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Heat Treatment and Corrosion Behaviour of Selected Steels in 3.5 M Sodium Chloride

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ABSTRACT: *Low carbon, medium carbon and high carbon steels were heat treated and the corrosion behaviour were studied in 3.5molar sodium chloride (NaCl) solution. Metallography of the steel samples revealed the presence of ferrite and pearlite in all the as-received and heat treated samples. Studies of the selected steels indicated that the highest corrosion resistance was exhibited by the high carbon steel at various heat treatments.*

Keywords: *Low carbon, Medium carbon, High carbon, heat treatments, Corrosion*

I. Introduction

Steels are very important in industrial applications and development, due to their excellent properties, such as; high tensile strength and very excellent impact resistance [1,2]. Carbon steels have been utilized in various applications such as low and high pressure boilers and vessels, fossil fired power plant, fuel gas desulphurization equipment, evaporator tubing, super heater reheating tubing and steam heaters and pipes [3].

Engineering materials, mostly steel, are heat treated under controlled sequence of heating and cooling to alter their microstructure and mechanical properties (ductility, hardness, yield strength, tensile strength and impact resistance) to meet desired engineering applications [4,5]. The electrical, corrosion and thermal conductivity are also slightly altered during heat treatment process [6].

Steels can be produced in various shapes and sizes ranging from simple to complex and intricate. History has proved that improper design of steel may lead to severe consequence. Failures as a result of poor mechanical properties and corrosion resistance have been reported from household equipment to industrial structure such as railways, road bridges, storage tanks and ocean liners [7].

Over the years, corrosion has been the major challenge in the application of steels. This has led to various researches geared towards the property improvement of steels for durability and long lasting ability in service, especially in highly corrosive environment [8]. Failure of steel structures as a result of corrosion attack could lead to loss of lives, properties, capital and may result in environmental pollution [9]. Resisting failures from corrosion attack could help improve on economic growth, wealth creation and sustainable development of developing countries. One promising approach to improve the mechanical, wear and corrosion properties of carbon steel is by subjecting them to thermal treatment [10].

The research aims to study the effects of various heat treatment techniques on the corrosion behaviour of some selected steels (low carbon, medium carbon and high carbon steels) in 3.5M sodium chloride solution.

II. Material And Methodology

The materials used for the study are; low carbon steels, medium carbon steels and high carbon steels. Sodium Chloride was selected as the corrosive medium for this research. The chemical composition of the steels determined by spectroscopy is presented in Table 1.

Table 1: Chemical Composition of the Selected Steels. Bal. Fe (wt%).

	C	Mn	Si	P	S	Ni	Cr	V	Cu	Mo
LCS	0.27	0.61	0.18	0.38	0.06	0.11	0.21	0.01	0.23	0.02
MCS	0.42	0.75	0.30	0.05	0.05	0.50	0.45	0.18	0.35	1.58
HCS	0.80	0.90	0.37	0.07	0.04	0.55	0.50	0.23	0.40	2.08

LCS = low carbon steel. **MCS =** medium carbon steel. **HCS =** high carbon steel

Heat Treatment

The carbon steel samples (low, medium, and high carbon steels) were heated to 810^0C, 780^0C and 730^0C respectively, being the upper critical temperature of the steels, derived by the use of Grange equation [11]. The steel samples were allowed to soak for thirty (30) minutes. The low, medium, and high carbon steels samples were subjected to annealing and normalizing operations respectively.

Microstructural Examination

A Zeiss Metallurgical Microscope with accessories for image analysis was used for optical microscopic investigation of the carbon steel samples. The specimens for the test were metallographically polished and etched before microscopic examination was performed. The polished samples were etched in dilute aqua regal solution to reveal the phases.

