Available online at www.sciencedirect.com
SCIENCE DIRECT®
Vacuum 78 (2005) 181–186
VACUUM
SURFACE ENGINEERING, SURFACE INSTRUMENTATION & VACUUM TECHNOLOGY
www.elsevier.com/locate/vacuum

Modification of the near surface layer of carbon steels with intense argon and nitrogen plasma pulses

B. Sartowska[a,*], J. Piekoszewski[a,b], L. Waliś[a], W. Szymczyk[b], J. Stanisławski[b], L. Nowicki[b], R. Ratajczak[b], M. Kopcewicz[c], J. Kalinowska[c], M. Barcz[d], F. Prokert[e]

[a]*Institute of Nuclear Chemistry and Technology, 16 Dorodna str., 03-195 Warsaw , Poland*
[b]*The Andrzej Sołtan Institute for Nuclear Studies, 05-400 Otwock/Świerk, Poland*
[c]*Institute of Electronic Materials Technology, Wólczyńska 133 str., 01-919 Warsaw, Poland*
[d]*Physic Institute Polish Academy of Science, al. Lotników 32/34, 02-668 Warsaw, Poland*
[e]*Forschungszentrum Rossendorf e. V. Institut für Ionenstrahlphysik und Materialforschung, Postfach 510119, D-01314 Dresden, Germany*

Abstract

Series of carbon steels with various contents of carbon were irradiated with high intensity (5–6 J cm^{-2}), short (μs range) nitrogen and argon plasma pulses. In all samples the near surface layer of the thickness in μm range was melted. The paper reports the results of investigation of changes induced by such treatment. The identified phases, profiles of retained nitrogen concentration, microhardness and wear resistance of the modified layer are presented and discussed.

Keywords: Intense pulsed plasma beams; Paramagnetic phases; Expanded austenite; SEM; SIMS; CEMS; GXRD

1. Introduction

When stainless steel is exposed to nitrogen at higher temperature using such techniques as ion implantation, plasma immersion ion implantation (PIII) and rf plasma nitriding, different nitride phases are formed according to the Fe–N phase diagram and depending on the process conditions. Of these phases an expanded austenite attracts a special interest of authors [1–5]. The authors reported that due to the presence of nitrogen-expanded austenite in stainless steel, good corrosion resistance is maintained while the wear resistance is increased. It is stated in [3,4] that this phase can only be formed if Fe, Cr and Ni are available in a system.

*Corresponding author. Tel.: +48 22 811 15 02; fax: +48 22 811 15 32.
E-mail address: bsarto@orange.ichtj.waw.pl (B. Sartowska).

0042-207X/$ - see front matter
doi:10.1016/j.vacuum.2005.01.023

The expanded austenite is an interstitial solution of nitrogen or carbon (denoted by γ_N or γ_C) in iron. As for Fe–C austenite it is accepted that carbon atoms are separately distributed among the octahedral sites in the fcc lattice and a repulsive interaction between the carbon atoms exists. As for the Fe–N austenite it is reported that interaction is strongly repulsive between the first nearest-neighbouring atoms and weakly attractive between the second nearest [6]. The expanded austenite can be identified by conversion electron Mössbauer spectroscopy (CEMS) and X-ray diffraction analysis with the grazing incidence angle.

In our experiment, the energy density of the pulse is high enough (for a given pulse duration) to melt the near surface region of the substrate and to introduce into it the elements brought by plasma pulses.

The aim of this work was to investigate the modification of the near surface layer of carbon steels irradiated with short (μs range), intense (5–6 J/cm^2) nitrogen and argon plasma pulses.

2. Experimental

Carbon steels with different concentration of carbon and heat treated with the standard procedures were used (Table 1). The plasma pulses were generated in a rod plasma injector (RPI) at the Andrzej Soltan Institute for Nuclear Studies [7]. To compare the effects of thermal processes and supplied reactive gas, the samples were irradiated with five plasma—argon or nitrogen pulses at an energy density about 5 J/cm^2. According to the computer simulation of heat evolution in the iron sample (Fig. 1) we expected that the melted layer could be about 1.5 μm thick. The samples were characterised by: nuclear reaction analysis (NRA) $^{14}N(d,\alpha)^{12}C$ for determination of retained nitrogen dose; scanning electron microscopy (SEM) for surface and cross-section observations; secondary ion mass spectroscopy (SIMS) for elemental profile measurements; CEMS for quantitative analysis of identified phases; X-ray diffraction with grazing incidence (GXRD) for determination of identified phases parameters, microhardness HV0.01 and wear resistance measurements.

Table 1
Composition and heat treatment parameters of steels used in the investigations

No.	Steel	Content of element (wt.%)											Heat treatment		
		C	Si	Mn	P	S	Cr	Mo	Ni	Al.	Cu	V	Austenitisation	Quenching	Tempering
1	Armco	0.018	0.01	0.03	0.013	0.016	0.05	<0.01	0.07	<0.01	0.09	<0.01	820 °C, 30 min, vacuum		
2	20	0.28	0.3	0.65	0.018	0.026	0.14	0.013	0.09	0.02	0.11	<0.01	920 °C, 30 min, vacuum		
3	45	0.52	0.28	0.58	0.021	0.024	0.12	0.22	0.19	0.02	0.08	0.06		840 °C, 20 min, endothermic atmosphere, oil	550 °C, 2 h, vacuum
4	65	0.63	0.28	0.74	0.02	0.025	0.09	<0.01	0.05	0.03	0.3	<0.01		840 °C, 20 min, endothermic atmosphere, oil	180 °C, 1 h, air
5	N9	0.93	0.19	0.11	0.015	0.016	0.04	0.017	0.07	0.02	0.24	<0.01		770 °C, 20 min, endothermic atmosphere, water	180 °C, 1 h, air