Low Temperature Nitriding of a Ferritic Stainless Steel

Tufan Gümüşlü*,+, Mertcan Kaba+, Doğukan Çetiner+, Faiz Muhaffel+, Erdem Atar*, Hüseyin Çimenoğlu+

* *Department of Materials Science and Engineering, Gebze Technical University*

Gebze Teknik Üniversitesi 41400 Kocaeli, TURKEY

tgumuslu@gtu.edu.tr, atar@gtu.edu.tr

+ *Department of Metallurgy and Materials Engineering, Istanbul Technical University*

İTÜ Ayazağa Kampüsü 34469 Maslak, Istanbul, TURKEY

mertcankaba@itu.edu.tr, cetinerd@itu.edu.tr, muhaffel@itu.edu.tr, cimenogluh@itu.edu.tr

***Abstract*— The motivation of this study was to improve the surface hardness and wear resistance of ferritic AISI 430 stainless steel by low-temperature gas nitriding. Nitriding of the samples was carried out in a fluidized bed reactor for 4 hours at 420 °C in a 60% NH_3 and 40% N_2 gas composition. Structural and chemical characterizations of the nitrided and untreated samples were done by the use of X-ray diffractometer (XRD), scanning electron microscope (SEM) and Energy-Dispersive X-ray spectroscopy (EDS). Afterwards, ball-on-disc wear test applied on untreated and nitrided samples and formed tracks examined under SEM and 2-D profilometer. As a result of the low temperature nitriding process, surface hardness and wear resistance were remarkably increased.**

***Keywords*— low temperature nitriding, AISI 430 stainless steel, ball-on-disc wear test, fluidized bed reactor, X-ray diffraction**

I. Introduction

Ferritic stainless steels are preferred in many applications such as automotive, chemical and food industries owing to their low cost, machinability and corrosion resistance [1,2]. However, low wear resistance and hardness of ferritic stainless steel has limited its usage for wear related applications [1].

In this respect, rather than conventional nitriding at 450 – 550 °C, nitriding at low temperatures (~ 400°C) was reported as a promising technique for austenitic stainless steels as it provides high surface hardness without sacrificing the corrosion resistance by inhibiting the formation of CrN [3–7]. However, characteristics of ferritic stainless steels after low temperature nitriding have not been extensively reported as austenitic stainless steels. In most of these studies' nitriding process have been employed by using plasma-based nitriding [1,8,9]. On the other hand, nitriding in fluidized bed reactor has also gained attention owing low gas consumption and relatively low investment cost. In this process, fine Al_2O_3 particles present in the reactor ensure homogeneous distribution of heat and the transfer of the process gases (NH_3 and N_2) to the samples by the bubbling and continuous mixing motion [7].

The present study was undertaken to investigate the effect of low temperature nitriding on the wear resistance of AISI 430 ferritic stainless steel.

II. Materials And Methods

The chemical composition of the AISI 430 stainless steel rod with diameter of 13mm used in the present study is presented in Table 1.

TABLE I
Chemical Composition Of AISI 430 Stainless Steel

Element	C	Cr	Mn	Ni	Si	Mo	Fe
wt. %	0.171	15.5	1.65	0.28	0.58	0.18	Balance

Before nitriding process, AISI 430 stainless steel samples were grinded, polished and cleaned with alcohol. The nitriding process took place in the fluidized bed reactor with selected parameters (Table 2).

TABLE III
The Selected Parameters For Nitriding Process

Gas Composition	60% NH_3 + 40% N_2
Temperature	420 °C
Time	4 hours

Structural and chemical characterization and comparison of the nitrided and untreated samples were done by the usage of XRD, SEM and EDS. The surface hardness measurements were done by Vickers indenter under the load of 25 g. Dry sliding wear tests were conducted on the untreated and nitrided samples by using ball-on-disc tribometer at the test parameters given in Table 3. SEM and 2-D profilometer were used for the analysis of wear track on the samples.

TABLE IIIII
Parameters For Ball-On-Disc Wear Test

Linear Speed	5 cm/s
Sliding Distance	100 m
Counter-face	6 mm dia. Alumina ball
Load	1 N
Testing Temperature	Room Temperature

III. Results And Discussion

XRD patterns of the nitrided and untreated samples are given in Fig. 1. In the XRD patterns of both samples peaks of α-Fe and MnS were appeared. There was no clear evidence of nitride formation on the XRD pattern of the nitrided sample, but the peaks of α-Fe were broadened and shifted to lower diffraction angles. When the most intense α-Fe (110) peak is of concern, lattice parameters were determined as 0.2870 nm and 0.2928 nm for untreated and nitrided samples, respectively. From these lattice parameters expansion of α-Fe lattice calculated as 2.02%. This observation indicates that the nitriding process sustained nitrogen atoms to dissolve in the BCC structure.

