TREATMENT OF STEEL SURFACES BY PLASMA FLOW GENERATED IN MAGNETOPLASMA COMPRESSOR

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1. Magnetoplasma accelerator

Magnetoplasma accelerator (MPA) is an experiment setup used for plasma compression and acceleration. Electrode system is positioned in the vacuum chamber where pressure is under external control and it its design enables avoidance of heavy electrode erosion. Presented MPA operates in an ion current transfer regime and it is a source of quasistationary compressed plasma flow (CPF).

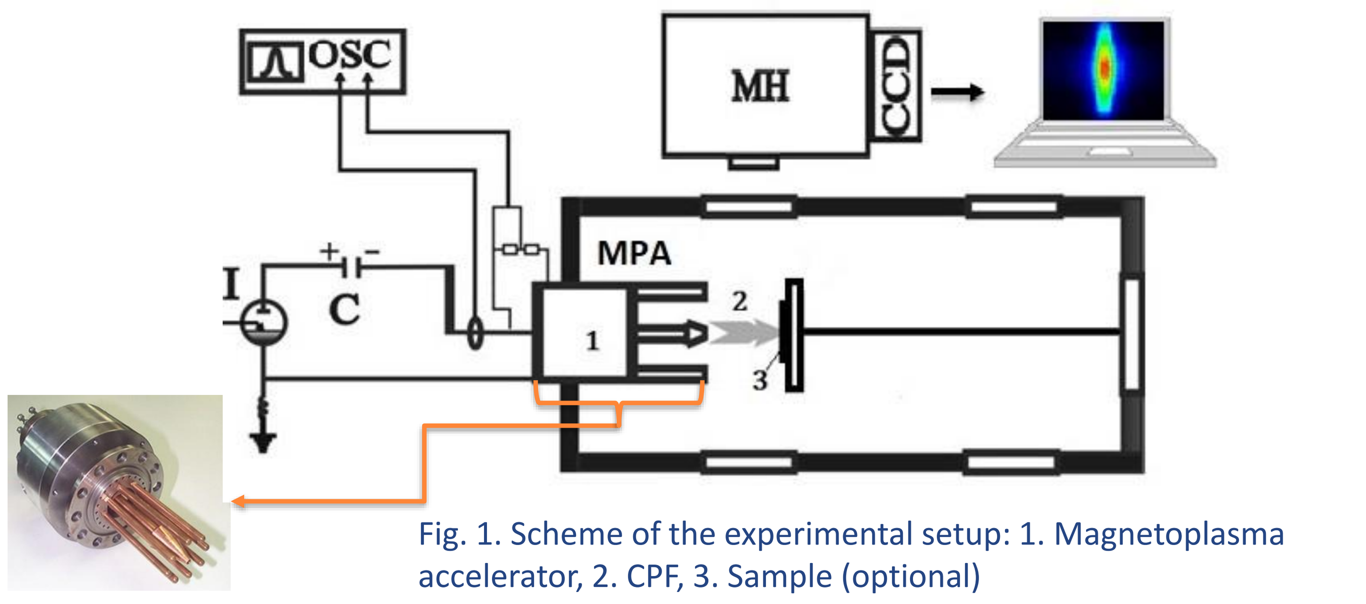

Fig. 1. Scheme of the experimental setup: 1. Magnetoplasma accelerator, 2. CPF, 3. Sample (optional)

Plasma formed within the electrode system during the process of capacitor discharge is compressed and accelerated. The plasma acceleration by the Ampere force in MPC interelectrode gap is accompanied by compression of the plasma flow (CPF) at the outlet of the discharge device. The plasma flow is compressed due to interaction of longitudinal current component with intrinsic azimuthal magnetic field (pinch effect).

