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Effect of Plasma Nitrocaburizing on the Mechanical and Corrosion Properties of SS 304

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Abstract. In this study, the mechanical properties and corrosion properties of plasma nitrocarburized 304 stainless steel at various processing times was investigated. Plasma nitrocarburizing was carried out at different processing time durations which varied from 60 min to 300 min at fixed temperature of 500 °C in an atmosphere of 78 vol.% N_2, 19 vol.% H_2 and 3 vol.% CH_4. An Optical microscope and SEM coupled with EDS have been used to characterize the microstructural and the elemental depth profiles in which the thickness of the modified layers is derived. Microindentation method is used for the study of mechanical performance of the nitrocarburized material. Corrosion properties were investigated using potentiostat method in a 1 wt% NaCl solution. The result shows that the microhardness increases to a maximum value of more than two times compared to that of the untreated one. The corrosion performance was found being treatment time duration dependent.

Introduction

Stainless steels, in particular austenitic grades, are commonly introduced into various industrial applications because of their excelent corrosion resistance. However, they exhibit relatively low wear resistance and relatively low microhardness which impede some of their specific applications. Thermo-chemical treatments of nitriding, carburizing and nitrocarburizing have been applied for a long time as single treatment techniques, essentially to address the problems. Different plasma techniques have been used for nitriding stainless steels such as ion implantation [1], low-energy high-current nitriding [2], plasma immersion ion implantation [3] and plasma nitriding [4]. Alternatively, plasma nitrocarburizing has been used recently for surface modification of 304 stainless steel [5]. The present paper aims mainly to study the effect of the nitrocarburizing process on the surface properties of 304 austenitic stainless steel using plasma nitrocarburizing. The microstructure, mechanical and corrosion properties of the treated austenitic stainless steel were correlated to the plasma processing time.

Experimental

The commercial bar of 304 stainless steel was cut into cylindrical specimens with dimensions of 14 mm in diameter and thickness of 3 mm. The samples were ground and mirror-like polished, ultrasonically cleaned in alcohol bath and placed into the plasma chamber. Gases of N_2 , H_2 and CH_4 were introduced into the chamber and the working gas was maintained at a fixed pressure of 1.6 mbarr at a temperature of 500^{o}C. Five different processing times which varied from 60 min to 300 min were applied. An optical microscope and a SEM coupled EDS were used to observe the microstructure of the specimens. The indentation hardness was measured using Matsuzawa MMT-X7 microhardness tester equipped with Vickers diamond pyramid indenter. The electrochemical studies in 0,9% NaCl solution of the specimens being nitrocarburized were conducted using a potentiostat PGS-201T. The scan rate used was 20 mV/minute in the range from

-2000 mV to +2000 mV. The corrosion potential (E_{corr}) and corrosion current density (i_{corr}) were determined using the Tafel Extrapolation Method.

Result

Figure 1 shows topographies of the surface of the untreated specimen (a) and the representative specimen being nitrocarburized for 3 hours (b). The figure indicates that plasma nitrocarburizing increases surface roughness of the treated specimens. Mandkarian and Mahboubi believe that surface roughening is due to the formation of cauliflower shaped carbonitride precipitates on the surface of the samples during nitrocarburizing[6]. The surface relief caused by volumetric expansion associated with formation of carbonitrides is also believed to result in surface roughening. Sputtering and redeposition of the sputtered material on the surface also play an important role in surface roughening [6].

