



Investigation of the Effects of Heat Treatment on the Corrosion Behaviour of Welded Low Carbon Steel in Different Environments

Ayodele C.O, Nenuwa O.B.

Mineral Resources Engineering Department,
Federal Polytechnic, Ado-Ekiti, Nigeria.

ABSTRACT

The effects of heat treatment on the corrosion behaviour of welded low carbon steel in distilled water, hydrochloric acid and sodium chloride solution at ambient temperature (25⁰C) was studied. Twenty 10x10x10mm low carbon steel samples were divided into four groups (A, B, C and D) with five samples in each group. Group A samples were not welded while group B, C and D were welded using electric arc welding techniques and then subjected to stress relieving annealing. Samples in group B, C and D were thereafter heat-treated by normalizing, annealing and quenching respectively. Samples in the four groups were dipped in 0.3M and 0.5M HCl, 0.3M and 0.5M NaCl and distilled water for 21days and the potential difference and weight loss were measured after every 3 days. The corrosion rate was calculated using the ASTM recommended relation. The result revealed that in distilled water and 0.3M NaCl, the annealed samples had better corrosion resistance than the normalized and quenched samples, but in 0.5M NaCl, the quenched sample had better corrosion resistance than the annealed and normalized samples. The normalized samples were found to have lower corrosion rate in both 0.3M and 0.5M HCl when compared with the annealed and quenched samples.

Keywords: Corrosion, Low-carbon steel, Welding, Normalizing, Annealing, Quenching

1. INTRODUCTION

Corrosion is a prevailing destructive phenomenon in science and technology [1]. Most industrial media are usually rich in elemental gases, inorganic salts, and acidic solutions most of which influence corrosion rates, and mechanisms. Metals are usually exposed to the action of bases or acids in the industries. Processes in which acid play a very important role are acid pickling, industrial acid cleaning, cleaning of oil refinery equipment, oil well acidizing and acid descaling [2]. Industry always suffers financial loss due to material deterioration which is a loss in materials directly or indirectly. A direct loss in materials is due to the corrosion of a part of equipment that will cause it to stop functioning correctly. This direct loss in materials may cause damage to parts that depends on the direct damaged part which produces the indirect loss. Such as the operation interruption of industrial plants, over dimension of structures and equipment and mainly the losses imposed to the society and the environment due to toxic or inflammable chemical accidents or leaks. The quantity of deteriorated materials varies from 15 to 25% of the steel produced in the world, making the cost of the product reaches 4.0% of the gross product industrially produced [3]. Gooch [4] stated that; the failures in metallic components may happen in a very fast way preventing from detecting the problem in time to be repaired, thus causing high costs expenses.

Failures as a result of poor mechanical properties and corrosion resistance have also found their places in the annals of times, from household equipment to industrial structures such as railways, road bridges, storage tanks and ocean liners. One of such failures is the corrosion cracking of a grade 304 stainless steel pipe improperly seam welded and meant for the conveying of glucose solution in Illinois USA [5]. The Point

Pleasant bridge disaster in Ohio was also traced to stress corrosion cracking initiated during welding [6]. Many other failures have proved to be welding prone or propagated. It is therefore pertinent to investigate the influence of the various heat treatment on welded carbon steel. Carbon steel, the most widely used engineering material accounts for appropriately 85% of the annual steel production worldwide. Prominent among these steel is low carbon steel. Low-carbon steel is steel with low carbon content and less than 1% total alloying additions. They include those in the AISI series C-1008 to C-1025. Carbon ranges from 0.005 to less than 0.3%, manganese ranges from 0.25 – 1.5% phosphorus is 0.004% maximum and sulphur is 0.005% maximum. The density of mild steel is approximately 7.85 g/cm³ [7]. Despite the relatively limited corrosion resistance of low-carbon steel, its increasing use in marine application, chemical processes, petroleum production, refineries, pipeline, transportation, mining construction and metal processing equipment may be as a result of its low cost, relatively good weldability, good formability and their strength.

