The Investigation of the Effect of Nitrocarburizing on the Corrosion Resistance of AISI 4140 Steel

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Abstract

The corrosion characteristics of nitrided and unnitrided AISI 4140 steel were investigated in this study. The purpose of this study is to determine the effect of the nitrocarburizing time on the corrosion resistance of the AISI 4140 steel under acidic and basic environmental conditions. Firstly, the surface of the AISI 4140 steel samples were polished to prepare for nitriding. The AISI 4140 steel samples were nitrided in a cyanide salt bath for 1, 2 and 3 h. The hardness values of the samples were measured with using the Vickers hardness method. The corrosion rates of nitrided and unnitrided AISI 4140 steel were determined by potentiodynamic polarization curves in the solution at pH value of 2 and 12. Scanning electron microscopy (SEM) with energy dispersive spectroscopy (EDS) were used for the characterization of the cross sections of the unnitrided and nitrided samples and X-ray diffraction (XRD) were used for the examining of the crystal structures of the surface of the nitrided samples. Finally, the effect of the nitriding time on the corrosion behaviour of AISI 4140 steel was investigated and it is determined that the nitriding time plays a big role on the corrosion resistance of the AISI 4140 steel.

1. Introduction

4140 steel is one of the most widely used steel of tempered steels of Cr-Mo with low alloy and is also known as chrome-molybdenum steel. The AISI 4100 series is also called steel, forged steel, low alloy structural steels, medium carbon steel and alloy steel. When considering their chemical composition, 4140 steels are constructional alloy steels suitable for hardening in terms of carbon content and exhibiting high toughness properties under certain loads at the end of the treatment. Applications of that include automotive and aircraft construction, grooved shaft, axle shaft and sleeve, crankshaft and similar high ductility parts, as well as gear wheel and bandage [1]. 4140 steels have superior fatigue and wear resistance with the property of the usability at temperatures as high as 480°C and this phenomenon makes it suitable for critical stressed applications. Pre-hardened and tempered 4140 can be further surface hardened by nitriding [2-5]. Hard coatings and various surface hardening treatments can be utilized in order to improve the surface properties of the materials. Nitriding is one of the most commonly used surface hardening processes. Nitrided steels are widely used due to their superior hardness and attractive surface hardness, fatigue life, and tribological properties [6]. Besides, nitrocarburizing is a thermochemical process in which nitrogen and carbon are diffused into the surface of a ferrous metal. It produces a thin case consisting of a ceramic iron-nitrocarbide layer and an underlying diffusion zone where nitrogen and carbon are dissolved in the matrix. This hardening is used to enhance wear and fatigue properties and to improve corrosion resistance. Nitrocarburizing can be followed by a post-oxidation step which is performed to develop the corrosion resistance of the material. The aim is the creating of a continuous layer of protective magnetite on the surface of the compound layer which has a black appearance [7].

2. Experimental Procedure

In this study, 4140 steel which that of composition given in table 1 was used as base material for the salt bath nitrocarburizing process. 4140 steel specimens were subjected to salt bath nitrocarburizing at 580 °C for 1, 2 and 3 hours, respectively followed by oxidizing process for 20 minutes at a temperature of 380-400 °C in a stainless steel-based pot to increase the corrosion resistance of the samples. Four different salts were used to prepare the nitrocarburizing and oxidation bath. These salts are NT-Reg, NT-1 and NaCN, and NT-Oxygen for the oxidation bath. These salts are procured from Orion Heat Technology Company, Turkey. The vickers microhardness of the nitrocarburized and untreated samples was measured in the Innova microhardness tester. The load applied to the samples was 50 grams and the
waiting time was chosen as 10 seconds. Seven measurement points were selected from each different sample and the averages were taken. Electrochemical technique was used to study corrosion behavior of uncoated and coated steel samples with Tafel analysis after potentiodynamic polarization measurements in terms of corrosion potential (Ecorr) and corrosion current density (Icorr) using GAMRY software. The aqueous solution (pH=2 and 12) at the room temperature was used as test solution for performing the potentiodynamic polarization. The open circuit potential and the scan rate were (-500) - (+500) mV and 1 mV/s respectively. The corrosion current density and corrosion potential provide the determining of electrolytic corrosion behavior of the samples and all data that exists during the tests are output of an average of the three different measurements. Corrosion surfaces investigated with a scanning electron microscoper (SEM).

| Table 1. The composition of 4140 steel |
|-------|-------|---|---|---|---|---|
| C     | Mn    | P   | S   | Si  | Cr  | Mo |
| 0.38-  | 0.75-  | 0.035 | 0.04 | 0.15- | 0.80- | 0.15- |
| 0.45   | 1.00   | (max) | (max) | 0.30  | 1.10  | 0.20 |

3. Results and discussion

Fig. 1. shows the microstructure of the untreated 4140 steel before the nitrocarburizing process for the samples in this study. Fig 2. shows the XRD patterns of the untreated and nitrocarburized samples for 1, 2 and 3 h. As can be seen from XRD peaks, for the nitrocarburizing process for 2 h, the compound layer is more clear than that of nitrocarburized samples for 1 and 3 h. Besides, the hard phases such as Fe2,3N,C, ε-Fe3N compose more than that of the other samples.

As can be understood in Fig. 3., the micro-hardness of the untreated sample shows the lowest hardness. with the increase of the nitrocarburizing time for the samples, the hardness increase. However, the samples nitrocarburized for 3 h shows the lower hardness than that of sample nitrocarburized 2 h because the microstructure with porosity on the surface of the sample compound with the increase of the nitrocarburizing time. SEM image from the cross section of nitrocarburized sample for 2 h was shown in Fig. 4. As it can be seen in the SEM image, the microstructure of the sample nitrocarburized at temperatures of 580 °C is composed of a compound layer and diffusion zone.
The potentiodynamic polarization curves of the untreated 4140 steel and nitrocarburized for 1, 2 and 3 h 4140 based steel at pH=2 and 12 was given in Fig. 5. and Fig. 6., respectively. According to results of the corrosion tests, it is determined that untreated 4140 steel sample has the highest corrosion rate of 30 μpy among the tested samples while the sample nitrocarburized for 2 h has the lowest corrosion rate of 0.16 μpy. The corrosion attack on the samples can be also seen in Fig. 7. and Fig. 8. As can be seen in these Figures, the samples nitrocarburized for 2 h were damaged less than the other samples.

Figure 5. Polarization curves of the samples at pH=2

Figure 6. Polarization curves of the samples at pH=12

Figure 7. The SEM images of the corrosion surfaces of the samples which was (a) untreated, (b) coated for 1 h, (c) for 2 h and (c) for 3 h at pH=2
4. Conclusion

The corrosion tests were carried out to the untreated 4140 steel sample and the samples nitrocarburized for 1, 2 and 3 h. It is understood that untreated 4140 steel sample has the lowest corrosion resistance while the 4140 steel sample nitrocarburized for 2h has the highest corrosion resistance in the solution has pH=2 and 12 from the polarization curves of the samples during the tests. Finally, as can be seen in polarization curves, from corrosion surfaces and the corrosion rates of the samples, the nitrocarburized time is effective much and all of the nitrocarburized samples has the higher corrosion resistance than untreated 4140 steel.

References

7. T. Holm, “Furnace atmospheres no. 3, gas nitriding and nitrocarburizing.”