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# Austenite formation of carbon and alloyed steels by intense argon and nitrogen plasma pulses: Role of carbon, chromium and nitrogen

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**Abstract**

Carbon and alloyed steels were subjected to transient treatment using high intensity argon and nitrogen plasma beams. In the former case the pulses induced only the heat effects whereas in the latter—the reactive atoms generated alloying effects. Austenitic phases have been studied with the use of conversion electron Mössbauer spectroscopy. Regularities between the alloying element contents (C, N, Cr) and austenitic phases have been established and discussed.


*Keywords:* Expanded austenite; Carbon steels; Alloy steels; Transient melting

## 1. Introduction

It is well documented, e.g. [1–6] that the presence of so called nitrogen (and/or carbon) expanded austenite $\gamma_N$ ($\gamma_C$) in stainless steels improves their tribological properties without reduction of their excellent corrosion resistance. These phases can be formed by using such methods as e.g. ion implantation or plasma immersion ion implantation techniques. Some of the authors, e.g. [3,4] claim that regardless the method of nitriding, the $\gamma_N$ phase can be formed only when Fe, Cr and Ni components are available in the system. This may be the case for stationary processing but it is not when transient melting process is applied. In [7,8] it was shown that the $\gamma_N$ phase can also be formed in carbon steels and even in pure α-iron if the substrate is treated with high-intensity nitrogen plasma pulses which melt the near surface layer of steel. The aim of the present work is to study how the alloying elements such as C, Cr and N influence the efficacy of austenite formation of carbon and alloyed stainless steels treated by high-intensity pulsed plasma beams (HIPPB) with argon and nitrogen plasmas.

## 2. Experimental

### 2.1. Samples

Three kinds of the carbon steels, i.e. 1C30, 1C45, and 1C60 (PN-EN 10083-2) and two kinds of stainless steel X20Cr13 and X39Cr13 (PN-EN 10088:1998) were used. The samples were cut in the form of 2 mm thick 20 mm diameter disks. All samples were subjected to the routine heat treatment according to the standards predicted for these steels and then polished to a roughness $R_a$ of about 0.2 μm.

### 2.2. Processing

To compare the effect of thermal process (TP) alone with that when apart TP there are also reactive atoms supplied,

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Table 1
Atomic concentrations of C, Cr and N and phase fractions for different steels treated by Ar and N plasma pulses

*Ar plasma*

| | at (%) | | | Phase fractions (%) | | |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Steel | C | Cr | N | $\gamma_0$ | $\gamma_C$ | $\gamma_0+\gamma_C$ |
| 1C30 | 2.7 | 0.15 | 0 | 6.22 | 3.10 | 9.3 |
| 1C45 | 3.5 | 0.13 | 0 | 10.56 | 4.9 | 15.6 |
| 1C60 | 4.2 | 0.12 | 0 | 22.9 | 12.4 | 35.3 |
| X20Cr13 | 2.5 | 14.5 | 0 | 25.3 | 2.6 | 27.9 |
| X39Cr13 | 3.5 | 13.8 | 0 | 45.9 | 3.04 | 48.94 |

*N plasma*

| | at (%) | | | Phase fractions (%) | | | |
|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Steel | C | Cr | N | $\gamma_0$ | $\gamma_C$ | $\gamma_N$ | $\gamma_0+\gamma_c+\gamma_N$ |
| 1C30 | 3.5 | 0.15 | 0.6 | 33.50 | 11.39 | 14.99 | 59.9 |
| 1C45 | 3.2 | 0.13 | 0.8 | 39.12 | 8.87 | 20.34 | 68.33 |
| 1C60 | 4.2 | 0.12 | 1.0 | 35.43 | 10.59 | 18.10 | 64.1 |
| X20Cr13 | 1.8 | 14.5 | 0.8 | 52.8 | 5.2 | 10.4 | 68.6 |
| X39Cr13 | 4.2 | 13.8 | 1.1 | 43.6 | 4.7 | 10.5 | 58.8 |

the samples were irradiated with five plasma argon and nitrogen pulses at an energy density of about 5 J/cm$^2$ and duration in the microsecond scale. The pulses were generated by so called rod plasma injector type of generator described in detail elsewhere [9].

### 2.3. Characterization

The samples were characterized by nuclear reaction analysis (NRA) $^{14}$N(d, $\alpha$)$^{12}$C to determine the retained dose of nitrogen, secondary ion mass spectroscopy (SIMS) for elemental profile measurements, X-ray diffraction for structural analysis, optical emission spectroscopy (OES) for elemental analysis of initial samples and conversion electron Mössbauer spectroscopy (CEMS) for quantitative analysis of identified phases. When martensitic phase is converted to austenite phase, one observes a single line in CEMS combined with a quadruple doublet in the central part of the spectrum. The isomeric shifts (IS) with respect to $\alpha$-Fe of the singlet and the doublet are usually around 0.00 and 0.1–0.2 mm/s, respectively. The quadrupole splittings (QS) in the doublets are typically around 0.3–0.6 mm/s for N and C alloying elements, respectively [10]. It is commonly accepted that the single line corresponds to the resonant transition in the $^{57}$Fe nucleus having no interstitial nitrogen neighbours and represents normal austenite $\gamma_0$. The doublet is due to the $^{57}$Fe nucleus having one or more nitrogen or carbon atoms as the nearest neighbours and representing the $\gamma_N$ and $\gamma_C$ phases. Combined computer fitting of CEMS spectra measured on full end reduced Doppler velocity scale enabled us to determine the contributions of the each of identified phase: ferritic $\alpha$-Fe , martensitic $\alpha'$-Fe and austenitic $\gamma_0$, $\gamma_C$ and $\gamma_N$ phases. Last three of them are shown in Table 1 in the next paragraph.

## 3. Results and discussion

Figs. 1 and 2 represent typical CEMS spectra observed for carbon- and stainless steel, respectively, before and after irradiation with argon and nitrogen plasma pulses. As it is seen in all austenitic phases, for Ar plasma only $\gamma_0$ and $\gamma_C$ can be distinguished while for N plasma all three phases exist. The atomic concentrations of C, Cr and N given in columns 2, 3 and 4 in Table 1 are the average values determined from SIMS for top 200 nm layer in which 90% of CEMS information originates [11]. The values for C in this region are on an average larger by 1.5% as compared to those determined by SIMS at the depth 3000 nm. The values obtained from SIMS at 3000 nm are in fair agreement with those measured independently by OES on initial samples. This means that some amount of carbon is supplied during the HIPPB treatment. Columns 5–8 in Table 1 give the values of phase fractions derived from the CEMS spectra analysis.

It is seen from the table that in absence of nitrogen the fraction of $\gamma_C$ phase grows with the content of C, as expected. However, other dependencies cannot be readily deduced and therefore we performed a numerical analysis of the obtained results.

Since we expect that efficacy of austenite formation is simultaneously a function of three variables (i.e. atomic concentration of: C, Cr and N), in order to find empiric formulae describing these dependences using the experimental data, a least square fit procedure based on the power series approximation was adopted. Assuming that