Effect of Plasma Nitriding and Nitrocarburising Process on the Corrosion Resistance of Grade 2205 Duplex Stainless Steel

Subroto Mukherjee[1] , Alphonsa Joseph[1], Ghanshyam Jhala[1], Satyapal M[2], A. S. Khanna[2], Pratipal Rayjada[1], Narendra Chauhan[1], Raja V. S.[2]

[1]Institute for Plasma Research, Gandhinagar, India
[2]Indian Institute of Technology, Bombay, India

Corresponding author
Dr. S. Mukherjee,
Institute for Plasma Research,
Bhat, Gandhinagar, Gujarat, India.
Phone: +91-79-23269011, 23269000
Fax No. : +91-79-23269000
E-mail: mukherji@ipr.res.in; dr_mukherjee@yahoo.co.in

Abstract:
Grade 2205 duplex stainless steel is a type of stainless steel possessing a nearly equal amount of the ferrite (α-Fe) and austenite (γ-Fe) phases as a matrix. Since this steel has a relatively low hardness of 256 HV0.1, an attempt has been made to improve its hardness and wear properties without compromising the corrosion resistance by plasma nitriding and nitrocarburising process. Plasma nitriding and plasma nitrocarburising process was performed with 80% nitrogen and 20% hydrogen gas and 78% nitrogen, 20% hydrogen and 2% acetylene gas respectively at 350, 400, 450 and 500 ^{o}C for 4 hours. The temperature played an important role in the distribution of nitrogen and carbon in the original austenite and ferrite phases present in the bulk material. As a result there was an improvement in microhardness and corrosion properties after these treatments. It was observed that plasma nitrocarburising process performed better than plasma nitriding process in improving the corrosion properties due to the presence of carbon.

Keywords

Duplex steel; Plasma Nitriding; Nitrocarburising; Hardness; Corrosion

Introduction

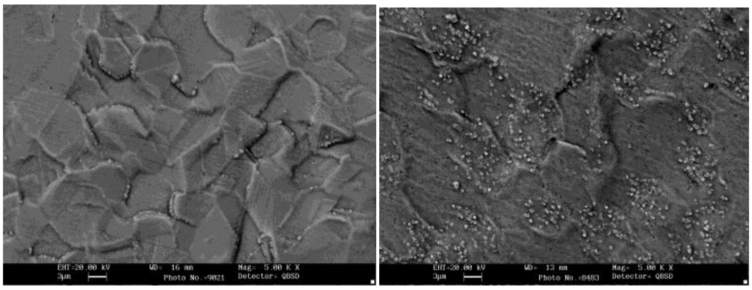
The ferritic-austenitic Duplex Stainless Steel (DSS), possesses good mechanical properties and high corrosion resistance. For this reason they are frequently used in chemical engineering, oil refining, food processing, dyeing, tanning and the paper industry [1]. The most common duplex grade used today is EN 1.4462 or 2205 (UNS S31803/S32205), which has a nominal composition of 22% Cr, 5%Ni and 3% Mo [2]. However, even in the DSS, there is still the necessity to increase surface hardness in order to obtain higher wear resistance without loss of corrosion resistance [3]. Plasma Nitriding process seems to be a reasonable method to improve the wear resistance of this steel but unfortunately it decreases the corrosion resistance properties due to chromium nitride precipitation. It was found that in case of austenitic steel when plasma nitriding was conducted at temperature below 500 °C it was possible to maintain high corrosion resistance due to formation of so called “expanded austenite" (named also γN , S-phase). Few works on plasma nitrided duplex steel confirmed the formation of this phase also. In a recent work by A. Triwiyanto eta al, the effect of carbon and nitrogen was investigated at 460 ^{o}C indicating an increase in surface hardness due to the presence of expanded austenite [4]. Till now, corrosion resistance properties have not been investigated after plasma nitriding and nitrocarburising process for this steel. In the present study, a comparison of both structural and corrosion properties have been made after plasma nitriding and plasma nitrocarburising process on 2205 grade duplex stainless steel.

