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Investigating the Effect of Heat Treatment on the Corrosion Susceptibility of 0.17% Low Alloy Steel

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Abstract

The safety of steel structures is of paramount importance in construction engineering and maintenance management. Corrosion causes strength deterioration and weakening of aged steel structures. Thus, if the right material is not selected for a particular application, the consequence of corrosion results in great losses, hence an investigation of the effects of annealing, normalizing, tempering and hardening heat treatments on the corrosion susceptibility of 0.17%C High Strength Low Alloy Steel in sea water was studied in this work. The samples were machined into cylindrical pieces of 16mm diameter and 40mm long and were properly labelled for easy identification. The non-heat treated and heat-treated samples were cleaned, weighted and immersed in sea water for various durations of 15, 30, 45, 60, 75 and 90 days. The optical micrographs were taken of the samples. The assessment of effect of corrosion on the steel samples used was carried out via weight loss at various exposure times which lasted for a maximum duration of 90 days. The weight losses were evaluated and used to determine the corrosion penetration rates of the samples in the medium. The results obtained shows that the corrosion rates for the samples are highest during the initial stages and thereafter reduce with time. The normalized sample shows a lower corrosion penetration rate of 6.40E-05 mg/cm^2/year when compared to other samples studied. Also, the normalized samples show a lower weight loss of 0.3 and hence corrode less while the control shows a higher weight loss 0.88.

1. Introduction

Heat treatment of steels is a process that requires steel to be exposed to one or more temperature cycles to confer certain desired properties. One method of enhancing mechanical properties of carbon steel is heat treatment [1.2] This is a science that originated as an art in man's attempt to improve the performance of materials in their applications. In present day metallurgical practices, heat treatment has come to represent whole class of techniques - involving thermal, mechanical and chemical treatment by which the desired properties of structural materials are obtained to suite a variety of application. When properly designed and implemented, the process of heat treatment results in the composition and/or distribution of phases; and corresponding changes in physical, chemical and mechanical properties are thus achieved in substantial measure. This implies that within the constraints of available resources, there is capability to considerably extend the performance of materials. The mechanical and chemical properties can be improved by varying the proportion of micro-constituents within the materials.

Heat treatment may be defined as ‘’Heating and cooling operations applied to metals and alloy (component) in solid state so as to obtain the desired properties [3]. The process consists of heating a metal or alloy to a specific predetermined temperature, holding at this temperature for required time and finally cooling from this temperature, all in the solid state of the material. By metal heating and cooling at certain rates, the mechanical properties can be enhanced, the microstructure of the metal is slightly affected though [4]. Heat treatment of metals is an important operation in final fabrication process of any engineering materials. Primary objective of the operation is to change the form in which carbon is distributed in the steel structure. The subject of this process is to make the metal better suited structurally and physically, for specific applications. Plain carbon and alloy steels are among the relatively few engineering materials that can be usefully heat treated in order to vary their chemical and mechanical properties. This is because of the structural changes that can take place within the solid Iron-Carbon alloys [3]. Stephen et al, [5], investigated the effects of heat treatment on corrosion rates of mild steel pipe weldments and pipe whip restraint devices in saltwater. They discovered that that corrosion rate decreased with increased pipe preheat temperatures but increases with increase in welding pass. Corrosion rate of mild steel was also found to depend on the tempering temperature and immersion time. They concluded that appropriate heat treatment could be used to minimize the corrosion rates of metallic structures in a corrosive medium. Shuaib-Babata et al., [6], also studied the corrosion behaviour of commercial mild steel in municipal tap water. The mild steel was subjected to various heat treatments (annealing, hardening, normalizing and tempering) and the result revealed the more corrosion resistivity was observed for heat-treated samples than untreated sample, most especially the annealed and normalized samples. Igwemezie and Ovri [7], studied the effects of microstructural change and corrosion susceptibility of heat-treated medium carbon steel in different corrosive media. The study showed that ferrite precipitation and carbide phases in the microstructures derived from the different heat treatment processes were sensitive to the environment. These phases led to setting up of microgalvanic cells within the microstructure with the carbide phase becoming cathodic and the ferrite anodic. Tahey also observed that combining effect of ferrite precipitation, transformation stress and carbide precipitation caused the martensitic structures to experience high corrosion rate, which could be attributed to high metastability (non-equilibrum position) of martensitic structure. In general, normalized structure showed the lowest susceptibility to corrosion attack while the martensitic structure showed the highest susceptibility to corrosion attack. More so, $0.5MH_2SO_4$ was the most aggressive environment, followed by 0.5MHCL, Seawater and lastly Effluent water. It is said that carbon content and heat treatment play a major role in the final outcome of the microstructure of a metal. [8] This research therefore is focusing on how the microstructure of a low alloy steel (0.17%) affects its corrosion in seawater, since the microstructure of each composition of steel varies with chemical composition.