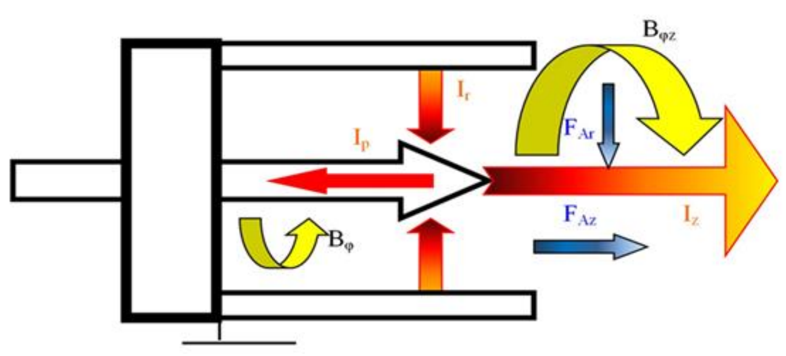

Fig. 2. CPF formation

The lifetime of the compressed plasma flow is around 150 μs, plasma velocity is up to 100 km/s, the order of electron density is $10^{23}\ \mathrm{m}^{-3}$ and plasma temperature of 20000 K. The length and radius of the CPF are 6 cm and 1 cm, respectively [2].

MPA can be used for material treatment with plasma, it is of interest for industry application as well as for fusion related experiments (investigation of candidates for plasma facing components).

Fig. 3. Discharge in MPA

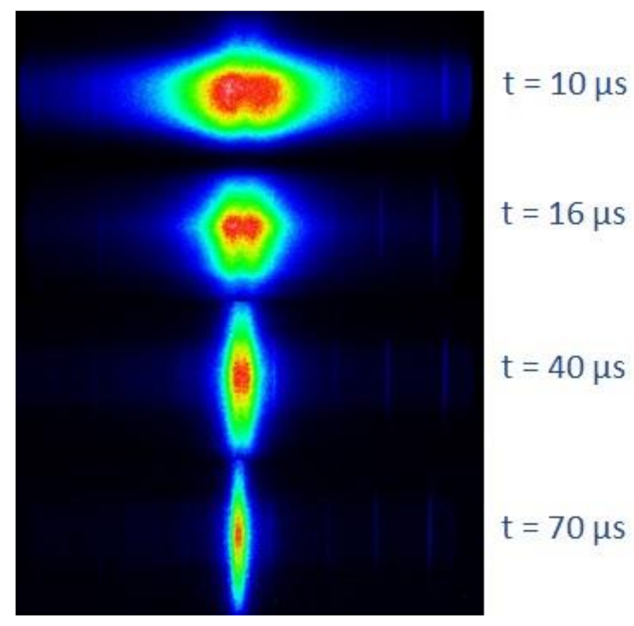

Fig. 4. Discharge in H_2: H_β line (486.1 nm)

2. Energy distribution within plasma flow

The total amount of energy stored in the capacitor bank is 6.4 kJ. Discharge is realized in residual gas regime with 10 mbar gas pressure in chamber. Current signal is measured by Rogowski coil.

Energy transported to the target by plasma flow has been determined using K type thermocouple and Fluke 8808A digital multimer. Brass target with known specific heat capacity has been used for energy calibration process. Radius and mass of the brass target are 1.4 cm and 1 g, respectively and it is in direct contact with thermocouple. Energy distribution within plasma flow, along z axis, (axis of discharge) was obtained for Helium with addition of 5% of Hydrogen, as working gas (Fig. 6.) [3].

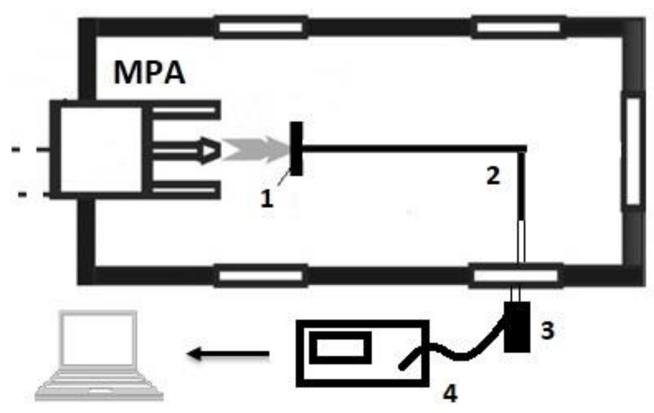

Fig. 5. Scheme of the experimental setup for energy calibration: 1. Brass target; 2. K type thermocouple; 3. Zero point; 4. Voltage device (Fluke 8808A digital multimer)