Corrosion involves the interaction (reaction) between a metal or alloy and its environment. Corrosive environments include the atmosphere, aqueous solutions, soils, acids, bases, inorganic solvents, molten salts and liquid metals. On a tonnage basis, atmospheric corrosion accounts for the greatest losses. Marine atmosphere are highly corrosive because of the presence of sodium chloride. Seawater contains predominantly sodium chloride, as well as some minerals and organic matters. Seawater is generally more corrosive than freshwater, frequently producing pitting and crevice corrosion. Soils have a wide range of compositions and susceptibilities to corrosion. Compositional variables include moisture, oxygen, salt



content, alkalinity and acidity as well as the presence of various forms of bacteria [8].

Welding is one of the most employed methods of fabricating steel components. It is basically a fusion of two or more pieces of metals by the application of heat and sometimes pressure [9]. It is not unusual to find that, although the wrought form of a metal or alloy is resistant to corrosion in a particular environment, the welded counterpart is not. Further, welds can be made with the addition of filler metal or can be made autogenously (without filler metal). There are times when the weld behaves in an erratic manner, displaying both resistance and susceptibility to corrosive attack. The cycle of heating and cooling that occurs during the welding process affects the microstructure and surface composition of welds and adjacent base metal. Consequently, the corrosion resistance of autogenous welds and welds made with matching filler metal may be inferior to that of properly annealed base metal because of: microsegregation, precipitation of secondary phases, formation of unmixed zones, recrystallization and grain growth in the weld heat-affected zone (HAZ), volatilization of alloying elements from the molten weld pool, contamination of the solidifying weld pool. [10]

The modification of microstructures to effect changes in metallic materials is done chiefly by alloying and heat treatment [11]. Heat treatment which involves the application of heat to bring about modification in the microstructure [12] essentially alters mechanical and chemical properties based on the retained austenite, grain size and defects such as dislocation, twinning, vacancies and so on.

Heat treatment is a method used to alter the physical and sometimes chemical properties of a material. One of the specific purposes of altering material properties is to improve their corrosion resistance characteristics. The relative limited service performance of welded steel materials as compared to non-welded parts under the same operating conditions is due to failure. Hence, the effect of various heat treatment methods on the corrosion rate of welded low-carbon steel in distilled water, acid and salt environments is of much interest. Recent investigations have revealed that less attention had been paid to heat treatment process for corrosion control. To this end, this work focuses on how to improve the corrosion resistance of welded low-carbon steel through heat treatment route using quenching, normalizing and annealing heat treatment processes. This is with the view to obtaining the best method of heat treatment process that could be given to welded structures of low carbon steel for optimum service performance in corrosive media.

Table I: Chemical composition of the “As – received” Low Carbon Steel

Element	Fe	C	Si	Mn	S	Cu	Al	Co	Ti	P	Ni
% weight	97.85	0.25	0.473	1.33	0.005	0.0033	0.006	0.047	0.006	0.003	0.027

2. MATERIALS AND METHOD

i. Materials

The materials used for this work are low-carbon steel plate of dimension 10x10x10mm obtained from metal scrap market at Owode-Onirin in Ikorodu, Lagos state, multi-purpose electrode (gauge 10) obtained at Victade Enterprises, off Ilesha road, Ondo state, concentrated hydrochloric acid (HCl) and sodium chloride salt (NaCl) which were obtained at Bisolab chemicals Limited, Ajilosun road, Ado-Ekiti.

ii. Chemical Analysis

The chemical analysis of the ‘as – received’ low-carbon steel sample was conducted at Nigeria Foundaries Limited, Ilupeju, Lagos by Optical Emission Spectrometry using an AR430 Metal analyzer. The chemical composition is shown in Table I.

iii. Samples Preparation

Twenty (20) samples of 10x10x10mm dimension were cut from the steel plate; the samples were divided into four (4) groups A, B, C and D with five (5) samples in each group. Group A samples were not welded which serves as the as-received samples while group B, C, D samples were welded using electric arc welding with general purpose electrode (gauge 10). Samples B, C and D were then subjected to stress relief annealing to remove the internal stresses imposed on them during welding. The samples B, C and D were then polished to remove scales resulting from this heat treatment and they were finally heat treated by normalizing, annealing and quenching respectively. All the heated treated samples were again thoroughly polished.

Stress Relief Annealing: Samples B, C and D were heated to a temperature of 650°C, soaked for 30minutes and allowed to cool in the furnace to ambient temperature (25°C).

Normalizing: Samples B were heated to 920°C soaked for 30minutes and cooled in still air to ambient temperature.

