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Research Article

Inductive Experimental Study of Corrosion Products of Medium Carbon Steel CK45 Hardened by Magnetized Water

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This paper concerns the inductive experimental study of corrosion products of the medium carbon steel CK45DIN using magnetized water as hardening media, where the water has been exposed to a magnetic field of 1000 Gauss and 2000 Gauss, respectively, for time durations of 1 to 5 hours, with a volumetric flow rate of 4 gal/min. Medium carbon steel CK45DIN samples were exposed to air as corrosive environment for reasonable time interval, and the corrosion product was weighed in order to determine the loss of weight. The results showed that the corrosion rate of all samples decreased as the experiment progresses over time. Corrosion resistance of the medium carbon steel CK45DIN increased when we raised its temperature to 870°C for 40 minutes and hardened by magnetized water applied in a magnetic field with a strength of 1000 Gauss for 3 hours as compared with the sample hardened by normal water.

1. Introduction

Corrosion is a natural process, in which an exposed surface of a refined metal is deteriorated to a more chemically stable form when it comes into contact with a gas or liquid, as a result of chemical reactions typically in the form of oxidation between the metal and its surrounding environment. Corrosion is dangerous, and in many cases it represents an enormous economic loss. Because of corrosion, buildings and bridges can fall, oil pipelines can fracture, and sewerages can flood. Corroded electrical contacts can produce blazes and other accidents; corrosion of medical implants in the human body can cause infection.

As a low-cost and attainable metal, the CK45 steel has applications in industries, which are abundant but still restricted because of its poor wear and corrosion resistance [1]. Hence, a large number of studies have been conducted in order to enhance the corrosion resistance. Heat treatment is a process of heating and cooling metals to obtain good physical and mechanical properties by modifying the crystalline structure. The heating temperature, length of time, and cooling rate are some of the important variables that can affect the properties of the heat-treated metals [2, 3].

The effect of heat treatment on mechanical properties under different cooling media (water and palm oil) was studied, which showed the best properties in strength and hardness would be in water compared to palm oil [4].

The aim of this paper is to conduct an experimental study on corrosion products of the CK45 carbon steel using magnetized water as hardening media and compare the results of that hardened by normal water. In [5], it is explained that the cavitational wear resistance of electroplated nickel composite layers was inspected by ASTM G32. Particles of diverse hardness (titania and silicon carbide) and diverse sizes from microscale to nanoscale were merged up to 30 vol.% into a nickel matrix. Martens hardness is developed by grain refinement via a particle merger. Magnetized water is simply known as the water that passes through a magnetic field or the water inside it or near a magnet for a certain period of time. The exposure of water to the magnetic field causes changing in many physical properties of water because water is a polarized liquid [6, 7].

In [8], this is compared between the effects of N-alloying through diverse processing and manufacturing routes on mechanical, metallurgical, wear, and corrosion properties of high N-containing stainless steels. Furthermore, the

investigation of relationship between the stress intensity factor and corrosion crack growth rate depended on static corrosion [9]. Damage of metals due to the influence of hydrogen and stress corrosion cracking is quite frequent and focuses on risky failures as well as on decreasing property and large compensational payments by insurance companies [10].

The properties of the water solution change when exposed to a magnetic field according to the following variables:

(1) The flow rate of water through the magnetic field.

(2) The presence of water in the magnetic field.

(3) magnetic field strength.

2. Experimental Procedures

(1) Eleven cylindrical samples of the medium carbon steel CK45DIN with a diameter 20 mm and a height of 30 mm were used in this experiment. The chemical composition of the samples was determined by using a chemical analytical instrument (BrukerS-1 TURBO SD) as shown in Table 1.

(2) Dipole-magnetized water was prepared using the device shown in Figure 1 by applying a magnetic field with a strength of 1000 Gauss on distilled water at a flow rate of 4 gallons/min and for periods of time extended from 1 hour to 5 hours. Then the magnetic field strength increased to become 2000 Gauss at the same periods of time and flow rate. The number of samples hardened by magnetized water becomes ten samples, in additon to the sample hardened by normal water. Thus, the number of samples becomes 11.

(3) The eleven steel samples were placed in the oven, and their temperature was raised to a hardening temperature of 870°C for 40 minutes.

(4) The samples were numbered from (1) to (11), so that the sample hardened by normal water took number (11) while the samples hardened by magnetized water were numbered from (1) to (10). The sample hardened by magnetized water applied in a magnetic field with a strength of 1000 Gauss for 1 hour took number (1), the sample hardened by magnetized water applied in a magnetic field with a strength of 1000 Gauss for 2 hour took number (2), and thus the rest of the samples took till number (5). The sample hardened by magnetized water applied in a magnetic field with a strength of 2000 Gauss for 1 hour took number (6), the sample hardened by magnetized water applied in a magnetic field with a strength of 2000 Gauss for 2 hour took number (7), and thus the rest of the samples took till number (10).