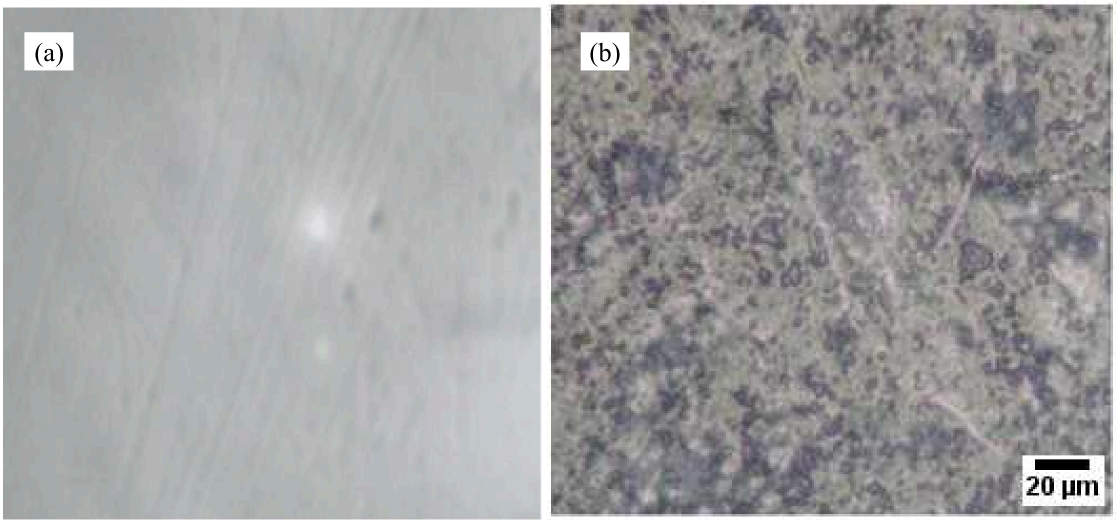


Figure 1. Optical micrograph of the surface of untreated specimen (a) and the specimen nitrocarburized for 3 hours (b).

The microhardness measurements of the nitrocarburized samples were performed using a microindentation technique. Figure 2 shows the surface microhardness values of both, untreated and treated samples, at different processing times. All specimens nitrocarburized at temperature 500^{o}C possess higher hardness values than those of untreatment specimens. It is observed that the surface hardness of the austenitic substrate increased from 619 VHN to 817 VHN after plasma nitrocarburizing at 500^{o}C for a processing time of 60 minutes. After that the microhardness value continuously increased with increasing the treatment time, reaching a maximum at 180 min and then slightly decreased with further increasing of processing time. The maximum microhardness of the nitrocarburized layer (1241 VHN) is approximately 2.0 times as compared to that of the untreated substrate (619 VHN). It has been found that the microhardness variation is mainly attributed to the trend of microstructure with the treatment time. However, the higher microhardness value obtained for nitrocarburized samples at a processing time of 180 min or longer can be ascribed to a denser microstructure of the nitrocarburized layer in which high concentration of nitrogen and carbon is detected in the near surface region and along the saturation region compared to that ones treated at shorter processing time. It is well known that the precipitation of the chemical compound phases on the grain boundaries leads to forming precipitation hardening effect. Another significant factor that affects the surface hardness is the formation of the expanded austenite phase with different lattice expansion. It is reported that higher nitrogen content leads to higher lattice expansion and higher microhardness values [7,8].

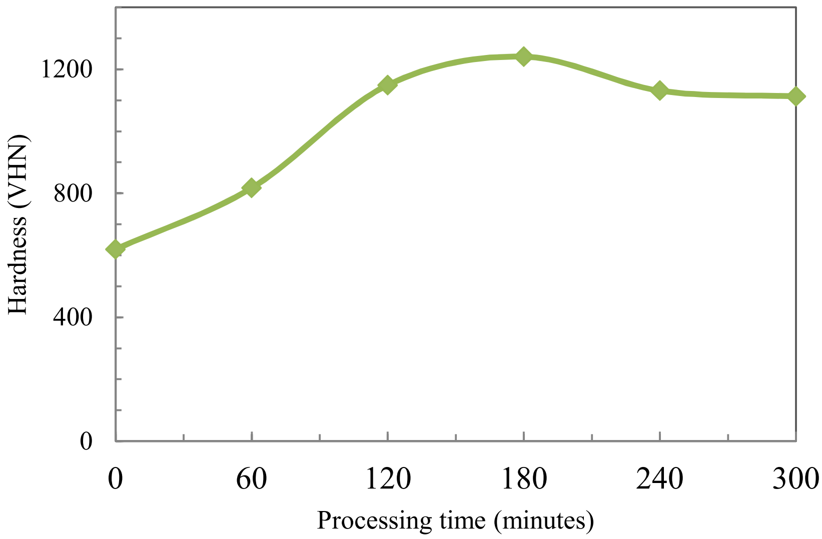


Figure 2. Variation of surface microhardness for untreated and nitrocarburized SS 304 specimen at different processing times.

Figure 3 depicts hardness profile for selected nitrocarburized specimen. The hardness profile of the specimen which measured from near surface to the deeper shows the decrease in hardness values with an increase of depth from their respective surfaces. The decrease of the difussed nitrogen and carbon content along with the depth may reduce the hardness.

