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Effect of carbon addition on low-temperature plasma nitriding characteristics of austenitic stainless steel

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Abstract

Attempts have been made in the present work to investigate the influence of carbon in the treatment atmosphere on the low-temperature plasma nitriding characteristics of austenitic stainless steels. It was found that treatment gas composition has a significant effect on the structural characteristics of the nitrided layer. The addition of a small amount of carbon-containing gas such as methane (CH_4) to the treatment atmosphere can alter the structural development in the alloyed zone and offer several beneficial effects to the nitriding process. Based on this discovery, a new process has been developed, which involves the simultaneous incorporation of both nitrogen and carbon into the alloyed zone to form a dual-layer structure, which is free from chromium nitride, and carbide precipitates. Such a hybrid structure not only possesses larger layer thickness, high hardness, and more favourable hardness gradient than nitrided-alone layers, but also exhibits much improved corrosion resistance.

Keywords: Plasma nitriding; Carbon; Stainless steel; Carburising; Hardness; Corrosion

1. Introduction

It has been established that the surfaces of austenitic stainless steels can be alloyed with nitrogen at temperatures below around 450 °C to form an alloyed zone supersaturated with nitrogen [1–8]. Such an alloyed zone possesses not only high hardness and much enhanced tribological properties, but also good corrosion resistance, which is even better than that of the unalloyed substrate [5,6]. The combined improvement in tribological properties and corrosion resistance is derived from the relatively low temperature employed during the alloying process. Employing a low temperature can eliminate the precipitation of chromium nitrides in the alloyed layer, thus maintaining the corrosion resistance of stainless steels, whilst the supersaturation of nitrogen in the face-centred-cubic (FCC) austenite leads to the formation of an expanded austenite phase (γ_N) and the hardening of the alloyed layer.

Among many techniques that can be used to perform low-temperature nitriding of austenitic stainless steels, including conventional gaseous nitriding [7], plasma nitriding [1–6], ion implantation [9,10], ion beam and plasma-based ion implantation [11–15], plasma nitriding is the most widely used due to its industrial availability, high production rate, low cost and suitability for nitriding difficult-to-nitride materials. Low temperature plasma nitriding of austenitic stainless steels is normally carried out at temperatures around 400 °C for up to several tens of hours, resulting in the incorporation of a large amount of nitrogen in the nitrided layer up to 20 μm thick to form an expanded austenite (γ_N) structure which is free from nitride precipitates [3,6]. Such a low-temperature nitrided layer, although it possesses good corrosion resistance and high hardness, is quite brittle and has relatively low load bearing capacity due to its small thickness and the abrupt hardness drop at the layer–core interface [16]. Another technical

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problem associated with the nitriding process is the non-uniformity of layer thickness across the treated surface [6].

In the present attempt to further improve the quality of the low-temperature nitrided layers for industrial applications, it was found that treatment gas composition has a significant effect on the structural characteristics of the nitrided layer. The addition of a small amount of carbon-containing gas such as methane (CH_4) to the treatment atmosphere can alter the structural development in the alloyed zone and offer several beneficial effects to the nitriding process. Based on this discovery, a new process has been developed, which involves the simultaneous incorporation of both nitrogen and carbon into the alloyed zone to form a dual-layer structure. This paper focuses on the influence of carbon addition on the structural properties and characteristics of the nitrided layers and highlights the technological importance of the newly developed hybrid process.

2. Experimental procedure

AISI 321-type austenitic stainless steel was used as substrate material. The chemical composition of this steel is as follows (in wt%): 18.78Cr, 11.04Ni, 0.45Ti, 1.91Mn, 0.10C and balance Fe. Disc specimens of 25 mm in diameter and 5 mm in thickness for plasma surface nitriding were cut from the as-received hot-rolled steel bars. The specimens were manually ground using SiC emery papers down to 1000 grade to achieve a surface finish around 0.1 μm (R_a).

Plasma nitriding was carried out in a DC plasma nitriding unit at temperatures between 400 and 430 °C for times up to 40 h. The maximum power of the nitriding unit was 20 kW and the discharge voltage used for the treatment was between 400 and 600 V. The gas mixture used was 80% N_2 + 20% H_2 for nitriding. Carbon was added to the treatment atmosphere by replacing the H_2 gas by CH_4 with 2–10% CH_4. After evacuating the chamber to below 0.1 mbar pressure, a glow discharge was initiated between the specimens (cathode) and the chamber walls (anode), and meanwhile the gas mixture was introduced into the chamber to gradually reach a pressure of 5 mbar, which was kept constant during the rest of the process. Upon completion of the treatment process, the gas introduction and glow discharge were terminated and the specimens were allowed to cool inside the chamber in vacuum down to room temperature.

The treated specimens were then characterized by X-ray diffraction for phase identification, metallography for layer morphology and thickness examination, glow discharge optical spectrometry for composition profiling, microhardness tests for surface hardness measurements, and electrochemical tests for corrosion resistance evaluation.

3. Results and discussion

3.1. *Effect of carbon addition*

Three experiments were first conducted in order to study the effect of carbon addition on layer structure, uniformity and hardness. The treatments were carried out at 420 °C for 5 h. The three processes include:

(1) NT treatment: nitriding alone in 80% N_2 + 20% H_2 mixture for 5 h,
(2) NTC + NT treatment: treating in 95% N_2 + 5% CH_4 for 1 h, followed by nitriding in 80% N_2 + 20% H_2 for 4 h,
(3) NTC treatment: treating in 95% N_2 + 5% CH_4 mixture for 5 h.

The resultant layer morphology is illustrated in Fig. 1 and the corresponding nitrogen and carbon concentration profiles are given in Fig. 2. It can be seen that both NTC and NTC + NT treatments produced a dual-layer structure with an N-enriched layer on top of a C-enriched layer. Due to the contamination of the chamber with carbon arising from previous treatments, a thin C-enriched layer was also produced by the NT treatment. However, the results show that NTC treatment produced the largest C-enriched layer thickness, whilst NT alone produced the smallest layer thickness. Table 1 lists the layer thickness values for various treatments. It can be seen that NTC and NTC + NT treatments produced similar N-enriched layer thickness, which is even larger than that produced by NT alone. Clearly, the addition of carbon, even in the early stage of the process, can increase the thickness of the N-enriched layer and the C-enriched layer, and thus the total alloyed zone thickness.

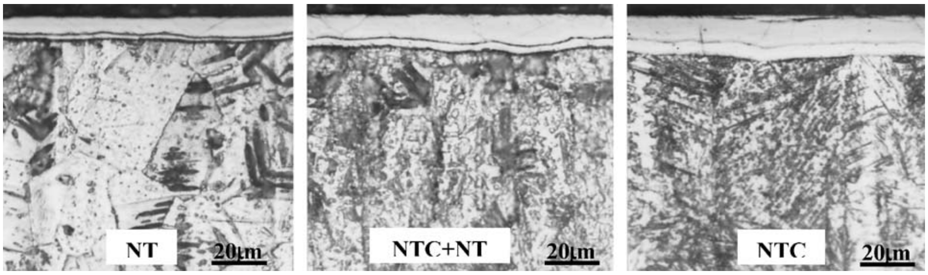

Fig. 1. Optical micrographs showing the cross-sectional view of the morphology of NT, NTC + NT and NTC treated layers produced at 420 °C for 5 h, showing the effect of methane in gas mixture on layer structure.