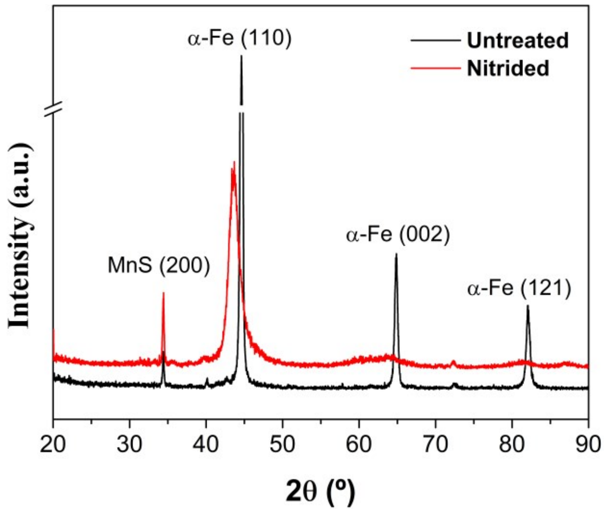

Fig. 1 XRD pattern of the untreated and nitrided samples

After nitriding, surface hardness of the AISI 430 grade ferritic stainless steel was increased from 251 HV to 1096 HV, which can be attributed to the solid solution strengthening mechanism visualized as lattice expansion (Fig. 1).

In Fig. 2 and Fig 3., 2-D profiles of the wear tracks and friction curves recorded during wear tests are given for untreated and nitrided samples. In accordance with higher hardness, under dry sliding condition nitrided sample exhibited lower wear loss (i.e. smaller wear track area) as compared to untreated sample and smaller friction coefficient.

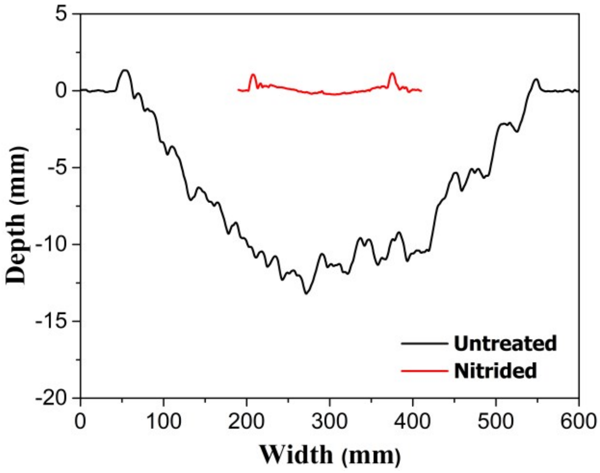

Fig. 2 2-D profiles of wear tracks untreated and nitrided samples

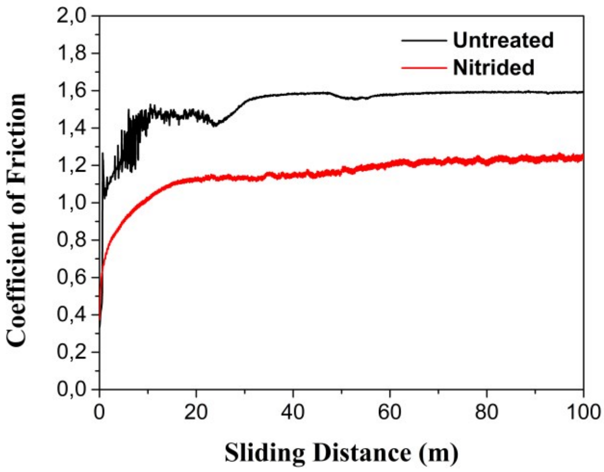

Fig. 3 Friction curves for the untreated and nitrided samples

Worn surface back-scattered SEM images of the untreated and nitrided samples are presented in Fig. 4. On the worn surface of untreated sample severe oxidation was detected while limited oxidation and arc-shaped micro-cracks were evident for the nitrided sample. It is observed that applied nitriding process caused shifting of wear mechanism from oxidative wear to fatigue wear.

