinding on one face using the pressure sensitive abrasive papers of grades 240,400, 600, 800 and 1200 silicon carbide. The dimensions of the pieces are 10mm length, 5mm width the cross-sectional area of the parts to be exposed to the corrosive medium (Insulating tape is placed to confirm the accuracy of area). the Samples were placed inside the mold The molding be on the two forms either Hot mounting press that use the heat to melt the resin as in Figure 3.4 that show the sample already pouring
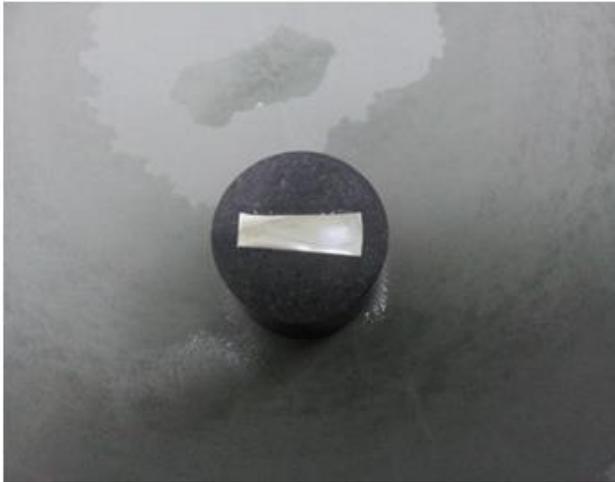

Figure 3.4 sample inside the poured by hot mounting

Cool mounting is often used with epoxy to mount samples by simply mixing the epoxy and pouring it over a sample that is positioned face down in a cold-mounting ring. When the epoxy cures the specimen can be prepared. Caution must be exercised when cold mounting due to relatively poor adhesion between the specimen edges and the epoxy Figures 3.5 (a), 3.5 (b) that illustrates how to pouring samples in pattern and the sample after pouring with wire connection respectively all mounting process after heat treatment.

(a)   (b)
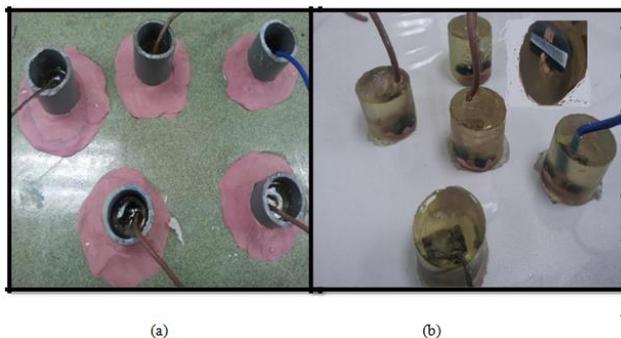
Figures 3.5 cold mounting (a) pouring sample in pattern (b) sample after pouring

The samples were divided into three groups; A, B and C as shown in Table 3.1.

Table 3.1 Classifying the samples according codes

Group name	Code	Details
A	RW00x	Samples without heat treatment
B	RA00x	Samples after annealing process
C	RH00x	Samples after hardened process

Group A consisting of three test samples marked as-received (without heat treatment) symbolized by the (RW00x), group B consists of three test samples marked „annealed" symbolized by the (RA00x), group C consisting of three test samples marked „hardened" symbolized by the (RH00x), where (x) is (1, 2 and 3) without soaking time, 96 hours soaking time and 240 hours soaking time.

3.3 Heat Treatment

The process of heat treatment is carried out first by heating the material then cooling it in the brine, water or oil. The purpose of heat treatment is to soften the metal, to change the grain size, to modify the structure of the material and to relieve the stress set up in the material after hot and cold working. The various heat treatment processes in this study is:

a) Annealing

The process consists of heating the samples (RA00x) by raising the heat with 16 °C per Minutes to high temperature 960 °C It is held at this temperature one hour (3600 second) to ensure complete homogenization then cooled inside the furnace 24 hours to room temperature the purpose is to soften higher carbon steel and allow more formability as shown in Figure 3.6.
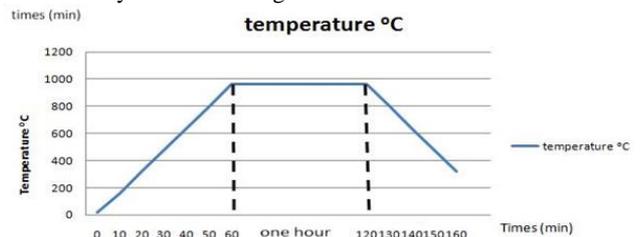

Figure 3.6 Schematic diagram of annealing process

b) Hardening

Samples heated to austenitic temperature of 960 °C and held for one hour to ensure complete homogenization, without excessive grain growth and then cooled (rapid cooling) inside the cold solution (water), the purposes of hardening are to improve the corrosion resistant of the metal.

3.4 Corrosion Experiment

The corrosion medium is a 3.5wt% Sodium Chloride (NaCl) was obtained from dissolved 35 g NaCl depending on weigh where the molecular weight of NaCl 58.44 g/mol2 on one liter of distilled water. The samples (RW002, RH002, RA002) were immersed in corrosion medium 96 hours and others samples (RW003, RH003, RA003) 240 hours while the samples (RW001, RH001, RA001) will be without soaking in solution medium.

3.5 Method of Experiment

a) Working Electrode (cathode)

The working electrode was piece of low carbon steel pipe, the cathode was placed length 10mm width 5mm dimensions. The metal specimen was immersed in the glass Container (beaker) in the 3.5 NaCl

b) Auxiliary Electrode (anode)

In polarization experiments, the auxiliary electrode was a rod made of high conductivity graphite, 1cm outside diameter, the length of the anode was 30 cm, and located vertically opposite to the cathode at the same level.

c) Reference Electrode

The cathodic potential was determined with respect to Saturated Calomel Electrode (SCE). A lugging capillary bridge leading to the reference electrode was mounted near the center along the cathode length to within ($\square$ 1mm) from the side of the cathode. The opening of the capillary tube near the sample metal (cathode) was equal to ($\square$ 1mm) in diameter.