2. Materials and Method

2.1 Materials

The steel used in this research work is low alloy steel rod of 20mm diameter. The 0.17%C steel was purchased from a local vendor in Lagos State. Chemical composition of 0.17%C steel was obtained by wet chemical method from the same company. The results obtained are presented in Table 1.

Table 1. Chemical Composition of the Steel Sample used for the research (wt%)

Element	C	Si	Mn	P	S	Cr	Mo	Ni
Weight (%)	0.1728	0.3016	1.2089	0.0352	0.0334	0.2559	<0.0100	0.1218
Element	Al	Cu	Ti	V	Nb	W	Co	B
Weight (%)	<0.0100	0.256	<0.0100	<0.0100	<0.0150	<0.0500	<0.0200	0.0047
Element	Sn	As	Pb	Fe				
Weight (%)	<0.0100	<0.0100	<0.0200	97.5604				

2.2. Heat Treatment

Some series of heat treatment were carried out on the samples. Firstly, the annealed samples were heated to 830^{o}C, soaked for 45 minutes and then cooled in the furnace to ambient temperature. The normalized samples were heated to 830^{o}C, soaked for 45 minutes and then cooled in still air to ambient temperature. The tempered samples were heated to 830^{o}C, soaked for 45 minutes, quenched and then re-heated to 330^{o}C for 45 minutes and then cooled in still air. The quenched samples were heated to 830^{o}C, soaked for 45 minutes and then cooled in water at ambient temperature. After heat treatment was carried out on the samples, they were collected before being immersed into the sea water medium. Some heat treated samples were used as control for better comparison with other samples.

2.2. Corrosion Rate Determination

The samples were divided into six (6) groups of A, B, C, D, E and F. Group A samples were soaked in sea water for 15 days, B for 30 days, C for 45 days, D for 60 days, E for 75 days and F for 90 days. All experiments were conducted at room temperature (25^{o}C). The experiment involved periodic weight loss measurement techniques. The corroded samples were removed from the medium, they were washed, cleaned, dried, reweighed by using the procedures and precautions as described by Afolabi et al [8].

The corrosion rates were calculated using the formula, corrosion rate (C.R) in mg/cm^2/year;

$$CPR = 87.6\frac{W}{DAT} \qquad 1$$

Where W = weight loss after exposure in milligrams (mg)
D = density of specimen, g/cm^3
A = exposed total surface area (cm^2)
T = exposure time in hours

Where,

$$A = 2\pi r^2 + 2\pi rl \qquad 2$$

$$A = 2\pi r(r + l)$$

For the samples,
l = 40mm = 4cm
r = 8mm =0.8 cm
Therefore;

$$Area(A) = 2 \times \frac{22}{7} \times 0.8(0.8 + 4)$$

$$A = 24.14cm^2$$

2.3. Optical Microscopy

Surface morphology of the samples after and before weight loss were analyzed by using optical microscopy. These samples were cleaned with acetone to remove any dust or impurity on the surface of specimens prior to microstructural investigation.

3. Results and Discussion

3.1. Effect of Corrosion on Weight Loss and Corrosion Penetration Rate

Table 2 shows that there is consistent and gradual loss in weight of the specimens with longer exposure time to the corrosion environment (sea water). The results of exposure of the various specimens i.e. control, annealed, normalized, hardened and tempered for soaking period of 15, 30, 45, 60 and 90 days are shown in Figures 1 and 2 respectively. It is obvious from the Figures that corrosion rates for all the samples are highest during the initial stages and thereafter reduces with time. The high initial corrosion might be due to the availability of fresh activated surface, and high initial oxygen content of the solution. The reduction might have resulted from the formation of a product layer which might have shielded the iron surface from further corrosion.

