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Enhancement of Surface Hardness and Corrosion Resistance of AISI 310 Austenitic Stainless Steel by Low Temperature Plasma Carburizing Treatment

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Abstract

The response of AISI 310 type austenitic stainless steel to the novel low temperature plasma carburizing process has been investigated in this work. This grade of stainless steel shows better corrosion resistance and high temperature oxidation resistance due to its high chromium and nickel content. In this experiment, plasma carburizing was performed on AISI 310 stainless steel in a D.C. pulsed plasma ion nitriding system at different temperatures in H_2-Ar-CH_4 gas mixtures. The working pressure was 4 Torr (533Pa approx.) and the applied voltage was 600 V during the plasma carburizing treatment. The hardness of the samples was measured by using a Vickers micro hardness tester with the load of 100 g. The phase of carburized layer formed on the surface was confirmed by X-ray diffraction. The resultant carburized layer was found to be precipitation free and resulted in significantly improved hardness and corrosion resistance

Keywords : AISI 310 Austenitic Stainless Steel, Plasma Carburizing, Hardness, Corrosion Resistance

1. Introduction

It has been established that austenitic stainless steels can be carburized at temperatures below 500 °C to form a hardened layer free from chromium carbide precipitation. During the low temperature carburizing process, carbon atoms are incorporated in the face centered cubic (f.c.c.) austenite lattices, forming an expanded austenite layer up to 40 µm thick supersaturated carbon atoms. This ensures that chromium remains in the free form, and thus maintains the corrosion resistant characteristics of stainless steels. So far, most of the research work has been conducted on various grades of austenitic stainless steels except the AISI 310 stainless steel. Grade 310, combining excellent high temperature properties with good ductility and weld ability, is designed for high temperature services. It is also used for intermittent service at temperatures up to 1040 °C. The high chromium and nickel content are intended to increase high temperature properties which will make this grade good aqueous corrosion resistance. Therefore, AISI 310 steels are widely used to furnace parts, oil burner parts, carburizing boxes, heat treatment baskets and jigs, heat exchangers and welding filler wire and electrodes [1]. In order to improve the surface characteristics and anti-corrosion performance of these cast components, it is necessary to study the response of this stainless steels to the novel low temperature carburizing process.

The low temperature plasma carburizing was implemented at temperature 400 °C to 520 °C for up to several tens of hours with the presence of carbon-containing gas which produces a carbon enriched layer up to 50 µm in thickness. Additionally, the carbon supersaturated austenite layer has excellent corrosion resistance, good toughness and high load-bearing capacity due to the larger layer thickness

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Table 1. The chemical compositions of AISI 310 austenitic stainless steel.

Materials	Fe	C	Mn	Cr	Ni	Si	S	P
Percentage (%)	Bal.	0.25	2.00	24.0-26.0	19.0-22.0	1.50	0.03	0.045

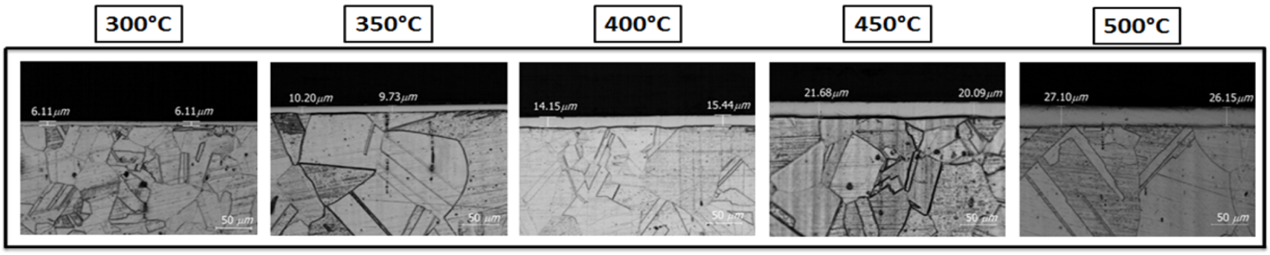


Fig. 1. Cross sectional micrographs of plasma carburized AISI 310 stainless steels with various carburizing temperatures.

compared with the nitrogen enriched layer [2-3]. The aim of this paper is to investigate the optimum carburizing treatment temperature for AISI 310 stainless steel after plasma ion carburizing at several temperatures.