Annealing: Samples C were heated to 920°C soaked for 30minutes and cooled in the furnace to ambient temperature.

Quenching: Samples D were heated to 920°C soaked for 30minutes and cooled in water at ambient temperature.



iv. Preparation of Corrosion Media

0.3M and 0.5M hydrochloric acid (HCl) and sodium Chloride (NaCl) solutions were prepared at the Chemistry laboratory of the Department of Science Laboratory Technology of the Federal Polytechnic, Ado-Ekiti, Ekiti state. Distilled water was also obtained separately as a corrosion medium. Equal volume of each corrosion medium was poured into four conical flasks to obtain a total of twenty corrosion media as follows:

0.3M HCl (4 Conical flasks), 0.5M HCl (4 Conical flasks), 0.3M NaCl (4 Conical flasks) and 0.5M NaCl (4 Conical flasks) and distilled water (4 Conical flasks).

v. Corrosion Test

The corrosion test was carried out at the Physical laboratory of the Federal University of Technology, Akure, Ondo state. All the twenty samples were weighed before immersion inside the corrosion media. Thereafter, the twenty samples from group A, B, C and D were totally immersed inside the conical flasks containing the corrosion media accordingly to obtain a total of twenty experimental set-ups. The weight of the samples was measured at an interval of 3days (72hours) for 21days (504hours) and the weight losses were obtained accordingly. The PH was measured on daily basis for 21days using Buffer tablets stabilized PH meter. The corrosion rate was calculated in millimetres per year (mm/yr) using the recommended ASTM relation (Eq.1) [13]

$$\text{Corrosion rate} = \frac{K \cdot W}{A \cdot T \cdot D} \quad (1)$$

3. RESULTS AND DISCUSSION

i. Chemical Composition of As-received Steel Sample

The chemical composition of the as-received low-carbon steel sample used for the work is shown in Table I, the table showed that the percentage weight of Iron, Fe is 97.85% while that of Carbon, C is 0.22% while other elements represented 1.93% of the entire composition.

ii. Corrosion Rate

A plot of corrosion rate of the sample against exposure time in distilled water is shown in Fig.I,

from the plot, it can be seen that the samples corrosion rate decreases gradually as time of exposure increases with the annealed sample exhibiting lowest corrosion rate throughout the exposure time. The quenched sample has the highest corrosion rate relative to other samples.

Fig.II is the plot of corrosion rate against exposure time of the samples in 0.5M NaCl solution, from the graph, it can be seen that the samples corrosion rate also decreases gradually as exposure time increases, with the annealed sample exhibiting the highest corrosion rate throughout the time of exposure. The as-received and the quenched samples have lower corrosion rate compared with other samples. The graph also shows that the various heat treatment processes does not have significant improvement on the corrosion resistance of the as-received sample.

Fig.III shows plot of corrosion rate of the samples against exposure time in 0.5M HCl solution, from the graph, the samples show a sharp initial decreasing rate of corrosion followed by a gradual decrease in corrosion rate. The as-received sample had the highest corrosion rate, followed by the quenched sample, then the annealed sample, while the normalized sample had the lowest corrosion rate.

Fig.IV is a plot of corrosion rate of samples against exposure time in 0.3M NaCl solution, from the plot, it can be seen that the normalized sample exhibits the highest corrosion rate followed by the as-received sample, then the quenched sample while the annealed sample had the lowest corrosion rate.

Fig.V is a plot of corrosion rate against exposure time for the samples in 0.3M HCl solution, from the graph, a relative sharp decrease in corrosion rate with increase in exposure time can be observed for the annealed and as-received samples while for the quenched and normalized samples, a somewhat gradual decrease in corrosion rate was observed. Annealed sample had the highest corrosion rate while the normalized sample had the lowest corrosion rate.

A closer look at Fig.II – V shows that the corrosion rate is more pronounced in 0.5M NaCl and HCl than 0.3M NaCl and HCl. This confirmed that most metallic materials are more susceptible to corrosion at higher concentration of corrosion medium.