Experimental details:

Circular disc of dimensions of 3cm diameter and 5mm thickness of 2205 grade duplex stainless steel (C 0.026%, Ni 4.6%, Cr 22.06%, Si 0.69%, Mn 1.74%, S 0.008%, P 0.025% and Mo 2.580% by weight, with Fe being the balance). The samples were mechanically polished up to 1 μm diamond paste and 0.5 micron alumina paste in order to obtain a final mirror finish of a mean roughness Ra value better than 0.01microns, and cleaned in acetone. The plasma nitriding and plasma nitrocarburizing processes with a gas mixture (80% nitrogen and 20% hydrogen) and (78% nitrogen, 20% hydrogen and 2% C_2H_2) respectively were performed at 5mbar. Prior to plasma processing surface cleaning was done at 250 °C/1 h by using pure H_2 atmosphere. The working temperature was controlled by monitoring a J- type thermocouple and adjusting the voltage as needed in order to maintain the substrate temperature of 350, 400, 450 and 500 °C for 4 hours. After plasma nitriding, the samples were cooled down to 180 ^{o}C in a nitrogen gas atmosphere to avoid oxidation before removing them from the vacuum chamber. The phases formed were identified using glancing angle X-ray diffractometer collected between 35 °≤2 θ <80° with Cu–Kα radiation (λ =1.5406 Å), at a step size of 0.06°. Surface morphology of the treated samples were observed under Scanning Electron Microscopy (SEM). Microvickers Hardness Tester was used to measure surface hardness with 100 grams load. Potentiodymanic studies were done with 3.5% NaCl solution using Gamry make Potentiostat.

Results:

a) **Surface Roughness:**



(a) (b)

Fig. 1: Surface morphology of Duplex 2205 at (a) plasma nitrided at 500 ^{o}C b) plasma nitrocarburised at 500 ^{o}C.

The surface roughness of duplex 2205 stainless steel samples increases with temperature after plasma nitriding and plasma nitrocarburising process. The increase in surface roughness after plasma nitrocarburising process at high temperatures is due to the presence of nitrides. This is evident in fig. 1b where small microparticles are present in austenite phases after plasma nitrocarburising compared to plasma nitriding processs as observed in fig.1 a.

b) Surface hardness

The experimental results demonstrated that the surface hardness of plasma nitrided specimens is significantly affected by nitriding. Very high microhardness values were found on the surface of samples treated at temperatures ≥450 °C as shown in Fig. 2. The initial hardness of Duplex 2205 is 250HV0.10. The maximum values measured from the 500 °C/4 h treated sample is 1326 HV0.10, which is about 5 times as hard as the untreated material. However, the surface hardness was lower after plasma nitrocarburising compared to plasma nitriding process due to low diffusion rate of carbon than nitrogen ions in 2205 duplex steel.

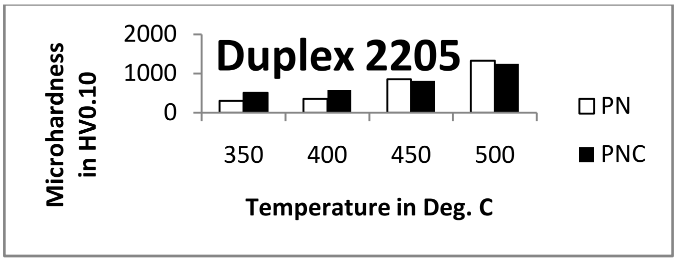


Fig. 2: Surface hardness after plasma nitriding and plasma nitrocarburising of Duplex 2205 steel at different temperatures

c) Phase Analysis:

The GIXRD of untreated duplex 2205 steel shows the presence of both ferrite and austenite phase. After plasma nitriding at 350 ^{o}C, there is a formation of expanded austenite and ferrite phase. The expanded austenite peaks are broad and shift towards the lower 2 theta angles. With increase in temperature i.e. 400 ^{o}C, there is presence of expanded austenite and ferrite but the shifts of expanded austenite phase are lower than that formed at 350 ^{o}C. With further increase in temperature the expanded austenite dissociates to form chromium nitride and ferrite along with iron nitrides (Fig. 3a). In case of plasma nitrocarburising at 350 and 400 ^{o}C the shifts of expanded austenite is more compared to that after plasma nitriding mainly due to the presence of carbon nitrogen supersaturated expanded austenite phase. At higher temperature there is presence of iron nitrides and chromium nitrides (Fig.3b).

