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Motivation for research and development of stainless steels with thick nitrogen-rich layers

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1. INTRODUCTION

Carbon is known to have a significant effect on the properties of steels: changes in carbon content together with heat treatment and mechanical treatment modify all the properties of steels. This effect is known to be primarily due to allotropic transformation of iron; the difference in the interstitial solubility of carbon and the effect of carbon when it is in solid solution in different phases of iron; the possibility of forming iron carbides and carbides of other alloying elements; and martensitic transformation.

Comparison of nitrogen and carbon reveals that nitrogen has greater solubility and less tendency to precipitate for a given degree of hardening; that, like carbon, it stabilizes the γ-phase of iron and allows martensite to form when quenching is used; and that, unlike carbon, when nitrogen is added to steel it increases the yield strength and tensile strength without sacrificing toughness when in the annealed condition [1]. In other words, the effect of nitrogen on the properties and performance of steels is similar to that of carbon but with several advantages.

The addition of nitrogen to steel has a significant effect on various properties, including hardness, elastic properties, plastic properties, fatigue limit, wear resistance and corrosion resistance. Inspired by this phenomenon, research groups around the world started to investigate the addition of nitrogen to steel and to analyze not only the processes involved, but also the resulting changes in properties. A search within the CAPES journal portal on March 28th, 2020, revealed that nitriding is an extremely topical subject: the search, which covered the last ten years and used the keywords *nitriding* and *steel*, identified 3225 peer-reviewed articles.

Nitriding of steel can be carried out for extended periods and at temperatures of up to 560 °C. The thickness of the composite diffusion layer formed depends on treatment temperature, time and atmosphere as well as the composition of the alloy. Genel et al. [2] plasma nitrided a quenched and tempered (320HV) AISI 4140 steel in a 30%N_2+70%H_2 atmosphere for 16 h at 475 ºC and observed compound layers with a thickness of 6 µm. The case depth for a hardness of 400 HV or higher was 350 µm.

However, if the material of interest is a stainless steel, nitriding temperatures are usually limited to 400 °C and the process is generally known as low-temperature plasma nitriding (LTPN). Higher temperatures or longer nitriding times normally result in precipitation of chromium nitrides. Chromium is the main element responsible for the formation of a passive layer in stainless steels. When chromium is present in the form of nitrides, the passive film does not always form, and when it does it may not be stable. The steel therefore has poor corrosion performance. If nitrogen is added to the steel in solid solution, the corrosion resistance can be improved. When steel is immersed in an aggressive electrochemical medium, the soluble nitrogen in it reacts with the medium according to the reaction $N+4H^++3e^- \rightarrow NH_4^+$. This reaction neutralizes the effect of the acidity and reduces the tendency for localized corrosion [3,4].

LTPN of stainless steels therefore allows high-nitrogen corrosion-resistant layers with thicknesses of usually less than 10 µm to be produced. In situations where fatigue strength is important, attention should be paid to residual stresses and case depth. According to [2], fatigue limit increases linearly with increasing case depth. For applications where wear performance is important, the layer hardness, surface yield stress and surface thickness should be used as optimization criteria. A thick, stiff, hard layer increases the separation between surfaces, reducing the contact area and friction coefficient [5], as well as improving abrasion re-

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sistance. Surface treatments that produce thick, stiff, hard layers with compressive residual stresses can be used in applications involving wear and fatigue.

Currently, thicker nitride layers (between 500 and 1000 µm) can be obtained using high-temperature gas nitriding (HTGN) and solution heat treatment after plasma nitriding (SHTPN). The latter treatment can be used to produce layers with thicknesses of up to 750 µm, hardnesses equivalent to those of quenched steels (up to 700 HV) and high residual stresses (up to 500 MPa) [6]. Surfaces produced in this way can then also be processed with LTPN to produce expanded-phase layers on top of the previous layer with thicknesses of the order of 10 µm and hardnesses of up to 1300 HV. Layers of this kind have high surface hardnesses and lower hardness gradients and provide a better support for the expanded-phase layer obtained by LTPN. For the interested reader, further information on HTGN and SHTPN can be found in [7-12].