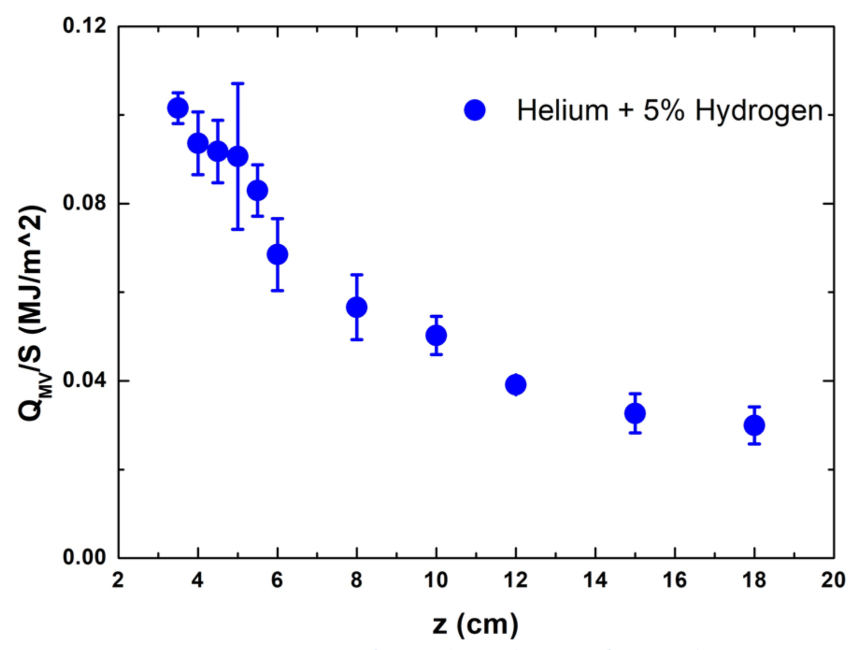

Fig. 6. Energy transferred to the surface, along z axis (axis of discharge)

3. Steel samples

During present experimental session the process of plasma-steel (type 100Cr6) interaction has been investigated. Helium with 5% of Hydrogen was used as working gas.

The position of the steel samples is fixed at z = 4.5 cm, where every plasma shot deposits 9 J/ cm^2 of energy to the surface of the treated samples

Steel samples (1 cm x 1 cm) were mechanically cut, polished and prepared for treatment in MPC device.

During plasma treatment, surface is melted. Due to the fast cooling of the melted surface layer, the surface structures formed during melt phase are freezing (quenched) during a process of the melt resolidification.

4. Spectroscopic diagnostics

The plasma layer next to the sample surface is monitored spectroscopically allowing additional diagnostics.

Mean values of electronic concentration and electron temperature averaged along the optical path parallel to the surface of the sample are calculated. Average value of electron density is calculated using distance between allowed and forbidden component of 447.1 nm line (Fig. 7) [1] (allowed transition is 4d-2p, forbidden component is 4f-2p) at t = 30 μs (when the plasma parameters reach maximum values) and its value is Ne = 2.42· $10^{22}\ \mathrm{m}^{-3}$. The electron temperature in the plasma layer next to the sample surface was estimated using relative intensity ratios of Fe I and Fe II lines and the Saha equation. The average electron temperature value in the region close to the target surface is 0.5 $10^{22}\ \mathrm{m}^{-3}$.