d) Gamry Machine

Conducted all ABC previous with Gamry Machine by Cable were analyzed polarization results and Tafel plot. As shown in Figure 3.7 illustrates the components diagram of the experience.
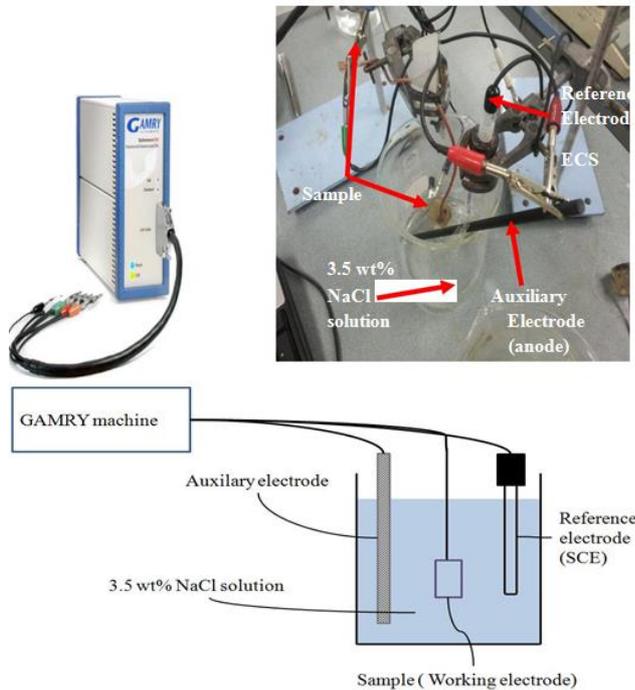
Figure 3.7 Diagram of electrochemical measurement cell

4. Analyzing and Testing

i. Etching Process

Three pieces were cut, grinding by silicon carbide paper (240, 400, 600, 800 and 1200) , polished and etched using Nital as etchant containing The samples were etched for 3s in Nital containing of alcohol and 3% nitric acid.

ii. Scanning Electron Microscope (SEM)

A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons the sample is tested before the heat treatment to obtain the microstructure, the thermal effect of the transactions on the micro structure and surface morphology to see the layers formed on the metal surface before and after the occurrence of corrosion device is shown in Figure 3.8 (Oxford, Model 7636).

Figure 3.8 A Scanning Electron Microscope (SEM) (oxford, model7636)

iii. Optical Microscope (OM)

Optical microscope is used to characterize structure by revealing grain boundaries, phase boundaries, inclusion distribution, and evidence of mechanical deformation. Scanning electron microscopy is also used to characterize fracture surfaces, integrated circuits, corrosion of materials, and other rough surfaces, especially when elemental microanalysis of small features is desired. Transmission electron microscopy is used to examine dislocation arrangements or structures and other small defects in metals and alloys. In this study tested to characterize revealed the structure and mechanical distortions border before and after heat treatment of the sample and the occurrence of corrosion. Device shown in Figure (3.9)

Figure 3.9 Optical Microscope Devices

iv. Polarization Measurements

In polarization measurements, by using Gamry machine, for saline solutions anodic and cathodic polarization curves were needed to measure the icorr. In the anodic polarization, at the end of cathodic polarization curve and arrived to corrosion potential were the current was zero by reversing the connection to the power supply, i.e. connected the working electrode to (+) and the auxiliary electrode standard calomel electrode (SCE) to the (-) of the power supply. The specimen was anodically polarized starting from the corrosion potential obtained from cathodic polarization measurements for clean surface. In the anodic polarization, each experiment was carried out in duplicate and each specimen was often used once. Figure 3.10 shows the anodic and cathodic polarization curves and the way used to measure the corrosion current (icorr) and the potential polarization (Ecorr) from Tafel slopes, empirical correlations for the corrosion rate.
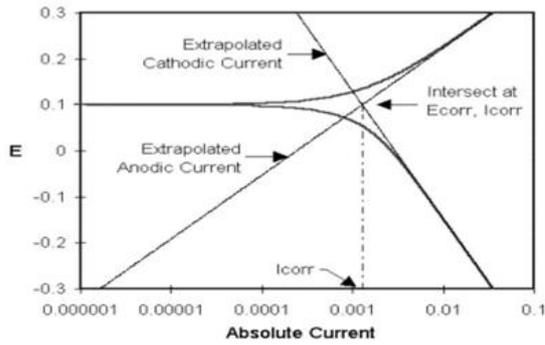
Figure 3.10 Classic Tafel extrapolation (Getting Started with Electrochemical Corrosion Measurement).

Results and Discussion

This part will be discuss the type of raw material, Effect of heat treatment (annealing and hardening) at 960 ºC of low carbon steel, the microstructure and surface morphology before and after heat treatment by using the optical microscope (OM) and scanning electron microscope (SEM) and corrosion behavior by corrosion polarization and Tafel Extrapolation.

i.   Analysis of Raw Material

Figure 4.1 shown the certificate test result of analysis sample low carbon steel (%C 0.14 - 0.22), (%Mn 0.4 - 0.60), all components see Appendix A1, A2

Figure 4.1 certificate of raw material test

Figure 4.2 was shown the result by using X-Ray Diffraction (XRD), which serves to give proportions of metal components obtained low carbon steel the chemical formula of the metal (C Mn5Si).
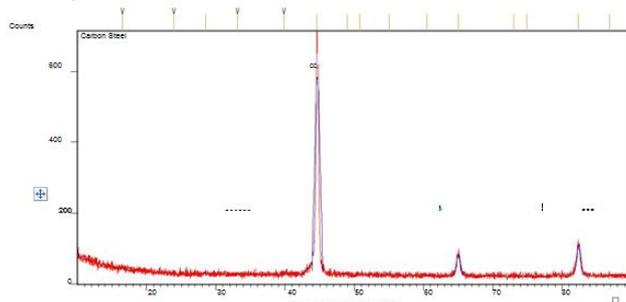

Figure 4.2 X-ray diffraction (XRD) analysis of low carbon steel

### ii.   Effect Of Heat Treatment On Mechanical Properties

a)   Hardness Test

From observation from Table 4.1 hardness experiments by applying a load of 2 kg for 15 seconds and taking the average of 5 individual readings, all reading see Appendix C1, C2 and C3. Shows decrease the hardness of sample from group B and increase back to group C compare with as resaved group A. The hardness reduced on group B, due to refinement of both Cementite particles and grains, the softening had been achieved

by annealing treatment. The hardness was increase at group C after hardening, due to the low carbon, rapid cooling or quenching resulted in one or more structures intermediate between austenite and pearlite (Wu and Xia 2008) Figure 4.3 illustrates hardness plot .