2. Experimental Procedure

Circular coupons of AISI 310 austenitic stainless steel of 14 mm diameter and 3 mm thickness were prepared for the treatment. The compositions of the AISI 310 Austenitic Stainless Steels are given in the Table 1. Before starting the plasma treatment the surfaces of the circular coupons were mirror polished by means of automatic polishing machine and then cleaned. Then, the samples were placed on the cathode table in the D.C. pulsed plasma ion nitriding system. In the next step plasma chamber was evacuated to 50 mTorr for the pre-sputtering operation. In this operation Ar and H_2 ion sputtering was performed at 300 °C for at least 40 minutes for further surface cleaning (Voltage: 400 V, gas composition: Ar/ H_2= 20 %/80 %, Time: 40 minutes). After sputtering, plasma carburizing process was immediately carried out with a pulsed D.C. potential at various temperatures (300 °C, 350 °C, 400 °C, 450 °C and 500 °C) for 15 hours in the glow discharge environment of a gas mixture of Ar, H_2 and CH_4 at a fixed voltage 600 V and pressure 4 Torr. After treatment the samples were cooled in the vacuum chamber up to the room temperature.

The plasma carburized samples were sectioned for metallographic examination and hardness profile determination. The cross-sectional single layer surfaces were first cut by low/high speed diamond wheel cutter manufactured by "TOPMET METSAW" and then etched with a special chemical solution which contains 50 % HCl, 30 % HNO_3 and 20 % H_2O. The microstructures of the surface of all the samples were observed by using a low magnification optical microscope named "OLYMPOUS BX60". The surface hardness of the treated and untreated samples was measured by "MITUTOYO MVK-H100" hardness tested using a constant load 100 gm. A Rigaku D/Max-200 X-Ray diffractometer was used to analyze different phases formed in the treated surfaces. A potentiostat polarization technique was applied to estimate the corrosion characteristics of the plasma carburized and post oxidized layer in a 3.5 % NaCl solution. 3.5 % KCl Ag/AgCl was selected for the reference electrode and Platinum (Pt) was used for the counter electrode by using "POTENTIOSTAT MODEL 273A". The anodic polarization curves were recorded with a sweep speed of 0.167 mV/sec by using Princeton Applied Research 273A. The carbon concentration profiles across the hardened layer were obtained by using Glow Discharge Optical Spectrometry (GDOS).

3. Results and discussion

Figure 1 shows the optical micrographs of plasma carburized AISI 310 stainless steel at different carburizing temperatures. During the carburizing treatment, there was a hardened layer formed on the outermost surface. This carbon supersaturated austenite layer is also known as S-phase (γ_C). This supersaturated austenite layer is resistant to the etchant due to their bright appearance under optical microscope, implying their good corrosion resistance in the chemical compared with the substrate [2]. It is also clear that the thickness of the carburized layer

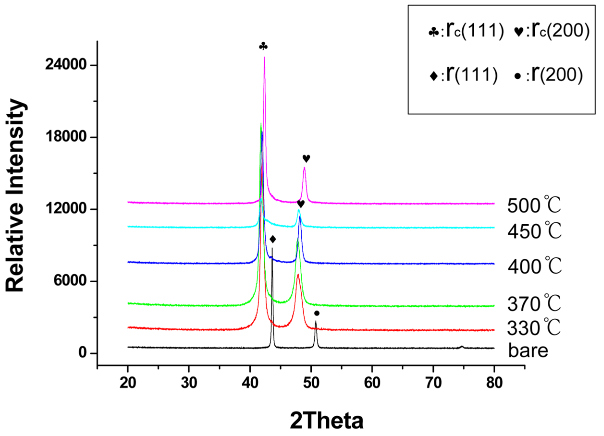


Fig. 2. XRD pattern of carburized layer on AISI 310 stainless steel with various processing temperatures.

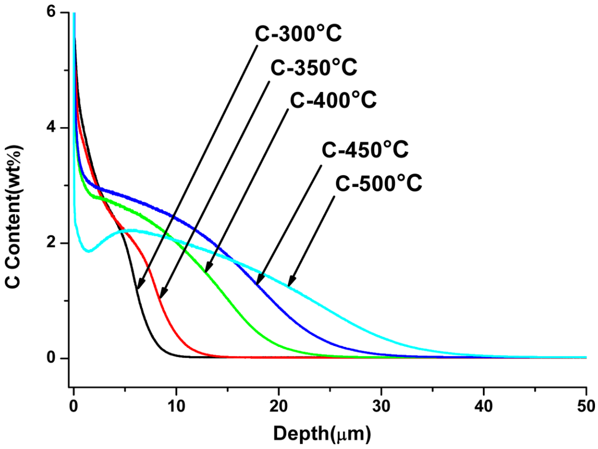


Fig. 3. GDOS pattern of carbon concentration profiles of carburized layer on AISI 310 stainless steel with various carburizing temperatures.