In Figure 2, it can be seen that the corrosion penetration rate decreases gradually as time of exposure increases with the normalized sample exhibiting lowest corrosion rate throughout the exposure time. The control sample has the highest corrosion rate relative to other samples, that is the rate of corrosion penetration rate is higher in the control specimen while the normalized specimen exhibits a slower rate of penetration. Also, the weight loss of the control specimen was higher while the normalized specimen shows the lower weight loss as the exposure time increase in Figure 1. This result is in agreement with the work done by Igwemezie and Ovri, [7]. They attributed the corrosion rates difference to precipitation of carbide and ferrite and phases. The carbide phase became the cathode and the ferrite anodic as a result of the micro-galvanic cells sets up within the microstructure in these phases. The normalized samples had their carbide particles finely distributed within the ferrite matrix that could explain why the corrosion of the ferrite phase (anodic phase) not too noticeable. The highest corrosion rate observed in the martensitic samples could be due to the combining effect of stress and carbide precipitation. (Igwemezie) This could be attributed to high metastability (non-equilibrum position) of martensitic structure.

Table 2. Table of Result for Weight Loss for 90 days

DAYS	Specimen	Weight before exposure to seawater (mg)	Weight after exposure to seawater (mg)	Weight Loss (mg)	Corrosion Peneration Rate
15	Control	50.57	50.25	0.32	4.10E-04
	Normalized	47.23	47.21	0.02	2.56E-05
	Hardened	58.58	58.39	0.19	2.43E-04
	Annealed	51.17	51.06	0.11	1.41E-04
	Tempered	53.87	53.79	0.08	1.03E-04
30	Control	78.43	77.91	0.52	3.33E-04
	Normalized	90.68	90.54	0.14	8.96E-05
	Hardened	77.35	77.02	0.33	2.11E-04
	Annealed	72.95	72.7	0.25	1.60E-04
	Tempered	78.56	78.39	0.17	1.09E-04
45	Control	75.32	74.92	0.4	1.71E-04
	Normalized	75.92	75.82	0.1	4.27E-04
	Hardened	81.6	81.36	0.24	1.02E-04
	Annealed	71.24	71.08	0.16	6.83E-05
	Tempered	80.32	80.21	0.11	4.70E-05
60	Control	81.52	80.92	0.6	1.92E-04
	Normalized	76.61	76.42	0.19	6.08E-05
	Hardened	79.05	78.67	0.38	1.22E-04
	Annealed	75.37	75.09	0.28	8.97E-05
	Tempered	75.12	74.91	0.21	6.72E-05
75	Control	81.03	80.25	0.78	2.00E-04
	Normalized	70.07	69.78	0.29	7.43E-05
	Hardened	72.89	72.39	0.5	1.28E-04
	Annealed	81.08	80.68	0.4	1.03E-05
	Tempered	70.63	70.32	0.31	7.94E-05
90	Control	77.6	76.72	0.88	1.88E-04

Normalized	77.62	77.32	0.3	6.40E-05
Hardened	77.41	76.72	0.69	1.47E-04
Annealed	74.29	73.77	0.52	1.11E-04
Tempered	80.85	80.52	0.33	7.04E-05