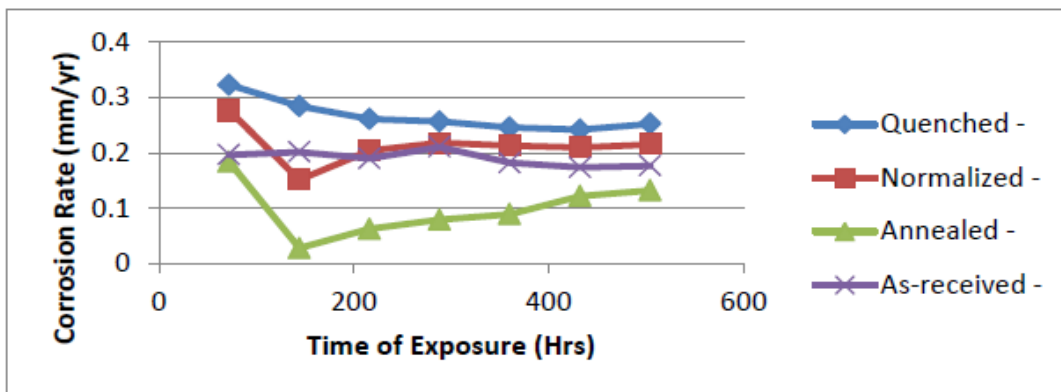


Fig I: Corrosion rate with time of exposure in distilled water

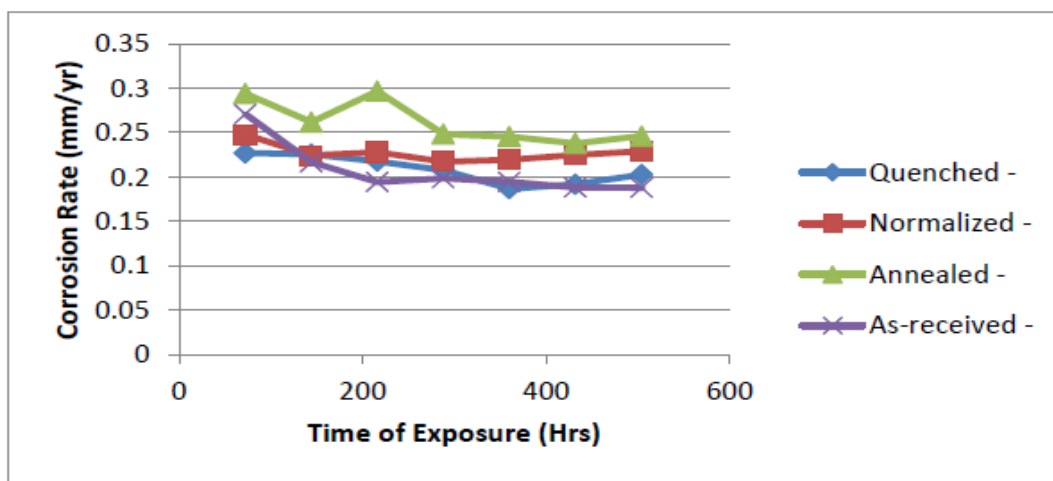


Fig II: Corrosion rate with time of exposure in 0.5M NaCl

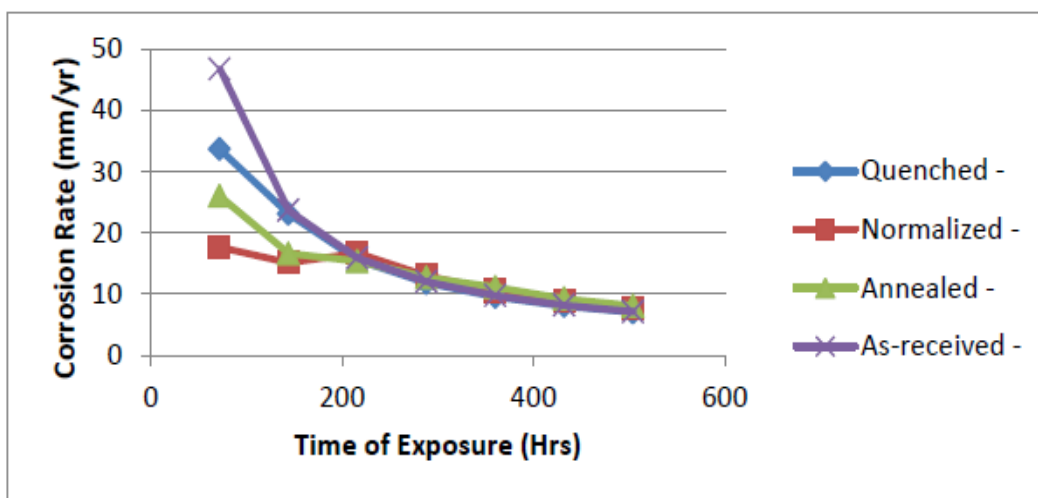


