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# TREATMENT OF STEEL 16MnCr5 AND STEEL 42CrMo4 BY PLASMA FLOW GENERATED IN MAGNETOPLASMA COMPRESSOR

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**Abstract.** Two types of steel samples (16MnCr5, 42CrMo4) have been treated with plasma pulses created in magnetoplasma compressor, using helium - hydrogen mixture as a working gas. The energy flux density of the plasma flow in the region of plasma-sample interaction area is 9 J/cm2. Plasma melts the near-surface layer. During the rapid cooling process, a thin layer with structure different from initial is created. Changes in the physical composition of the substrate are monitored depending on the number of plasma treatments. After treatment with a plasma produced within MPC, a significant improvement of hardness has been achieved.

## 1. INTRODUCTION

Magnetoplasma compressor (MPC) is a plasma accelerator with operation based on the common theory of dense plasma flow and acceleration developed by Morozov, see Morozov 1968. High thermal loads, produced by plasma formed, accelerated and compressed within MPC device, are used for modification of steel samples. Steel 16MnCr5 has very good machinability, mechanical properties and weldability. Steel 42CrMo4 is a steel for tempering, with a good combination of strength and toughness in the quenched and tempered condition. The treatment with a plasma can further enhances the favorable characteristics of these materials.

## 2. EXPERIMENTAL SET-UP AND METHODS

The experimental setup is described in detail in Puric et al. 2003. The lifetime of the compressed plasma flow within analyzed experimental condition is around 150 μs, plasma velocity is up to 50 km/s, electron density and temperature are of the order of $10^{22}$ $m^{-3}$ and 1 eV, respectively.

Four types of analysis have been used to characterize the modifications on steel surfaces after treatments with plasma: optical microscopy, hardness measurement (Zwick Mic 10 Hand Hardness Instrument), roughness measurement (MarSurf XR1 Surface Roughness Tester) and X-ray diagnostics (Rigaku Smartlab X-ray Diffractometer). Spectral investigation of the plasma-surface interaction area is realized using one meter spectrometer and PIMAX1 ICCD camera.

## 3. RESULTS AND DISCUSION

The experimental setup enables spectra recording at the position where plasma – material interaction is realized. Radiation is collected using the optic fiber. Collected data includes radiation from different spatial coordinated along the one analyzed optical path, with different electron densities contribute simultaneously to the overall profile. Hβ line has been fitted with two Voigt functions whose widths have been used for electron density calculation (Fig. 1). The wide Voigt function represents the influence of the radiation from the central region of the plasma flow, while the narrow function represents the influence of the outer region of the plasma flow. The average electron temperature value in the region close to the target surface is 1 eV and it was estimated using the Saha equation and relative intensity ratio of Fe I and Fe II lines.

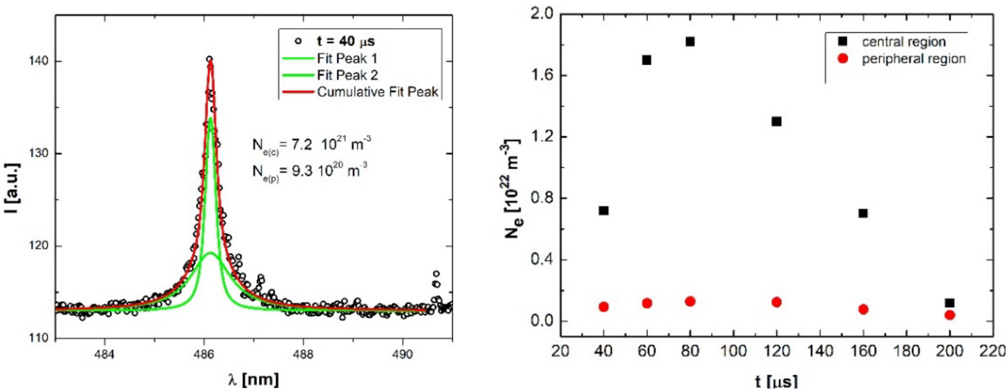

Figure 1: Fitting of $H_\beta$ line and calculation of electron density.

Steel samples (1 cm x 1 cm) were divided into five groups: untreated, exposed to one plasma shot, to three, to five and to ten plasma shots. Position of the steel samples is fixed at z = 4.5 cm. Every plasma shot deposits 9 J/cm$^2$ of energy to the surface of the treated material, based on the results of calorimetric measurements, see Trklja et al. 2019.

After one plasma pulse, structures in the shape of the vortex are formed during fast cooling process (quenching effect). After the next pulses, new vortex structures are formed and the morphology of the surface is changing, see Trklja Boca et al. 2021.