2.4 Corrosion Test

Weight loss method was used to access corrosion behaviour of the carbon steel samples. Mass loss and corrosion rates were determined and used to analyze the rate of corrosion penetration. Following standard procedures, the corrosion test was performed by immersion of the test specimens in stagnant 3.5M NaCl solutions at room temperature. Prior to immersion, the test steel samples were dried and then mechanically polished using progressively finer abrasive paper (220 down to 600 grit), de-greased with acetone, washed in distilled running water and dried in air. After weighing, the samples were vertically exposed in the test solution. At interval of two days of exposure the samples were withdrawn from the test solution and rinsed with distilled water. Corrosion products were removed from the samples by chemical cleaning in accordance with ASTM G31 standard recommended practice [12]. The samples were then reweighed to determine their mass loss (g/cm^2) and the corrosion rate (mm/y) during exposure to NaCl solution. The test was monitored for a period of 60 days.

III. Results and Tables

Microstructure

The microstructure of the as cast, normalised and annealed low carbon steel is presented in figure 1a-c. It is observed that the microstructure of the as cast low carbon steel (Figure 1a) showed a combination of ferrite (white) and pearlite (black), While in the optical micrograph of normalized low carbon steel, the ferrite (light) structure as shown in Figure 1b became more obvious than the pearlite (dark) structure. The pearlite particle is finer compared to that of the as-received and some undissolved spots can be seen, which may be impurities/inclusions such as oxides and sulphides. As a result of considerable slow cooling in a full annealing process, Figure 1c is the micrograph of annealed steel sample. It shows coarse particles of pearlite and ferrite as compared to the as-received.

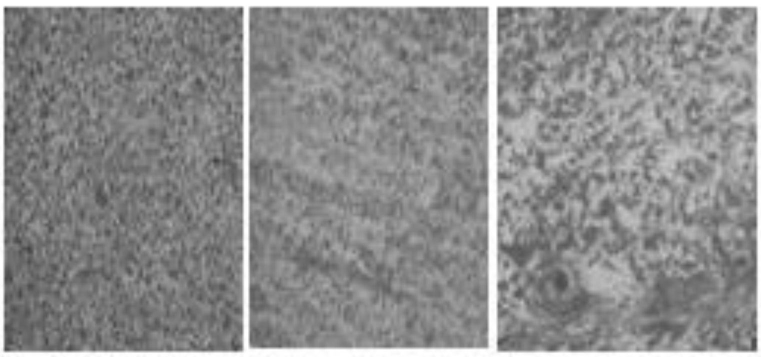

Figure 1: Optical micrograph of low carbon steel (a) as cast (b) normalized(c) annealed (X100).

Figure 2a: is the micrograph of as-received, normalized and annealed medium steel sample. It consist of the ferrite (light) and pearlite (dark) microstucture. Spherical in shape porosity is also shown in the microstructure of the sample. The normalized steel sample as depicted by Figure 2b micrograph shows the ferrite with pearlite microstructure, which is finer than that of the as-received. It is observed in the furnace-cooled/annealed steel sample micrograph (Figure 2c) that the particles of the pearlite and the ferrite matrix becomes coarser compared to that of the normalized steel sample after cooling in the furnace which makes the steel to be soft and ductile with little or no internal stress.

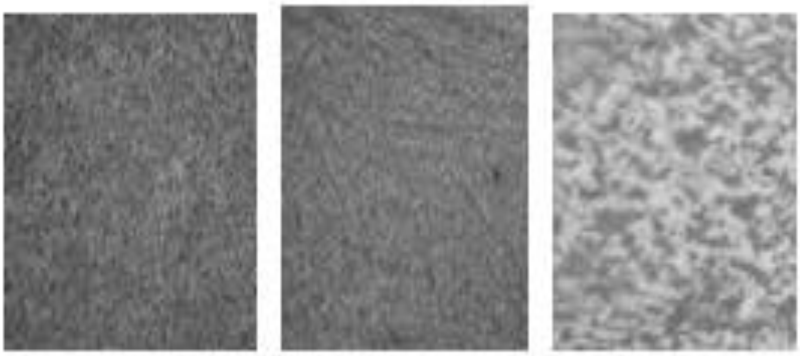

Figure 2: Optical micrograph of medium carbon steel (a) as cast (b) normalized(c) annealed (X100).

