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Surface & Coatings Technology 200 (2005) 1645 – 1651

SURFACE & COATINGS TECHNOLOGY

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Low temperature plasma nitriding of 316 stainless steel by a saddle field fast atom beam source

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Available online 12 September 2005

Abstract

Nitriding by plasma is a promising method for surface treatment to improve hardness, corrosion, wear and fatigue resistance of materials (ferrous and non-ferrous). But in conventional plasma nitriding techniques, the processing temperature depends on plasma process parameters and it cannot be controlled independently of the plasma source. In this present work, a new low temperature and low pressure plasma nitriding process on AISI 316 stainless steel sample by a saddle field fast atom beam source is reported. Plasma nitriding was carried out at 420 °C and at a pressure of 0.1 Pa for 8 h. Optical microscopy investigation of the cross-section of the nitrided sample revealed a thin nitrided layer separated from the core material by a distinct etch line. Irregular surface morphology similar to austenitic grain boundaries was visible on the surface of the nitrided sample when viewed under Scanning Electron Microscope. Energy dispersive X-ray spectroscopy study showed the presence of nitrogen in the nitrided surface whereas no nitrogen was found in the non-nitrided sample. The crystal structure of expanded austenite or S phase was identified by X-ray diffraction analysis without any CrN precipitation. A high hardness value on the nitrided surface and in the nitrided layer in comparison with a low value of hardness in the core material was observed by Vickers microhardness testing. The results show that this is a promising method for low temperature plasma nitriding of austenitic stainless steel.

Keywords: Plasma nitriding; Saddle field fast atom beam; 316 stainless steel; S phase

1. Introduction

Austenitic stainless steels have been widely used in diverse industrial sectors such as biomedical industries, food and chemical processing industries, nuclear reactor technology etc. because of their superior corrosion resistance resulting from a native passive layer (e.g., Cr_2O_3). Nevertheless, they have poor tribological (e.g., high friction and wear rate) and mechanical (e.g., low hardness, low load-bearing capacity) properties. Thermochemical diffusion processes such as nitriding can improve the tribological and mechanical properties of these steels by enriching the near surface region with nitrogen. The conventional nitriding processes (e.g., gas nitriding, salt-bath nitriding) have several disadvantages such as higher distortion of the workpiece, longer processing time, poor surface finish etc. compared to plasma or glow discharge nitriding. On the other hand, Czerwiec et al. [1] identified some problems with the conventional plasma nitriding. A higher sample temperature, which is set by the discharge parameters and cannot be controlled independently, and a comparatively higher operating pressure increases the possibility of surface contamination, which retards the diffusion of nitrogen. Higher current density, required to maintain an abnormal glow discharge, leads to overtempering of the workpiece. Plasma nitriding at high temperature (around 500 °C or higher) also reduces the corrosion resistance of the austenitic steel. This fact is explained by the precipitation of chromium nitride, which results in the depletion of chromium in the austenitic solid solution [2]. This chromium depletion layer is very prone to corrosion.

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doi:10.1016/j.surfcoat.2005.08.083

Recently, more attention has been given to low temperature (below 500 °C) plasma nitriding to control nitride layer formation compared to the conventional plasma nitriding processes, and thus to acquire enhanced surface properties (e.g., tribological and mechanical) without losing corrosion resistance [1,3–9]. This effect can be correlated with the formation of a layer composed of a phase generally recognized as S phase [10] or expanded austenite [11,12] with a face centred tetragonal (fct) crystal structure, which is a metastable and supersaturated solid solution of nitrogen in the face centred cubic (fcc) austenitic phase [6,13,14]. The resulting nitrided layer is precipitation-free and retains the corrosion resistance of a nitrided surface formed at low temperature. Furthermore, the S phase produces a significant hardening effect on the austenite stainless steel surface due to the solid solution strengthening.