(S-phase) increases with increasing temperature. The diffusion of carbon atoms was influenced by the treatment temperature. The activation energy of the carbon atoms are increasing at elevated temperatures which will accelerate the diffusion of the carbon atoms through the matrix [3]. Therefore, as the treatment temperature increased 50 °C more in each stage the thickness is also increased 5 μm at average.

Figure 2 reveals the XRD pattern at different carburizing temperatures where untreated sample showed typical austenite peaks. These peaks became shifted towards lower Bragg angles after carburizing at various treatment temperatures. This happened due to the super saturation of carbon atoms in the S-phase which expanded the f.c.c. lattice structure of the substrate. It is also noticeable that the expanded and distorted austenite planes are more widely shifted which will increase the lattice constant of the f.c.c unit cell [2,4]. Besides, after carburizing treatment the peaks of γ_C(200) plane become broader with increasing treatment temperature compared with the peaks of γ_C(111) plane. This indicates that large amount of carbon atoms are supersaturated during elevated temperatures and longer treatment time. There is no sign of chromium carbide peaks in the XRD pattern even in the 500 °C.

The carbon concentration depth profiles of carburized layer as a function of temperature is presented in Fig. 3. The amount of carbon diffused into the bulk austenitic substrate at temperature ranges of 300 °C to 500 °C were determined by calculating the area under their elemental profile. It was found that the lowest carbon content is observed for sample treated at relatively low treatment temperature of 300 °C and increased abruptly at highest treatment temperature 500 °C. Also the depth of penetration of carbon atoms is increased with increasing carburizing temperature. In the GDOS profile, the carbon atoms penetrated approximately 9 μm at 300 °C temperature while it infiltrated around 35 μm at 500 °C. However, this gradual increase of the carbon content as increasing temperature can be ascribed to the mechanism of concentration gradient. The concentration gradient means that plasma species diffuse from the higher concentration region (on the surface layer) to the lower one (in the bulk material) [5]. Therefore, the concentration of carbon is found higher in the near surface region compared to underneath.

The correlation between surface hardness and thickness of the carburized layer is illustrated as a function of treatment temperature under a fixed treatment time in the Fig. 4. The hardness of the treated as well as untreated surfaces was measured by Vickers micro hardness tester using a standard load of 100gm indenter and the thickness was taken from the optical microscopic measurement. It is evident that as the temperature increases the hardness of the treated surfaces increase significantly. The real cause of increasing hardness is due to the incorporation of foreign interstitial atoms like carbon atoms into the f.c.c austenitic stainless steel. The carbon atoms are expanding and distorting the austenite phase which will restrict the motion of dislocation due to the build-up of internal stress, indicating that the carburized layer has a reasonable load bearing capacity [6]. The surface hardness reached up to 1107 $HV_{0.1}$ which is about three times higher than that of the untreated sample (386 $HV_{0.1}$).

The carburized samples were exposed to Potentiodynamic polarization tests in a 3.5 wt.% NaCl solution to study the corrosion behavior which is represented by the Fig. 5. The result shows that the corrosion potential and current density were improved after carburizing compared with the bare sample.

The untreated specimen was passivated at potentials below 0.5 V (SCE), above which pitting occurred leading to a sudden increase in current density. Instead, the carburized surface showed a more passive corrosion potential and a lower current density which increased gradually with potential [6]. But the corrosion current density was increased after carburizing at 500 °C. From the Fig. 5, sample treated at 300-400 °C showed very good corrosion potential and corrosion current density. The reason behind the improvement of passivation ability is due to the supersaturated austenite layer composed with carbon atoms. It was experimentally proved that the concentration of chrominum in the passive film was increased with increasing carbon content in the alloy, thereby making the passive film more protective. These corrosion test results confirm the benefits of the novel low temperature plasma carburizing process in achieving combined improvements in mechanical properties and corrosion resistance of 310 austenitic stainless steels.