Fig. III: Corrosion rate with time of exposure in 0.5M HCl

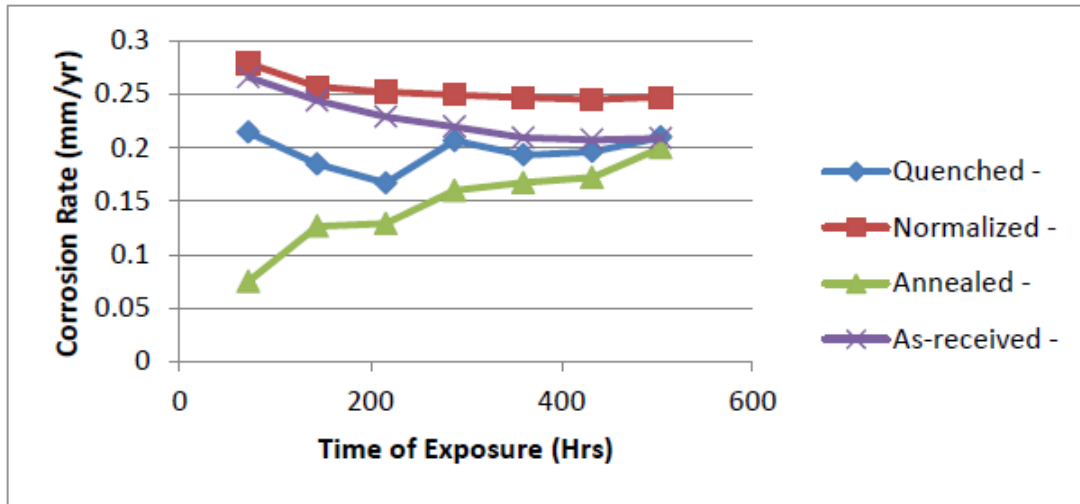


Fig. IV: Corrosion rate with time of exposure in 0.3M NaCl

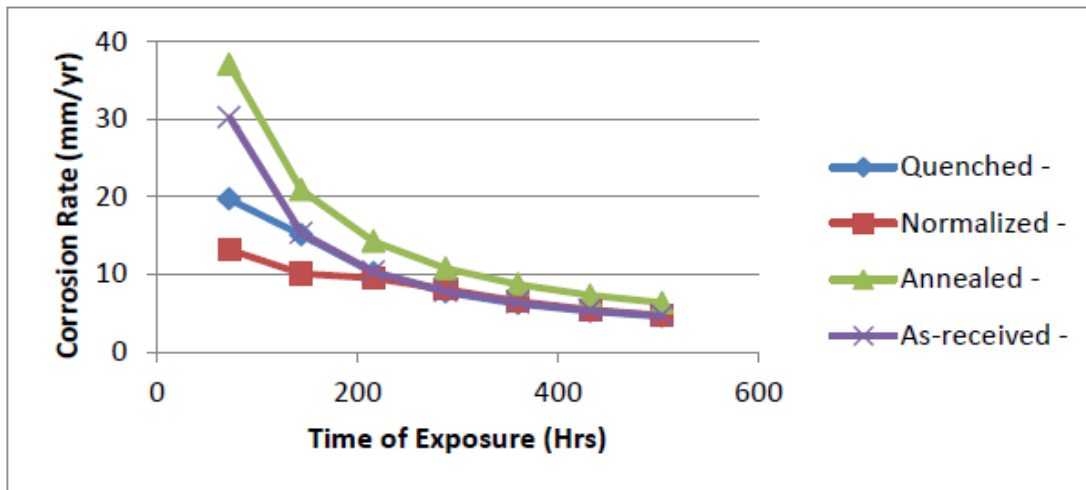


Fig.V: Corrosion rate with time of exposure in 0.3M HCl

iii. Hydrogen Potential (PH)