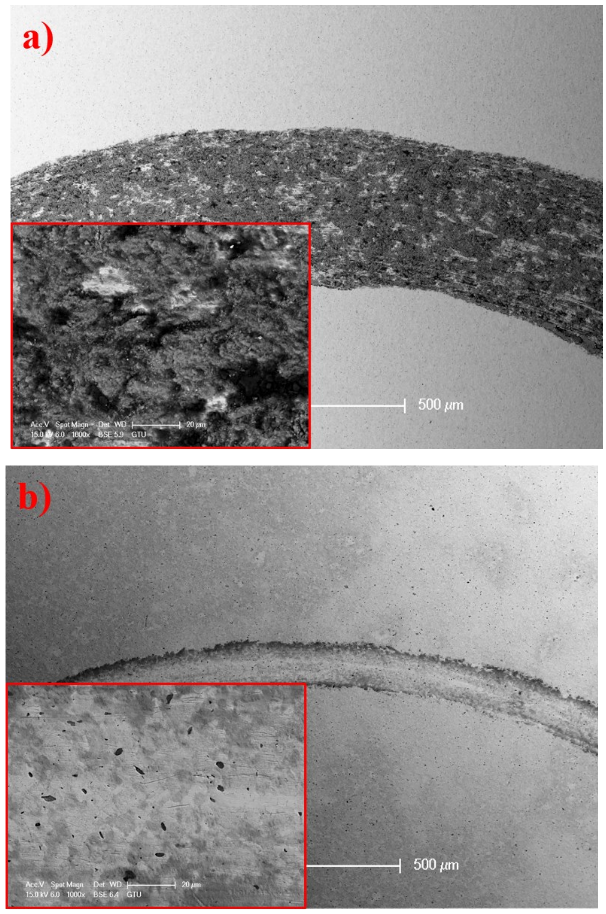

Fig. 4 SEM images of ball-on-disc wear test tracks
a) Untreated sample b) Nitrided Sample

IV. Conclusion

The nitriding process applied to AISI 430 grade stainless steel caused distortion of the bcc lattice by dissolution of nitrogen atoms and let a significant increase in the surface hardness. The increase in surface hardness was accompanied by remarkable reduction in wear loss and friction coefficient by changing wear mechanism from oxidative wear to fatigue wear.

References

[1] W. Tuckart, M. Gregorio, L. Iurman, *Sliding wear of plasma nitrided AISI 405 ferritic stainless steel*, Surf. Eng. 26 (2010) 185–190.

[2] H. Aydin, A. Bayram, Ş. Topçu, *Friction characteristics of nitrided layers on AISI 430 ferritic stainless steel obtained by various nitriding processes*,Medziagotyra. 19 (2013) 19–24.

[3] Y. Sun, T. Bell, *Sliding wear characteristics of low temperature plasma nitrided 316 austenitic stainless steel*, Wear. 218 (1998) 34–42.

[4] B. Larisch, U. Brusky, H.J. Spies, *Plasma nitriding of stainless steels at low temperatures*, Surf. Coatings Technol. 116–119 (1999) 205–211.

[5] J. Baranowska, S.E. Franklin, A. Kochmańska, *Wear behaviour of low-temperature gas nitrided austenitic stainless steel in a corrosive liquid environment*, Wear. 263 (2007) 669–673.

[6] M. Chemkhi, D. Retraint, A. Roos, C. Garnier, L. Waltz, C. Demangel, G. Proust, *The effect of surface mechanical attrition treatment on low temperature plasma nitriding of an austenitic stainless steel*, Surf. Coatings Technol. 221 (2013) 191–195.

[7] O. Celik, M. Baydogan, E. Atar, E.S. Kayali, H. Cimenoglu, *Fatigue performance of low temperature nitrided AISI 321 grade austenitic stainless steel*, Mater. Sci. Eng. A. 565 (2013) 38–43.

[8] T. Michler, M. Grischke, K. Bewilogua, H. Dimigen, *Properties of duplex coatings prepared by plasma nitriding and PVD Ti-C:H deposition on X20Cr13 ferritic stainless steel*, Thin Solid Films. 322 (1998) 206–212.

[9] J. Alphonsa, S. Mukherjee, V.S. Raja, *Study of plasma nitriding and nitrocarburising of AISI 430F stainless steel for high hardness and corrosion resistance*, Corros. Eng. Sci. Technol. 53 (2018) 51–58.