

Effect of Quenching and Tempering on Corrosion of Low Carbon Steel in Acid Environment

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ABSTRACT

The degradation of infrastructures particularly in salt and acid environment has continued to generate a lot of worries to researchers in this noble area which necessitate investigation of quenching and tempering on corrosion rate of low carbon steel in 1M HCl acid solution using conventional weight loss method in view to procure lasting solution to the problem. A total number of twenty (20) samples were heat treated at a temperature of 950°C for a period of 2 hours with five (5) samples left untreated which serve as control. Ten (10) each of heat treated samples were quenched in water and engine oil after soaking and five (5) samples each of water quenched and oil quenched were further tempered to a temperature of 450°C for 1 hour. The untreated, quenched and tempered samples were immersed in 1M HCl acid solution for a period of 1 to 5 days. The weight loss was recorded, corrosion rate was determined and the result revealed that corresponding quenched samples resulted in higher corrosion rate than the untreated and tempered samples while the tempered samples reduce corrosion susceptibility.

Keywords : Heat Treatment, Corrosion Rate, Low Carbon Steel, Hydrochloric Acid

I. INTRODUCTION

Steel over the years has remained the most versatile and most widely used engineering material. The quest for very high reliability and efficiency of engineering systems and applications had led to the search for ways of improving the properties of this vital material (steel) in order to enhance the quality of life and improve industrial safety, at a reasonably competitive cost [1]. Carbon steels are the most important alloys used in petroleum and chemical industries since they account for over 98% of the construction materials. Among the most widely used of these alloys is low-carbon steel, because of its wide range of applications in industries such as chemical, oil gas storage tanks and transportation pipelines due to its moderate strength, good weldability and formability [2]. Pipeline deterioration as a result of corrosion has come to be accepted worldwide as an

unavoidable fact of life. 2241 major pipeline accidents were reported [3]. Metallurgical control of corrosion includes inhibition, coating and heat treatment [4]. The modification of microstructures to effect changes in metallic materials is done chiefly by alloying and heat treatment [5]. Heat treatment which involves the application of heat to bring about modification in the microstructure essentially alters mechanical and chemical properties based on the retained austenite, grain size and defects such as dislocation, twinning, vacancies and so on [6]. Many researches have been reported on heat treatment and corrosion behavior of dual phase steel. For example, [7] worked on annealing heat treatment effect on steel welds, [8] worked on corrosion behavior of heat treated rolled medium carbon steel in marine environment, [9] worked on effect of heat treatment of the stress corrosion cracking of alloy 690, [10] worked on the effect of heat treatment on corrosion

behavior of austenitic stainless steel in mild acid medium, while [11] worked on the effect of heat treatments on corrosion of welded low carbon steel in acid and salt environments. Most of their results are to some extent conflicting and contradictory. Hence, this research is poised to examine the effect of quenching and tempering on corrosion rate of low carbon steel in acid environment.

II. METHODS AND MATERIAL

The materials used in this work include low carbon steel, water, SAE Engine oil and corrosion reagent. Equipments used include: lathe machine, muffle furnace (electric resistance furnace), digital weigh balance and polishing machine.

Method

The chemical analysis of the “as-received” low-carbon steel was conducted by optical emission spectrometry with an AR430 metal analyzer. The chemical composition is shown in Table 1.

Table 1 : Chemical Composition of As-received Low Carbon Steel

Elements	Fe	C	Si	Mn	S	Cu	Al	Co	Ti	P	Ni
%Weight	97.75	0.22	0.474	1.331	0.005	0.044	0.007	0.057	0.006	0.003	0.027

Twenty (20) samples of 10x10x10 mm dimensions were heated to an austenitic temperature of 950oC soaked for 2 hours with five (5) untreated samples left to serve as control. Ten (10) each of the heat treated and soaked samples were quenched in water and engine oil and five (5) each of the quenched were subjected to tempering at a temperature of 450oC for 1 hour.