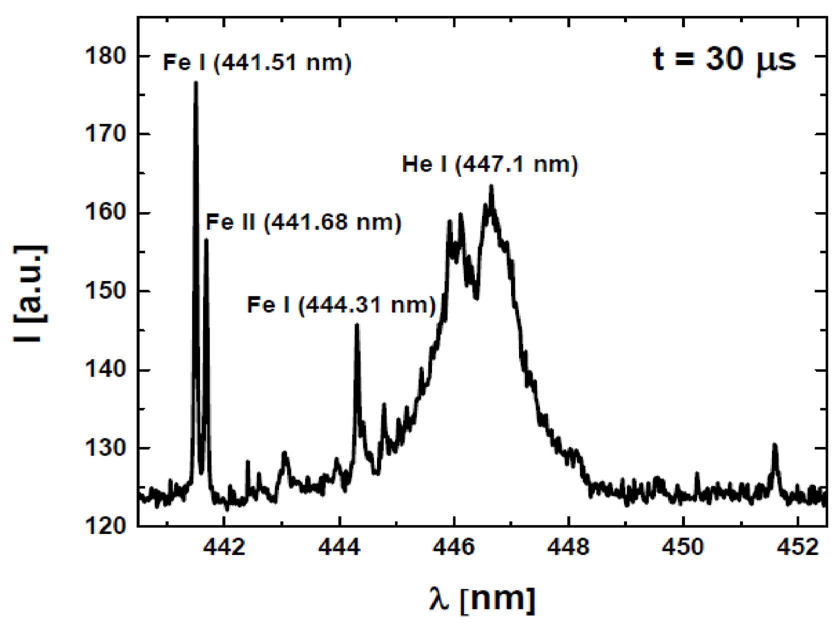

Fig. 7. Discharge in MPC in helium – hydrogen mixture.

5. Optical microscopy

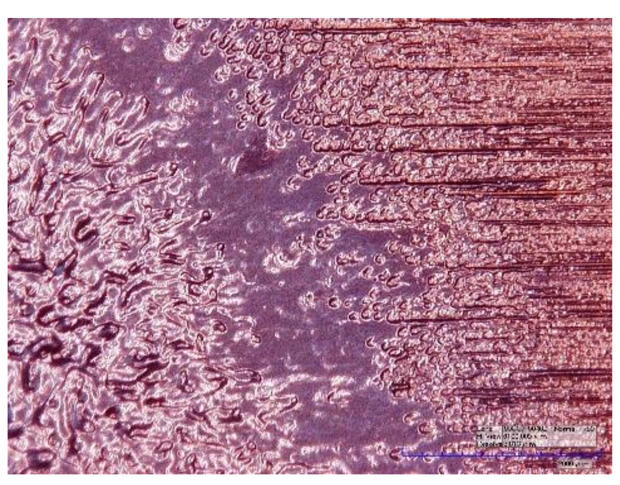

Fig. 8. Untreated and treated steel 100Cr6 sample

Optical microscope images of the treated samples indicate the formation of vortex structures. Fig. 8. represents the surface of one steel sample treated with five plasma shots (which is not positioned on the center of the CPF, but it is useful for the present description) obtained by an optical microscope. There are three areas on this surface: the right part is the untreated region where the plasma hasn`t interact with the surface; the left part of this sample is the region where CPF hits the sample directly; the middle area represents the peripheral zone of plasma – sample interaction in which material from the central area of plasma - surface interaction is blown and smooth area is formed.

6. Hardness measurements

Hardness (HV) measures the resistance of a sample to material deformation due to a constant compression load from a sharp object.

Hardness has been measured using Zwick Mic 10 Hand Hardness Instrument.

Before plasma treatments, hardness of steel 100Cr6 sample is 200 HV. Plasma shots make steel target firmer after just one plasma treatment. Three plasma shots lead to a hardness value of 350 HV and after more than three plasma shots, it comes to saturation (Fig. 9).