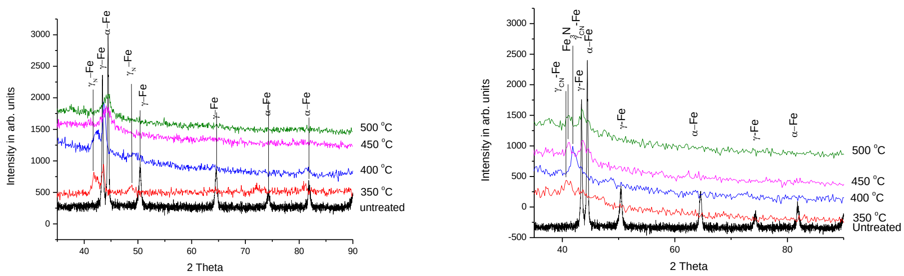


Fig. 3: GIXRD pattern of Duplex 2205 steel a) plasma nitrided b) Plasma nitrocarburised at different temperatures.

d) Potentiodynamic studies:

Fig. 4 shows the potentiodynamic polarization curves for both untreated and treated duplex samples at different temperatures studied using 3.5 wt% NaCl environment. The corrosion current density of plasma nitrided samples at 350 ^{o}C was more positive than other samples including the untreated sample (fig.4a). This improvement is due to the presence of γ_N phase formed at 350^{o}C. Whereas the samples treated at 450 & 500 ^{o}C nitriding temperature are more susceptible to corrosion due to the formation of CrN phases.

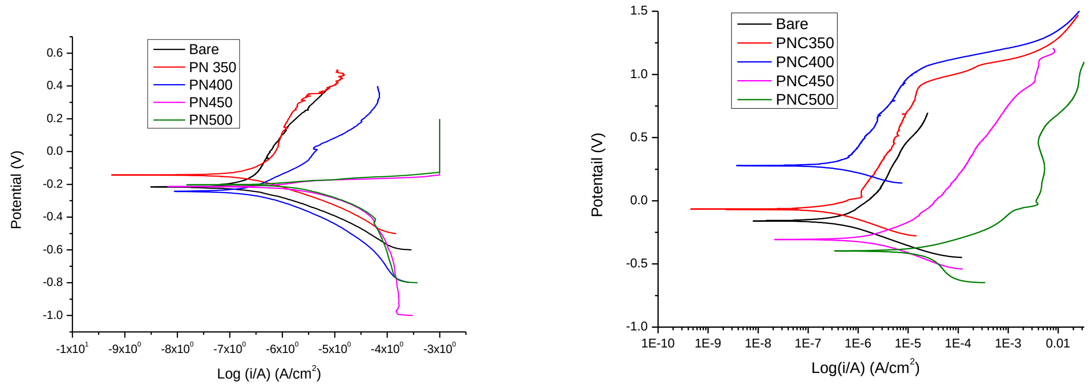


Fig.4 Potentiodynamic curves of a) plasma nitrided b) plasma nitrocarburisied duplex steels in 3.5% NaCl solution

After plasma nitrocarburising process it was found the the corrosion current density was the lowest for duplex samples treated at 350 ^{o}C as shown in figure 4b. Also the corrosion rate obtained from these curves is lower than plasma nitrided samples indicating that the improvement in corrosion resistance is due to the presence of carbon-nitrogen supersaturated expanded austenite phase.

Conclusion:

It was concluded from this investigation that both surface hardness and corrosion resistance of duplex steels can be enhanced by plasma nitriding and plasma nitrocarburising process. It was observed that the duplex samples treated at 350 ^{o}C exhibited better corrosion resistance then samples which were treated at higher temperatures. Moreover, samples treated by plasma nitrocarburising process performed better than plasma nitrideing process due to the presence of carbon which was responsible in forming carbon nitrogen supersaturated expanded austenite phase.

References:

[1] Rim Dakhlaoui, Chedly Braham, Andrzej Baczma´nski, Mechanical properties of phases in austeno-ferritic duplex stainless steel—Surface stresses studied by X-ray diffraction, Materials Science and Engineering A 444 (2007) 6–17.

[2] Iris Alvarez-Armas, Duplex Stainless Steels: Brief History and Some Recent Alloys, Recent Patents on Mechanical Engineering 1 (2008) 51-57.

[3] H. Dong, “S-phase surface engineering of Fe-Cr, Co-Cr and Ni-Cr alloys,” Int. Mater. Rev., vol. 55, no. 2, (2010) 65–98.

[4] A.Triwiyanto1, P. Hussain2, M. Che Ismail, Behavior of Carbon and Nitrogen after Low Temperature Thermochemical Treatment on Austenitic and Duplex Stainless Steel, Applied Mechanics and Materials Vols. 110-116 (2012) 621-62.