Fig.VI is the plot of samples PH against time of exposure in distilled water, from the plot, it is generally observed that samples PH decreases with increasing time of exposure with annealed sample showing lower PH relative to the quenched and normalized samples. Fig. VII is the plot of the PH against the time of exposure in 0.3M NaCl, unlike in the case of distilled water, there is an increase in the PH of the samples with increasing time of exposure, only small marginal differences in increase could be observed for the samples. The

plot of PH against time of exposure in 0.3M HCl is shown in Fig.VIII, from the figure, differential gradual increase in PH could be observed as compared to that of 0.3M NaCl with the annealed sample exhibiting higher values of PH than others. The plot of PH against time of exposure in 0.5M HCl is shown in Fig.IX, from this plot, there was an increase in the PH values of the samples with the quenched sample showing the highest values. The plot of pH against time of exposure in 0.5M NaCl is shown in Fig.X, an increase in the PH value of the samples over the exposure time is observed.

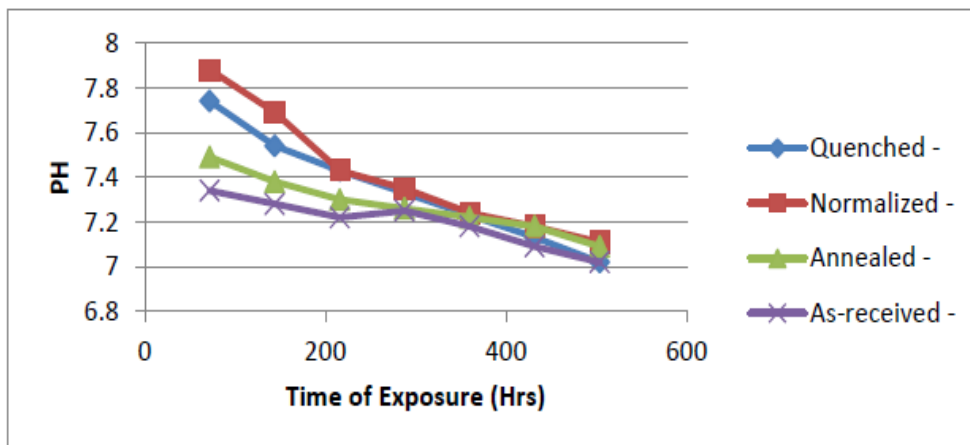


Fig VI: PH with time of exposure in distilled water

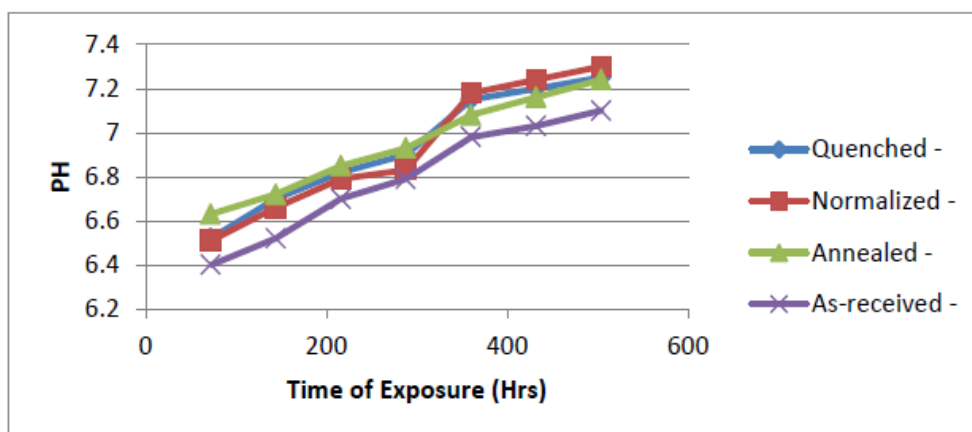


Fig. VII: PH with time of exposure in 0.3M NaCl

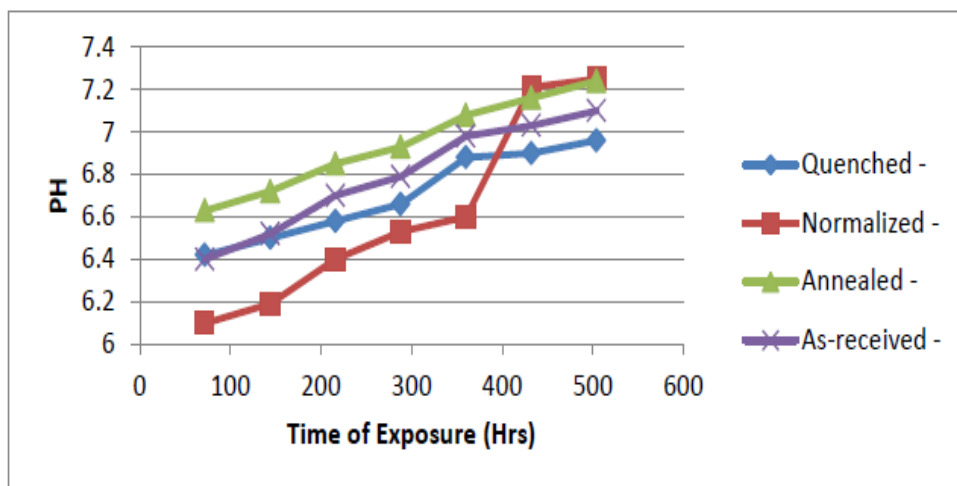


Fig. VIII: PH with time of exposure in 0.3M HCl

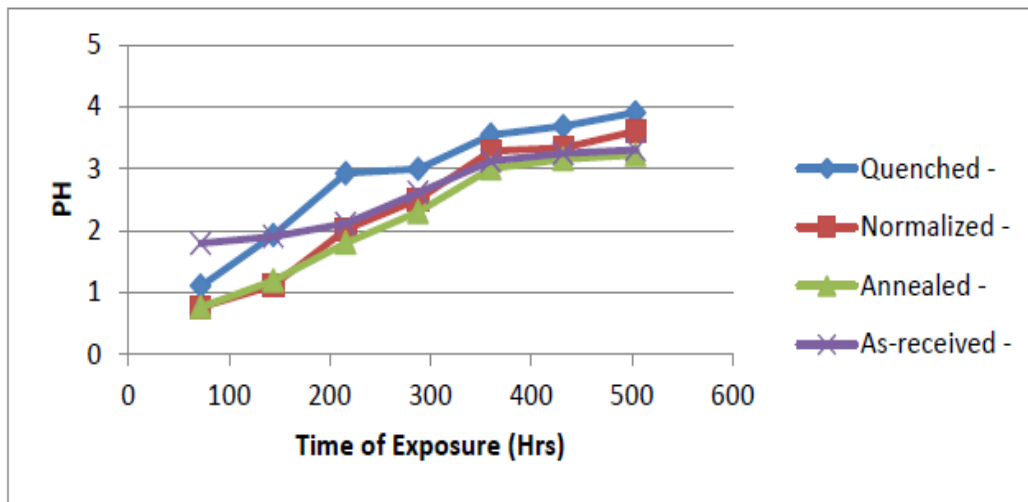


Fig. IX: PH with time of exposure in 0.5M HCl

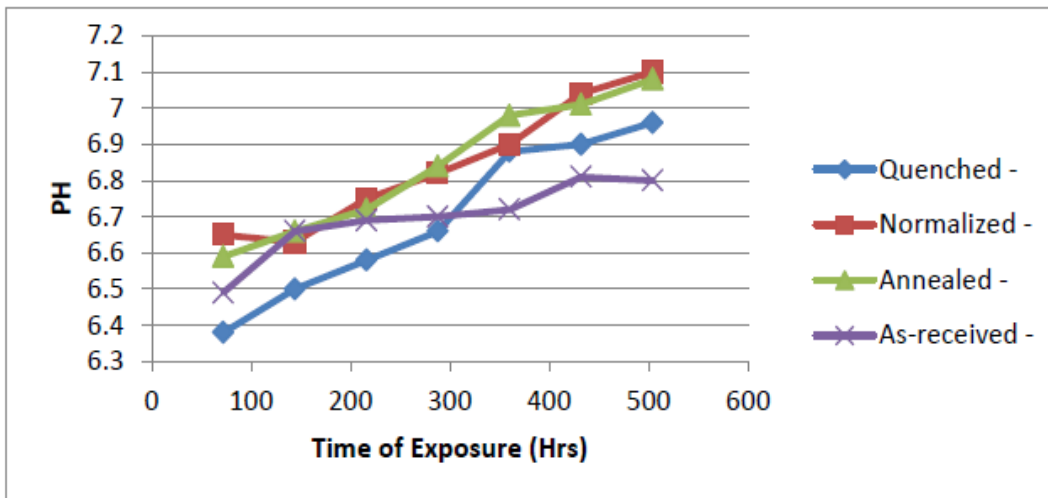


Fig. X: PH with time of exposure in 0.5M NaCl

4. CONCLUSION