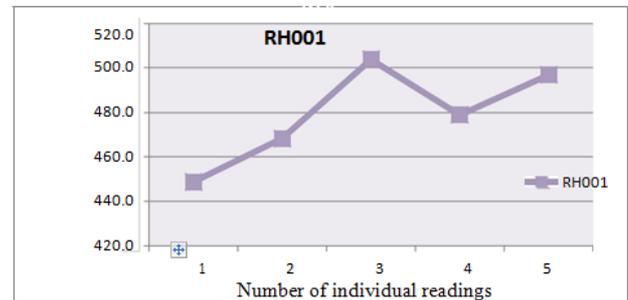**Table 4.1** Vickers hardness value of the sample before corrode

Samples group	A	B	C
Average Hv kg/mm^2	203.9	131.2	479.3
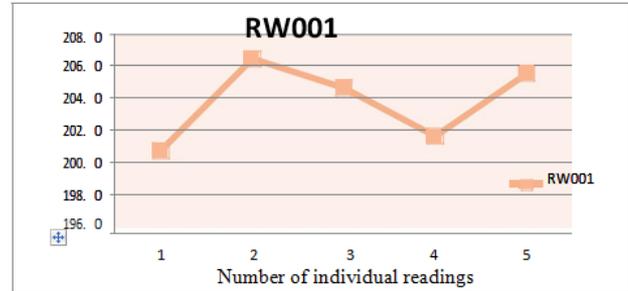
(a)
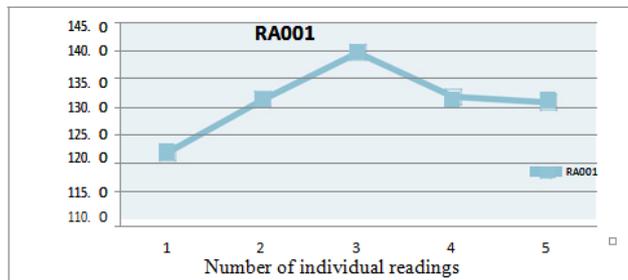
(b)

(c)

Figure 4. Individual.3Illustrationreadinghardness plot (a) group A (b) group B (c) group C

iii. Physical Properties

a)   Surface Color

From Figure 4.4 shows change the color of the material due to heat treatment observed by naked eyes observed from, Figure 4.4 (a) shown the color as–received that lighting color consisted of pearlite, Figure 4.4(b) and (c) shows the dark color consisted of ferrite this result is the same on (Dong et al.,2003)
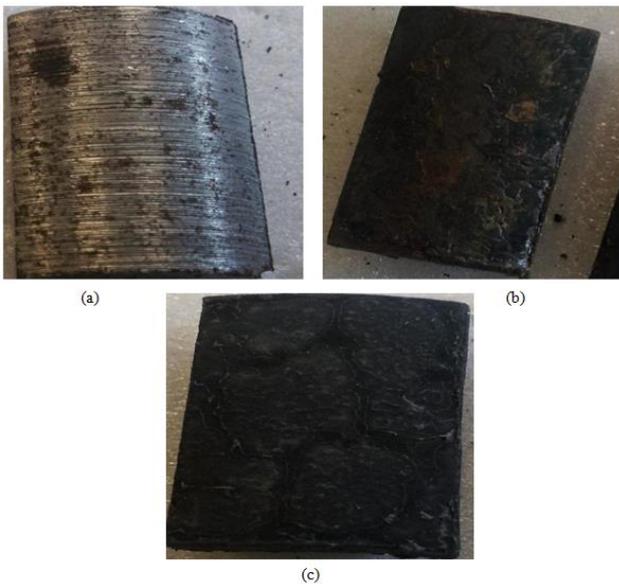
Figure 4.4 Un-corroded samples surface (a) Sample as-received (b) Sample annealed (c) Sample hardened

b) Optical Microscope Observation

Figure 4.5 shows the microstructure of low carbon steel using OM, Figure 4.5 (a) shows the sample as received observed dark pearlite on surface Figure 4.5 (b) shows the sample after annealing without corrode, the annealed structure consists of dark pearlite phases in a ferrite. Figure 4.5 (c) shows non-corroded hardened sample consists of structures intermediate between austenite and pearlite (Atanda et al., 2012). Because the sample is (pipe) not flat Image features appear deformed so will focus on SEM
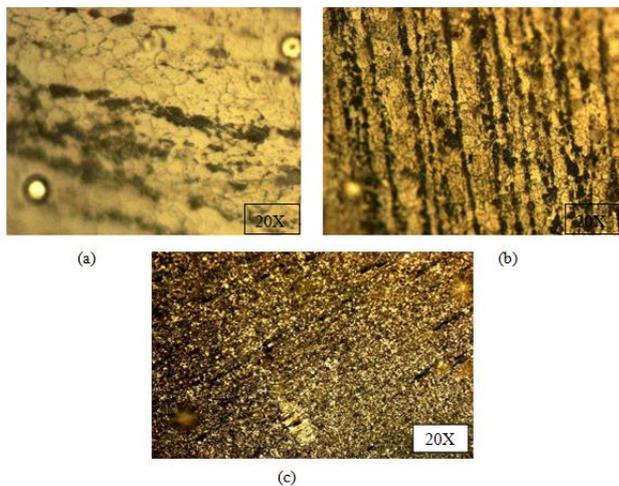

Figure 4.5 Microstructure of low carbon steel without heat treatment by using OM of material (a) As received (b) after annealing (c) after hardening

c) Scanning Electron Microscope (SEM) Observation

Figure 4.6 shows the microstructures of the as-received of low carbon steel without heat treatment by using SEM with different magnification aligned lamellar cementite can be clearly observed in the pearlite colonies this observation same as result by Wu and Xia 2008.
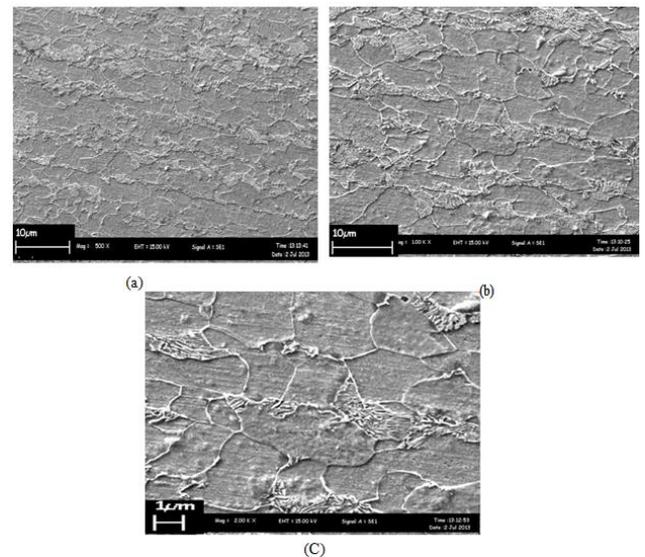