Thereafter, the control, quenched and tempered samples were weighed and exposed to 1M

hydrochloric acid solution attack for a period of 5 days at a day interval after being subjected to grinding with 240, 320, 400, 600 and 1200 grits of emery papers. The weight loss method was adopted in evaluating the corrosion rate. On each day of monitoring, a sample is withdrawn from the acid environment, washed thoroughly using distilled water, rinsed in acetone and dried. A digital weigh balance was used to weigh the samples before and after immersion. Corrosion rate was evaluated using recommended ASTM relation.

$$\text{Corrosion Rate} = 365W/AT$$

Where:

W = Weight loss (gram)

A = Total area of exposure (cm²)

T = Time of in hours;

g/mm²/yr = gram per square mm per year (corrosion rate units)

III. RESULTS AND DISCUSSION

Visual Observation

Corrosion action on the test samples were assessed by visual observation and corrosion rate measurement. Formation of corrosion product (dull brown colour) on the surfaces and edges of the steel samples were observed to have occurred after 24 hours exposure. Areas of attack on the surfaces of the samples by 1M HCl acid solution were visually to be more for the water quenched as compared to oil quenched, untreated, and tempered samples.

Corrosion Rate of Untreated and Quenched Samples

The corrosion behavior of Untreated and quenched samples in 1M HCl acid solution is presented in Figure 1 in terms of corrosion rate with immersion time. It can be observed that the rate of corrosion of the samples slightly decreases for both untreated, oil quenched and water quenched with increase in exposure time. The decrease in corrosion rate may be

due to formation of oxide layer, which is adherent, non-porous and uniformly lay on metal [12]. This oxide layer is magnetic (Fe_2O_3) and passivates very well. Hence, formation of protective film greatly reduces corrosion rate. The water quenched samples were found to possess higher corrosion rate, while the oil quenched samples experienced relative high corrosion rate than the untreated samples. The higher corrosion rate observed from water quenched samples could be due to formation martensite structure which normally results in smaller grain structure. The rate of cooling from the austenite region affects grain size and (ferrite-pearlite) phase transformation [13]. It has been revealed that heat treatment affects rate of corrosion and posited that the larger the grains of a material, the more its resistance to corrosion [14]. Hence, untreated samples with larger grain size resulted in lower corrosion rate compared to the water quenched and oil quenched.

quenched and tempered decreases with increased exposure period. The corrosion rate of the tempered samples were found to be lower than the corresponding quenched samples Figures 2 and 3. The low corresponding corrosion rate experienced from tempered samples could be attributed to increase in the relative amount of ferrite which nucleated from martensite and already existing ferrite, thereby leaving the microstructure with a mixture of ferrite and tempered martensite after tempering. This increased amount of ferrite in the microstructure tends to reduce the cathode to anode (martensite to ferrite) area ratio and thus reduce corrosion rate, because on exposure to corrosion environment martensite becomes cathodic while ferrite anodic to the micro-galvanic cell that are setup [15]. Further more, internal stresses are also relieved during tempering which subpressed stress corrosion cracking of the tempered samples in comparison with the corresponding quenched ones.