When 16MnCr5 steel samples are treated with plasma, the initial hardness value is increased, independent of the number of plasma shots. From the initial 160 HV, the hardness goes up to 270 HV (Fig. 2). When samples are made from steel with the addition of chromium and molybdenum (42CrMo4), the hardness is increased after each treatment with plasma, indicating that it may continue to increase, no saturation was reached. After ten plasma shots, the hardness is 375 HV (Fig. 2).

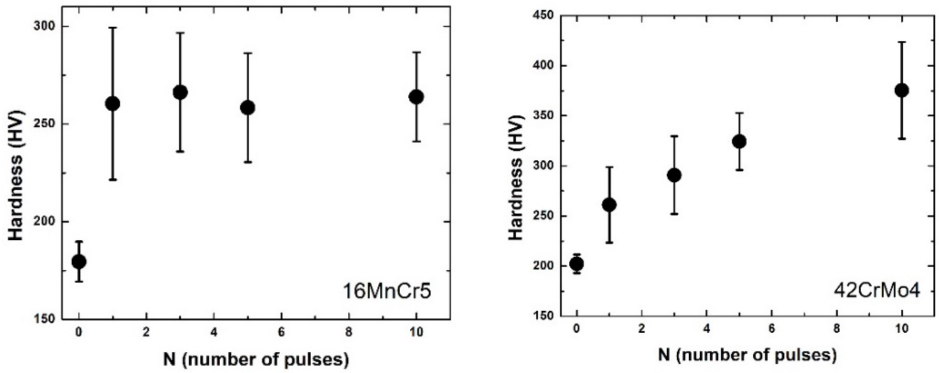


Figure 2: Hardness of the steel samples before and after 1, 3, 5 and 10 plasma treatments.

The roughness was measured in a fraction of the radius along the surface relative to the center of incidence of the plasma flow. Ten plasma pulses make a peripheral region of every treated sample smoother then the central region, see Fig. 3. The molten material of the sample is blown away by the plasma flow and forms a smooth layer on the periphery.

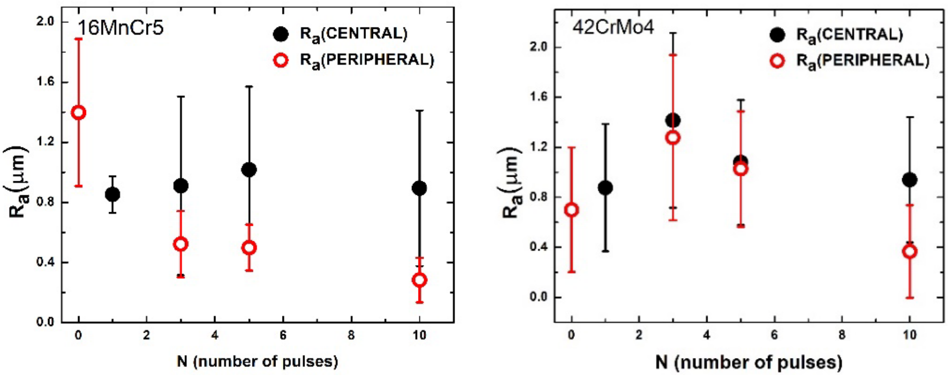


Figure 3: Roughness of the steel samples before and after 1, 3, 5 and 10 plasma treatments

Untreated thin surface layer of all analyzed steel samples contains only α-Fe. Small phase changes of only several weight percent of γ-Fe in the treated 16MnCr5 and 42CrMo4 steel samples were diagnosed.

## 4. CONCLUSIONS

Modification of steel 16MnCr5 and steel 42CrMo4 samples treated by an accelerated and compressed plasma flow formed within MPC have been monitored depending on the number of plasma treatments. Significant change of several characteristics of steel materials treated by a plasma produced within MPC, such as surface hardness and roughness, without compromising the properties within the depth of the sample, has been achieved.

## References

Morozov, A. I.: 1968, *Soviet physics – technical physics*, **12**, 1580

Purić, J., Dojcinovic, I. P, Astashynski, V. M., Kuraica, M. M., Obradovic, B. M.: 2003, *Plasma Sources* Sci. Technol., **13**, 74.

Trklja, N., Iskrenovic, P. S., Miskovic, Ž. Z., Krstić, I. B., Obradovic, B. M., Mitrović, R, M., Kuraica, M. M.: 2019*, JINST*, **14**, C09041.

Trklja Boca, N., Mišković, Z.Ž., Mitrović, M. R. Obradović, M.B., Kuraica, M.M.: 2021, *Surf.and Surf.Coat*., **416**, 127157.