Figure 3a is the micrograph of as-received high carbon steel sample, which shows coarse structure of pearlite (dark) in the ferrite (light) matrix. The diagonal-like boundaries observed in the as cast high carbon steel may be as a result of effect of rolling because the sample is a plate. The diagonal-like boundaries were observed to reduced in the normalized steel sample (Figure 3b), pearlite particles are finer compared to that of the as-received. Normalizing process improves the strength of the steel. The porosities can still be seen in the microstrure of the sample. Figure 3c shows the annealed high carbon steel, it is observed that the pearlite appears to be coarser compared to that of the normalized sample.

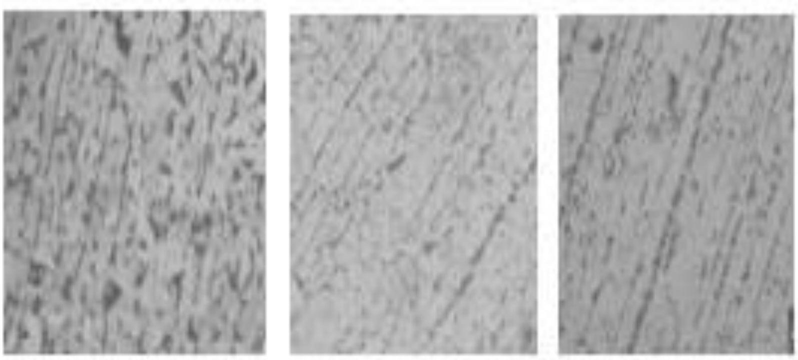

Figure 3: Optical micrograph of high carbon steel (a) as cast (b) normalized(c) annealed (X100).

Corrosion

Figure 3.1-3.3 presents the corrosion rate, weight loss and electrode potential plots for the as-received low carbon, medium carbon and high carbon steel samples, immersed in 3.5M NaCl solution. The high carbon steel has the least corrosion rate of the three test samples. For all the three samples, corrosion rate increased at the earlier stage of immersion, but most intense corrosion rate was observed in the medium carbon steel as its corrosion rate gradually decreases uniformly as shown in Figure 3.1. It is observed that weight loss in figure 3.2 is predominant for the medium carbon steel in comparison with the other carbon steels. The electrode potential of the 3 samples (Figure 3.3) is observed to increase at earlier stage of immersion. After the 3rd day, the electrode potential of all the 3 samples decreased. Between the 10th and the 36th day, there was a consistent rise and fall in the electrode potentials of the high carbon steel. On the 36th day, electrode potential of the 3 samples increased and immediately a decrease is observed after an increase on the 38th day. The decrease on the 38th day for the low carbon steel is very much and immediately increased sharply. The three samples began to decrease on the 43rd day without any sign on increasing until the end of the immersion.

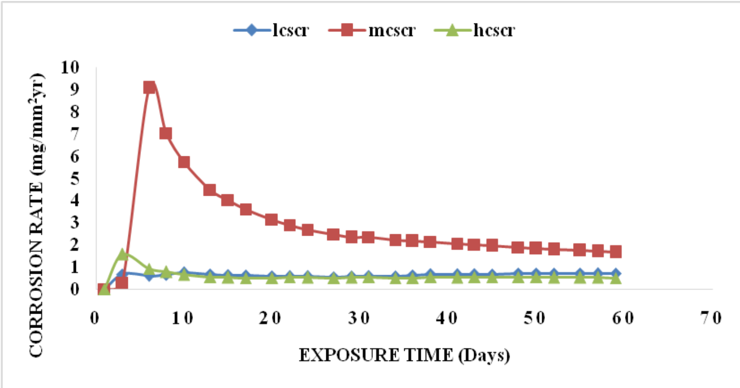

Figure 3.1: Variation of corrosion rate with exposure time of as-received low carbon, medium carbon and high carbon steels in 3.5 molar NaCl Solution.