(5) After the completion of the hardening process, the samples were prepared as follows:

(i) Grinding of the samples was done with smooth satin paper with softness from 180 to 1200 Grit number.

(ii) The samples were polished using aluminum oxide solution (Al_2O_3) in water by 15% and by using a universal rotary polishing machine. After that, we used a 1-micron fine linen sheet.

Table 1: Percentage of sample components under study.

Symbol	Fe	Mn	Si	C	Cr	Sn	Cu	P
Percentage	98.02	0.72	0.63	0.53	0.04	0.03	0.02	0.01

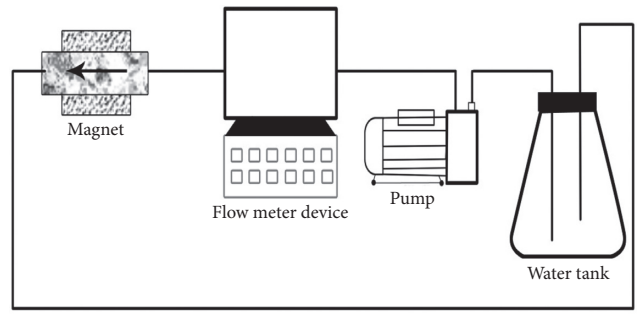

Figure 1: Water magnetization device.

3. Results and Discussion

3.1. Weight Loss. All medium carbon steel CK45DIN samples were exposed to air as a corrosive environment for reasonable time interval and completely polished with polish paper to remove all corrosion products and then the pieces of each sample were weighed to determine the loss of weight. The weight losses in a gram of sample hardened by normal water and samples hardened by magnetized water applied in a magnetic field for time intervals (1, 2, 3, 4, and 5 hours) with a strength of 1000 Gauss and 2000 Gauss, for a certain exposure time, are presented in Figures 2 and 3.

From Figure 2, it can be observed that the sample applied in a magnetic field with a strength of 1000 Gauss for 3 hours has the highest corrosion resistance since the lowest weight was lost during the exposure period. This is followed successively by the samples applied in a magnetic field for 3 hours, the samples applied in a magnetic for 2 hours, the sample hardened by normal water, the sample applied in a magnetic field for 4 hours, and lastly the sample applied in a magnetic field for 5 hours.

From Figure 3, it can be observed that the sample applied in a magnetic field with a strength of 2000 Gauss for 5 hours has the highest corrosion resistance. This is followed successively by the sample hardened by normal water and lastly the sample applied in a magnetic field for 3 hours has the lowest corrosion resistance.

The general observation on the results shown in Figures 2 and 3 is an evident increase of weight loss with exposure time and a similar progression pathway of cumulative weight losses for all the samples with increase in exposure time. The reason for the constant difference in weight loss from the start until the end could be due to the difference in composition and structure generated by heat treatment.

3.2. Corrosion Rate. The corrosion rate was calculated from decrease in weight observed in samples in weight loss tests using the following formula [11]:

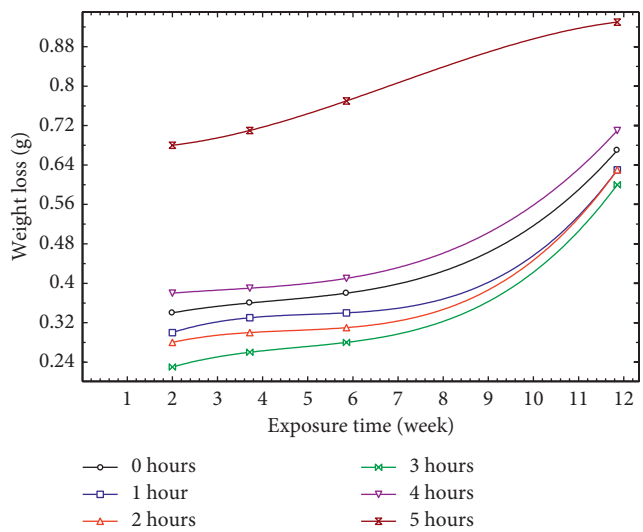

Figure 2: Weight losses versus exposure time for the samples hardened by magnetized water applied in magnetic field with a strength of 1000 Gauss.