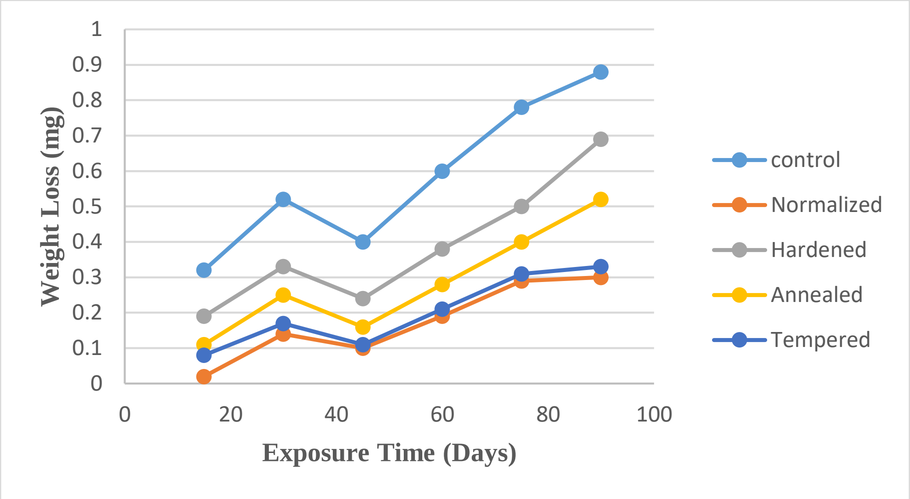

Figure 1. Plot of weight loss against Exposure time of 90 days

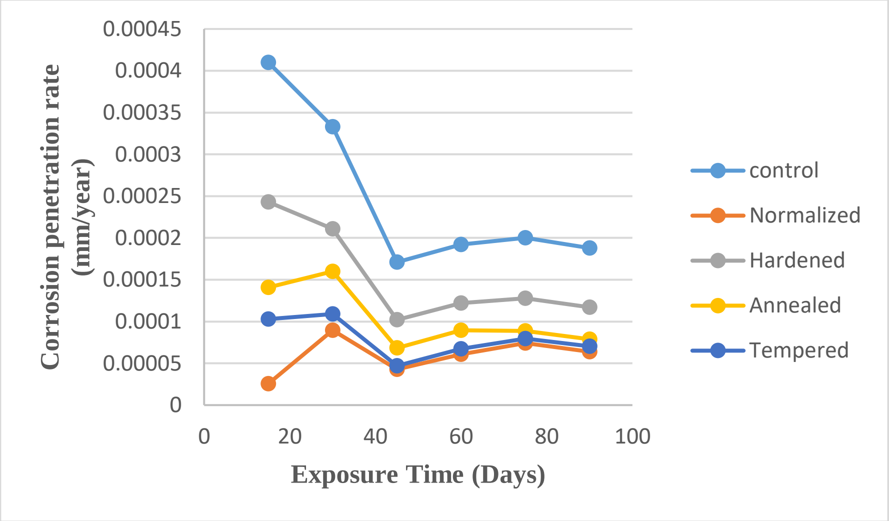

Figure 2. Plot of Corrosion Penetration Rate against Exposure time of 90 days

3.2. Effect of Corrosion on Weight Loss and Corrosion Penetration Rate

Table 2 shows that there is consistent and gradual loss in weight of the specimens with longer exposure time to the corrosion environment (sea water). The results of exposure of the various specimens i.e. control, annealed, normalized, hardened and tempered for soaking period of 15, 30, 45, 60 and 90 days are shown in Figures 1 and 2 respectively. It is obvious from the Figures that corrosion rates for all the samples were high during the initial stages and thereafter reduces with time. The high initial corrosion might be due to the availability of fresh activated surface, and high initial oxygen content of the solution. The reduction might have resulted from the formation of a product layer which might have shielded the iron surface from further corrosion.