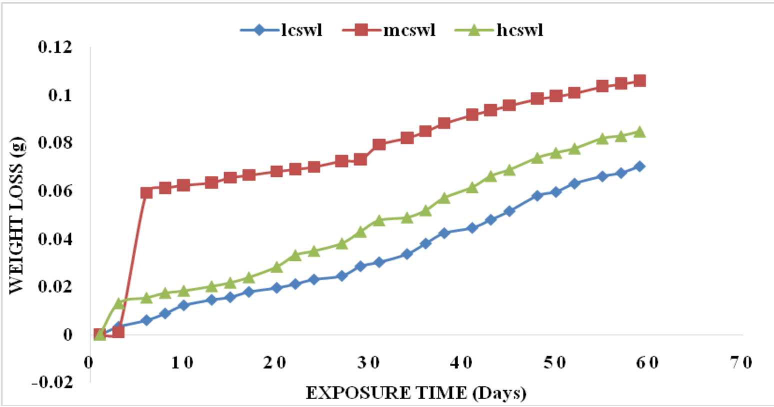

Figure 3.2: Variation of weight loss with exposure time of as-received low carbon, medium carbon and high carbon steels in 3.5 molar NaCl Solution.

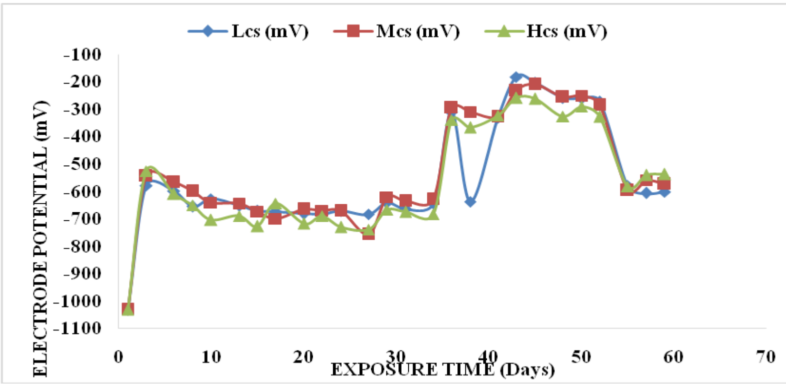

Figure 3.3: Variation of electrode potential with exposure time of as-received low carbon, medium carbon and high carbon steels in 3.5 molar NaCl Solution.

The plots of the corrosion rate, weight loss and electrode potential for the normalised low carbon, medium carbon and high carbon steel samples immersed in 3.5M NaCl solution are shown by Figure 3.4 – 3.6. At earlier stage of immersion, the corrosion rate of the samples as shown in Figure 3.4 increased sharply and immediately decreased before it began to increase again, except for the medium carbon steel which continued to increase until the 10^{th} day. The high carbon steel is observed to increase in its corrosion rate and started to decrease uniformly on the 15^{th} day until the end of immersion test, in contrast to the low and medium carbon steel samples that decreased on the 10^{th} day and were seen in figure 3.4 to increase on the 27^{th} day until the end of the immersion test.

The high carbon steel sample in Figure 3.5 shows the least weight loss in comparison with the medium carbon steel sample that is least at the earlier stage of immersion and increased uniformly on the 13^{th} day until the end of the immersion test. In Figure 3.6, the earlier stage of immersion of the three steel samples shows increase in electrode potential and decreased on 3rd day until the 34th day where all the three steel samples also increased in their electrode potential. Between the 3rd and 52nd day, the high carbon steel electrode potential is observed to increase before decreasing sharply until the end of the immersion test.

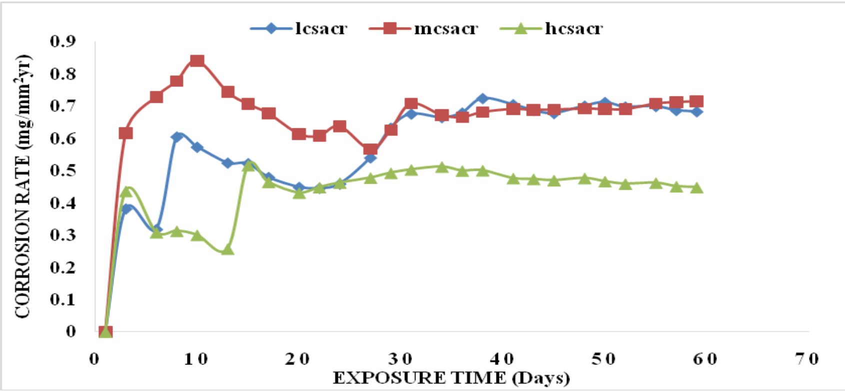

Figure 3.4: Variation of corrosion rate with exposure time of normalised low carbon, medium carbon and high carbon steels in 3.5 molar NaCl Solution.

