Stress induced and concentration dependent nitrogen diffusion in austenitic stainless steel

Arvaidas Galdikas, Teresa Moskaliovienė

Physics Department, Kaunas University of Technology, Studentų 50, LT-51368 Kaunas, Lithuania
arvaidas.galdikas@ktu.lt

Abstract

A novel mass transport model of nitrogen atoms in austenitic stainless steels (ASS) taking place during plasma nitriding at moderate temperatures (below nitrides formation) is proposed. The model considers diffusion of nitrogen in presence of internal stresses as driving force of diffusion, i.e. this model is developed taking into account the stress – diffusion interaction during the nitriding process of ASS. Nitrogen diffusion in ASS is a complicated process and still not fully understood. The nitrogen depth profiles in nitrided ASS exhibit plateau-type shapes slowly decreasing from the surface, followed by a rather sharp leading edge, which cannot be explained by the simple Fick's diffusion laws. In addition, the nitrogen diffusivity is faster than expected from classical diffusion. Commonly trapping and detrapping (TD model) effects are used to explain the plateau shape of nitrogen depth profile and the high diffusivity in nitrided ASS [1, 2, 3]. While in this work it was shown that internal stress induced diffusion is responsible for plateau formation in nitrogen depth profile which is characteristic for nitriding process. Furthermore, the nitrogen concentration and internal stresses gradients are the driving forces of fast (with unusually high diffusion coefficient) nitrogen diffusion. Thus, proposed nitrogen stress induced diffusion model can be as an alternative to the TD model. The applicability of the proposed stress–induced diffusion model was checked and proved for different types of austenitic stainless steel (1Cr18Ni9Ti and AISI 316L – see Fig.1 and Fig. 2, respectively) nitrided with different experimental conditions (temperature, time, flux of nitrogen; experimental results were taken from Ref. [4] and [5]). By fitting of experimental nitrogen depth profiles it was found that nitrogen diffusion coefficient in ASS during plasma nitriding vary with nitrogen concentration according to Einstein–Smoluchowski relation $D(C_N) = f(1/C_N)$ (see Fig. 3). Furthermore, it was shown that swelling (or surface expansion, i.e. a change in linear dimensions of the modified region) has significant influence to the nitrogen distribution in plasma nitrided AISI 316L steel. Thus the main processes which occur during plasma nitriding of ASS below temperatures of nitrides formation are nitrogen concentration gradient and internal stress induced diffusion with concentration dependent diffusion coefficient and also swelling. Including those processes into kinetic differential equations gives not only good fitting of nitrogen depth profiles for different nitriding time samples, but also calculated swelling values very good correspond with experimentally measured ones (see Fig. 4; experimental points were taken from Ref. [6]). This aspect proves that diffusion model based on influence of internal stresses as a driving force for diffusion works good and explains nitriding process and nitrogen penetration mechanisms in stainless steel. In our previous works Refs. [7], [8] and [9] the detailed description of proposed stress induced nitrogen diffusion model with a concentration independent diffusion coefficient and numerical solution of the diffusion kinetic differential equations are presented.

The dependencies of nitrogen flux, nitriding time and nitriding temperature on nitrogen concentration, nitrogen surface concentration and penetration depth are analyzed by proposed model. It is shown that, with the increase of nitriding time and temperature the compositionally-induced stresses and thickness of stressed steel layer increases. An interpretation of the modelling results showed that the nitrogen diffusion coefficient in nitrided ASS obeys the Arrhenius' law.

References

[1] S. Parascandola, W. Moller, D. L. Williamson, Applied Physics Letters, **76** (2000) 2194.
[2] A. Martinavičius, G. Abrasonis, W. Möller, C. Templier, J. P. Rivière, A. Declémy, Y. Chumlyakov, Journal of Applied Physics, **105** (2009) 093502.
[3] T. Moskalioviene, A. Galdikas, J. Riviere, L. Pichon, Surface and Coatings Technology, **205** (2011) 0257–8972.
[4] M. K. Lei, X. M. Zhu, Surface and Coatings Technology, **193** (2005) 22.
[5] C. Templier, J.C. Stinville, P. Villechaise, P.O. Renault, G. Abrasonis, J.P. Rivière, A. Martinavičius, M. Drouet, Surface and Coatings Technology, **204** (2010) 2551–2558.
[6] J. C. Stinville, C. Templier, P. Villechaise, L. Pichon, Journal of Materials Science, **46** (2011) 5503–5511.
[7] A. Galdikas, T. Moskalioviene, Computational Materials Science, **50** (2010) 796–799.
[8] A. Galdikas, T. Moskalioviene, Surface and Coatings Technology, **205** (2011) 3742–3746.
[9] T. Moskalioviene, A. Galdikas, Vacuum, **86** (2012) 1552–1557.