Finally, the impossibility of achieving thick layers using LTPN has encouraged researchers to study the use of processes such as HTGN and SHTPN either on their own or in conjunction with other surface treatments. These studies may prove important given the potential of thick, hard, nitride layers with high residual stresses for use in the metalworking industry.

2. BIBLIOGRAPHY

[1] SIMMONS, J. W., "Overview: high-nitrogen alloying of stainless steels", *Materials Science and Engineering*, v.207, p. 159-169, 1996.

[2] GENEL, K., DEMIRKOL, M., ÇAPA, M., "Effect of ion nitriding on fatigue behaviour of AISI 4140 steel", *Materials Science and Engineering A*, v.279, pp. 207–216, 2000.

[3] GRABKE, H.J., "The role of nitrogen in the corrosion of iron and steels", *ISIJ International*, v.36, n.7, pp. 777–786, 1996.

[4] OLEFJORD, I., WEGRELIUS, L., "The influence of nitrogen on the passivation of stainless steels", *Corrosion Science*, v. 38, n.7, pp.1203–1220, 1996.

[5] TAKASHI, N., KATO, T., "Influence of a hard surface layer on the limit of elastic contact Part II: Analysis Using a Modified GW Model", *Jounal. Tribribology*, v.124, n.4, pp. 785-793, 2002.

[6] BERTON, E.M., "Corrosão e propriedades mecânicas da martensita de nitrogênio formada sobre o aço AISI 409 tratado pelo SHTPN", Tese de D.Eng. UTFPR, Curitiba, Pr, Brasil, 2019.

[7] GARZÓN, C. M. & TSCHIPTSCHIN, A. P. "Nitretação gasosa em alta temperatura de aços inoxidáveis". *Revista Matéria*, v. 10, n. 4, p. 502 – 525, 2005.

[8] BERTON, E. M., NEVES, J. C. K., MAFRA, M., *et al*., "Nitrogen enrichment of AISI 409 stainless steel by solution heat treatment after plasma nitriding", *Kovove Mater*., v. 55, pp. 1–5, 2017

[9] SUNG, J.H. KONG, J.H. YOO, D.K., *et al*., "Phase changes of the AISI 430 ferritic stainless steels after high-temperature gas nitriding and tempering heat treatment", *Materials Science and Engineering A*, 2008, doi:10.1016/j.msea.2007.11.078

[10] REIS, R. F., MALISKA A. M., BORGES P. C. "Nitrogen surface enrichment of austenitic stainless steel ISO 5832-1", *J Mater Sci*, v.46, p846–854, 2011.

[11] BORGES, P. C., ROCHA L. A., "Solution heat treatment of plasma nitrided 15-5PH stainless steel Part I. Improvement of the corrosion resistance", *Kovove Mater*., v.49, p107–117, 2011.

[12] TSCHIPTSCHIN, A.P., VARELA, L.B., PINEDO, C.E., *et al*., "Development and microstructure characterization of single and duplex nitriding of UNS S31803 duplex stainless steel", *Surface & Coatings Technology*, v. 327, pp. 83–92, 2017

[13] MAFTOUM, R.A., BORGES, P.C., MARQUEZE, C.M., "Influência do nitrogênio na resistência à erosão por cavitação do aço inoxidável martensítico", *Revista Matéria*, v. 22, n. 1, e11933, 2017.

[14] REIS, R. F., BORGES P. C., PANDOLFO, V., "Nitretação por plasma do aço ISO 5832-1 em alta temperatura: Influência do tempo de tratamento e sua aplicação no processo SHTPN", *Revista Matéria*, v.18, n.4, pp. 1525 – 1540, 2013.

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