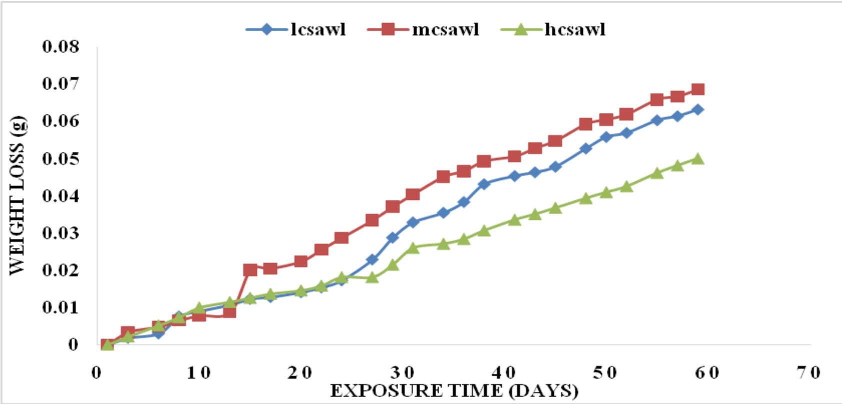

Figure 3.5: Weight loss with exposure time of normalised low carbon, medium carbon and high carbon steels in 3.5 molar NaCl Solution.

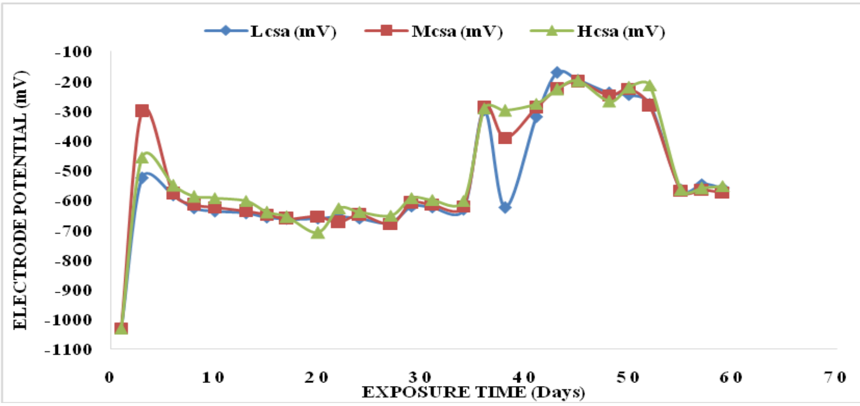

Figure 3.6: Electrode potential with exposure time of normalised low carbon, medium carbon and high carbon steels in 3.5 molar NaCl Solution.

Figure 3.7-3.9 shows the corrosion rate, weight loss and electrode potential plots for the annealed low carbon, medium carbon and high carbon steel samples, immersed in 3.5M NaCl solution. The earlier stage of immersion shows increase in the corrosion rate of the three steel samples. Between the 3rd and 24th day, Figure 3.7 shows an increase in the corrosion rate of the high carbon steel, although it is lowest compared to that of the low and medium carbon steels with higher corrosion rates which decreased for the medium carbon steel until the 34th day. But the low carbon steel experienced a rise and fall in its corrosion rate between the 3rd and 10th day and it decreased thereafter until the end of the immersion test. The high carbon steel shows the least corrosion rate.