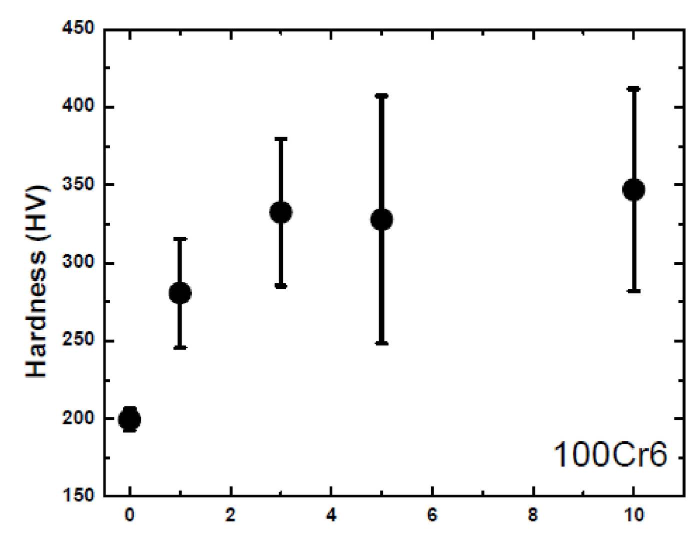

Fig. 9. Hardness of the steel 100Cr6 samples depending on the number of plasma treatments

7. Roughness measurements

Roughness was tested with MarSurfXR 1 Surface Roughness Tester in different regions of treated samples and comparison with roughness values measured before plasma action.

From the results of the roughness measurement (Fig. 10) it can be seen that after treatment with three and more plasma shots, the peripheral region of the treated surface becomes noticeably flat. The central area of the treated surface become significantly rough after several treatments because during each plasma-target interaction, the surface material is again melted and mixed.

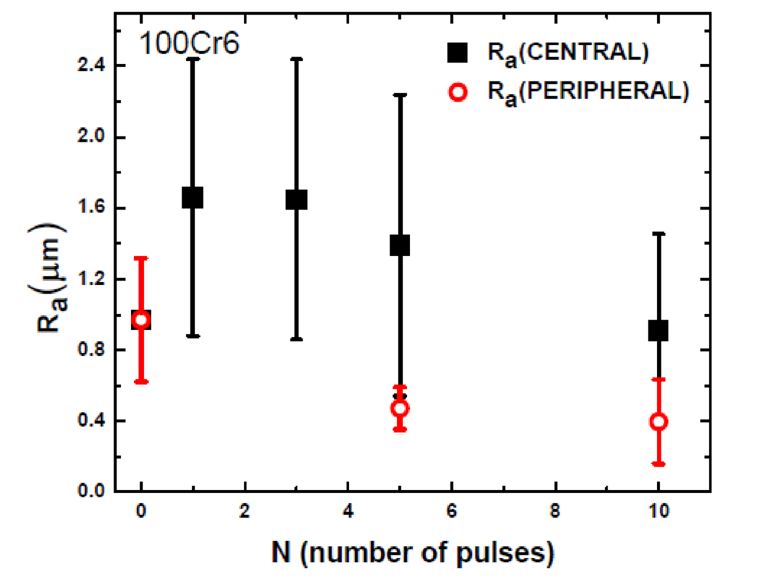

Fig. 10. Roughness of the steel 100Cr6 before and after 1,3, 5 and 10 plasma treatments

8. X-ray diagnostics

Structural studies of the thin surface layer of the sample were performed using X-ray diagnostics, which allows investigation of the existence of phase change on treated samples. The X-ray diffraction (XRPD) investigation was con-ducted on automated multipurpose Rigaku Smartlab X-ray Diffractometer in Θ – Θ geometry (the sample in horizon-tal position) in parafocusing Bragg-Brentano geometry using D/teX Ultra 250 strip detector in 1D XRF suppression mode with CuKα 1,2 radiation source (U = 40kV and I = 30 mA).