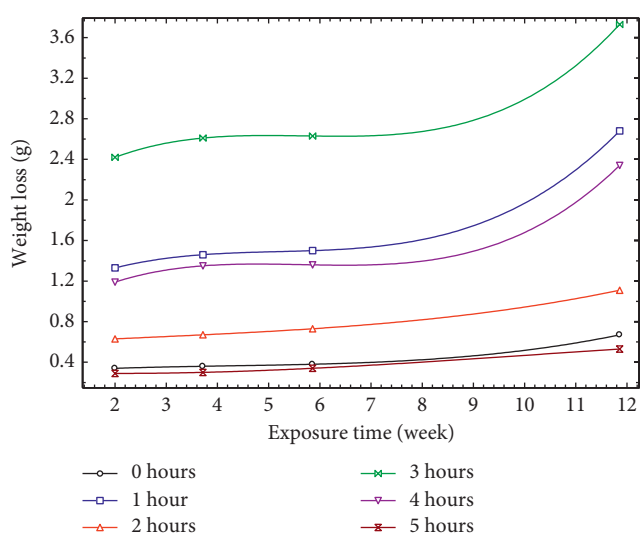

Figure 3: Weight losses versus exposure time for the samples hardened by magnetized water applied in magnetic field with a strength of 2000 Gauss.

$$\text{corrosion rate (mpy)} = \frac{534\,W}{D * A * T}, \tag{1}$$

where mpy is mils penetration per year (1 mil·10^{-3} inch.); W is the weight loss (mg); D is the density of the sample (g/cm^3); A is the area of the sample (inch^2); and T is the exposure time (hr)

The corrosion rates are calculated for the sample hardened by normal water, samples hardened by magnetized water applied in a magnetic field for time intervals (1, 2, 3, 4, and 5 hours) with a strength of 1000 Gauss and a strength of 2000 Gauss, for a certain exposure time, and the data obtained are plotted in Figures 4 and 5.

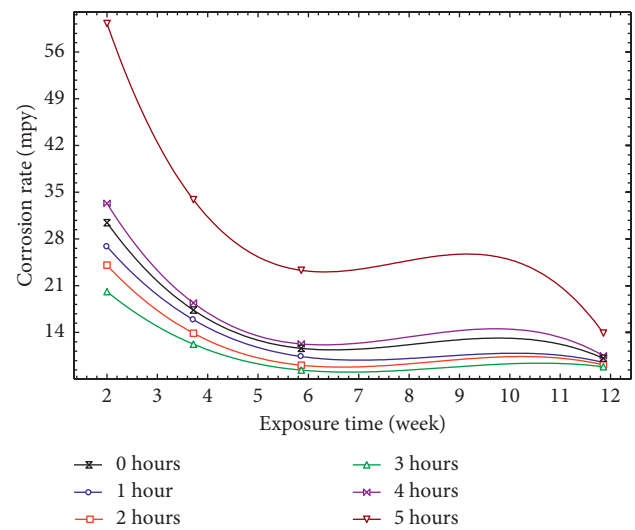

Figure 4: Variation of corrosion rates with exposure time for the samples hardened by magnetized water applied in magnetic field with a strength of 1000 Gauss.

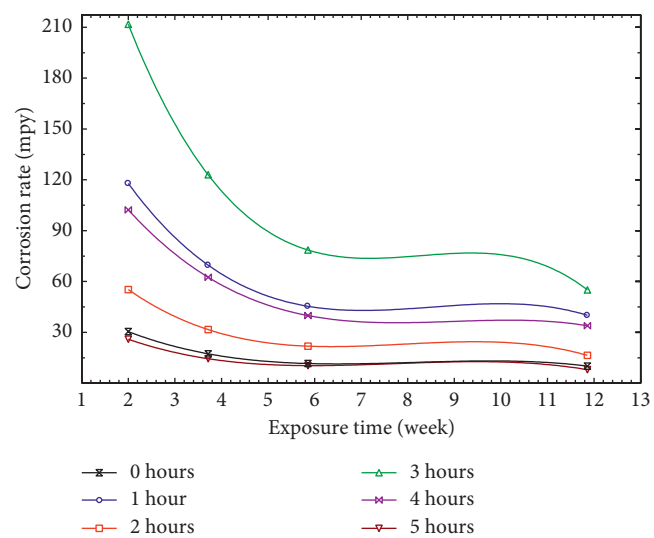

Figure 5: Variation of corrosion rates with exposure time for the samples hardened by magnetized water applied in magnetic field with a strength of 2000 Gauss.

As in Figures 4 and 5, the corrosion rate of all samples decreased as the experiment progresses over time. The corrosion rate was very low with the sample hardened by magnetized water applied in a magnetic field with a strength of 1000 Gauss for 3 hours as compared with the sample hardened by the normal water since it has the highest corrosion resistance. However, the corrosion rate was very high with the sample hardened by magnetized water applied in a magnetic field with a strength of 2000 Gauss for 3 hours as compared with the sample hardened by the normal water since the corrosion attack increased.

4. Conclusion

From the results of the investigation, the following inferences can be deduced:

(1) The corrosion rate of all samples decreased as the experiment progressed over time.

(2) Corrosion resistance of the medium carbon steel CK45DIN increased when we raised its temperature to 870°C for 40 minutes and hardened by magnetized water applied in a magnetic field with a strength of 1000 Gauss for 3 hours as compared with the steel hardened by normal water.

(3) The corrosion rate decreased by 4% if magnetized water was applied in magnetic field with a strength of 2000 Gauss.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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