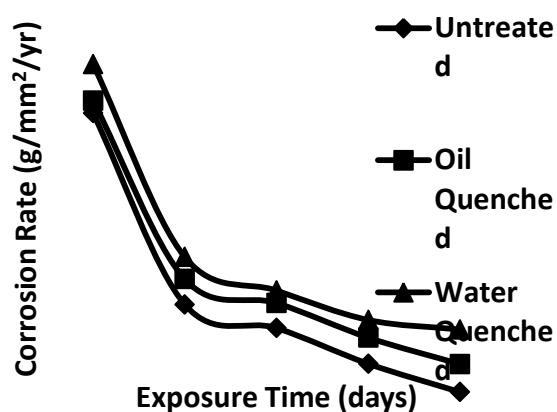


Figure 1: Corrosion Rate of Untreated and Quenched Samples with Time

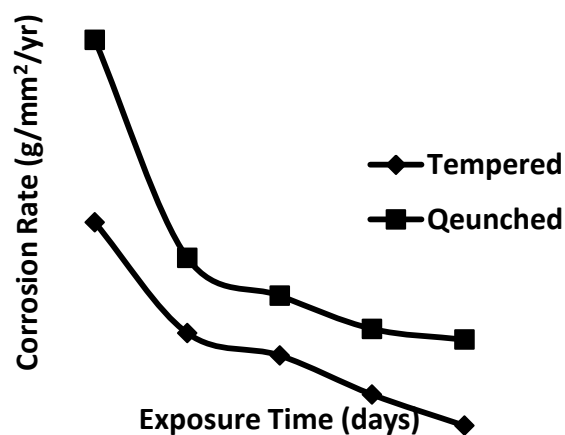


Figure 2: Corrosion Rate of Water Quenched and Tempered Samples with Time

Corrosion Rate of Quenched and Tempered Samples

The corrosion rate of water quenched and quenched and tempered samples are depicted in Figure 2 against exposure time in 1M HCl acid solution which also revealed decrease in corrosion rate with increased immersion time. Similarly, Figure 3 shows that corrosion rate of the samples oil quenched and

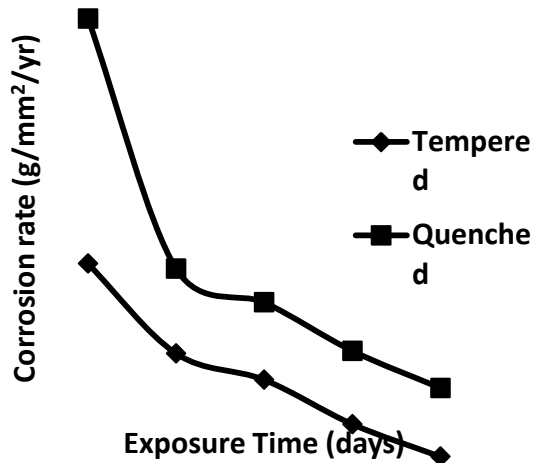


Figure 3 : Corrosion Rate of Oil Quenched and Tempered Samples with Time

Corrosion Rate of Quenched and Tempered Samples in Water and Oil

Variation of corrosion rate of water quenched and tempered and oil quenched and tempered samples against exposure time in 1M hydrochloric acid solution is shown in Figure 4. The Figure 4 shows decrease in corrosion rate as the immersion time of both water and oil quenched and tempered samples increases. Samples quenched and tempered in water recorded higher corrosion rate than the corresponding samples quenched and tempered in oil. The higher corresponding corrosion rate experienced with water quenched and tempered samples could likely be as a result of transformation of martensite and retain austenite into tempered martensite and bainite (ferrite and epsilon carbide) having different microstructural phases which promotes galvanic-phase coupling with different electrode potentials leading to distinct localized anodic and cathodic microstructural area. This developed microstructural inhomogeneities which act as micro-electrochemical cell in the presence of a corrosive medium result in high corrosion rate.

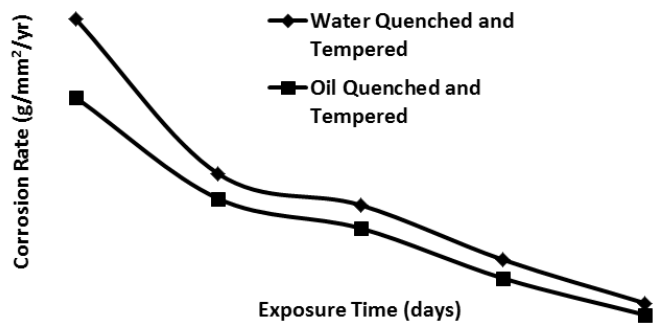


Figure 4 : Corrosion Rate of Tempered Samples with Time

IV. CONCLUSION

Based on the analysis of the results obtained and the observations made during the course of this work, the following conclusions can be made.

1. Water quenched and tempered samples result in higher corrosion rate compared with the oil quenched and tempered samples.
2. Quenching and tempering reduces corrosion susceptibility of low carbon steel in 1M hydrochloric acid solution.

Applications of low carbon steels exposed to chloride environment is strongly recommended to be tempered after queching.

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