Corrosion control can be best achieved by recognizing and understanding corrosion mechanism, by using corrosion resistant materials and design, and by using protective system devices and heat treatment. From the results of heat treatment approach used in this work, it was observed that the effectiveness of the heat treatment depends largely on the method of heat treatment employed and the concentration of the media in which the materials are subjected. For instance, in distilled water and 0.3M NaCl, the annealed sample was found to have better corrosion resistance than the normalized and quenched samples, but in 0.5M NaCl, the quenched

sample had better corrosion resistance than the annealed and normalized samples. The normalized samples were found to have lower corrosion rate at both 0.3M and 0.5M HCl when compared with the annealed and quenched samples.

Based on the obtained experimental results, the following recommendations are made:

- i. Further researches on the behaviour of welded low-carbon steel in NaCl and HCl environments should be carried out at higher concentrations.
- ii. Other heat treatment methods should be employed for treating the welded low-carbon steel; the products of such heat



treatment should be subjected to corrosive environments to ascertain the effect of the modification on the corrosion characteristics of the material.

- iii. To guarantee the integrity of welded low-carbon steel in other media such as H_2SO_4 and HNO_3 , researches on welded low-carbon steel should be conducted in these environments at low and high concentrations.

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REFERENCES

- [1] **Ita, B.I. and Offiong, O.E. (1999):** Adsorption studies on the corrosion inhibition properties of 2-acetylpyrole and 2-acetylpyrole-(2-acetylthiosemicarbazone) and mild steel in hydrochloric acid medium, *Global J. Pure and App. Sci.* 5(4): 497-501.
- [2] **Osarolube, E., Owate, I.O. and Oforka, N.C. (2008):** Corrosion behavior of mild and high carbon steels in various acidic media, *Scientific Research and Essay* Vol.3(6), pp. 224-228.