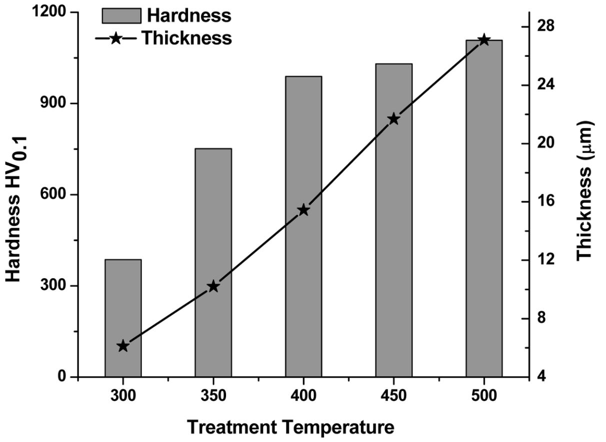
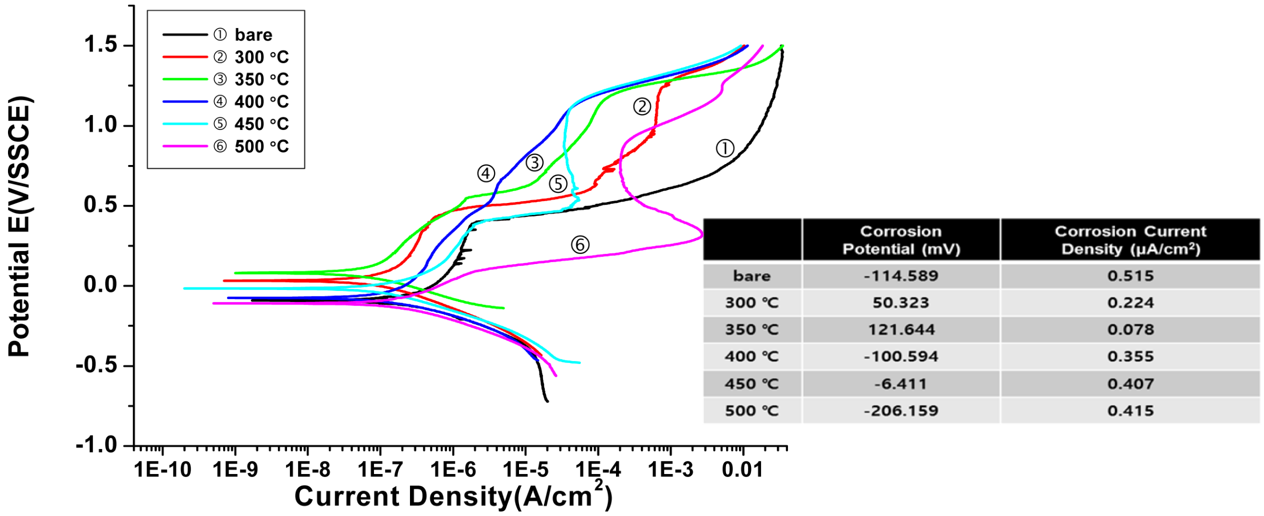


Fig. 4. Surface hardness and thickness of carburized layer on AISI 310 stainless steel with various carburizing temperatures.

4. Conclusions

In the light of experimental work in this research the following conclusions can be drawn:

1. The novel low temperature plasma carburizing process can be effectively applied to AISI 310 austenitic stainless steel which produces a continuous expanded austenite layer supersaturated with carbon.
2. The resultant carburized layer is precipitation free and possesses a high hardness with a favorable carbon concentration and hardness gradient, and much improved corrosion resistance in 3.5 % NaCl solutions, as compared to the original material.
3. Compared with the bare sample after carburizing a passive layer was formed and no pitting corrosion was observed through potentiodynamic polarization test at open-circuit potential for 1000 seconds at RT. The specimen treated at 350 °C showed the highest corrosion resistance, comparing with those obtained at other temperatures in terms of a lower corrosion



	Corrosion Potential (mV)	Corrosion Current Density (μA/cm²)
bare	-114.589	0.515
300 °C	50.323	0.224
350 °C	121.644	0.078
400 °C	-100.594	0.355
450 °C	-6.411	0.407
500 °C	-206.159	0.415

Fig. 5. Anodic Potentiodynamic Polarization curves of carburized layer on AISI 310 stainless steel with various carburizing temperatures.

current density and higher corrosion potential.

4. At more elevated carburizing temperature of 500 °C, corrosion resistance of the carburized specimen became poorer than that of untreated sample, which could be attributed to the formation of very small amount of chrome carbide precipitates in the expanded austenite (S-phase) layer although any chromium carbide peak was not detected in the XRD analysis.

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