Figures

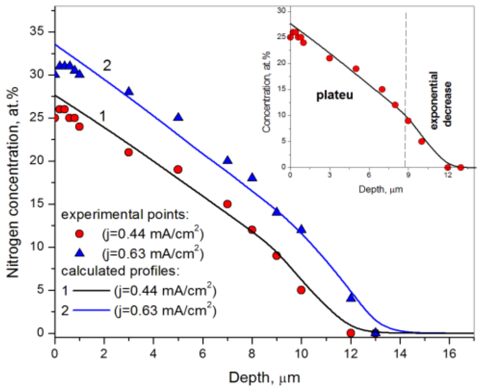

Fig. 1. Experimental points from Ref. [4] and calculated depth profiles of nitrogen after plasma nitriding (for 4 h at temperature 380 °C and at two different nitrogen ion current densities 0.44 mA/cm^2 and 0.63 mA/cm^2) of austenitic stainless steel 1Cr18Ni9Ti.

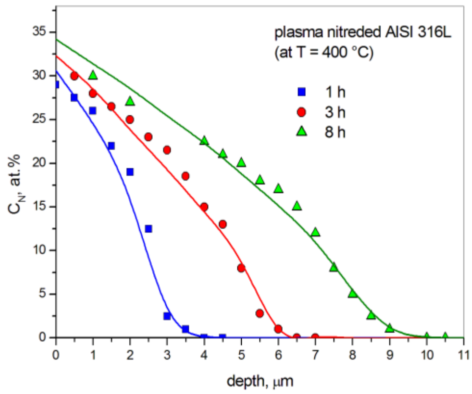

Fig. 2. Experimental points from Ref. [5] and calculated (by stress induced nitrogen diffusion model with $D(C_N)$ and taking into account swelling process) depth profiles of nitrogen after plasma nitriding of austenitic stainless steel AISI 316L at 400 °C for 1, 3 and 8 hours.

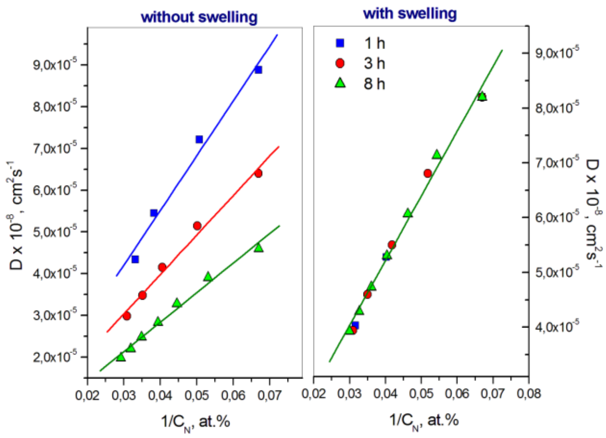

Fig. 3. The linear dependence of $D(C_N) \sim (1/C_N)$ for plasma nitrided AISI 316L at different nitriding times without swelling (case (a)) and with swelling (case (b)).

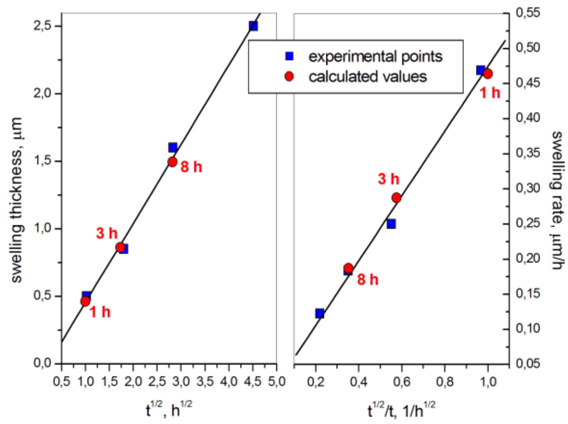

Fig. 4. Experimental points form Ref. [6] and calculated (extracted from fitted data) values of swelling thickness and swelling rate.