Materials and Design 108 (2016) 745–753

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Enhanced surface properties of plain carbon steel using plasma nitriding with austenitic steel cathodic cage

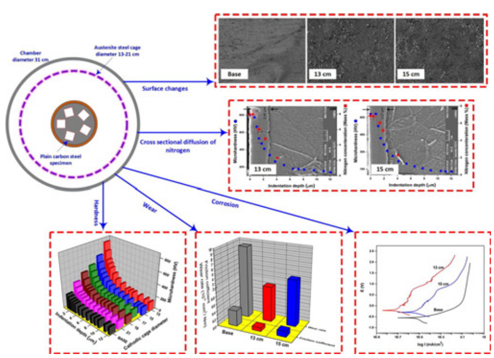
M. Naeem [a], M. Shafiq [a], M. Zaka-ul-Islam [b], A. Ashiq [a], J.C. Díaz-Guillén [c], M. Shahzad [d], M. Zakaullah [a,*]

[a] Department of Physics, Quaid-i-Azam University, 45320 Islamabad, Pakistan
[b] Department of Physics, Faculty of Science, Jazan University, P.O. Box 114, Jazan, Saudi Arabia
[c] CONACYT Research Fellow, Mexican Corporation for Materials Research, Saltillo, Coahuila, Mexico
[d] PE Materials Division, PINSTECH, Nilore, Islamabad, Pakistan

HIGHLIGHTS

- Plain carbon steel is successfully nitrided by cathodic cage technique without any pre-treatment or alloys admixing.
- Plasma diagnostics show a good correlation with the nitriding results.
- Cathodic cage diameter significantly influences nitriding efficiency.
- Wear and corrosion rates are significantly reduced.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 29 February 2016
Received in revised form 18 June 2016
Accepted 10 July 2016
Available online 12 July 2016

Keywords:
Plain carbon steel
Wear resistance
Corrosion resistance
Austenitic cathodic cage

ABSTRACT

Non-alloyed steels are very popular in a wide range of applications due to their low cost, but unfortunately, they are not favorable to surface enhancement by nitriding process because of high brittleness. This problem can be overcome by introducing special alloying elements (such as chromium) on the surface by pre-treatment or admixing of alloys in the bulk, but it is not very cost effective. In this study, plain carbon steel specimens are processed by the cathodic cage plasma nitriding (CCPN) technique using an austenitic stainless steel cathodic cage (CC) having variable diameters (13–21 cm). It is observed that the nitriding process significantly improves the hardness without any pre-treatment or admixing of alloys, which is very useful for industrial applications due to reduced cost and processing time. Also, the corrosion and wear rates are significantly reduced. The results are understood in terms of phase structure, crystalline size and strain using XRD analysis, reactive species emission from the plasma using optical emission spectroscopy and SRIM simulation.

1. Introduction

Non-alloyed steels, commonly known as plain carbon steels, are vital for a broad range of industrial applications including automotive components [1]. This is due to their low cost compared to alloyed steels; however, for certain applications their use is limited due to lower mechanical strength. Plasma nitriding is a surface modification technique which is extensively used to improve the mechanical as well as corrosion properties of alloyed steels. It is known that plasma nitriding cannot significantly enhance the surface mechanical strength of the non-alloyed steels. This is due to the known problem of in-depth diffusion of nitrogen and as a result formation of iron nitrides at higher depths in non-alloyed steels [1,2].

* Corresponding author.
E-mail address: mzakaullah@qau.edu.pk (M. Zakaullah).

http://dx.doi.org/10.1016/j.matdes.2016.07.044
0264-1275/© 2016 Elsevier Ltd. All rights reserved.

The comparison of nitrided alloy (En40B) and plain carbon steel (Ck45) under similar processing conditions showed that while the bulk hardness is quite similar, the surface hardness is 900 HV and 470 HV, respectively [1]. Nevertheless, the hardness of steels can be effectively enhanced by the plasma nitriding process if special alloying elements (such as chromium, molybdenum, aluminum, vanadium, etc.) are admixed or pre-deposited on the surface [2,3]. This is due to the formation of hard nitrides at the surface, caused by the high affinity of the alloying elements to the nitrogen [1,4]. While these approaches increase the time and total cost of the process, some are also not very feasible for the wide range of commercial applications, where large quantity is required [3,4].

Recently, the cathodic cage plasma nitriding has been effectively employed for various materials including several steel grades [5–14]. In this technique, the entire workload is enclosed by a metallic cage at the cathodic potential, called the cathodic cage. The workload (specimens to be processed) is at a floating or relatively lower cathodic potential [5,15]. In this arrangement, the cathodic cage plays dual function for the plasma sustainment i.e. it confines the electrons in the discharge by electrostatic force as well as it generates extra secondary electrons from the surface [16,17]. Additionally, the sputtered particles from the cathodic cage are deposited on the workpiece as hard nitrides or later convert into nitrides [17,18]. As discussed earlier, the deposition of alloying elements is beneficial for the surface hardness of plain carbon steels. It is therefore expected that if an alloy cathodic cage is used for the nitriding of carbon steel, the sputtered alloying elements from the cage will contribute in enhancing the surface hardness.