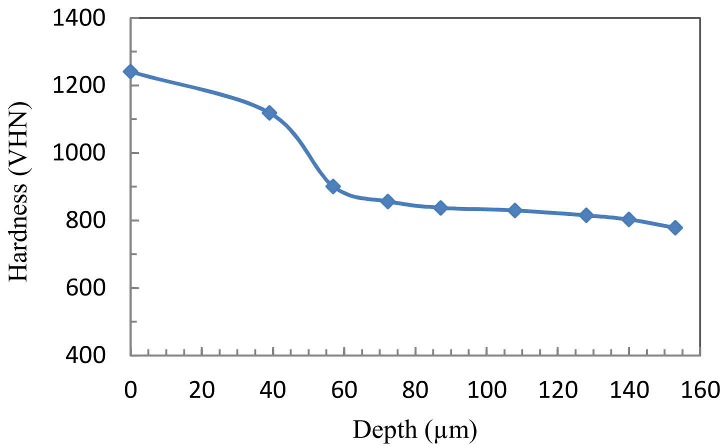


Figure 3. Hardness profile of the nitrocarburized specimen at temperature of 500^{o}C for 180 minutes processing time.

Microstructure observation demonstrates that there was found 2 zones being affected (Figure 4). First, at near surface coumpound layer was observed with the thickness about 29 micrometer. Second, in the deeper zone called a difussion zone, especially specimen after nitrocarburized at temperature 500^{o}C for 3 hours, it can be seen very clear that there is a diffusion area of N and C atoms in the 304 stainless steel. Theoretically, the maximum depth of carbon and nitrogen atoms that diffused in 304 stainless steel was 189 micrometer.

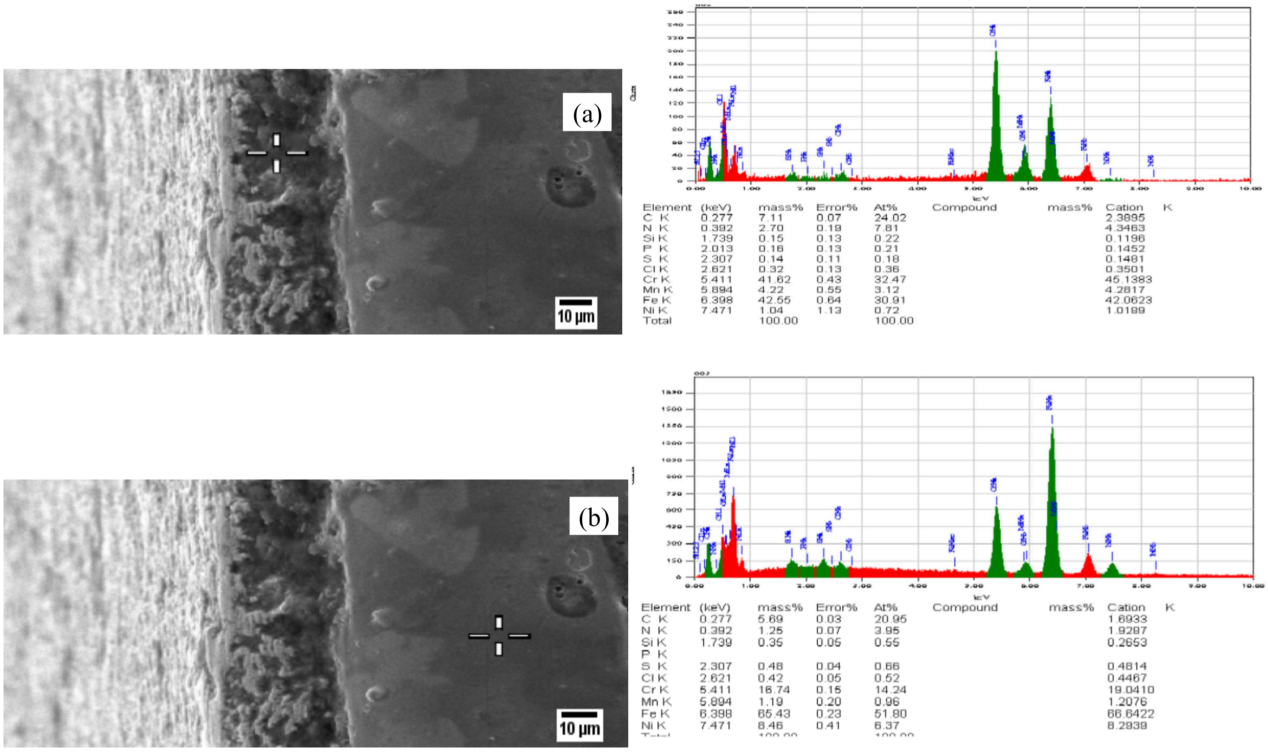
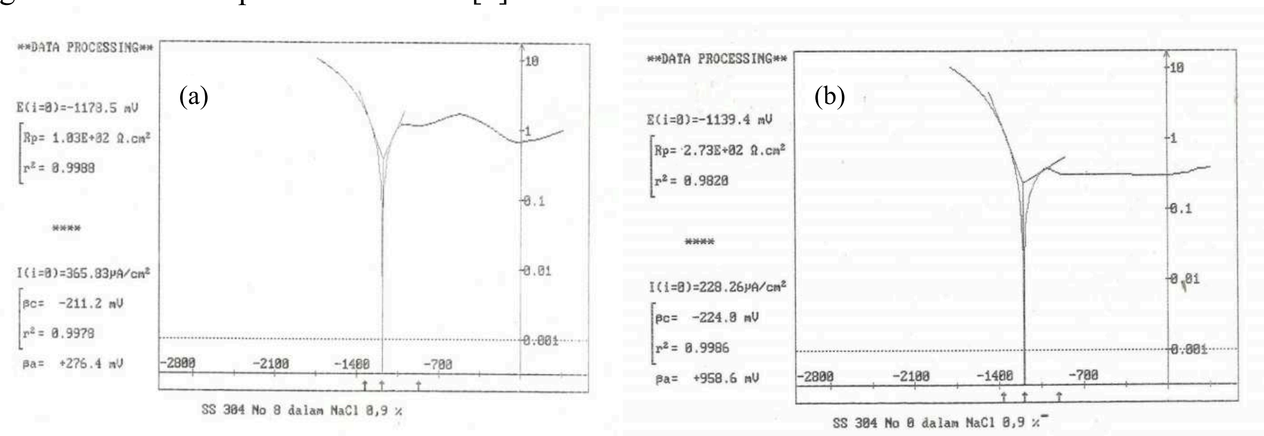