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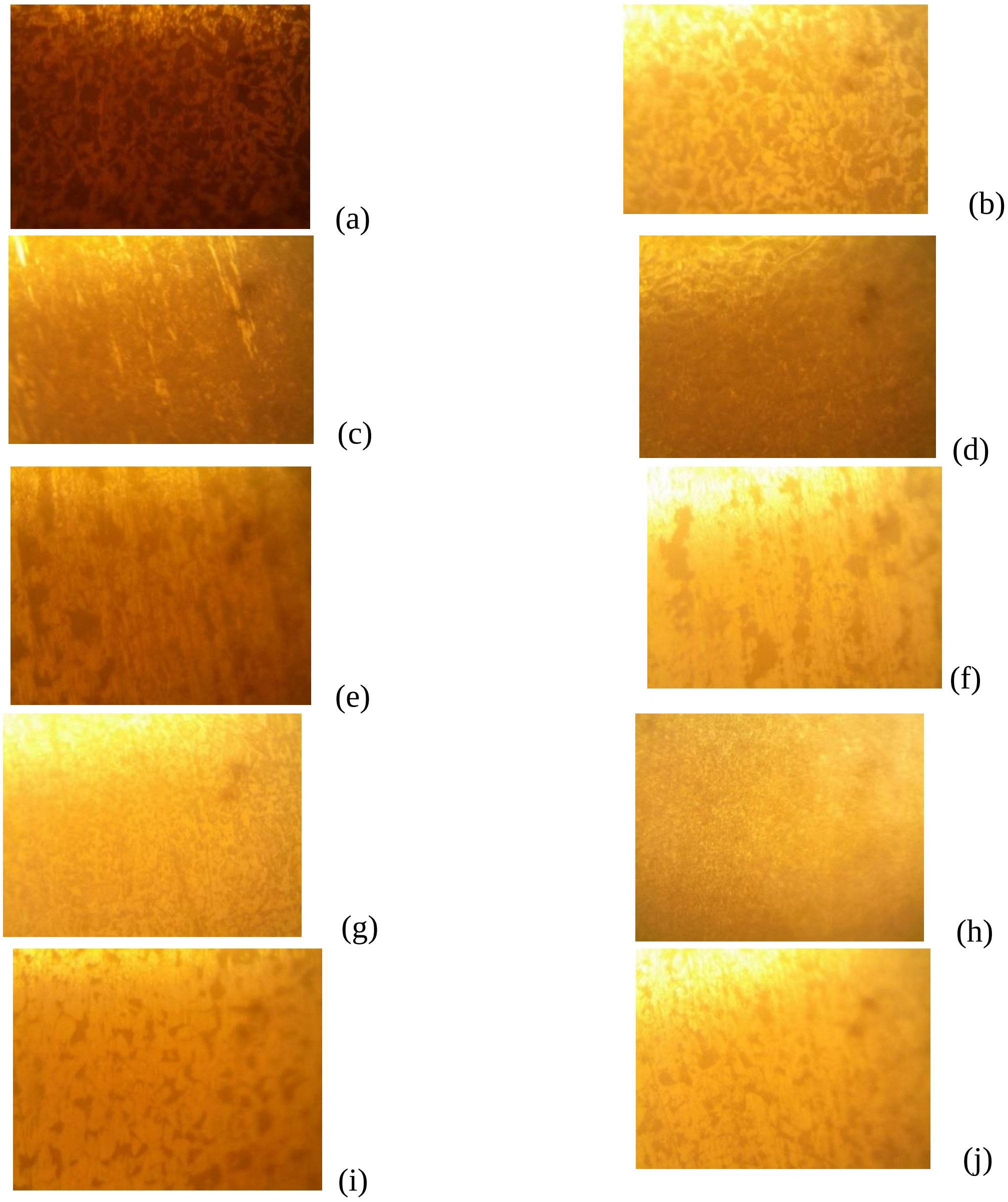

Figure 3. (a) Control sample as received (X1000), (b) Control sample after 90 days (X1000), (c) Hardened sample (Control) (X1000), (d) Hardened sample exposed for 90 days (X1000), (e) Annealed sample (control) (X1000), (f) Annealed sample exposed for 90 days (X1000), (g) Normalised sample (control) (X1000), (h) Normalised sample exposed for 90 days (X1000), (i) Tempered sample (control) (X1000), (j) Tempered sample exposed for 90 days (X1000)