Again plasma nitriding at low pressure where the plasma source is separate from the workpiece, such as rf discharge, microwave discharge, plasma source ion implantation, triode discharge etc. produces plasma containing a large number of active species. This increases the nitriding efficiency and allows more flexibility in controlling the process parameters [5,15]. The low pressure nitriding processes can be used to form duplex coatings: deposition of hard coatings on the nitrided surface in the same processing chamber [9]. In this study for the first time, a new low temperature and low pressure plasma nitriding by a saddle field fast atom beam source on AISI 316 stainless steel has been investigated. Plasma Enhanced Chemical Vapor Deposition (PECVD) chamber where the plasma source is separate from the workpiece has been used to conduct the nitriding process.

2. Saddle field fast atom beam source and its advantages

A saddle field fast atom beam (FAB) is defined as energetic neutral particles ranging in energy from a few electron volts to several thousand electron volts [16]. In the FAB plasma source, there are two positive parallel anode rods symmetrically arranged around the main axis of a rectangular cathode cylinder based on the McIlraith's principle of the electron electrostatic oscillator [17]. By the application of high voltage to the rod anodes, electrons oscillate at high frequency backward and forward through a saddle point of the electrostatic field between the anodes. With this arrangement, the electrons can follow a long oscillatory path and a large number of ions are produced when these electrons collide with gas molecules, i.e., a high intensity cold cathode discharge is produced at low pressures. The cathode attracts the ions and majority of the ions are then converted into fast atoms either by neutralization in charge-transfer collisions with neutral gas molecules or by recombination with the emitted secondary

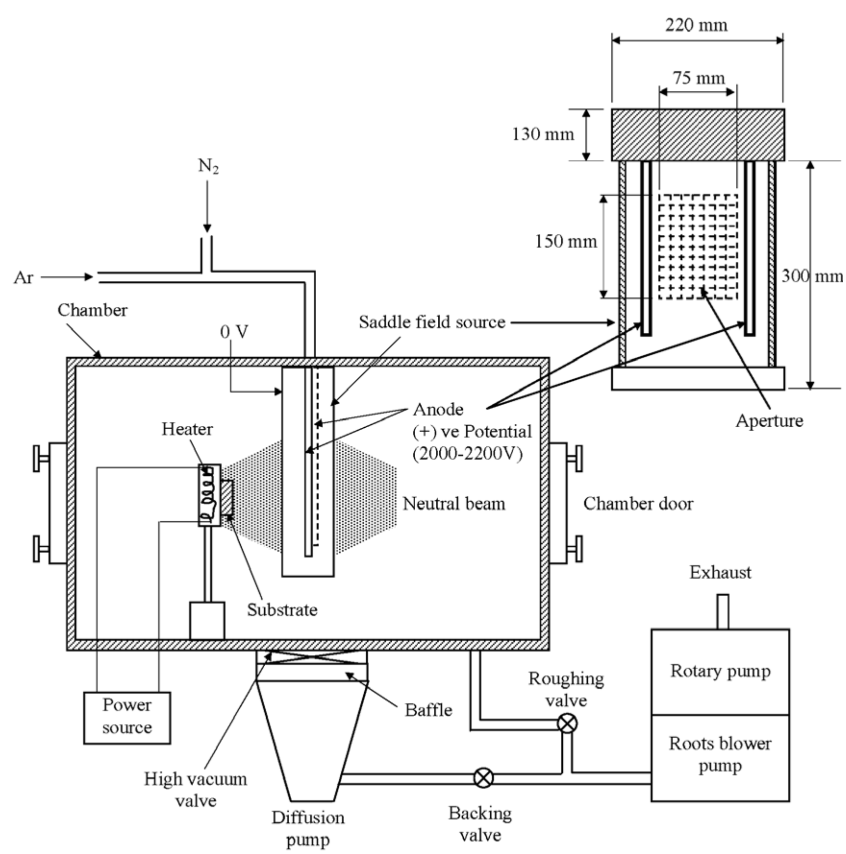

Fig. 1. Schematic diagram of plasma nitriding experimental set-up.