Figure 4. SEM micrograph of nitrocarburized specimens at temperature of 500°C for 3 hours processing time and its respective chemical composition at different points of depth: compound layer (a), diffusion area (b)

The increase in the corrosion current and decrease in corrosion potential indicate a degradation of the corrosion resistance for the treated samples. While the untreated 304 stainless steel provides an excellent region of passivity and good corrosion resistance, the treated specimens show lower corrosion resistance than that of the untreated specimen (Figure 5). Yet, the increase of processing time increase the corrossion resistance of the treated specimen up to 180 minutes processing time and further increase results in considerably stable I_{corr}. This treatment temperature may be critical. At this temperature the chromium atom difussivity can start to be more significant and the number of localized CrN and CrC precipitation phenomena or called as sensitization phenomena may occur resulting in decrease in corrosion resistance. This result is in good agreement with the previous research [9].



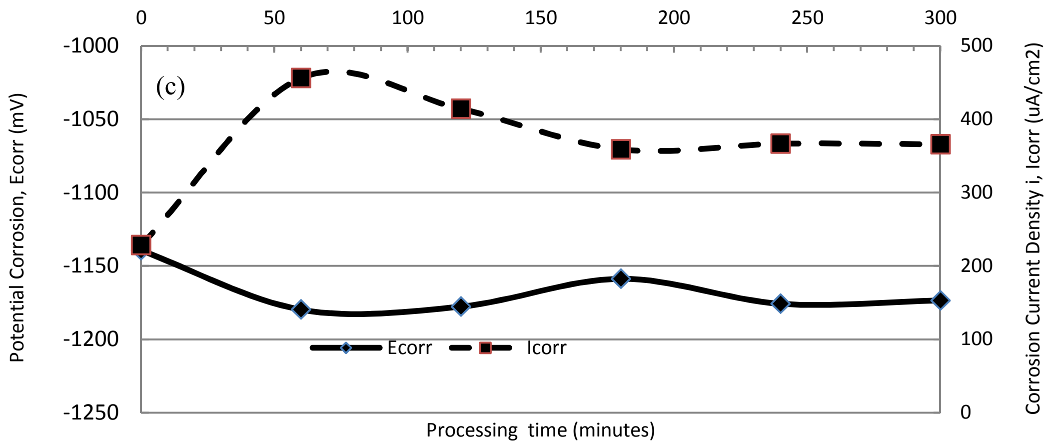


Figure 5. Tafel plot for the nitrocarburized specimen at temperature of 500°C for 5 hours (a) and untreated specimen (b). Variation of the potential corrosion (E_{corr}) and corrosion current density (i_{corr}) of the nicrocarburized specimens for processing time of 0, 60, 120, 180, 240 and 300 minutes (c).

Conclussion

It can be concluded that plasma nitrocarburising on 304 stainless steel at temperatur of 500°C increases the surface hardness values and the corrosion rate. Maximum hardness value and maximum corrosion resistance property were found at processing times of 3 hours.

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