- [3] **Strobel, E.F., Mariano, N.A., Strobel K., Dionizio M.F:** Effect of the heat treatment in the resistance corrosion of a martensitic stainless steel CA6NM. 2nd Mercosur Congress on Chemical Engineering. Available online <http://www.enpromer2005.eq.ufrj.br/Inq/en/index.php>
- [4] **Gooch, T. G. (1995):** Heat treatment of welding 13%Cr - 4%Ni martensitic stainless steel for sour service. *Welding Research Supplement*, pp. 213-222.
- [5] **James, G.K. (2000):** Chronology of corrosion disasters. *Amer. Metal Soc. Handbook 5*, New York, NY, USA.
- [6] **Chamberlain, J. and Trethewey, A.R. (1988):** Corrosion for student of science and engineering. Longman Scientific and Technology Books, London, England.
- [7] **Elert, G. (2004):** [Density of Steel](http://hypertextbook.com/facts), hypertextbook.com/facts.
- [8] **William, D. and Callister, J. (1997):** *Materials Science and Engineering: An Introduction*. John Wiley and Sons, Inc, Canada.
- [9] **Agarwal, R.L. (1992):** *Welding Engineering - A Textbook for Engineering Students*, 4th ed., Khanaa Publ., Nai Sarai, Delhi, India.
- [10] **ASM (1987):** *Metal Handbook, Corrosion*: ASM International, USA.
- [11] **Kamma, C.M. (1993).** Design of microstructure in mild steel by thermochemical treatment. *Proceedings of Nigerian Metallurgical Society*, Vol. 11, pp 8-18.
- [12] **Rajan, A. (1993).** Heat treatment principles and techniques. Prentice Hall of India, New Delhi., pp 1-6.
- [13] **ASTM (2004):** Standard Practice for Laboratory Immersion Corrosion Testing of Metals, Designation G 31-72 (Reapproved 2004), ASTM International: 1- 8.

NOMENCLATURE

- W = Weight loss (gram)
 A = Total area of exposure (cm^2)
 T = Exposure time in hours
 K = Constant = 87600
 D = Density of low carbon steel = $7.86g/cm^3$