Figure 4.6 Microstructure of low carbon steel without heat treatment (group A) by using SEM (a) 500 x (b) 1000x (c) 2000x magnification

Figures 4.7 and 4.8 shows the microstructure of low carbon steel after heat treatment (annealing and hardening) respectively by using SEM the microstructures of the material which was annealed at 960°C for 60 minutes are shown in Figure 4.7. Most cementite became fully austenite with the remnants of cementite after annealing this observation same as repainted by (Gas, 2008).
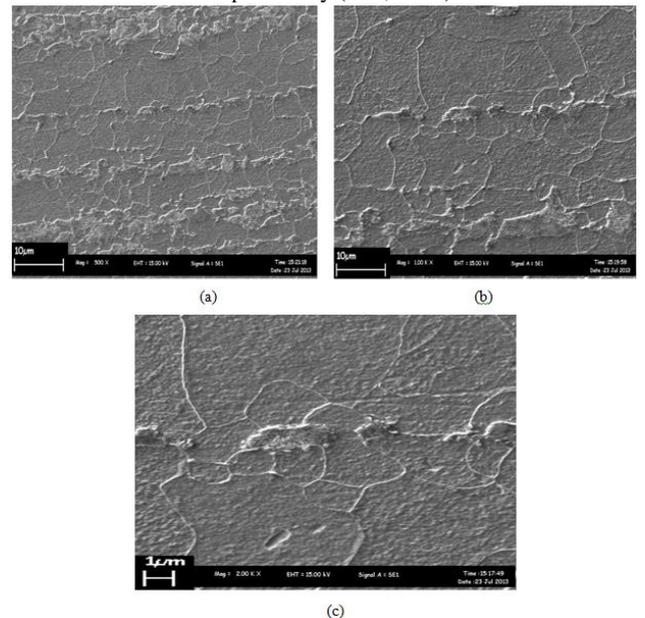

Figure 4.7 Microstructure of low carbon steel after annealing heat treatment (group B) by using SEM (a) 500 x (b) 1000x (c) 2000x magnification

Due to the rapid quench after hardening at temperature at 960°C for 60 minutes of the low-carbon steel (group C) note change the microscopic structure of the composition of metal layer the Martensite (The austenite will transform upon quenching to the hard microstructure Martensite if the quenching rate is fast enough) (Gas,2008) as shown in Figure 4.8.
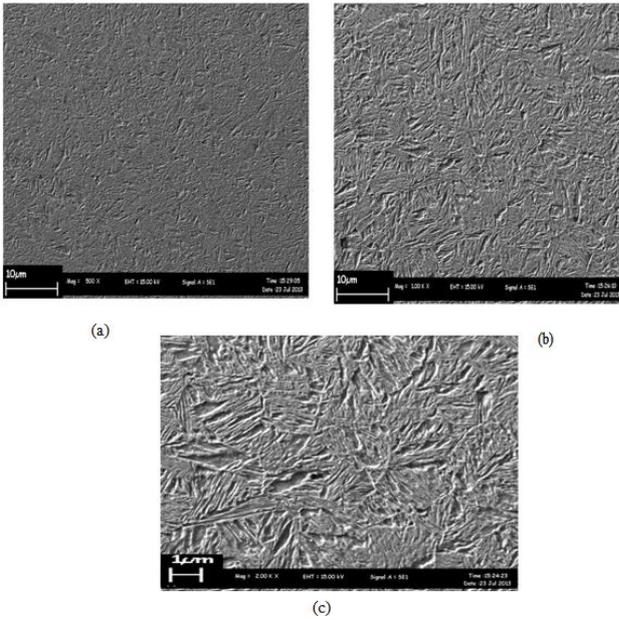
Figure 4.8 Microstructure of low carbon steel after hardening heat treatment (group C) by using SEM (a) 500 x (b) 1000x (c) 2000x magnification

5. Corrosion Test

Experimental work was carried out to determine the corrosion rate of a low carbon steel specimen under static salt solution with NaCl by using an electrochemical polarization method. Tafel curves recorded for low carbon steel electrode in 3.5 wt% NaCl solution without and with various heat treatments Figure 4.9. It is shown tafel plot as observation from group (C) other groups see appendix (D, D1) both cathodic and anodic reactions of low carbon steel corrosion in 3.5 wt% NaCl solution.
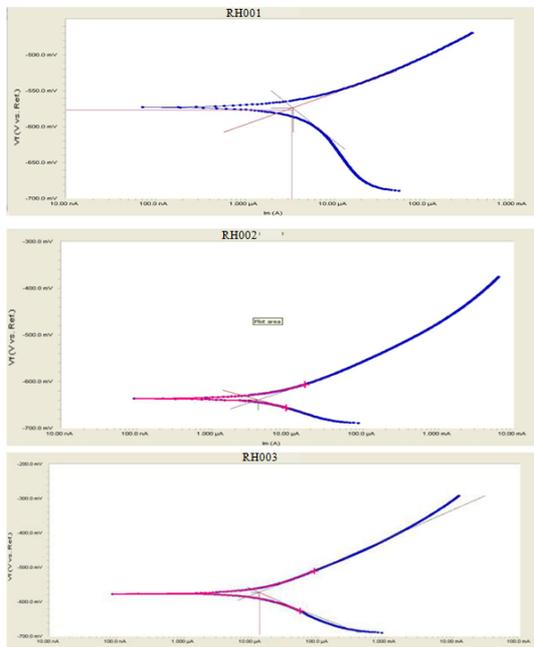

Figure 4.9 Anodic and cathodic polarization curves recorded for (grope C) low carbon steel after hardening in 3.5wt% NaCl solution

a) Tafel Extrapolation

Based on the corrosion current determined from Tafel plot for, the corrosion rates on group A samples (RW001, RW002, RW003) in 3.5wt% NaCl solution can be represent from current density (icor) . The results of calculations are tabulated in Table

4.2. The corrosion rate can be determined by the following Equation 2.5

$$CR = K\frac{i_{cor}}{\rho}(EW)$$

Where CR is corrosion rate in millimeters per year, EW is equivalent weight in grams, ρ is the density of the metal or alloy in g/cm^3, and icorr is corrosion current density in $\mu A/cm^2$ (Arenas and Reddy 2003).The equivalent weight for low carbon steel is 27.92 and the density is 7.85 g/cm^3 corrosion rate of samples without heat treatment from (0.0528) to (0.269) mpy at 240th hour. To get the value of corrosion current density (icorr , $\mu A/cm^2$) the Equation of 2.6. In the RW001 result as an example of calculation, we have a value of Icorr = 8.26 μA and the area of the specimen is 0.5 cm^2.

