Surface hardening and enhancement of Corrosion Resistance of AISI 310S Austenitic Stainless Steel by Low Temperature Plasma Nitrocarburizing treatment.

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Abstract

A corrosion resistance and hard nitrocarburized layer was distinctly formed on 310 austenitic stainless steel substrate by DC plasma nitrocarburizing. Basically, 310L austenitic stainless steel has high chromium and nickel content which is applicable for high temperature applications. In this experiment, plasma nitrocarburizing was performed in a D.C. pulsed plasma ion nitriding system at different temperatures in H_2-N_2-CH_4 gas mixtures. After the experiment structural phases, micro-hardness and corrosion resistance were investigated by the optical microscopy, X-ray diffraction, scanning electron microscopy, micro-hardness testing and Potentiodynamic polarization tests. The hardness of the samples was measured by using a Vickers micro hardness tester with the load of 100 g. XRD indicated a single expanded austenite phase was formed at all treatment temperatures. Such a nitrogen and carbon supersaturated layer is precipitation free and possesses a high hardness and good corrosion resistance.

1. Introduction

Austenitic stainless steels are ternary Fe-Cr-Ni alloys with excellent corrosion resistance and commonly used in biomedical, food and chemical, pulp and paper chemical, petrochemical, heat exchange and nuclear power plant industries at present [1]. However, their tribological properties, such as hardness and wear resistance are poor [1]. An increase in hardness without losing corrosion resistance could significantly broaden their applications. 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].

Generally, low temperature plasma nitriding was carried out at temperatures lower than 450° C for up to several tens of hours which produces a precipitation free nitrogen-enriched layer about 20 μm in thickness. This treatment results better surface hardness and good corrosion resistance than the untreated sample. Anyway, the layer on the surface will face some technical problems, which includes a low load-bearing capacity, an abrupt hardness drop at the layer-core interface, a poor toughness of the layer due to its extremely high hardness and non-uniformity of the layer thickness across the treated surface [2].

On the other hand, low temperature plasma carburizing was implemented at temperature 400 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 compared with the nitrogen enriched layer. In spite of having the larger layer thickness the carburized layer has lower hardness than nitrided layer [2].

To obtain good corrosion resistance, hardness and toughness a new treatment was introduced which is the combination of nitriding and carburizing. And this method is termed as plasma nitrocarburizing process, where both nitrogen and carbon containing gases are employed during the treatment. In addition, the treatment temperature during the plasma nitrocarburizing should be below 450° C. Otherwise, there is a huge possibility of forming CrC/ CrN in the layer. During this low temperature plasma nitrocarburizing treatment the nitrogen and carbon atoms infiltrated on the surface of the austenitic stainless steel by means of plasma media without inducing nitride and carbide precipitates, resulting in a dual-layer structure. This dual layer is also known as S-phase and containing N-enriched layer (γ_N) with high nitrogen content on the top of a C-enriched layer (γ_C) with high carbon content. Such a dual-layer (S-phase) structure possesses not only much increased hardness and corrosion resistance, but also better uniformity of thickness and load-bearing capacity compared with that obtained for individually nitrided layers [2]. The focus of this paper is to investigate the influence of low temperature plasma nitrocarburizing process on 310 austenitic stainless steel regarding the surface hardness and anti-corrosion performance.

2. Main Body

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).

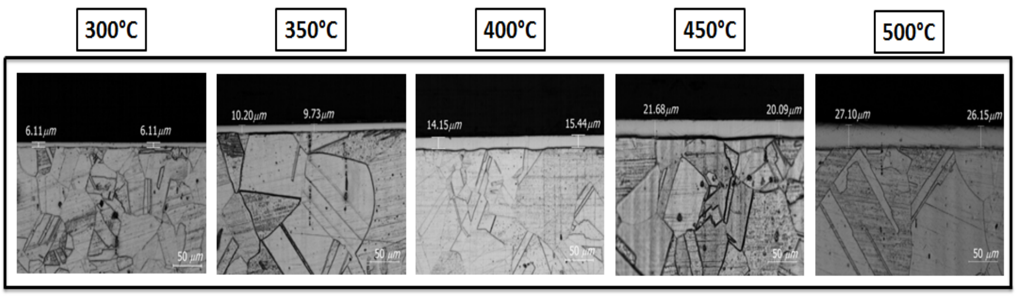

Fig.1. Cross sectional micrographs of plasma nitrocarburized AISI 310 stainless steels at various temperatures.

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.

Figure 1 shows the cross-sectional microstructures of plasma nitrocarburized AISI 310 stainless steel at various temperatures after etching. During the nitrocarburizing treatment, a hardened layer formed on the outermost surface which is also knowm as S-phase or dual layer. It is noticeable that the carburized layer (S-phase) thickness increases with increasing temperature. Because the diffusion rate of nitrogen and carbon atoms were greatly influenced by the nitrocarburizing temperature.

The nitrocarburized samples were exposed to Potentiodynamic polarization tests in a 3.5 wt% NaCl solution at room temperature to study the corrosion behavior which is represented by the Fig. 2.

The result shows that the corrosion potential and current density were improved after nitrocarburizing compared with the bare sample. Compared with the untreated specimen surface the plasma nitrocarburized surfaces show higher corrosion potential and lower current density as provided in the table 2. Having a very high nitrogen concentration on the nitrocarburized surfaces is the main reason for enhancement of corrosion resistance. The top layer which is composed of nitrogen increase the PH which is associated with the development of NH_4^+ ($N + 4H^+ + 3e^- \rightarrow NH_4^+$) in the acid pits, resulting in increasing the passivation ability and retarding the corrosion rate. However, lowest passive film was observed at nitrocarburized at 500° C due to the chrome nitride (Cr_2N) formation as detected by XRD pattern.

Table I. Chemical compositions of AISI 310 Austenitic Stainless Steel.

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

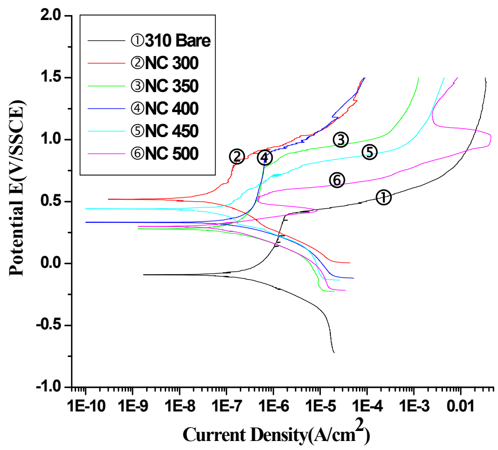

Fig. 2. Anodic Potentiodynamic Polarization curves at various nitrocarburized temperatures.

Table 2: Corrosion potential and current density of the treated and untreated sample

Sample	**Corrosion Potential E_C (V)**	**Corrosion Current Density I_C (A/cm^2)**
Untreated	-0.0876	1.508E-7
NC 300	0.5252	2.248E-8
NC 350	0.2815	7.001E-8
NC 400	0.3372	1.084E-7
NC 450	0.4364	3.724E-8
NC 500	0.3006	5.709E-8

3. Conclusions

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

1. The novel low temperature plasma nitrocarburizing process can be effectively apply to AISI 310 austenitic stainless steel which produces a corrosion protective expanded austenite layer which is supersaturated with nitrogen and carbon.
2. Compared with the original untreated sample the corrosion potential improved significantly after nitrocarburizing. The specimen treated at 300° C showed a much enhanced corrosion resistance in terms of a lower corrosion current density and higher corrosion potential as compared to the untreated steel.

References

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