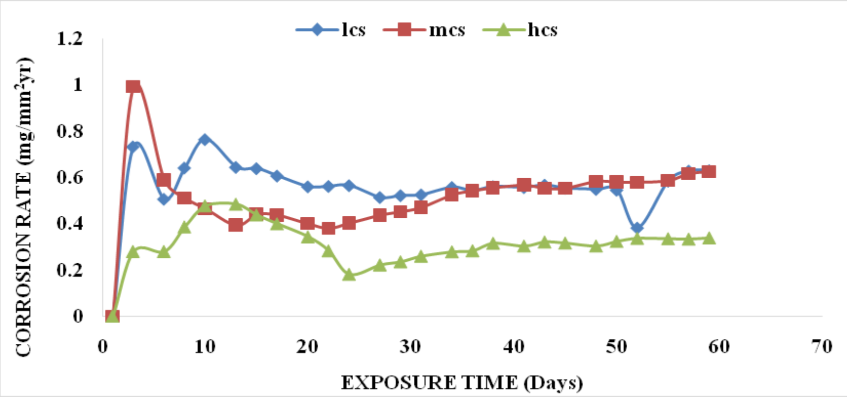

Figure 3.7: Corrosion rate with exposure time of furnace-cooled low carbon, medium carbon and high carbon steels in 3.5 molar NaCl Solution.

In Figure 3.8, medium carbon steel exhibits a uniform weight loss until the end of the immersion test, unlike the high carbon and low carbon steels that show decrease in their weight loss on the 24th and 52nd days respectively. The three steel samples show increase and decrease in their electrode potential as shown in figure 3.9. Between the 3rd and 50th days where decrease is observed, until the end of the immersion test.

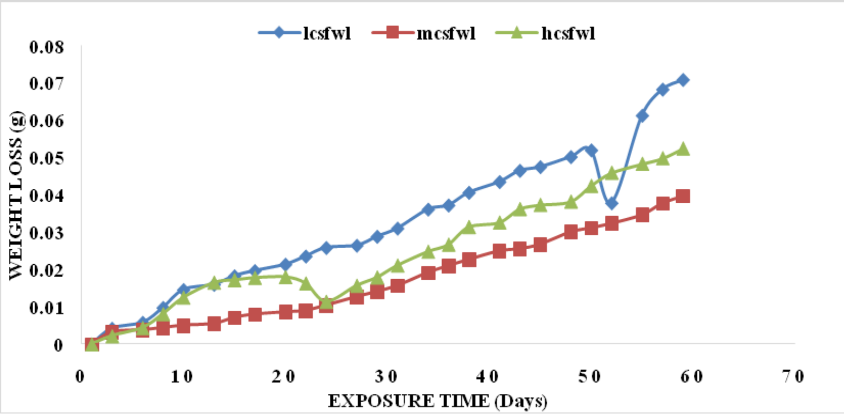

Figure 3.8: Weight loss with exposure time of furnace-cooled low carbon, medium carbon and high carbon steels in 3.5 molar NaCl Solution.

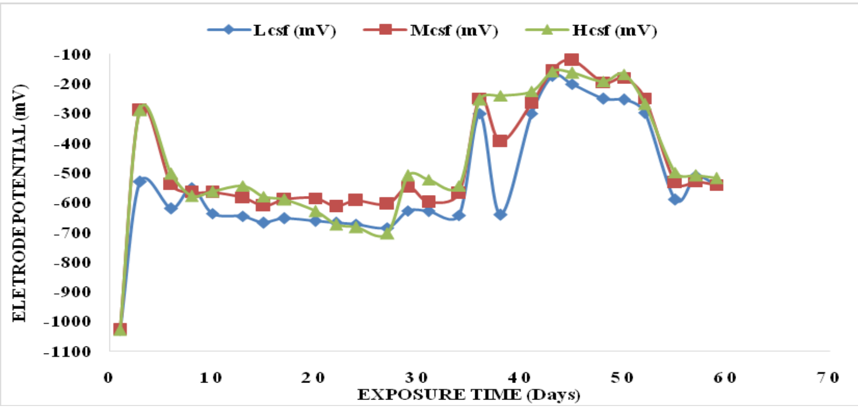

Figure 3.9: Electrode potential with exposure time of furnace-cooled low carbon, medium carbon and high carbon steels in 3.5 molar NaCl Solution.

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IV. CONCLUSION

- Metallography of samples revealed the presence of ferrite and pearlite in the as-received, normalized and furnace-cooled samples.
- Studies of the selected steels indicated that the highest corrosion resistance was exhibited by the high carbon steel at various heat treatments.
- Medium carbon steel exhibited the lowest corrosion resistance.

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