Table 4.2 corrosion rate of the group A (RW001, RW002, RW003) in 3.5wt%NaCl solution

Sample	Total anodic current (I_{corr}, µA)	Corrosion current density (i_{corr}, µA/cm^2)	Corrosion potential (E_{corr}, mV)	Corrosion penetration rate (mpy)
RW001	2.27	4.54	-461	0.0528
RW002	9.33	18.66	-587	0.217
RW003	11.6	23.2	-602	0.269

From Table 4.2 observed the corrosion rate will be 0.0528 as the reference rate and the corrosion potential is the larger (-461) the corrosion rate increased with soaking time and when the corrosion potential is smaller (-602) the corrosion rate is higher. Figure 4.10 shown corrosion rate chart of group A
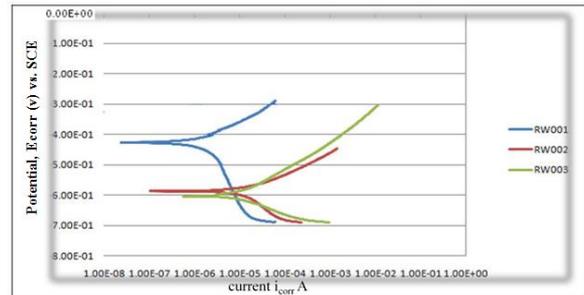

Figure 4.10 Tafel corrosion rate plot of group A in 3.5wt%NaCl solution

The group B the samples under annealing heat treatment also obtained from tafel plot the corrosion rate of samples after annealing without soaking , 96 hours and 240 hours soaking time in 3.5wt%NaCl solution respectively. The results obtained are shown in Table 4.3.

Table 4.3 Corrosion rate of Group B samples (RA001, RA002 and RA003) in 3.5wt%NaCl solution

Sample	Total anodic current (I_{corr}, µA)	Corrosion current density (i_{corr}, µA/cm^2)	Corrosion potential (E_{corr}, mV)	Corrosion penetration rate (mpy)
RA001	0.799	1.598	-314	0.018
RA002	7.67	15.34	-602	0.178
RA003	1.21	2.42	-422	0.028

From Table 4.3 initial corrosion rate after 96 hours was 0.178 mpy observed increase the corrosion rate of RA002 because of remnants of cementite also the corrosion potential (Ecorr) -602 is lowest at this group. A drop in the corrosion rate and increased the corrosion potential (Ecorr) -422 mV between the 96th hour and the 240th hours was observed (Ecorr) of (RA003) still lower than reference sample (RA001) sample but higher than RA002 this indicates that the (RA002) sample was unstable because when the finish of the remains become more stable forms a protective layer of austenite (Berduque et al., 2009)The corrosion rate decreased due to the thicker corrosion

products covering the surface of the sample, thus it formed a kind of protective film on the surface which retarded the corrosion rate towards the end of the experiment (Atanda et al., 2012). Figure 4.11 shown the corrosion rate of group B.
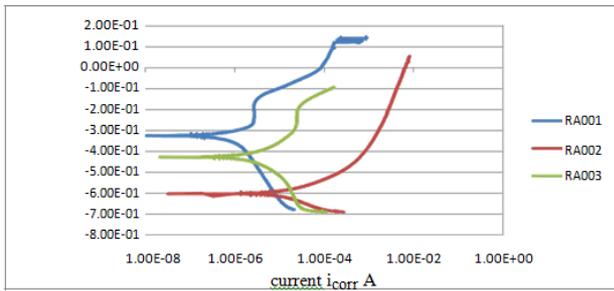

Figure 4.11 Tafel corrosion rate plot of group B in 3.5wt%NaCl solution

From figure 4.11 shows the oxidation on (RA001) and (RA002) probably due to the small bubbles on the surface of the metal during the experiment that make the curved is not smooth. While from tafel plot of group C has hardening heat treatment as shown in Figure 4.12 Tafel corrosion plot samples after hardening without soaking, 96hours soaking time in 3.5wt%NaCl solution and 240hours respectively. The results obtained are shown in Table

Table 4.4 Corrosion rate of group C (RH001, RH002 and RH003) in 3.5wt%NaCl solution

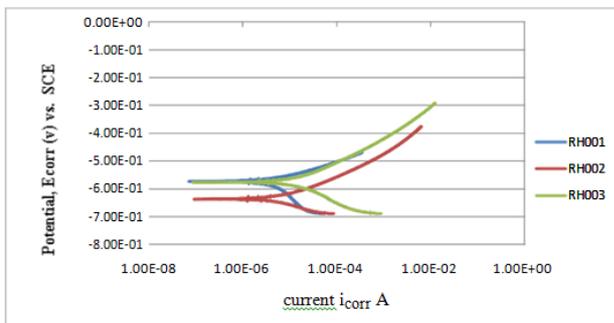| Sample	Total anodic current (I_{corr}, μA)	Corrosion current density (i_{corr}, μA/cm^2)	Corrosion potential (E_{corr}, mV)	Corrosion penetration rate (mpy)
RH001	3.30	6.60	-572	0.076
RH002	13.00	26.00	-639	0.302
RH003	4.1	8.2	-577	0.095

Figure 4.12 Tafel corrosion rate plot of group C in 3.5wt% NaCl solution

From the Table 4.4 and Figure 4.12, the current density of the (RH001) sample without soaking is 6.60μA/cm2, the initial corrosion rate notice at the 96th hour was the highest (RH002) and the lowest corrosion potential Ecorr -639mV. the corrosion rate was decreases with increase Ecorr from 96th to the 240th hour (RH003). This initial rise in corrosion rate could be because of the residual stresses containing surface of the two layers perlite and Martensite in the steel which may have occurs due to rapid cooling .The corrosive product film on the metal sample became thicker after the 96th hour, that will reduced corrosion rates. Figure 4.13 shown the relations between three groups corrosion rate after 96 hour soaking (RW002, RA002 and RH002)
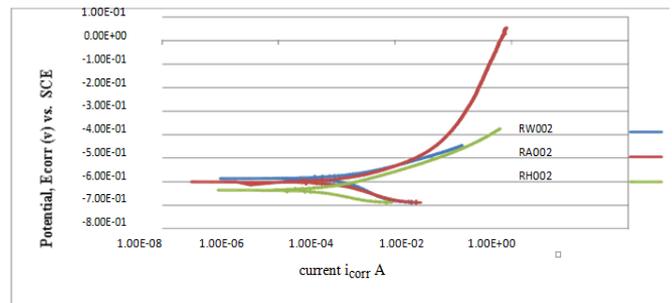