Result of x-ray analysis of the sample treated with ten plasma shots is represented in Fig.4. Starting sample (steel 100Cr6) is solely composed from α-Fe. Treatments with plasma shots leads to partially transformation to γ-Fe of thin surface layer of the sample.

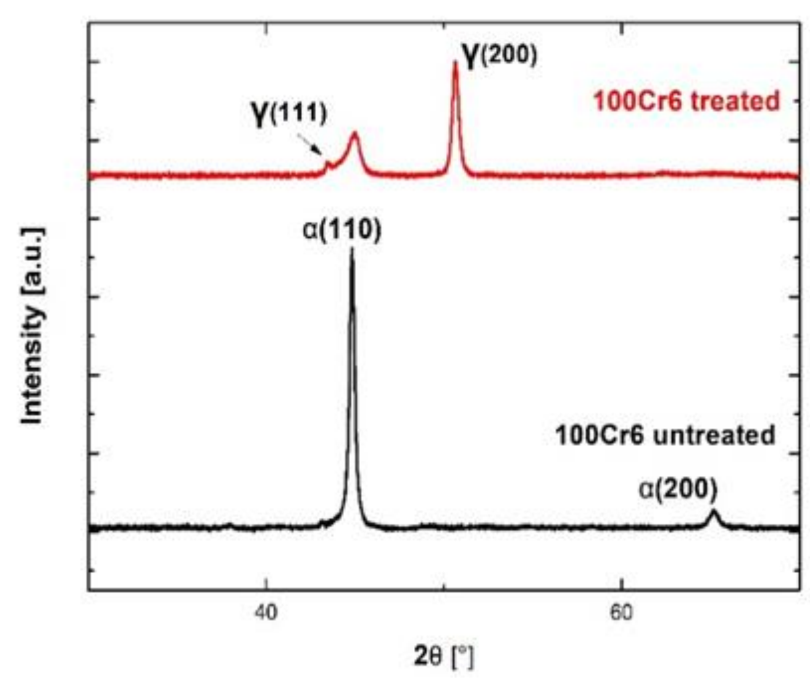

Fig. 11. X-ray diagnostics

9. Conclusions

Modifications of steel 100Cr6 samples treated by a plasma produced within MPC have been monitored depending on the number of plasma treatments. Significant improvement of hardness has been achieved.

Presented type of experimental investigation is useful for industry application and it is of interest for fusion related experiments concentrated on material treatment within plasma accelerators and analysis of the surface modification under high thermal loads.

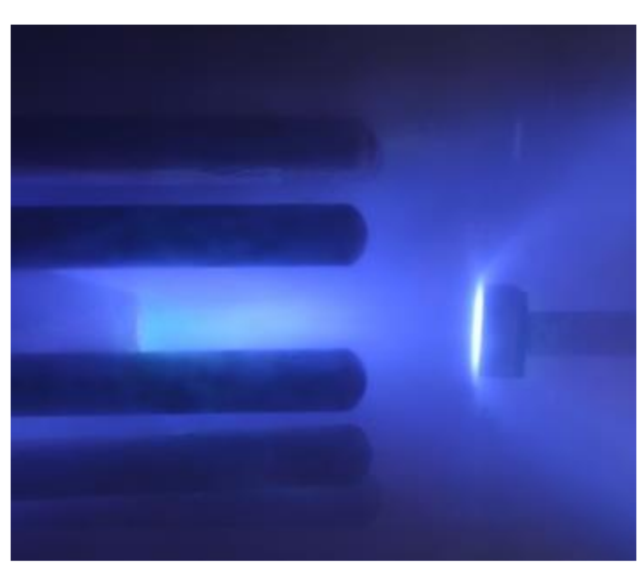

Fig. 12. Surface (steel 100Cr6) treatment by CPF

10. References

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30th SPIG

Belgrade, Serbia, August 24-28, 2020

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This work is supported by the Ministry of Education and Science of the Republic of Serbia through the Project No. 171034.