exposure time. The control sample has the highest corrosion rate relative to other samples, that is the rate of corrosion penetration rate is higher in the control specimen while the normalized specimen exhibits a slower rate of penetration. Also, the weight loss of the control specimen was higher while the normalized specimen shows the lower weight loss as the exposure time increase in Figure 1. This result is in agreement with the work done by Igwemezie and Ovri, [7]. They attributed the difference in corrosion rates to precipitation of ferrite and carbide phases. These phases probably led to micro-galvanic cells setting-up within the microstructure with the carbide phase becoming cathodic and the ferrite anodic. The normalized samples had their carbide particles finely distributed within the ferrite matrix that could explain why the corrosion of the ferrite phase (anodic phase) was not too noticeable. The combining effect of stress and carbide precipitation could have resulted in higher corrosion rate in the martensitic structures. This is also in agreement with Bagliani et al, [10] This could be attributed to high metastability (non-equilibrum position) of martensitic structure. Figure 3a, c,e,g and i shows the heat treated samples. (control, Hardened, Annealed, Normalized and Tempering respectively). Figure 3a shows dispersion of cementite particle in equiaxed ferrite grain with less visible grain boundaries. Figure 3c shows fine plate like martensite evenly distributed within the matrix. Figure 3e shows visible coarse pearlite distributed over a long distance within the ferrite grain. Figure 3g shows fine dispersion of cementite evenly distributed within the ferrite grain. The cementite evenly distributed within the ferrite in Figure 3g could be the reason why the normalized steel had the least corrosion rate. The cementite which acts as the cathode seems to be everywhere within the ferrite matrix, given little room for corrosion of the ferrite which acts as the anode. Figure 3i shows fine dispersion of cementite within the ferrite grain. With prolong exposure to sea water environment, there was a consistent depletion of the ferrite phase of 0.17%C steel as revealed by the subsequent microstructure of the corrosion specimens and also the grain boundaries gradually begin to be non-visible as shown in Figure b, d, f, h, and j

4. Conclusion

The extents to which normalizing, annealing, tempering and quench hardening heat treatments can enhance corrosion resistance of high strength low alloy steel in sea water has been procedurally investigated. Prolonged exposure to the corrosive sea water environment results in the depletion of the ferrite phase of the material. The normalized steel was found to have the lowest corrosion rate, while the hardened sample was found to have the highest corrosion rate.

References

[1] Biswas, P., Kundu, A., Mondal, D. and Bardhan, P.K., 2018, June. Effect of heat treatment on microstructure behavior and hardness of EN 8 steel. In IOP Conference Series: Materials Science and Engineering Vol. 377(1) p. 012065

[2] Wang G. Y., Teschler T., and Weinreich, 2014 "Influence of Localized Pit Distribution on the Ultimate Compressive Strength of Steel Plating for Shipping". Ina. Assoc. Corros. Eng. Corros. *J.*, Vol.70(9), pp. 915–917.

[3] Vernon J.B (1992) – “Introduction to Engineering Materials”, 3rd edition, Macmillian Press, London. pp 221-248 and 348-406.

[4] Brooks, C. R "Principles of the Heat Treatment of Plain Carbon and Low Alloy Steels". *ASM International.* 1996.

[5] Stephen, J.T., A.J. Alawode, and O.I. Oluwole, 2008, Effects of Heat Treatment on Stress Corrosion Cracking of Pipe Weldments and Pipe-Whip Restraint Devices in Seawater Medium. Journal of Engineering and Applied Sciences, Medwell Publications, **3**(4): pp. 350-356.

[6] Shuaib-Babata, Y.L., A.G.F. Alabi, and N.O. Dirisu, 2009, Investigation into Corrosion Behaviours of Commercial Mild Steel in Ilorin (Nigeria) Tap Water from Asa and Agba Dams. Journal of engineering and earth science, **3**(1): pp. 62-69.

[7] Igwemezie, V.C. and Ovri, J.E.O., 2013. Investigation into the effects of microstructure on the corrosion susceptibility of medium carbon steel. *IJES*, *2*(6), pp.11-26.

[8] Georgina, U.U. and Oghenerobo, A., 2019. Effect of Microstructural Morphology on the Cavity formation of 0.17% C Low Alloy Steel and 0.32% C Steel. NIPES Journal of Science and Technology Research, 1(1).

[9] Afolabi A, S (2007). Corrosion and Stress Corrosion Behaviors of Low and Medium Carbon Steels in Agro-Fluid Media. Leonardo Electronic Journal of Practices and Technologies 1583-1078, p. 55-66

[10] Bagliani, E.P., Santofimia, M.J., Zhao, L., Sietsma, J. and Anelli, E., 2013. Microstructure, Tensile and toughness properties after quenching and partitioning treatments of a medium-carbon steel. *Materials Science and Engineering: A*, *559*, pp.486-495.