Figure 4.13 Comparison between three group's corrosion rates after 96 hour soaking in 3.5wt%NaCl solution

From Figure 4.13 can be observed the corrosion rate of RH002 highest compare to other and also have lowest corrosion potential Ecorr due to lower stability of this sample. However the corrosion rate of RA002 was higher than RW002 the reason for the low of corrosion rate in RW002 to higher stability from other samples. Figure 4.14 shows the relations between three groups after 240 hour soaking (RW003, RA003 and RH003).
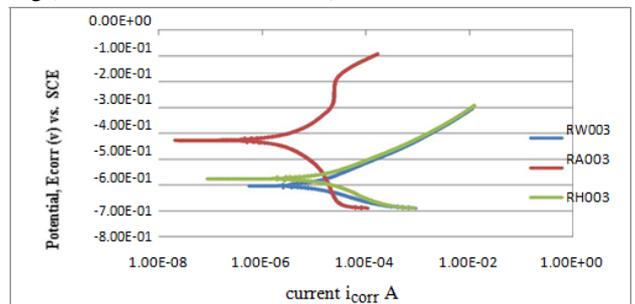

Figure 4.14 Comparison between three group's corrosion rates after 240 hour soaking in 3.5wt%NaCl solution

It was observed that the sample RA003 corrosion rate reduced that indicates the arrival to the austenite stability state also decreased the corrosion rate on RH003 while RW003 continuing to rise due to lack of protective layer

b)   Surface Morphology After Corrosion

The scanning electron microscope of all groups" low carbon steel samples is shown in Figure 4.15. The SEM surface micrograph of group A without heat treatment .The SEM micrograph of carbon steel (RW002) after 96 hours immersed in 3.5wt% NaCl solution is shown in Figure 4.15 (a) observed the roughness of the metal surface by the corrosive environment and the porous layer of corrosion product is present, growth of corrosion on the metal surface. This indicates a clear increase in the corrosion rate, Figure 4.15 (b) shows are the thin layers indicating the corrosion occurred inside the metal and dissolved layer by layer out that the full removed the metal of (RW003) surface other image with higher magnification
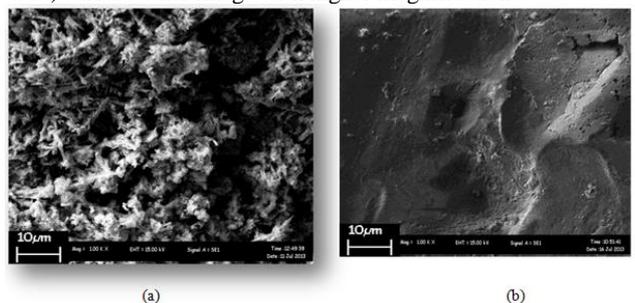

(a)   (b)

Figure 4.15 The SEM surface morphology of low carbon steel sample without heat treatment after soaking in 3.5 wt% NaCl solution (a) RW002 (b) RW003

Figure 4.16 is shown SEM micrograph of low carbon steel surface of group B with Annealing heat treatment. An initial corrosion rate raise was observed after 96 hours. This corrosion rate could be attributed to the larger portion of pearlite formed from cooling austenite. After 96 hours of soaking, a thick film of corrosion products was observed to over material surface Figure 4. 16(a) sample RA002. This is due to the depletion of both pro-eutectoid ferrite and pearlite in the structure. A drop in the corrosion rate was observed in Figure 4.16(b) sample RA003, between the 96th hour and the 240th hour. The corrosion rate decreased due to the thicker corrosion products covering the surface of the sample, thus it formed protective film on the surface which retarded the corrosion rate towards the end of the experiment the images with 1000x magnification other image with higher magnification
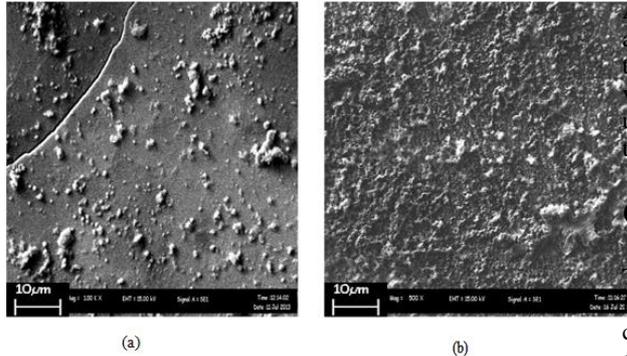

(a)   (b)

Figure 4.16 The SEM surfaces morphology of low carbon steel samples after annealing after soaking in3.5 wt% NaCl solution (a) RA002 (b) RA003

Figure 4.17 is shown SEM micrograph of low carbon steel surface with hardening heat treatment corrosion behavior of the hardened sample had the most pronounced behavior of all the different modes of heat treatment. This sample showed the initial corrosion rate notice at the 96th hour Figure 4.17(a) sample (RH002) was the highest after which it took a dive from the 96th to the 240th hour Figure 4.17(b) sample (RH003). This initial rise in corrosion rate could be because of the residual stresses in the steel which may have arisen due to rapid cooling as explained previously
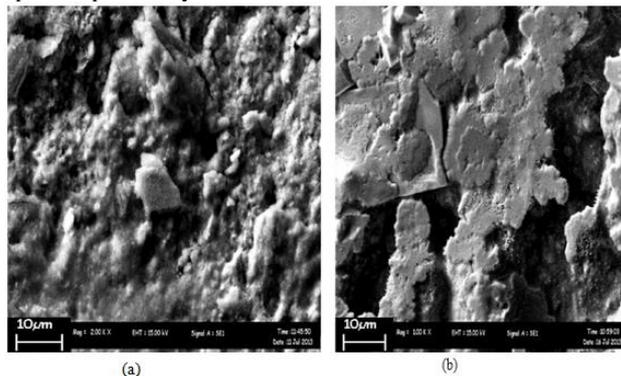

(a)   (b)

Figure 4.17 The SEM surface morphology of low carbon steel samples after hardening after soaking in 3.5 wt% NaCl solution (a) RH002 (b) RH003

Figure 4.18 could be illustrated the relationship of corrosion behavior between three groups clear the highest initial corrosion at hardening phase, that is not mean the hardened has greatest corrosion resistance. The annealed sample is better than other treatment because it provide protection from corrosion.
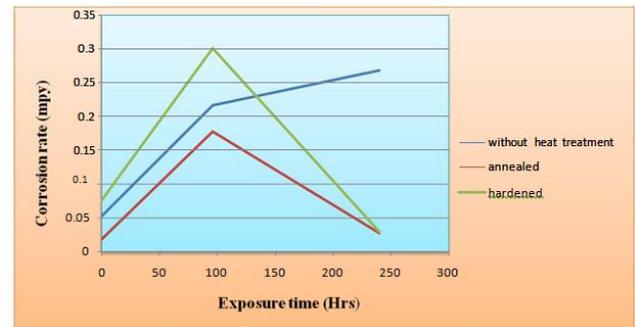

Figure 4.18 Relationship of corrosion behavior between three groups after soaking.