So, in this work, plain carbon steel specimens are processed in cathodic cage plasma nitriding reactor with an alloyed cathodic cage (austenitic stainless steel AISI 304) of variable dimension (13–21 cm). The results show that the nitrided specimens achieve a surface hardness of ~800 HV in a comparatively short treatment time of 4 h, without any pre-treatment or admixing of alloys. Also, the wear and corrosion rates are significantly improved. The results of the surface properties are finally correlated and explained with optical emission spectroscopy during the nitriding process.

2. Experimental details

2.1. Plasma reactor and diagnostics system

The plasma system along with the diagnostics is schematically presented in Fig. 1(a). The cylindrical chamber has ~31 cm internal diameter and ~33.5 cm height. The austenitic stainless steel AISI 304 CC has ~18 cm height, ~ 2 mm wall thickness, and diameters of ~13, 15, 17,

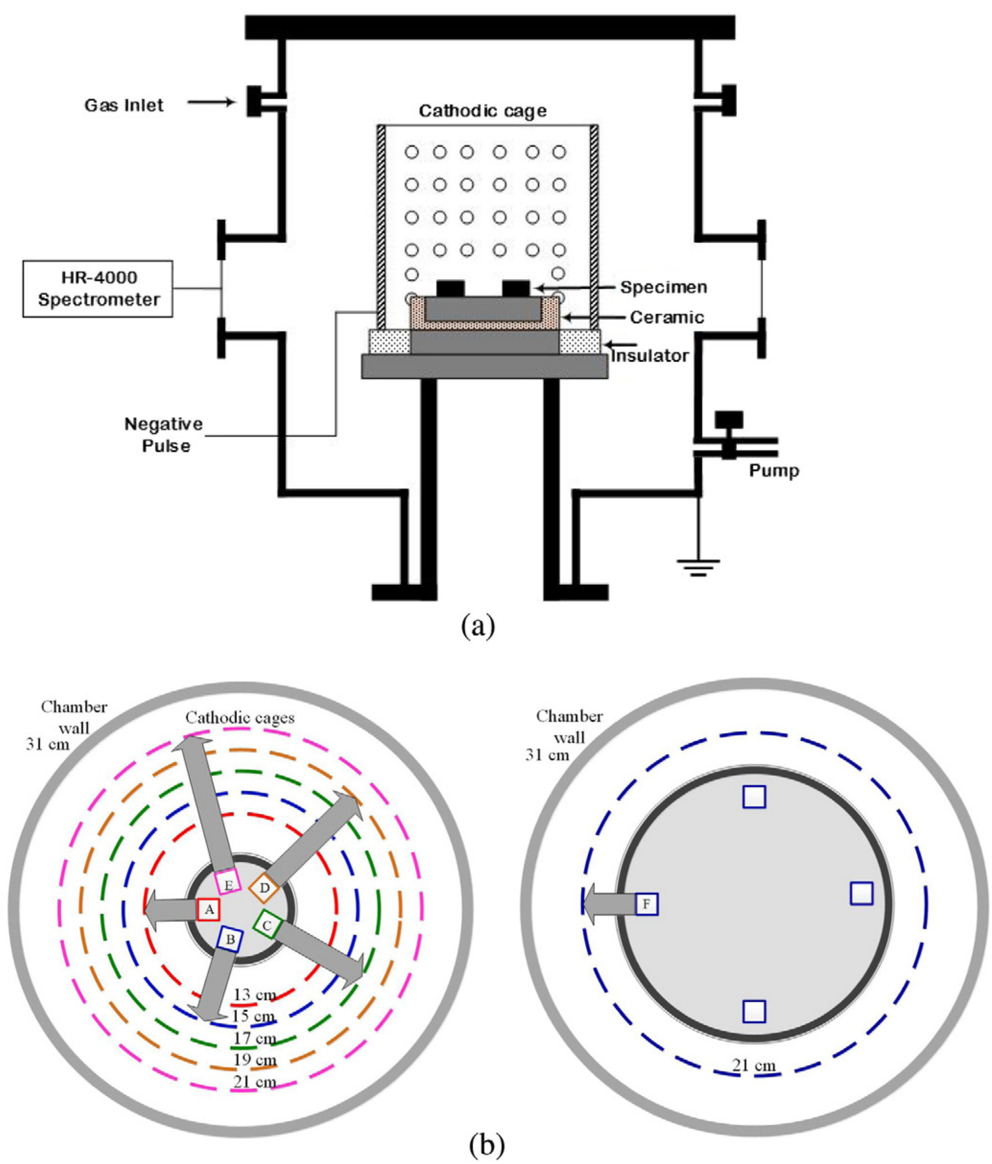


Fig. 1. Schematic illustration of (a) plasma nitriding reactor (b) specimen's placement on the substrate, screen configuration and specimens labeling.