According to (Atanda et al., 2012) from the 240th to the 288th hour a rise in the corrosion rate was noticed. This sample so far revealed the poorest corrosion resistance. From a thermodynamic point of view the high energy state of the hardened/quenched sample is unstable and will want revert naturally to a lower energy state, hence, the rapid corrosion with evidence of pitting occurrence.

Conclusion

The study conducted has yielded some conclusion based on the findings that were summarized in the previous suction. These conclusions are the following. This study is focused on effect of different heat treatment (annealing and hardening) on low carbon steel (%C 0.14 - 0.22), (%Mn 0.4 - 0.60) corrosion behavior by using Tafel Extrapolation with soaking on salt solution for four days and ten days . The research also amid to study effect of heat treatment on the mechanical properties of material and the physical properties by using optical microscope (OM) and scanning electron microscope (SEM). From the results, it can be concluded that the best heat treatment method to improve steel corrosion resistance in (3.5wt% NaCl solution) is annealing due to increased corrosion potential Ecorr passive film formation. Other hand based on results of this work, it could be concluded that the hardened sample gave the poorest resistance to corrosion with the most significant corrosion rate, and should be avoided in practice. However the hardness will be increased in hardening heat treatment due to rapid cooling or quenching. The heat treatment formed the different layer depend on the method of sample's cooling this layers was not stable at primary this instability of metal makes the loss of corrosion protection. From result annealing protect layer is best of anther because all austenite phase keep protect surface.

Future Work

Some suggestions are recommended in order to improve this method in further study. The recommended that suggested as shown below:

i.   Study the effect of other heat treatment (Tempering ,Normalizing) and comparing between the results
ii. Study the corrosion rate with different solution for example (NaSO4, HCL, H2SO4)
iii. Studying the effect of heat treatment on the corrosion rate and used inhibitor under static conditions.
iv. Using the weight losses technique to find corrosion rate.
v.   Increase soaking time and study the corrosion behavior.

References

[1]   Amin M. A., Ahmed M. A., Arida H. A., Arslan T., Saracoglu M., and Kandemirli F., 2011 "Monitoring Corrosion and Corrosion Control of Iron in HCl by Nonionic Surfactants of the TRITON-X Series Part II Temperature Effect, Activation Energies and Thermodynamics of Adsorption", Corrosion Science, vol. 53, pp. 540–548,.

[2] Arenas, M.F., and Reddy R.G. 2003. "Corrosion of Steel in Ionic Liquids." Journal of Mining and Metallurgy, Section B: Metallurgy 39 (1-2): 81–91. doi:10.2298/JMMB0302081A. (http://www.doiserbia.nb.rs/Article.aspx?ID=1450-53390302081A).

[3] Ashida Y. , McMillin L. G. and Taylor G., 2007 "The Effect of Temperature Oscillation on the Passive Corrosion Properties of Alloy 22", Electrochemistry Communications, No. 5, vol. 9, pp.1102-1106,.

[4] Atanda P., Olorunniwo O., Alabi O., luwole. (2012), "Effect of Iso-Thermal Treatment on the Corrosion Behavior of Low Carbon Steel (Nigerian C2R grade) in a Buffered Solution containing Chloride and Carbonate Ions International Journal of Materials and Chemistry, 2(2): 65-71.

[5] Aung N.N. And Zhou W, 2002, "Effect of heat treatment on corrosion and electrochemical behaviour of AZ91D magnesium alloy" Journal of Applied Electrochemistry 32: 1397– 1401, 1397 _ 2003 Kluwer Academic Publishers. Printed in the Netherlands.

[6] Bagotsky V. S., 2006, "Fundamentals of Electrochemistry", Second Edition, John Wiley and Sons, Inc., Hoboken, New Jersey.

[7] Berduque, Alfonso, Zongli Dou, and Rong Xu. 2009. "Electrochemical Studies for Aluminium Electrolytic Capacitor Applications : Corrosion Analysis of Aluminium in Ethylene Glycol-Based Electrolytes": 20–23.

[8] Bornstein N. S. and Decrescent M. A. 1971, "The Role of Sodium in the Accelerated Oxidation Phenomenon Termed Sulfidation", Metall. Trans. No. 10, vol. 2, pp.2875- 2883.

[9] Brodkey, R. S. and Hershey H. C. , (1989), "Transport Phenomena", second edition, McGraw Hill, New York.

[10] Callister D., Williams Jr. 2003.5th Edition "Fundamental Materials Science and Engineering", an Introduction. Toronto: John Wiley and Sons, Inc.

[11] Cifuentes L. 1987. "Anti-corrosion", November, 4th edition, UK Book Company.

[12] Daramola O.O., Adewuyi B.O. and Oladele I.O. (2010), Effects of Heat Treatment on the Mechanical Properties of Rolled Medium Carbon Steel, Journal of Minerals and Materials Characterization and Engineering; Vol. 9, No. 8, pp. 693 – 708.

[13] David and James T., (2008) "corrosion scince and technology", CRC press LL.C, (www.crcpress.com).

[14] Dong Hyuk Shin, Soo Yeon Han, Kyung-Tae Park, Yong-Seog Kim and Young-Nam Paik 2003, "Spheroidization of Low Carbon Steel Processed by Equal Channel Angular Pressing Materials Transactions", Vol. 44, No. 8 pp. 1630 to 1635. The Japan Institute of Metals.

[15] Eid N.M.A. 1989 "Localized Corrosion at Welds in Structural Steel under Desalination Plant Conditions Part II: Effect of Heat Treatment, Test Temperature and Test Media", Corrosion Science, vol. 73, pp. 407-415.

[16] Falak Niaz, Muhammad Riaz Khan, Ihsan-ul-Haque.,2010, "Microstructural Characterization Of Low Carbon Steel Used In Aircraft Industry", JPMS Conference Issue.

[17] Fontana M.G., 1986. "Corrosion Engineering," 3rd edition, McGraw-Hill Book Company, NewYork,(http://www.amazon.com/gp/search?index=books&linkCode=qs&keywords=14 02077440).

[18] Fouda A.S., Elewady G.Y. and El-Haddad M. N., 2011 "Corrosion Inhibition of Carbon Steel in Acidic Solution Using Some Azodyes" Canadian Journal on Scientific and Industrialn Research, No. 1, vol. 2.

[19] Gas,(2008). "Special Edition . Linde Gas Furnace Atmospheres No . 2 Neutral Hardening and Annealing Preface" (2).

[20] Gedeon G, 2000, "Corrosion Overview", corrosion, vol. 4 pp. 37- 43.

[21] George K. and Nesic S., 2004, "Electrochemical Investigation and Modeling of Carbon Dioxide Corrosion of Carbon Steel in the Presence of Acetic Acid", Corrosion 2004 NACE, vol. 04379, pp.25.

[22] Gerhardus H., Michiel, Brongers, and Neil G. Thompson, 2002 "Cost of Corrosion", NACE International, publication no. fhwa-rd-01-156, (http://www.battlle.org).

[23] Goebel J. A, Pettit F. S. and Goward G. W., 1973, "Mechanisms for the Hot Corrosion of Nickel-Base Alloys", Metall. Trans., No. 1, vol. 4, pp. 261- 278.

[24] Guthrie J., B. and Gretchen C., (2002). "Accelerated Corrosion Testing" Advanced Materials and Processes Technology Quarterly, No. 3, vol. 6, pp.11.

[25] Ismaeel A. and Turgoose, 1999, Studies On Corrosion Of Carbon Steel In Deaerated Saline Solutions In Presence Of Scale Inhibitor, Presented at the WSTA IV Gulf Conference, Bahrain, 13-18 February.

[26] Johnsirani V., Sathiyabama J., Prabhakar P. and Susai Rajendran, February , 2013, "Inhibition of Corrosion of Carbon Steel in Sea Water by an Aqueous Extract of Eclipta alba Leaves Zn2+ system" Research Journal of Chemical Sciences ISSN 2231-606X ,Vol. 3(2), 10-15.

[27] Kruger J., (1986), Corrosion of metal: An overview in M.B Bever (ed),ency. of materials science and engineering vol 2.

[28] Lyon W. 1996, "Standard Handbook of Petroleum and Natural Gas Engineering", vol.1, Gulf Company, Houston, Texas.

[29] Mahato B. K., Stewrd F. R. and. Shimlit L. W, 1968. "Steel Pipe Corrosion under Flow Condition - II Mass Transfer Correlations with Temperature Effects"Corrosion Science J., vol.8, pp.737–749.

[30] Memet J.B,. Girault P., Sabot R., Compe`re C., Deslouis C., (2002) "Electrochemical impedance spectroscopy of a free-standing oxide film" Electrochimica Acta 47 1043–1053.

[31] Murugan V.K., 2012, "Surface Hardness Behaviour of Heat Treated Ni-Cr-Mo Alloys", International Journal of Engineering Science and Technology, ISSN : 0975-5462 Vol. 4 No.12.

[32] Ogunleye I. O., Adeyemi G. J and Oyegoke A.O.V, 2011 "Effect of Grape Fruit Juice on the Corrosion Behaviour of Mild Steel in Acidic Medium," American Journal of Scientific and Industrial Research, No. 4, vol. 2, pp. 611-615.

[33] Perez N., 2004. "Electrochemistry and Corrosion Science"[e-book] Kluwer Academic Publishers, USA available in Springer, amazon.com (http://www.amazon.com/gp/search?index=books&linkCode=qs&key words=1402077440)

[34] Perry R.H, and. Green D.W, 1997 "Perry Chemical Engineers Handbook", 7th Ed. M.C. Graw-Hill, United States.

[35] Ponce-de-Leo´n C., Low C. T. J., Kear G., and Walsh F. C., 2007 "Strategies for the Determination of the Convective-Diffusion Limiting Current from Steady State Linear Sweep Voltammetry", J. Appl. Electrochem. , vol. 37, pp. 1261– 1270.

[36] Rajappa S., Zhang R., and Gopal M., 1998, "Corrosion in Multiphase Systems Center", Corrosion 98 NACE, vol.26, pp.2-26.

[37] Revie R.W. and Uhlig, 2008 "Corrosion and Corrosion Control an Introduction to Corrosion Science and Engineering" fourth edition, John Wiley & Sons, Inc., Hoboken New Jersey,.

[38] Robert G., Kelly and Scully J., Shoesmith D. W, and. Buchheit R. G, 2003,"Electrochemical Techniques in Corrosion Science and Engineering", Marcel Dekker, Inc. New York.

[39] Roberge P. R. 2000. "Handbook of Corrosion Engineering" McGraw-Hill Companies, United States of America.

[40] Samuel J. Gana, Nosa Egiebor, Ramble Ankumah, 2011, Effect of High Temperature Treatment on Aqueous Corrosion of Low-Carbon Steel by Electrochemical Impedance Spectroscopy, Materials Sciences and Applications, 2, 81-86 doi:10.4236/msa.2011.22011 (http://www.SciRP.org/journal/msa).

[41] Shreir L.L., Jarman R.A. and Burstein G.T., 2000, "Corrosion Metal / Environment Reactions" third edition, Butterworth-Heinemann Volume I, Great Britain.

[42] Stringer J., "Hot Corrosion in Gas Turbines", 2007, ASM International, High Temperature Corrosion and Materials Application, vol. 9, pp. 249-258.

[43] Syed S., 2006. "Atmospheric Corrosion of Materials" Emirates Journal for Engineering Research, No. 1, vol. 11, pp.1-24.

[44] Talbot D.E.J. and Talbot.D.R. J, 1998. "Corrosion Science and Technology", by CRC Press LLC, U.S.A.

[45] Wan N. W.B., Ahmad A., Rosliza R., Prawoto Y. and Zulkifli F., 2011 "The Study of Temperature Effect on Mild Steel Coated with Aerosol Paint", International Journal of Engineering Science and Technology, No. 9, vol. 3, pp.7175-7179.

[46] Wu, X, and K Xia. 2008. "Microstructure and Property of A Medium Carbon Steel Processed By Equal Channel Angular Pressing" 32.

[47] Zvandasara T., 2009, "Influence of Hydrodynamics on Carbon Steel Erosion Corrosion and Inhibitor Efficiency in Simulated Oil Field Brines", PhD thesis.